International Federation of Airworthiness

Flight Safety Foundation

International Air Transport Association

Joint meeting of the FSF 58th annual International Air Safety Seminar IASS,
IFA 35th International Conference, and IATA

SAFETY

IS EVERYBODY'S BUSINESS

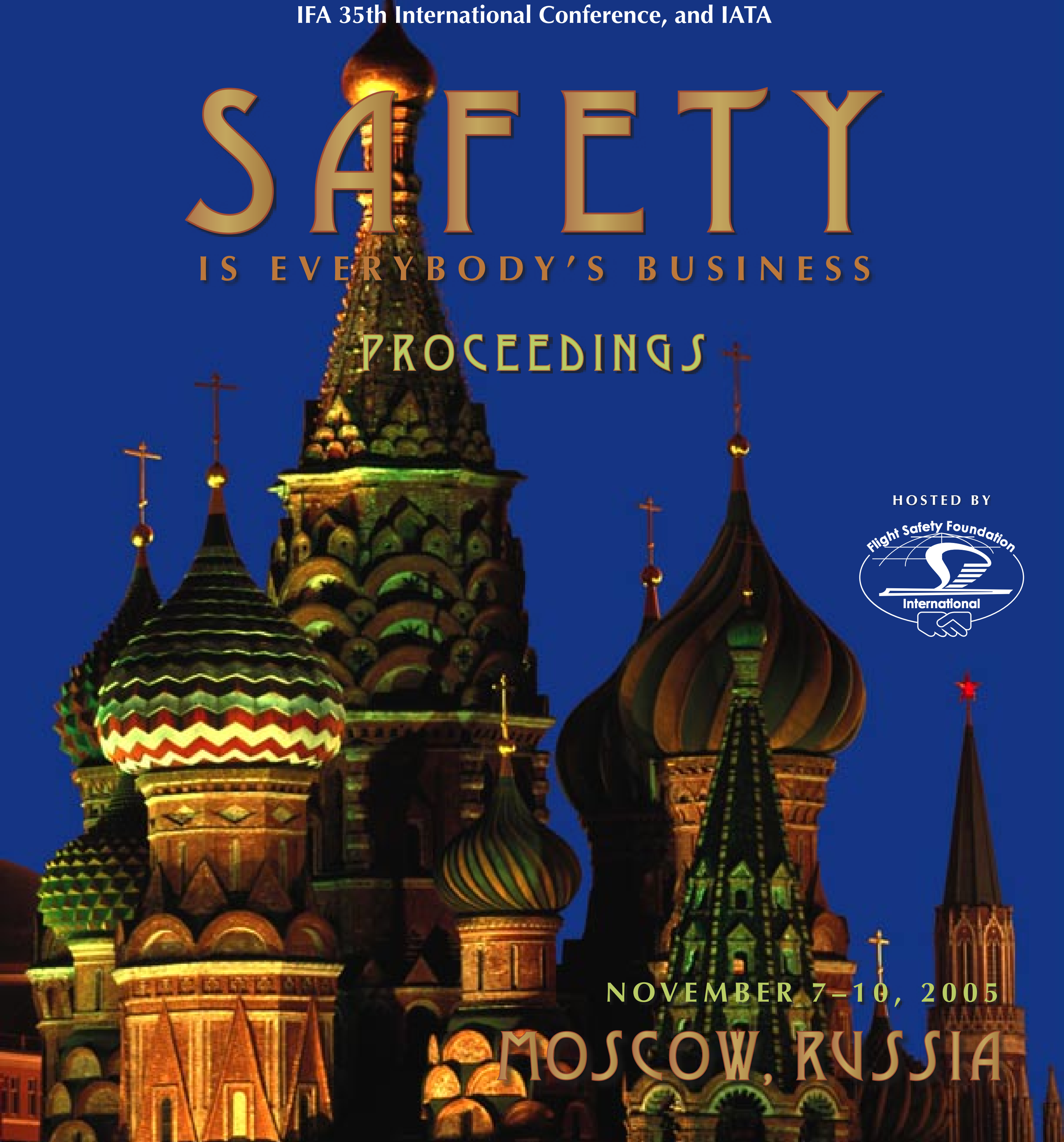
PROCEEDINGS

HOSTED BY

Flight Safety Foundation International

NOVEMBER 7–10, 2005

MOSCOW, RUSSIA



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Safety Is Everybody's Business

November 7–10, 2005
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Notice

The proceedings of the Flight Safety Foundation 58th annual International Air Safety Seminar (IASS), part of the joint meeting with the International Federation of Airworthiness 35th International Conference and the International Air Transport Association in Moscow, Russia, feature presentations on safety issues of interest to the aviation community. All the papers presented here have been reformatted for publication in the proceedings and have undergone minor editing for style. This information is not intended to supersede operators' or manufacturers' policies, practices or requirements, or to supersede government regulations. The Foundation, publisher of the proceedings, is not responsible for errors or omissions.

Preface

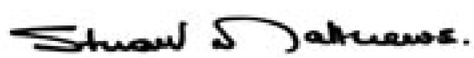
These proceedings of the Flight Safety Foundation (FSF) 58th International Air Safety Seminar (IASS), part of the joint meeting with the International Federation of Airworthiness (IFA) 35th International Conference and the International Air Transport Association (IATA), reflect this year's theme, "Safety Is Everybody's Business."

Some presentations discuss aviation safety topics from a global aspect. Others survey the scene from a regional perspective. Some apply to operations, while others are concerned with maintenance. Still others relate to various specialties. The message is clear: There are many ways to look at safety and many levels on which the work of enhancing an already safe worldwide aviation system can go forward.

The venue for this year's meeting — Moscow, Russia — is significant. Several of the presentations illustrate the progress that continues to be made in Russia and the Commonwealth of Independent States.

Collectively, these presentations show that, whatever your role in aviation, your contribution is vital in maintaining an admirably low accident rate and lowering it further.

As always, we are grateful to the presenters, agenda development committee, sponsors, exhibitors and FSF members for their support of the seminar.



Stuart Matthews
President and CEO
Flight Safety Foundation

November 2005

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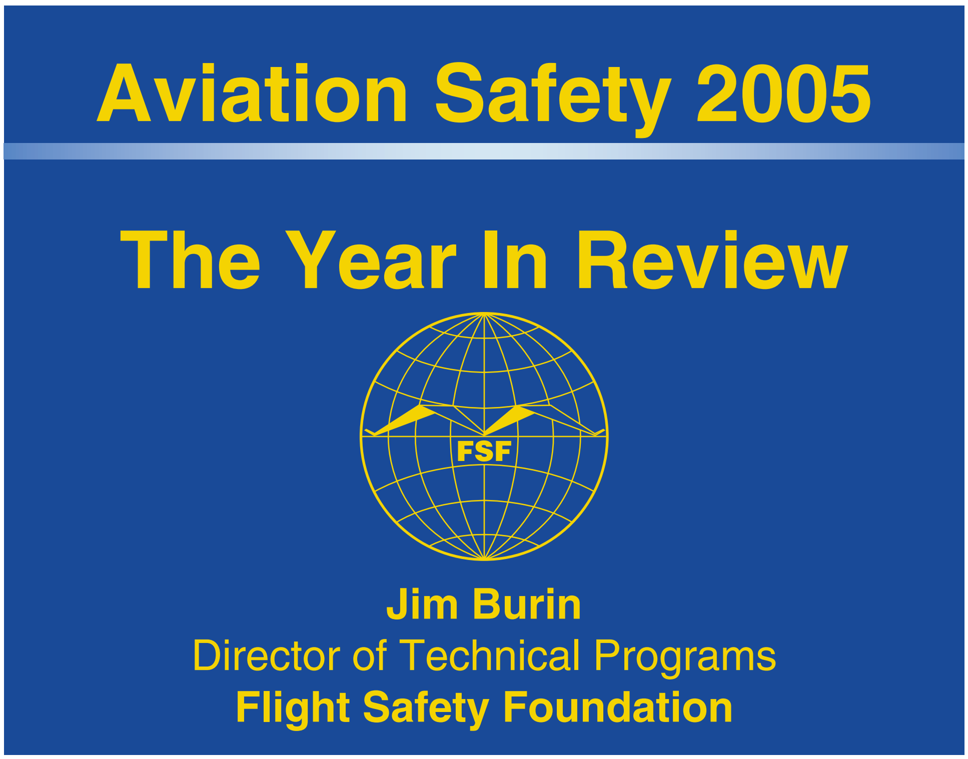
Aviation Safety 2005: The Year in Review

James Burin
Flight Safety Foundation



This morning we will look at aviation safety data for this year and compare it to past years.

This year we will again include some data for Eastern-built aircraft. These will be noted in the brief.

I would like to acknowledge the assistance of Paul Hayes and Airclaims and Andrew Sachs and Boeing in compiling the data presented here.

I will be reviewing this year’s safety performance and looking at where commercial aviation stands safety-wise.

I will start with turbojets, both large (greater than 60,000 pounds maximum takeoff weight) and small.

Information on commercial turboprops will also be presented.

We will also look more closely at the three highest risk areas: CFIT, approach and landing, and loss of control.

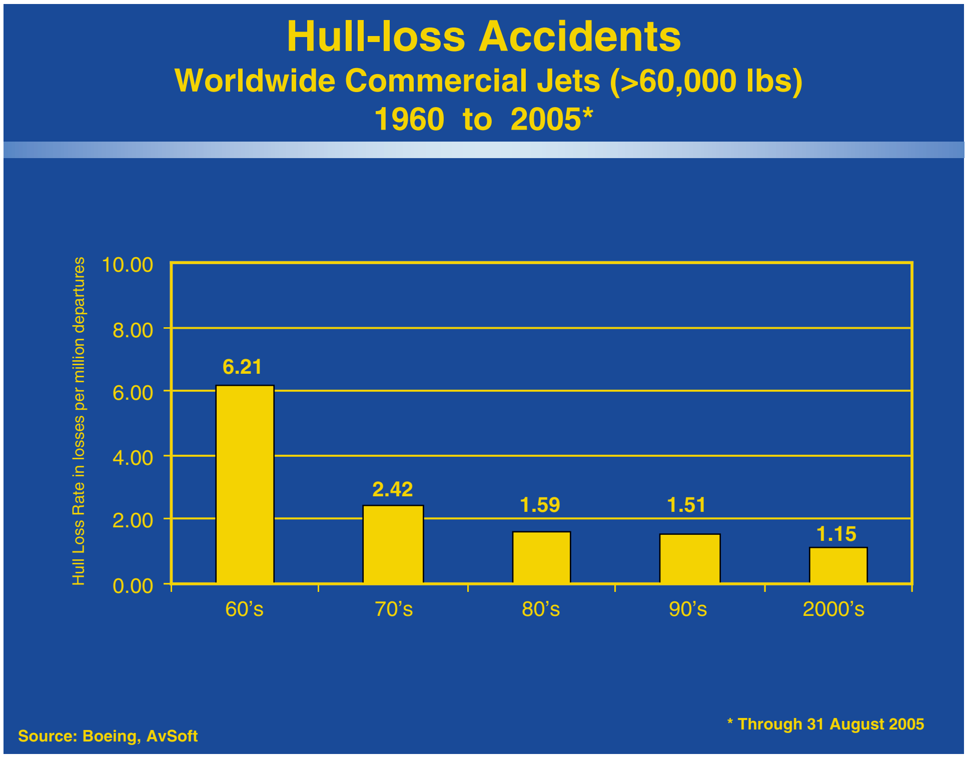
Finally, we will look at the main safety challenge that we need to address.

The Fleet — 2005

Type	Western-built	Eastern-built	Total
Turbojets	19,445	3,072	22,517
Turboprops	9,232	3,699	12,931
Business Jets			13,535

As a starting point, this is what the commercial and corporate aircraft fleet looks like in 2005.

The turbojet and business jet numbers are growing while the overall turboprop numbers are staying almost constant.



This shows the improvement in the hull-loss accident rate we have made over the past four-plus decades since the introduction of the jet airliner.

You can see we have maintained a steady decrease in the accident rate — an average improvement of 32 percent per decade.

That means we have reduced the accident rate by an average of one-third every 10 years.

Even for an already safe system, that is an impressive accomplishment.

Now on to this year's data.

Hull-loss Accidents Worldwide Commercial Jets (> 60,000 lbs) 1 January to 1 September 2005					
Date	Operator	Aircraft	Location	Phase	Fatal
4 January	Tri M.G. Intra Asia	B-737	Banda Aceh, Indonesia	Landing	0
8 January	Aerorepublica	MD-80	Cali, Colombia	Landing	0
3 February	Air West Cargo	IL-76	Khartoum, Sudan	En route	7
3 February	Kam Air	B-737-200	Kabul, Afghanistan	En route	104
19 March	Race Cargo Airline	B-707-300	Entebbe, Uganda	Approach	0
23 March	Airline Transport	IL-76	Mwanza, Tanzania	Takeoff	8
7 April	ICARO Air	F-28	Coca, Equador	Landing	0
20 April	Saha Air	B-707-300	Tehran, Iran	Landing	3
10 May	Northwest	DC-9	Minneapolis, USA	Taxi	0
19 June	Mahfooz Aviation	B-707	Addis Ababa, Ethiopia	Landing	0
1 July	Biman Bangladesh	DC-10	Chittagong, Bangladesh	Landing	0
2 August	Air France	A-340	Toronto, Canada	Landing	0
14 August	HELIOS Airways	B-737-300	Grammatikos, Greece	En route	121
16 August	West Caribbean	MD-82	Machiques, Venezuela	En route	160
23 August	TANS Peru Airlines	B-737-200	Pucallpa, Peru	Landing	40

Source: Airclaims, Aviation Safety Network, News Reports

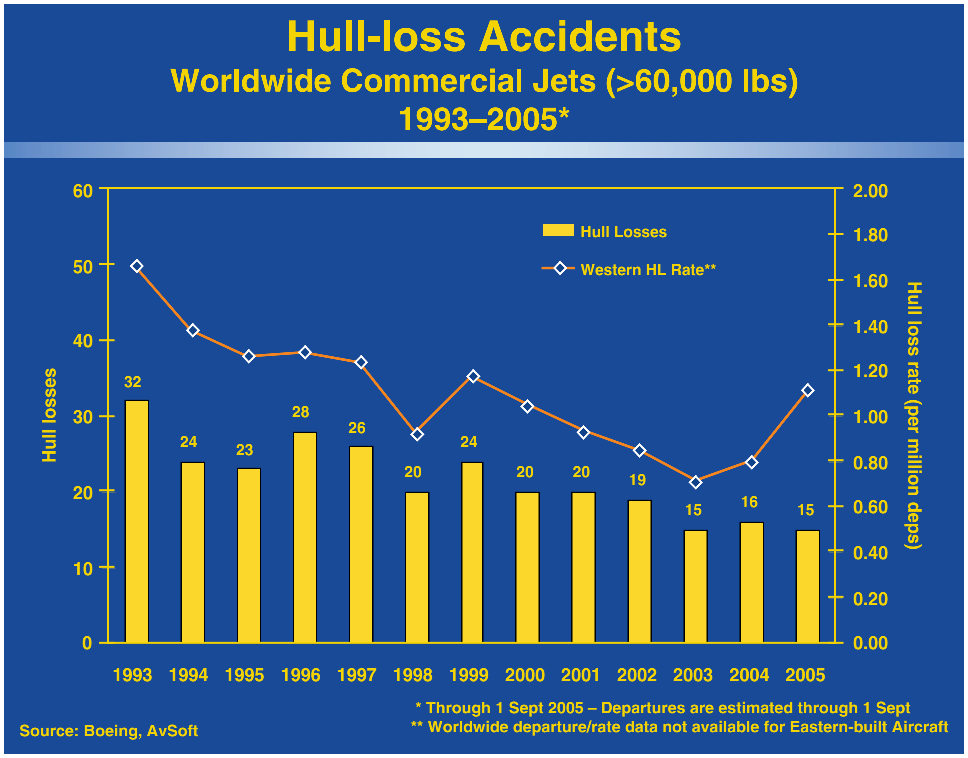
This chart lists the hull-loss accidents that have occurred up to 1 September 2005 to commercial jet airplanes over 60,000 pounds maximum takeoff weight. All cargo and passenger operations for Western- and Eastern-built aircraft are included in this chart.

You can see that there have been 15 hull-loss accidents so far in 2005.

Note that eight of the 15 accidents (more than half) had no fatalities.

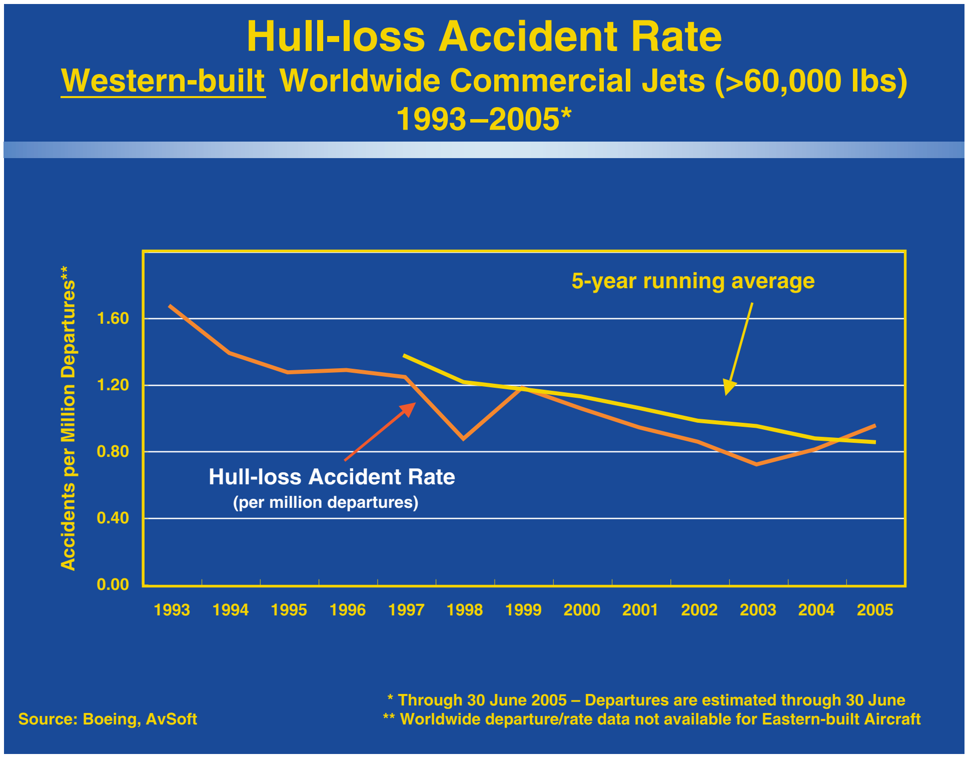
Also note that eight have been approach-and-landing accidents (ALAs), and there were two CFIT accidents.

This chart shows both the number of hull losses and the hull-loss rate in losses per one million departures for the last 10 years.



The hull-loss numbers are for both Eastern- and Western-built aircraft.

The rate is only for Western-built aircraft because, even though we have the numbers of hull losses for Eastern-built aircraft, we do not have reliable worldwide exposure data to calculate rates for them.



This chart shows both the hull-loss rate in losses per one million departures for the last 10 years, and the five-year running average of that rate.

Again, this chart is only for Western-built aircraft since it involves rates.

The rate shows a decreasing trend.

Hull-loss Accidents

Worldwide Business Jets* (< 60,000 lbs)
1 January to 1 September 2005

Date	Operator	Aircraft	Location	Phase	Fatal
1 January	Jet Services	Citation II	Ainsworth, NE, USA	Approach	0
28 January	Million Air	Learjet 35	Kansas City, MO, USA	Landing	0
2 February	Platinum Jet	Challenger 600	Teterboro, NJ, USA	Takeoff	0
21 February	Scott Aviation	HS 125	Bromont, Canada	Approach	0
16 February	Circuit City Stores	Citation V	Pueblo, CO, USA	Approach	8
24 February	Colima State Gov	Westwind	Morelia, Mexico	Enroute	7
8 March	Air Global	Citation I	Caracas, Venezuela	Approach	2
9 May	Compas Acquisitions	Sabreliner	Brownwood, TX, USA	Takeoff	0
15 May	Weibel Scientific	Citation I	Atlantic City, NJ, USA	Landing	0
20 May	Jet 2000	Falcon 20	Moscow, Russia	Descent	0
15 July	Aspen Aviation	Learjet 35	Vail, CO, USA	Landing	0

Source: Airclaims, Aviation Safety Network, News Reports * Business, Corporate, or Executive Jet Operations

This chart lists the hull-loss accidents that have occurred up to 1 September to jet airplanes less than 60,000 pounds in commercial or corporate operation.

You can see that there have been 11 hull losses so far in 2005.

Seven have been ALAs, none CFIT so far.

Hull-loss Accidents

Worldwide Commercial Turboprops (> 14 seats)
1 January to 1 September 2005

Date	Operator	Aircraft	Location	Phase	Fatal
8 January	Service Air	Antonov 12	Uganda	Approach	6
13 January	AirNow	Embraer 110	USA	Landing	1
22 January	ANAF	Antonov 8	D.R. Congo	Approach	0
27 January	Farnair Hungary	Let 410	Romania	Approach	2
16 February	Trident Aviation	DHC-5 Buffalo	Sudan	Approach	0
22 February	Missionary Aviation	DHC-6 Twin Otter	New Guinea	Approach	2
22 February	TAM	Convair CV-580	Bolivia	Takeoff	0
16 March	Regional Airlines	Antonov 24	Russia	Approach	28
26 March	West Caribbean Airways	Let 410	Colombia	Climb	8
28 March	Aerocaribbean	Ilyushin 18	Venezuela	Takeoff	0
31 March	RPS Air Freight	Antonov 12	Yemen	Takeoff	0
12 April	GT Air	DHC-6 Twin Otter	Indonesia	En route	17
20 April	Aero Union	Lockheed P-3	USA	En route	3
25 April	ATMA	Antonov 12	Afghanistan	Landing	0
1 May	Wideroe	Dash 8	Norway	Landing	0
2 May	Airwork NZ	Metro	New Zealand	En route	2
5 May	Kisangani Airlift	Antonov 26	D.R. Congo	Approach	11

Source: Airclaims, Aviation Safety Network, News Reports

This chart and the next one list the commercial turboprop hull-loss accidents up to 1 September in 2005. This is for all Western- and Eastern-built turboprop aircraft with greater than 14 seats.

Hull-loss Accidents

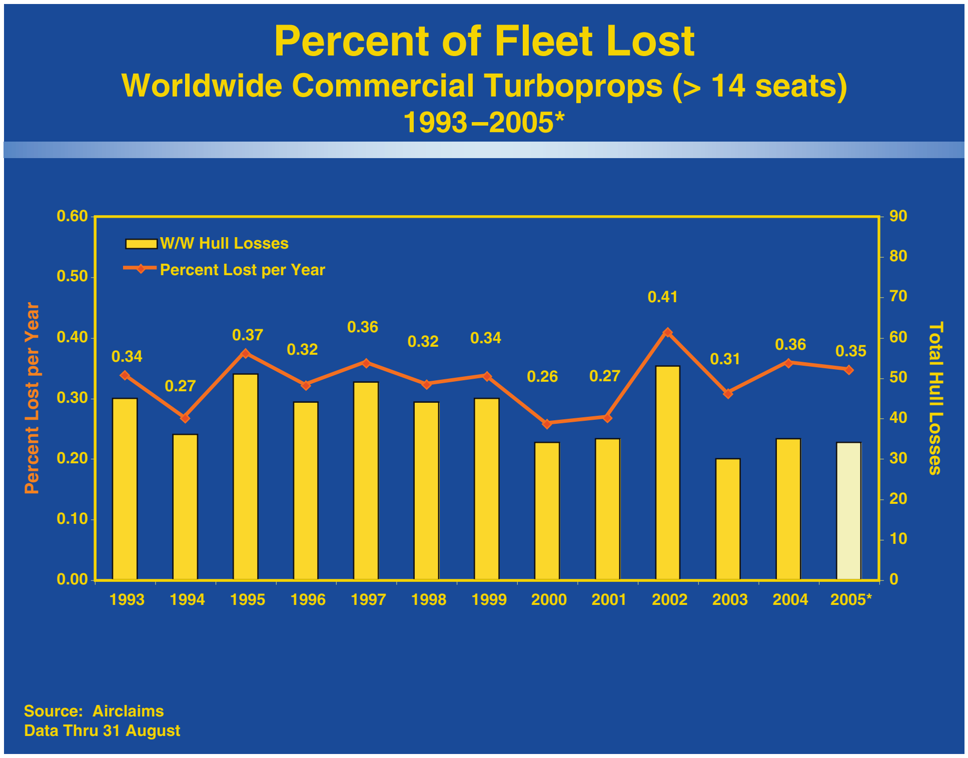
Worldwide Commercial Turboprops (> 14 seats)
1 January to 1 September 2005 Cont'd

Date	Operator	Aircraft	Location	Phase	Fatal
7 May	Aero-Tropics	Metro	Australia	Approach	15
25 May	Victoria Air	Antonov 12	D.R. Congo	En route	26
2 June	Marsland Aviation	Antonov 24	Sudan	Takeoff	7
2 June	TAG	Let 410	Guatemala	Climb	0
4 June	AerOhio	DHC-6 Twin Otter	USA	Landing	0
10 June	TransAfrik	Lockheed Hercules	Kenya	Landing	0
10 June	748 Air Services	HS 748	Kenya	Landing	0
16 July	Equatair	Antonov 24	Guinea	En route	62
21 July	Securite Civile	CL 415	France	En route	2
6 August	Tuninter	ATR 72	Palermo, Sicily	En route	16

Source: Airclaims, Aviation Safety Network, News Reports

You can see that there were 27 turboprop hull losses so far compared with the 15 commercial jet hull losses.

Twelve have been approach-and-landing accidents, and seven (that's more than 25 percent) have been CFIT accidents.



- Determining a standard type of accident rate for turboprops is difficult due to the lack of accurate hours or departure information. As a substitute for a rate based on hours or departures, this graph shows the loss rate by percentage of the fleet lost each year.
- As you can see, the turboprop percentage of the fleet lost each year has been consistently around 0.33, and it is high compared with the 0.05 loss rate for commercial jets.
- This is not a surprise, since the turboprop fleet is a little more than half the size of the commercial jet fleet, yet it has a higher number of hull losses.

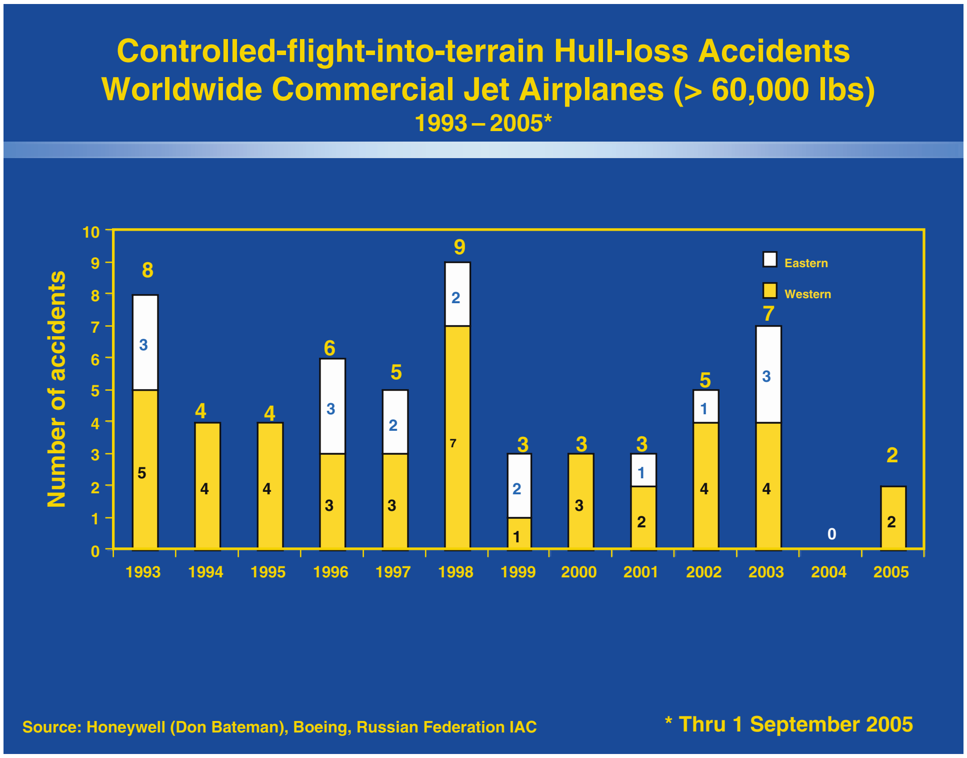
- Now let’s shift from general data to some specific problem areas.
- As was the case for the last 20 years, controlled-flight-into-terrain (CFIT), approach-and-landing, and loss-of-control accidents continue to claim the majority of our aircraft involved in accidents and account for the majority of our fatalities.

Controlled-flight-into-terrain Hull-loss Accidents
Worldwide Commercial Jet Airplanes (> 60,000 lbs)
1 January through 1 September 2005

Date	Airline	Aircraft	Location	Phase	Fatal
4 February	Kam Air	B-737-200	Kabul, Afghanistan	Approach	104
19 March	Race Cargo Airline	B-707-300	Entebbe, Uganda	Approach	3

Source: Honeywell (Don Bateman), Boeing, Russian Federation IAC, Airclaims

This is a list of the CFIT accidents for Eastern-and Western-built commercial jets in 2005.



This is a summary of CFIT accidents over the last ten years for commercial jets. It shows the breakdown in CFIT accidents between Western- and Eastern-built aircraft. This isn't done to single out the differences, but rather to show that the pattern is similar.

You will note that last year was our first ever with none. It highlights that sustaining low CFIT rates has been difficult. We have continued to average four CFIT accidents a year for the last 10 years.

Let me also point out that every CFIT accident on this chart, and indeed every CFIT accident to big jets, small jets and turboprops happened to aircraft without EGPWS installed.

Approach-and-landing Hull-loss Accidents Worldwide
Commercial Jet Airplanes (> 60,000 lbs)
1 January through 1 September 2005

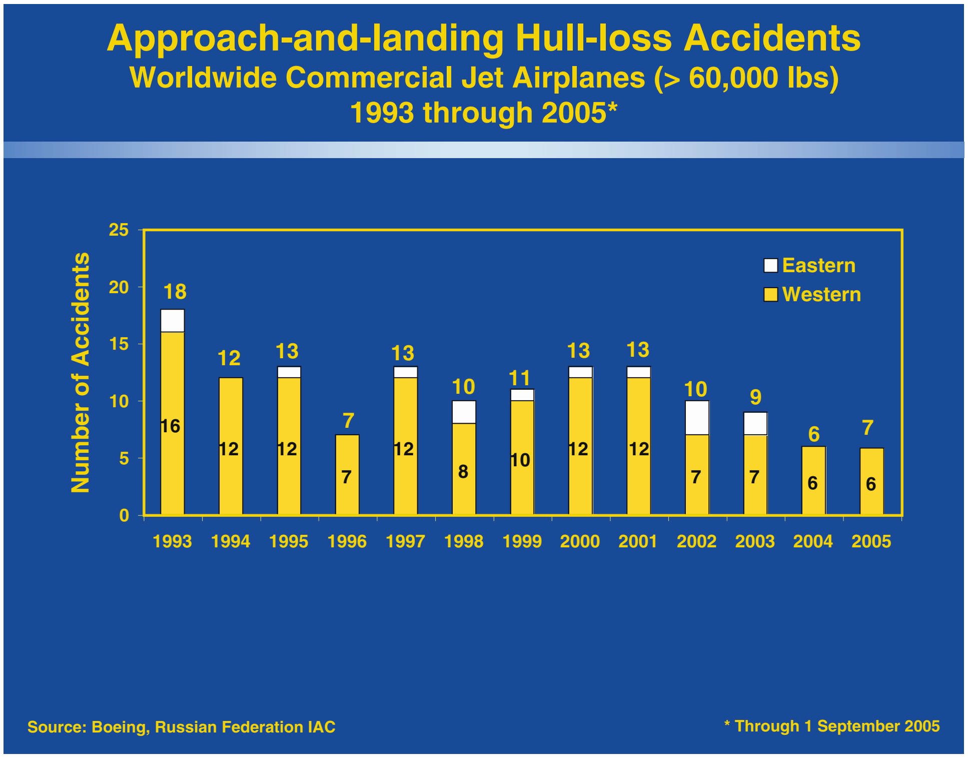
Date	Airline	Airplane Type	Location	Phase	Fatal
4 January	Tri M.G. Intra Asia	B-737	Banda Aceh, Indonesia	Landing	0
11 January	Aerorepublica	MD-80	Cali, Colombia	Landing	0
3 February	Air West	IL-76	Khartoum, Sudan	Approach	7
19 March	Race Cargo Airline	B-707-300F	Entebbe, Uganda	Approach	3
7 April	ICARO Air	F-100	Coca, Spain	Landing	0
20 April	Saha Air	B-707-300	Tehran, Iran	Landing	3
2 August	Air France	A-340	Toronto, Canada	Landing	0
23 August	TANS Peru Airline	B-737-200	Pucallpa, Peru	Landing	40

Source: Boeing, Russian Federation IAC, Airclaims

This is a list of the approach-and-landing hull-loss accidents involving commercial jets in 2005.

Again, note that four of the eight accidents had no fatalities.

Remember also that five of the nine hull losses involving jets less than 60,000 pounds happened during approach and landing and 60 percent of the turboprop hull losses were approach-and-landing accidents.



Here are the approach-and-landing hull-loss accidents for the last 10 years.

Clearly, the industry must continue to focus on this phase of flight. Most, if not all, of the causes of these accidents are well documented and addressed in the ALAR tool kit — NPA, weather, unstable approach, lack of go-arounds — there is nothing new.

As you know, the Foundation's CAAG team is continuing its worldwide ALAR campaign with regional workshops to address this challenge. In the past year we have conducted ALAR workshops in New Zealand, Alaska, United Arab Emirates and Oman.

Hopefully, some of the success we are seeing now is because of the CAAG team's efforts.

If you are interested in an ALAR workshop for your region, talk to me.

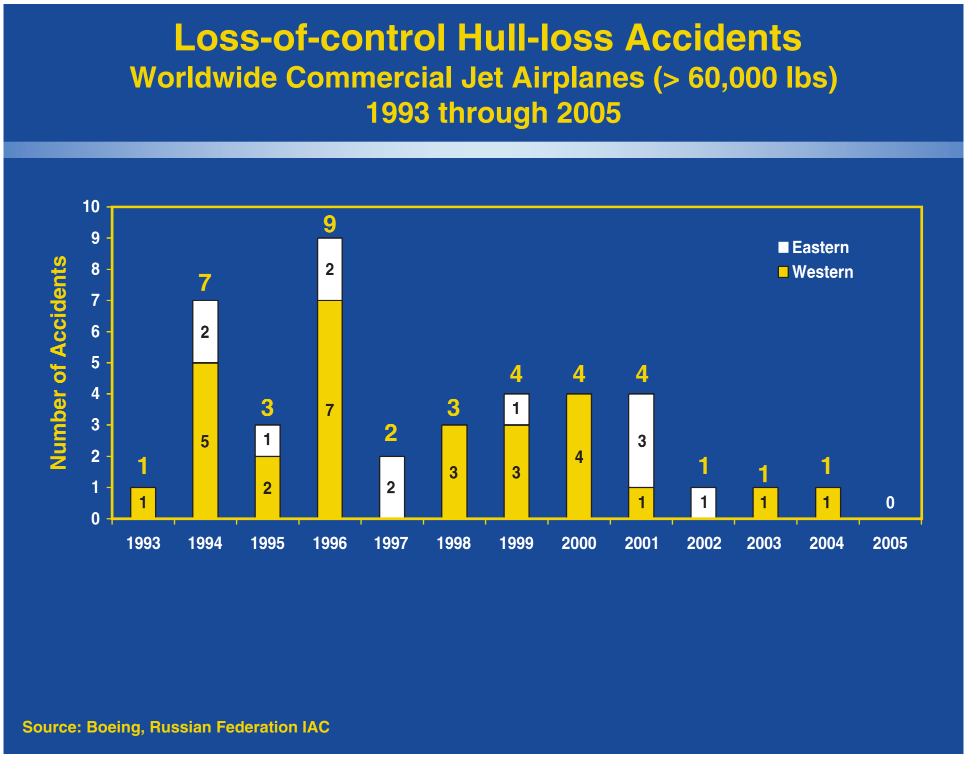
Loss-of-control Hull-loss Accidents
Worldwide Commercial Jet Airplanes (> 60,000 lbs)
1 January through 1 September 2005

Date	Operator	Airplane Type	Location	Phase	Fatal

No Loss-of-control Accidents for 2005

Source: Boeing, Russian Federation IAC, Airclaims

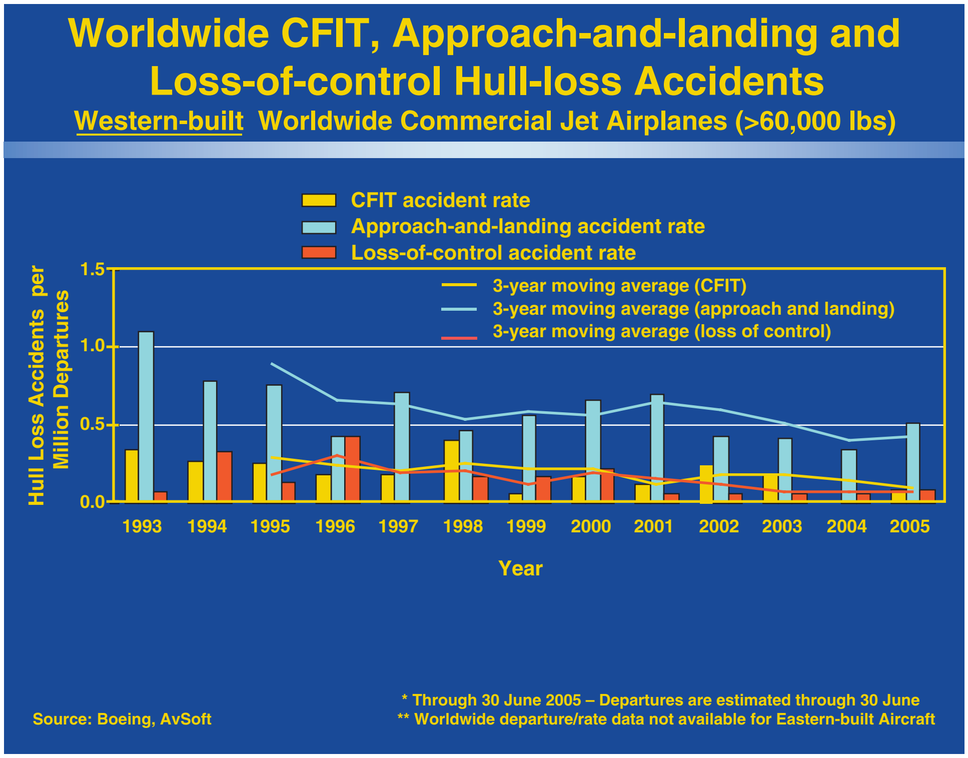
There have been no loss-of-control accidents so far in 2005.



Here are the last 10 years of loss-of-control accidents.

You can see that there is not a consistent pattern over this time period, but things have improved greatly over the last four years.

The revised version of the Upset Recovery Training Aid will hopefully enable us to continue to reduce the risk in this critical area.



This shows CFIT, approach-and-landing, and loss-of-control accident rates in hull losses per million departures for the last 10 years. It also shows the three-year moving average of each. Again, since these are rates, they are for Western-built aircraft only.

As you can see, CFIT and loss of control, the two biggest killers, are both showing a downward trend.

Now let me move away from numbers and charts and talk about the major challenge for the international aviation community.

Let me start by showing you a goal I think we can all agree on …

Simply stated:

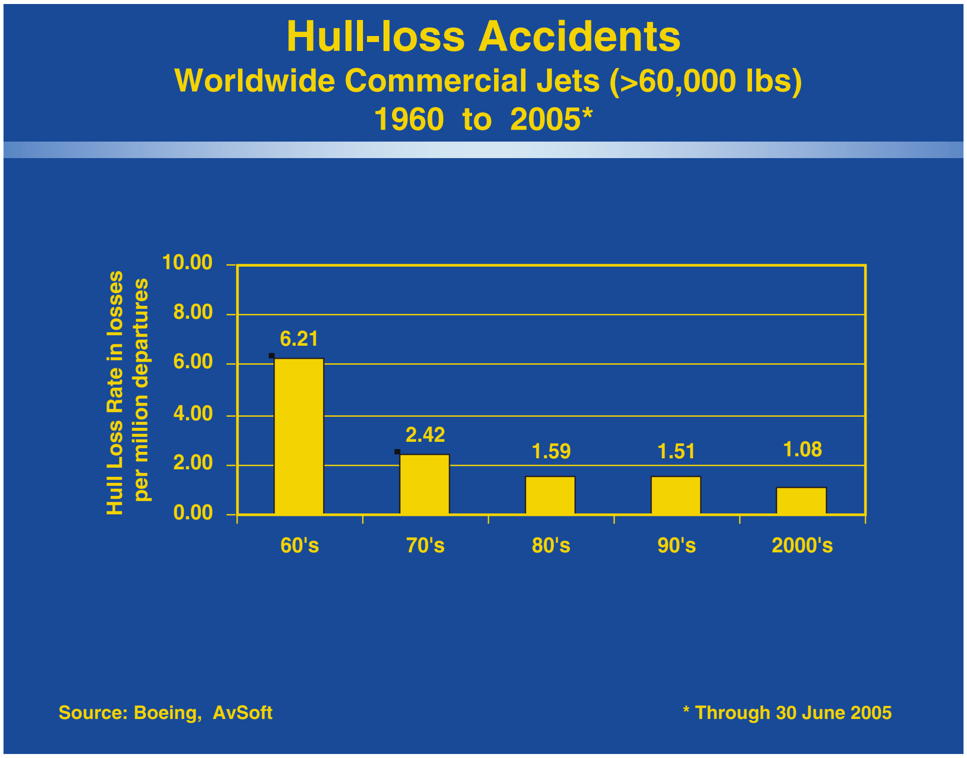
The Foundation exists to make aviation safer.

- One good question to ask after all those numbers I showed you is: “So what?”
- What does this mean to you? With less than one hull-loss accident for every million departures in commercial aviation — and corporate and general aviation rates improving: most likely your organization did not have an accident last year, or maybe in any year — don’t forget that you had the risk of one every time you flew.
- Commercial aviation has never had a year with no accidents — so there is work to do and challenges to address.

This is a challenge we all face every day. It is indeed the biggest challenge we face — making this system, this ultra-safe system — even safer.

How have we been doing at this massive task?

Here is an interesting piece of trivia: During the last 30 years, the best year ever was 1984 — 0.67 hull losses for every million departures. The worst year ever was 1983, when the rate was 2.41. Both happened over 20 years ago.

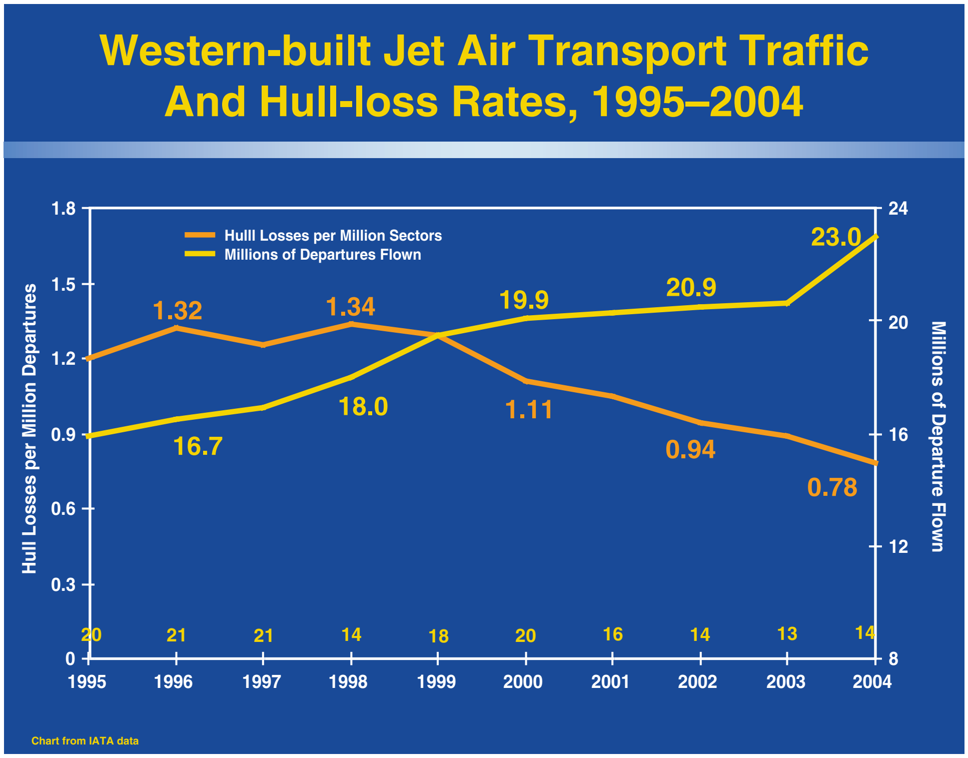


You saw this slide earlier. It shows the improvement in the hull-loss accident rate we have made over the past four-plus decades since the introduction of the jet airliner.

You can see that we have maintained a steady decrease in the accident rate — an average improvement of 32 percent per decade.

That means we have reduced the accident rate by an average of one-third every 10 years. Even for an already safe system, that is an impressive accomplishment.

Don't forget, it looks impressive (and is) when you reduce the rate one-third from six to four or from 2.5 to 1.7. But remember, it is equally impressive (but not as visible) when you reduce it by one-third from 0.9 to 0.6.



Here is another chart showing the last 10 years of departures and hull-loss rates. The number of hull losses is above the year. Over this period, the number of accidents has actually decreased while we continue to fly more and more departures. That is an impressive accomplishment.

Now a question we all need to ask is, how are we getting the rate so low? Why have we been so successful? Here are some factors to consider. Is the reason for our success …

- The aircraft?
- Training?
- Technology? (EGPWS, TCAS, EFBs)

Organizations? (CAST, PAAST, COSCAP, JSSI, ICAO, FSF, IATA, IASI)

Processes/Programs? (such as FOQA, ASAP, LOSA)

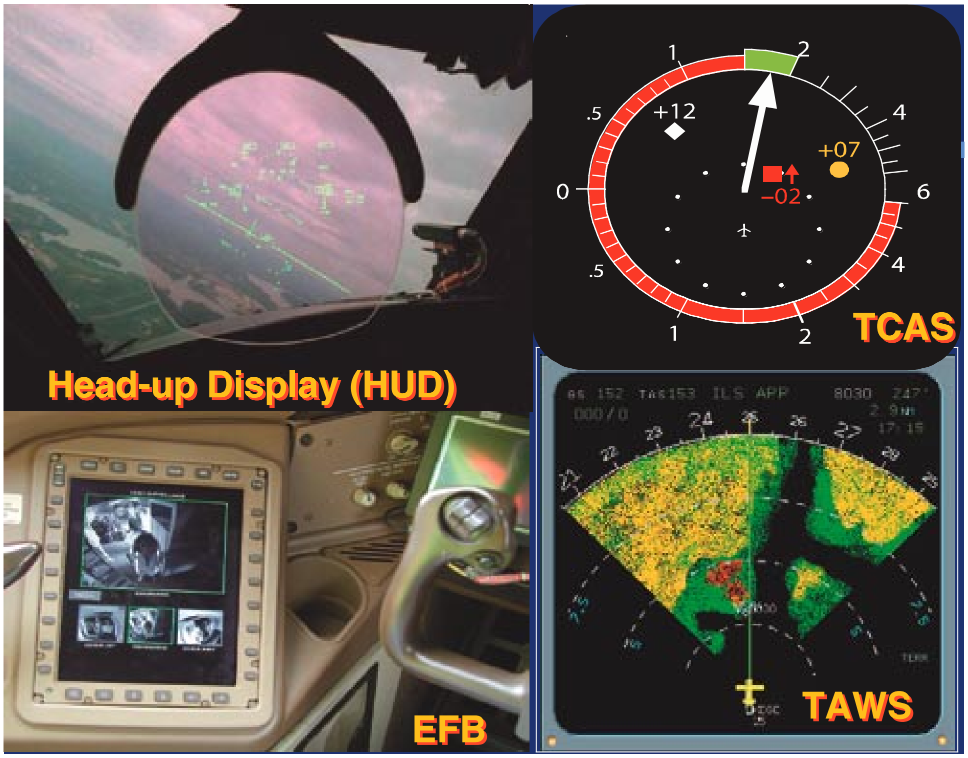
Or being data-driven ? The answer is, all of these.

First of all, it is because of the aircraft. Each new generation has been better, safer, and the accident rates show that. In addition, the aircraft accident rates of the new aircraft have started low and stayed there.

For example, until the recent A340 accident in Canada, there had not been an accident with the newest generation of aircraft – B-777, A330, A340 – in over 14 years of commercial operation.

Training is another area where we have made great strides. With the advent of programs like AQP, LOFT and other training initiatives, training has been a great asset in reducing risk.

Technology has helped in training, and in other areas …



Here are some examples of the kinds of technology that have contributed to our great success.

HUDs are just coming into more widespread use — but those who are using them are quite impressed with their capabilities — and their risk-reduction potential.

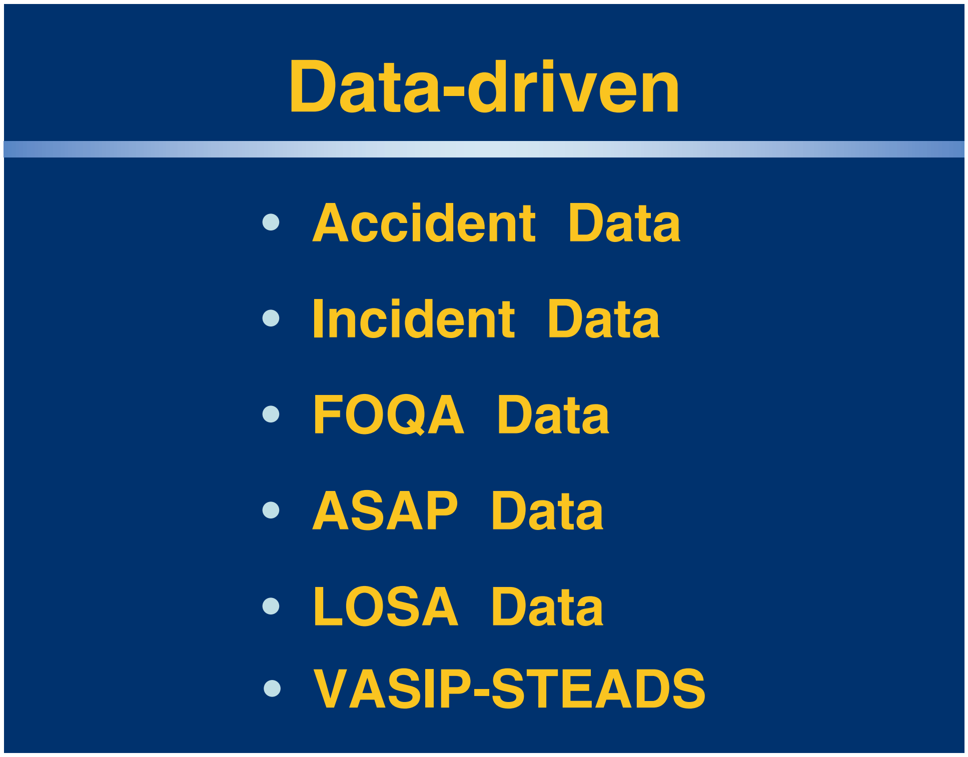
Electronic flight bags (EFBs), like HUDs, are just coming into use — but the risk-reduction potential they bring is significant.

TCAS continues to reduce the risk of midair collisions, and the midair safety data reflects its great success.

Terrain awareness and warning system (TAWS) is in most commercial jets today. Despite an average of four CFIT accidents a year over the last 12 years for commercial jets, there has still never been a CFIT accident involving a TAWS-equipped aircraft. This one piece of equipment has probably saved more lives than any single piece of aviation equipment.

Now another reason we are so successful is that we are all data-driven. We use data to find the high risk areas, and we use data to see if the safety interventions we produce are indeed working.

Being data-driven in our safety efforts means we don’t try to focus on things like giraffe strikes when reducing things like CFIT and loss of control are much more effective in reducing the overall risk.



To get the data, we don't just rely on just accidents anymore.

The good news is that we have so few accidents that it is hard to get much data.

We use new sources of data — proactive or preventive type data.

In addition, we now have programs that utilize shared data — which makes the data even more powerful.

In addition to aircraft, training, technology and being data-driven, safety efforts today are more focused and more cooperative — both within regions, and between governments and industry.

CAST is a great example of industry and government working together.

PAAST is an example of a regional effort that has really accomplished great things.

The COSCAP programs are attempting to do the same in regions of the world that are new to this type of effort.

ICAO has become much more active in the international safety effort in many areas, including areas like the protection of safety information.

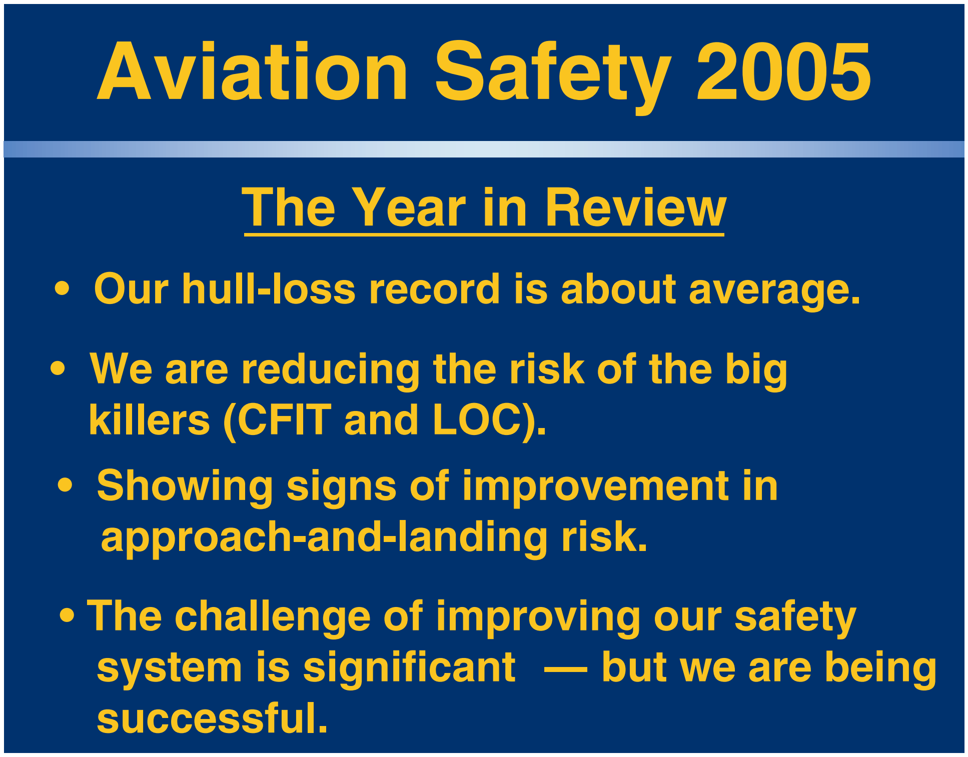
So why have we been so successful? It is everything I have listed: It's the aircraft, training, technology, being data-driven, and having cooperative efforts on an international level that have done it.

However, as I have said before, despite our impressive record and our great success, the public expects us to get better. This was evident in August when, after five tragic hull losses, the public questioned air safety, despite our proven record.

We all accept this and want to do even better. We have the tools, the procedures and the organizations to do that, but it will still take the commitment and effort to continue our record of improvement of our already safe system.

In summary, this is what we see so far in 2005:

- Our record, up to September, is average (which for commercial aviation means it is excellent).



- The historic leading killers for commercial jets, loss of control and CFIT, seem to be under control so far this year.
- We are finally showing signs of reducing the risk of approach-and-landing accidents.

The key is to make this a trend and not just a one-year event. That will not just happen — we all need to work at it.

And finally, we are meeting our greatest challenge, making our safe system even safer.

Back to our goal:

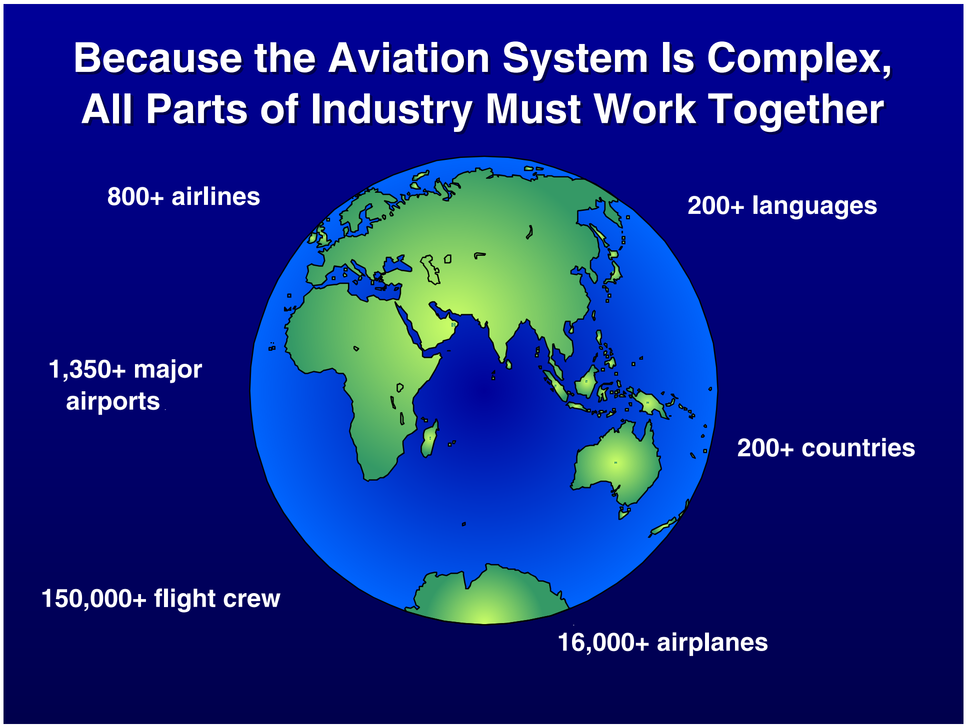
- In an industry where the risk will never be zero, and the public expects perfection as the minimum acceptable standard, we have quite a challenge.

- But all of us, working together, can meet that challenge and achieve our goal of reducing the risk of an accident.

♦♦♦♦

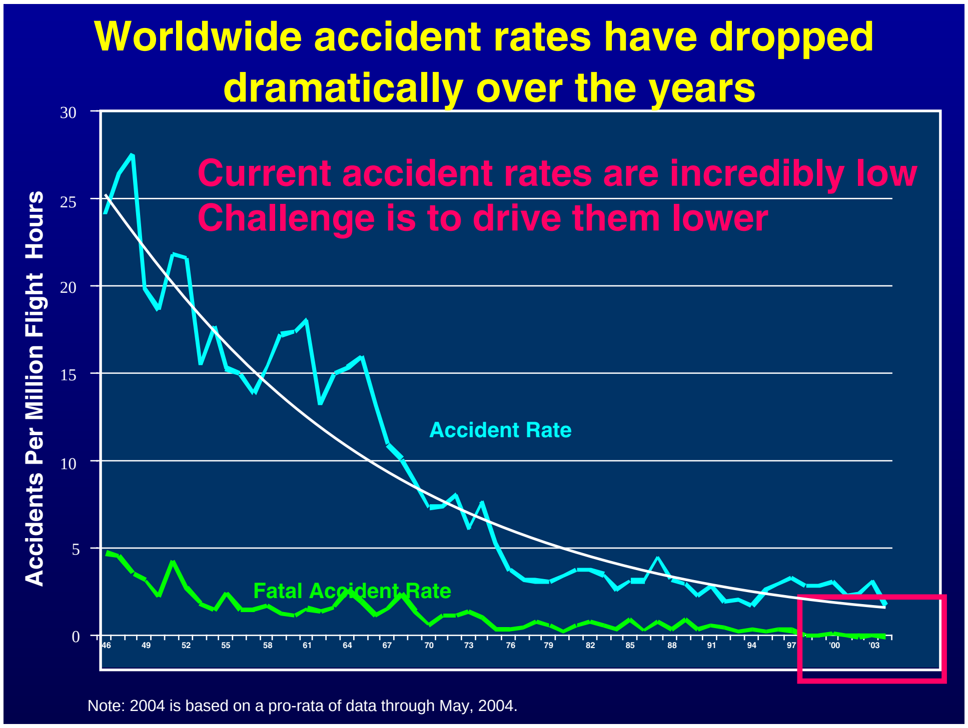
Regional Safety Team Efforts Overview

Kyle L. Olsen
U.S. Federal Aviation Administration



Over the years, many different approaches to improve safety have been developed. The most successful ones have resulted from industry, regulators, manufacturers and other involved organizations working together to address a common safety issue.

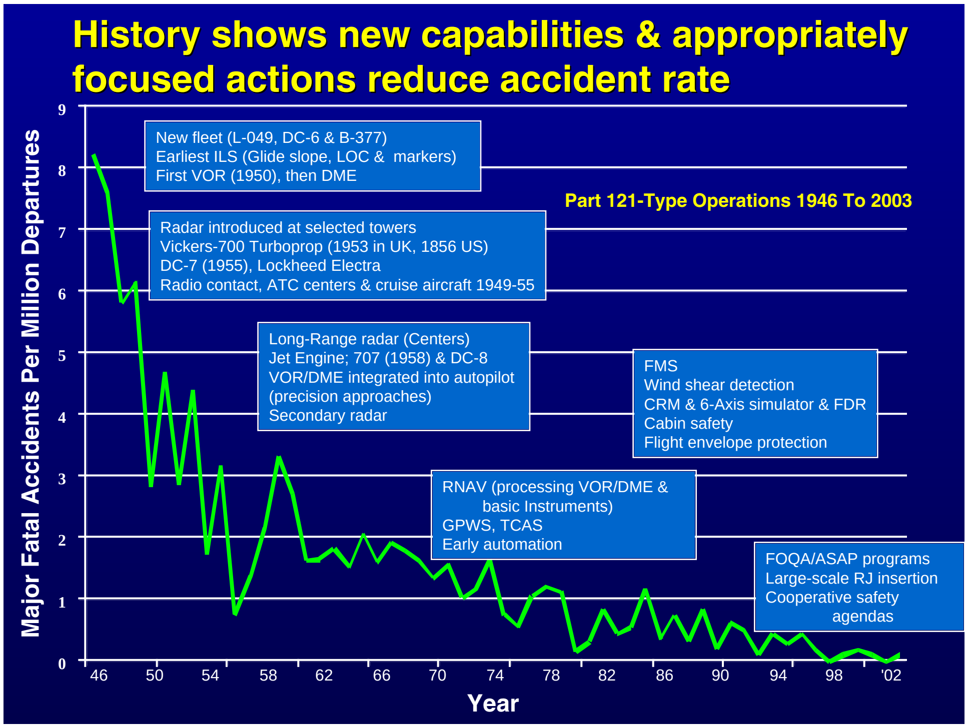
Recent years have seen a significant improvement in establishing and using joint teams in the safety arena.



Thanks to the dedication of everyone involved in the air transportation system, the global accident rate is very low. The challenge today is to drive this already low rate even lower.

If we are to achieve the next major breakthrough in that rate, we must move beyond the traditional government-industry model, complete with its adversarial role playing of regulator versus the regulated.

History provides a guide on how to achieve this breakthrough.


History shows new capabilities & appropriately focused actions reduce accident rate
Part 121-Type Operations 1946 To 2003
New fleet (L-049, DC-6 & B-377)
Earliest ILS (Glide slope, LOC & markers)
First VOR (1950), then DME
Radar introduced at selected towers
Vickers-700 Turboprop (1953 in UK, 1856 US)
DC-7 (1955), Lockheed Electra
Radio contact, ATC centers & cruise aircraft 1949-55
Long-Range radar (Centers)
Jet Engine; 707 (1958) & DC-8
VOR/DME integrated into autopilot
(precision approaches)
Secondary radar
FMS
Wind shear detection
CRM & 6-Axis simulator & FDR
Cabin safety
Flight envelope protection
RNAV (processing VOR/DME & basic Instruments)
GPWS, TCAS
Early automation
FOQA/ASAP programs
Large-scale RJ insertion
Cooperative safety agendas
Major Fatal Accidents Per Million Departures
0
1
2
3
4
5
6
7
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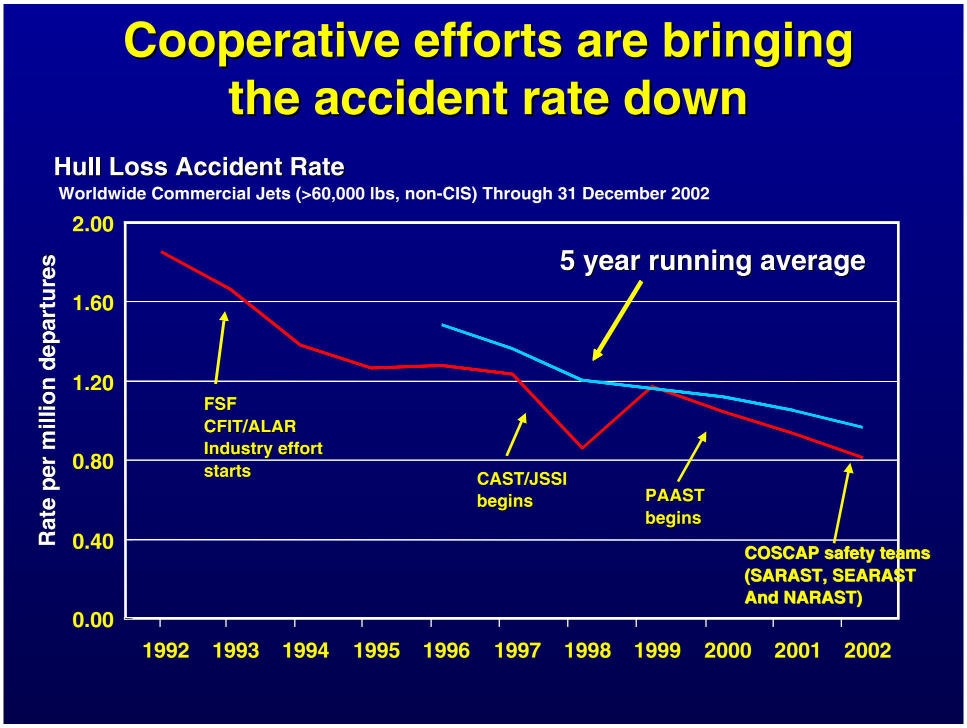
98
'02
Year



This chart shows the hull loss accident rate in losses per million departures and the five-year running average of that rate.

As you can see, the five-year average shows a definite and encouraging downward trend.

So, there is still work to be done. Our success in improving safety has made it more challenging to identify actions that will bring even more effective and affordable safety improvements.

Over the years, teams have been formed around the world to address threats to aviation safety. All of these teams rely on joint industry-regulatory cooperation. Operators, manufacturers, labor organizations and government provide members to support these teams.

Flight Safety Foundation sponsored the CFIT/ALAR Action Group (CAAG) to help implement basic aviation training that will improve safety throughout the world.

The Flight Safety Foundation CFIT and ALAR (Approach and Landing Accident Reduction) Action Group (CAAG), comprising government and industry representatives, developed the *ALAR Tool Kit*.

The Tool Kit is a CD with 34 briefing notes on subjects such as

1. Normal Checklists
2. Standard Callouts
3. Normal and Non-normal Operations
4. Effective crew/ATC communications
5. among other items.

The Tool Kit also contains

1. The CFIT Check List
2. Standard Operating Procedures (SOP) Template
3. Two CFIT training videos
4. Background reports

Flight Safety Foundation has distributed over 28,000 copies of the Tool Kit worldwide and the Federal Aviation Administration is distributing the Tool Kit to all FAA principal inspectors. The Tool Kit was initially released in 2000.

The Action Group (CAAG) developed the concept of Regional Team Leaders. These individuals accept the responsibility to be the focal point in their particular part of the world. Using information from Flight Safety Foundation, CAST, JSSI, etc., they develop plans tailored to their region to improve aviation safety in the region.

In North America, The Commercial Aviation Safety Team, known through its acronym of "CAST," was formed to bring all the players, including regulators, to the table in response to the challenge from then-U.S. Vice President Gore to reduce the fatal accident rate by 80 percent by 2007.

CAST is led by industry and government co-chairs.

Goals reflect the challenges put forward by the White House Commission on Aviation Safety & NCARC recommendations:

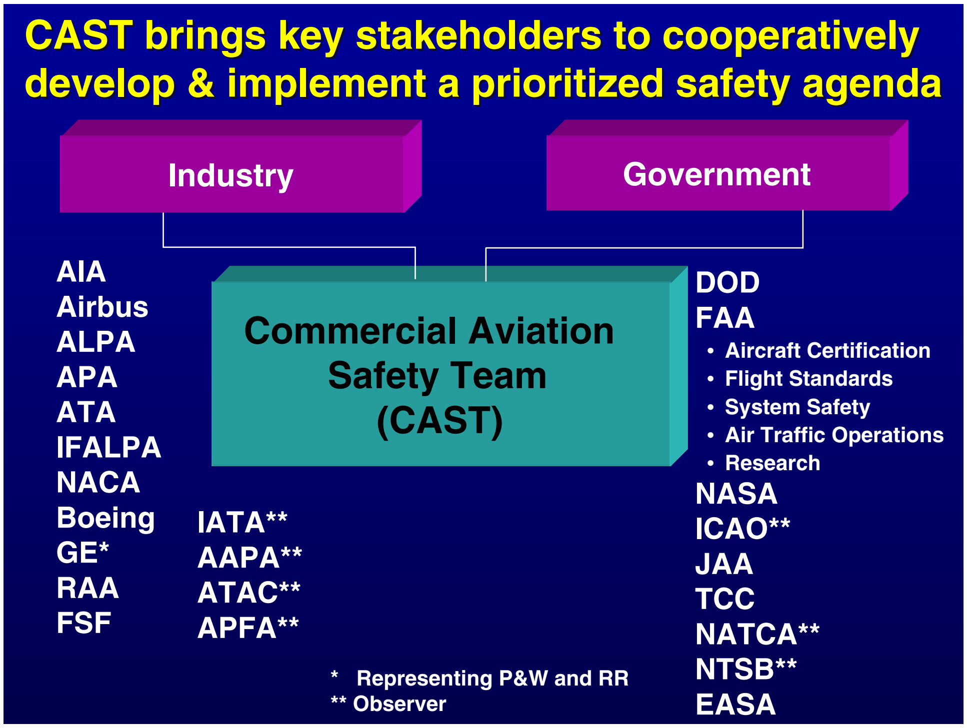
- Reduce the U.S. commercial aviation fatal accident rate by 80 percent by 2007.
- Work together with international organizations to reduce the worldwide commercial aviation fatal accident rate.

Goals originally viewed to be extremely aggressive

Now viewed as achievable

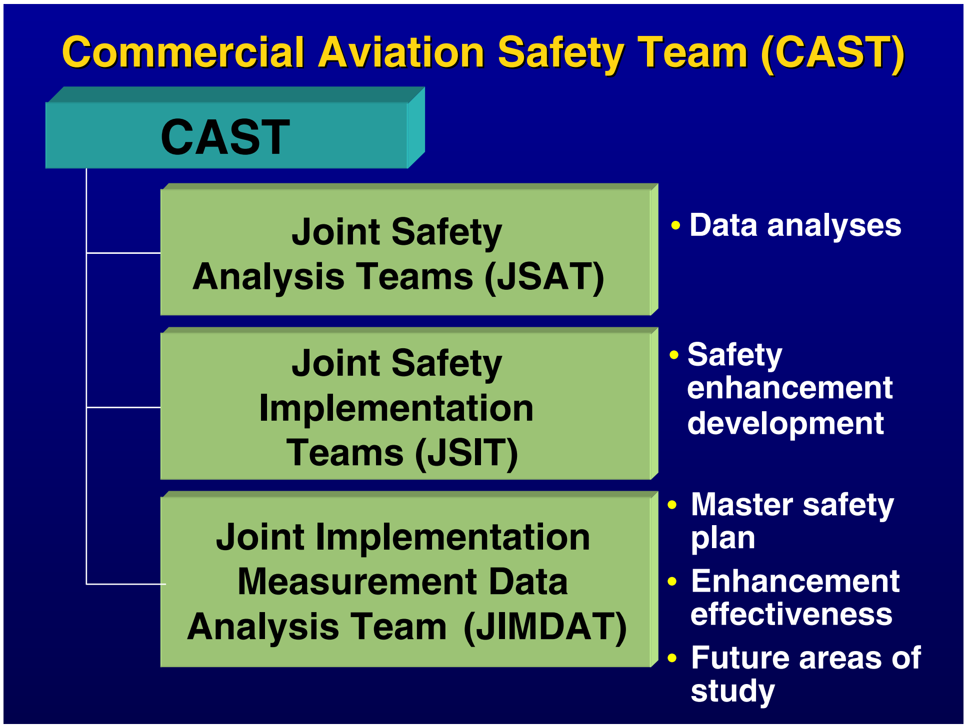
- In sight
- On track to meet

Maintain commitment and resolve



The strength of CAST lies in its extensive membership, its proactive commitment to safety and its ability to effect change. CAST has proven effective because it is a voluntary partnership of key stakeholders in the operation of the commercial aviation system, and safety leaders from those organizations who are able to commit and effect change. These organizations have come together voluntarily to improve aviation safety:

- Aerospace Industries Association (AIA)
- Department of Defense (DOD)
- Federal Aviation Administration (FAA)
- Allied Pilots Association (APA)
- Air Line Pilots Association, International (ALPA)
- National Aeronautics and Space Administration (NASA)
- International Civil Aviation Organization (ICAO)
- National Air Carrier Association (NACA)
- Joint Aviation Authorities (JAA)
- Pratt & Whitney (P&W)
- Air Transport Association (ATA)
- Transport Canada (TCC)
- Regional Airline Association (RAA)
- National Air Traffic Controllers Association (NATCA)
- Flight Safety Foundation (FSF) (observer)
- National Transportation Safety Board (NTSB)
- International Air Transport Association (IATA)
- European Aviation Safety Agency (EASA)
- Association of Asia Pacific Airlines (AAPA)
- Air Transport Association of Canada (ATAC)
- Association of Professional Flight Attendants (APFA)
- General Electric (GE)
- Rolls-Royce (RR)



Straightforward and rigorous process

JSAT — Analyze data

- Identify problems or precursors
- Propose interventions against those problems (can be out-of-the-box proposals)

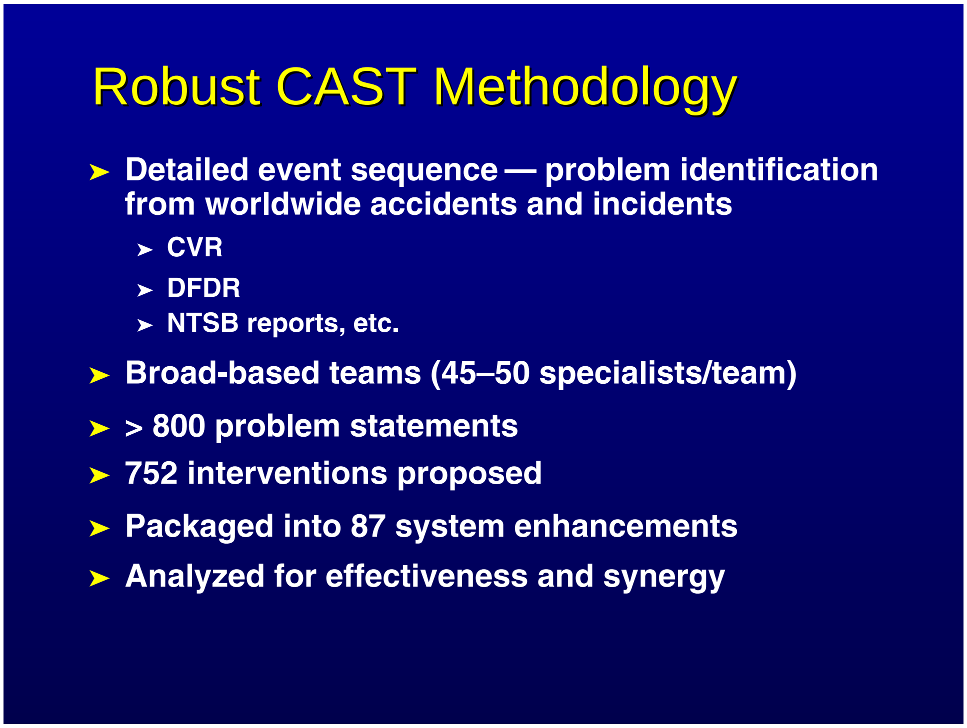
JSIT — Develop candidate safety enhancements

- Assess feasibility of interventions
- Group promising interventions into package of enhancements
- Develop Detailed Implementation Plans (DIPs)

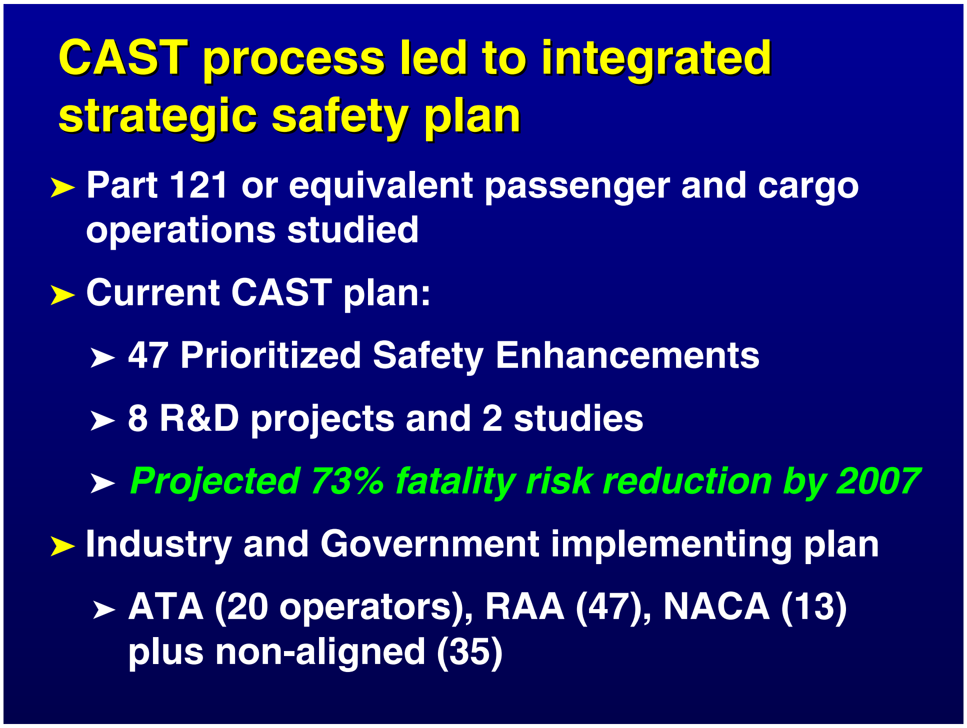
JIMDAT — Prioritization/Evaluation of Effectiveness

- Determine overall effectiveness of proposals
  - Some much more effective than others
  - Identify synergies
  - Recognize resource requirements
  - Develop into integrated, prioritized package of enhancements to the aviation *system* for CAST review

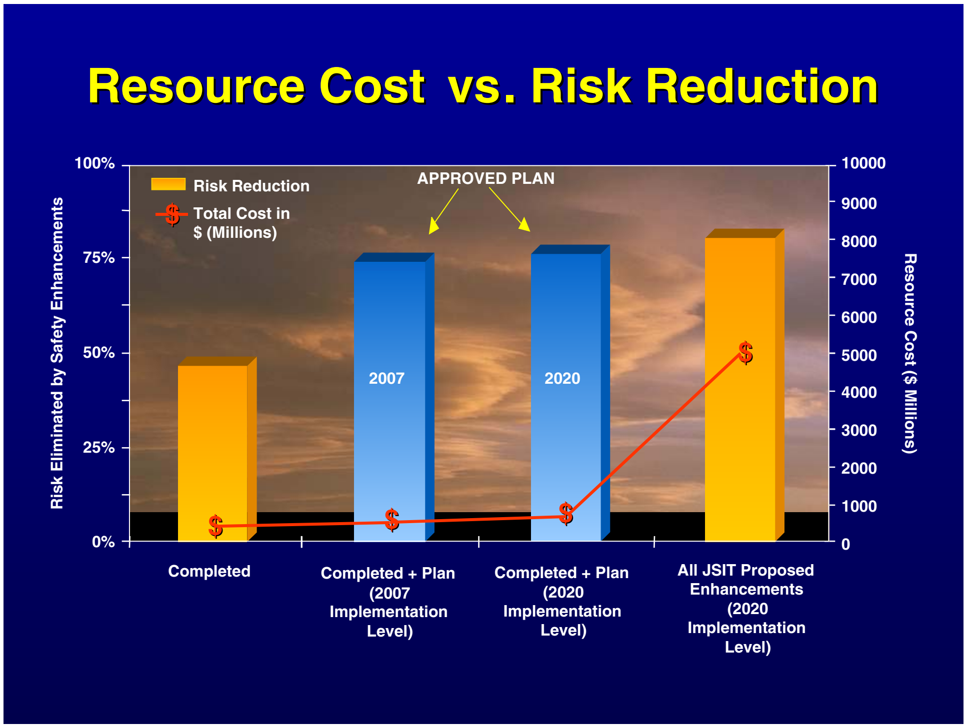
JIMDAT/JSIT interaction may be iterative to maximize effectiveness of the detailed implementation plans



- Extremely robust and disciplined process
- Amazing array of talent brought to bear to develop CAST plan
- Evidence of commitment of participants to the CAST process



Other ongoing enhancements bring the number to 78 percent.

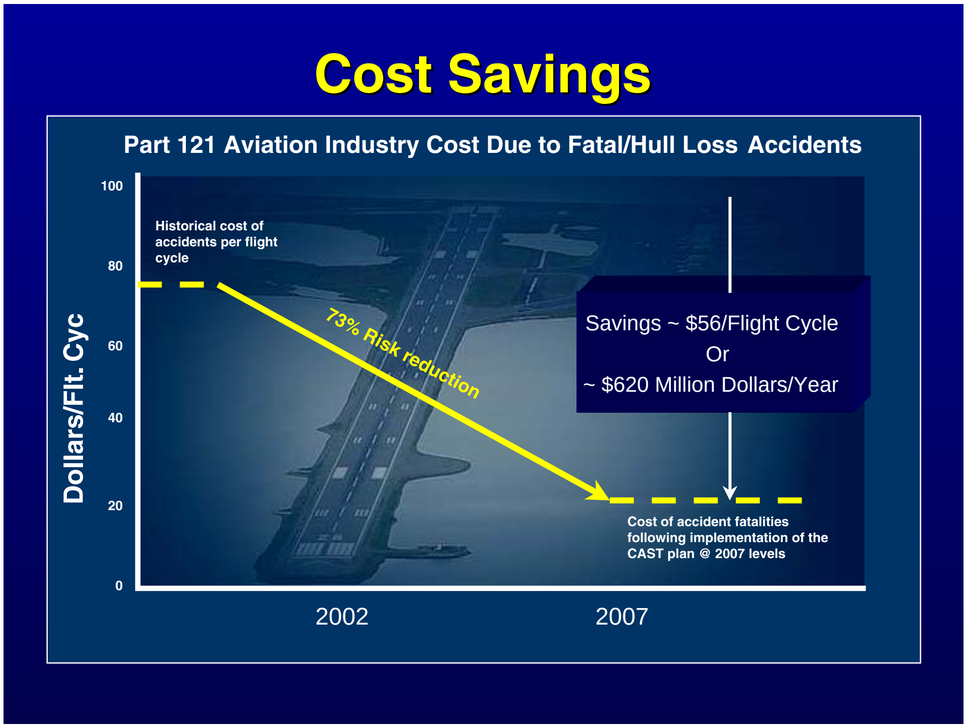


A graphical representation of resource application versus risk reduction, which also depicts the CAST JIMDAT prioritized selection criteria for the draft strategic plan.

In the example plot, it can be seen how the CAST plan items for 2007 and 2020 were selected using benefits versus resources and the rationale for not selecting all the solutions.

This represents the "sweet spot" in terms of prioritizing safety enhancements. The blue bars go well above 70 percent and approach 80 percent when we take credit for the effects that completed enhancements are bringing, as some of them are exceeding their projected success levels.

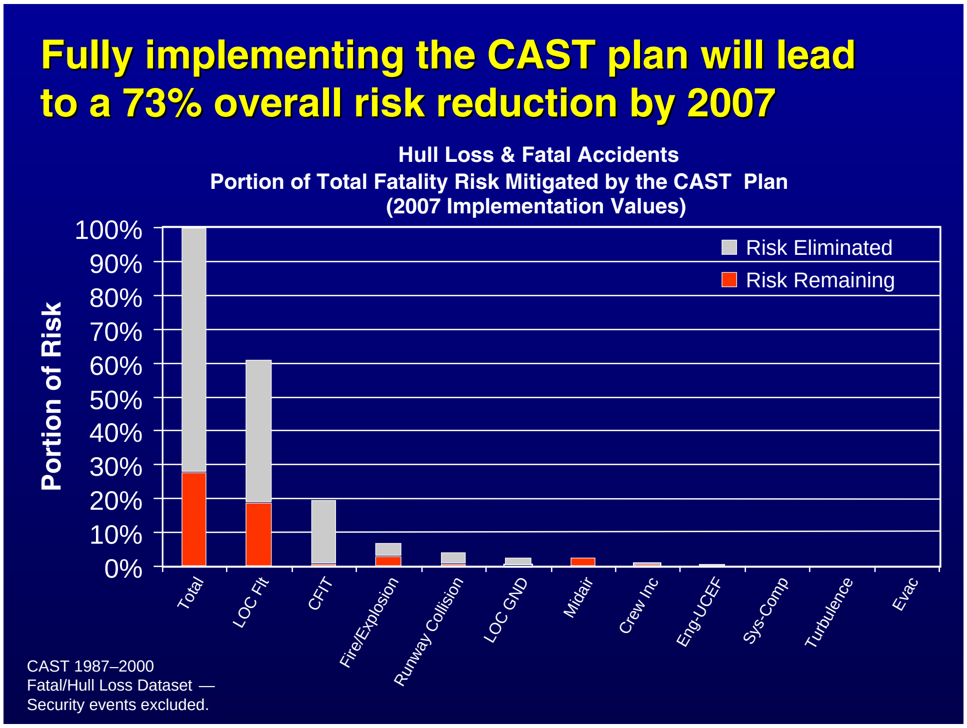
The tool developed by CAST to determine the priorities of various enhancements is included in the CAST CD, which will be distributed to all attendees. The CD contains not only the results of our analysis of the worldwide accident data from 1988–2001 but a "generic" spreadsheet with use instructions that can be tested in your own operating environment.



When we break down costs of our current accident rate, accidents cost us $76 for every flight.

By implementing the 46 carefully selected, data-driven safety enhancements, we will have reduced these costs by $56 per flight.

This adds up to a savings about $620 million *every year* into the future.



The CAST plan will reduce the fatal accident risk 73 percent by 2007.

This value increases to 78 percent when the beneficial effects of other ongoing safety initiatives developed outside of CAST by industry and government are considered.

The analysis also shows where there is more work to do (areas of remaining risk).

- Bulk of remaining risk is related to loss-of-control accidents.

We'll see more later about what CAST is doing to address this.

As you can see from this chart, we've made heavy emphasis on preventing CFIT — and though CFIT is still happening, it is on airplanes not yet upgraded with these enhancements.

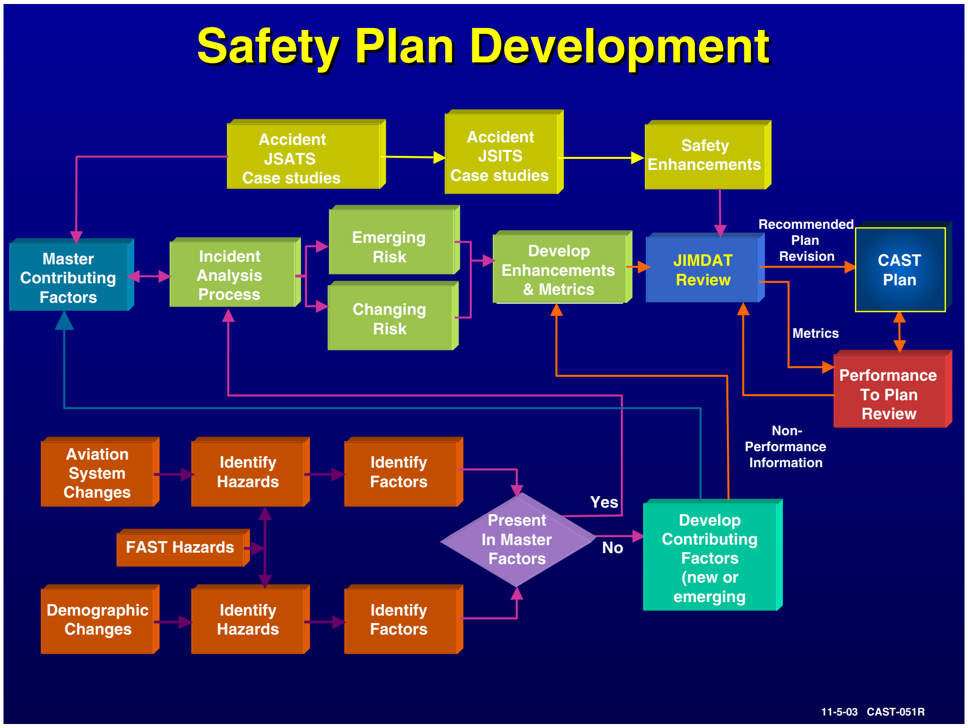
- CFIT-PAI-Vertical Angles — Increases the use of precision approach through addition of vertical angles on approach plates to achieve constant angle descent.
- CFIT-MSAW — All U.S. ATC minimum safe altitude warning radars have been site checked to ensure no obstructions exist and all ATC personnel have been trained on timely MSAW alerts to flight crews.
- CFIT Prevention Training — All U.S. carriers have incorporated CFIT prevention training in their curriculums.
- CFIT ATC Training — All ATC personnel have received CFIT prevention training to eliminate CFIT hazards such as "slam dunk" approaches.

CAST Safety Plan (cont.)

17 Committed Safety Enhancements

- Policies and Procedures
- Aircraft Design
- Flight Crew Training (additional aspects)
- Runway Incursion Prevention
- Precision Approaches (additional projects)

Eight R&D Projects and Two Studies



We have completed the historical study of CFIT, Loss of Control, Approach-and-Landing, Runway Incursion and Turbulence accidents and hull losses which have occurred in U.S. FARs Part 121 operations over the time frame of 1987 to 2001. Additionally we have completed an assessment of accidents and hull losses worldwide over that same time frame.

The yellow boxes, "Accident JSAT's," etc. depict this historical study of accidents from which CAST has identified safety solutions to proactively apply and prevent/mitigate recurrence. But what is the future direction of CAST? Where do we go next to look at future risks?

CAST is developing an incident analysis process that will allow us to become more proactive in accident prevention by identifying changing and emerging risks. This is shown by the purple boxes, "Incident Analysis Process," "Emerging Risk," "Changing Risk," etc.

Safety enhancements from this activity will be rolled into the CAST plan, related metrics will be developed and any newly identified contributing factors will be added to the Master Contributing Factor list.

Also to reach further yet into the future (as shown in green), CAST will examine and identify hazards that may result from "Aviation System Changes" and "Demographic Changes."

Much of this work has been done by CAST's sister organization, the JAA Future Aviation Safety Team (FAST), which is analyzing future hazards based on their study of future areas of changes.

CAST will incorporate the results from the FAST analysis into the CAST plan; safety enhancements and related metrics will be developed and the newly identified contributing factors will be added to the Master Contributing Factor list.

A CD with much of the CAST material has been developed. A copy has been provided to each of you.

JSSI

- Members include national authorities, manufacturers, aviation organizations, the European Commission, etc.
- The JSSI aim is continuous improvements of its effective safety system, leading to further reductions of the annual number of accidents and fatalities irrespective of the growth of air traffic.

In Europe the Joint Airworthiness Authorities (JAA) is sponsoring the JAA Safety Strategy Initiative (JSSI). This effort began in early 1998, modeled on the CAST activity which began in late 1997.

JSSI members include representatives from both government and industry:

1. JAA Central offices
2. JAA member States
3. Airbus, Boeing, FAA
4. Aviation and Labor Associations (AECMA, AEA, ECA, ERA, ETF, ERAA, IFA, EUROCONTOL (Air Traffic Control)
5. European Commission

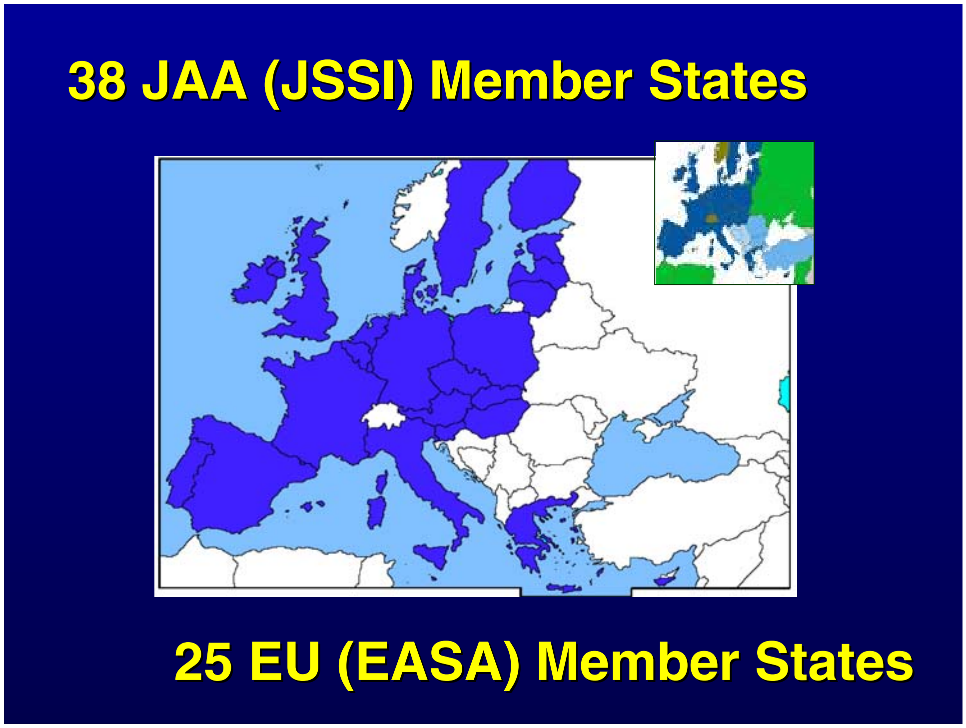
In addition to the CAST areas of interest (CFIT, Approach and Landing, Loss of Control, Runway Incursions, Weather), the JSSI looked at Design Related issues and Occupant Safety and Survivability.

Using CAST Safety Enhancements as a basis, JSSI has defined who is the responsible action party in Europe and the timeline for implementing the Safety Enhancements in Europe.

The JSSI Future Aviation Safety Team (FAST) is developing methods and tools to study future trends in aviation from a systems approach. Areas of Change have been identified and prioritized. Work is being completed on defining hazards and developing recommendations on the most significant Area of Change, increasing reliance on flight deck automation.

Examples of other areas of change include:

- Emergence of new concepts for airspace management
- Introduction of new technologies with unforeseen human factors aspects
- Proliferation of heterogeneous aircraft with widely varying equipment and capabilities
- Introduction of new technologies with unforeseen human factors aspects
- Aging avionics, powerplants, electrical and mechanical systems, and structures
- Etc.



Society of equals

European Strategic Safety Initiative — Governance

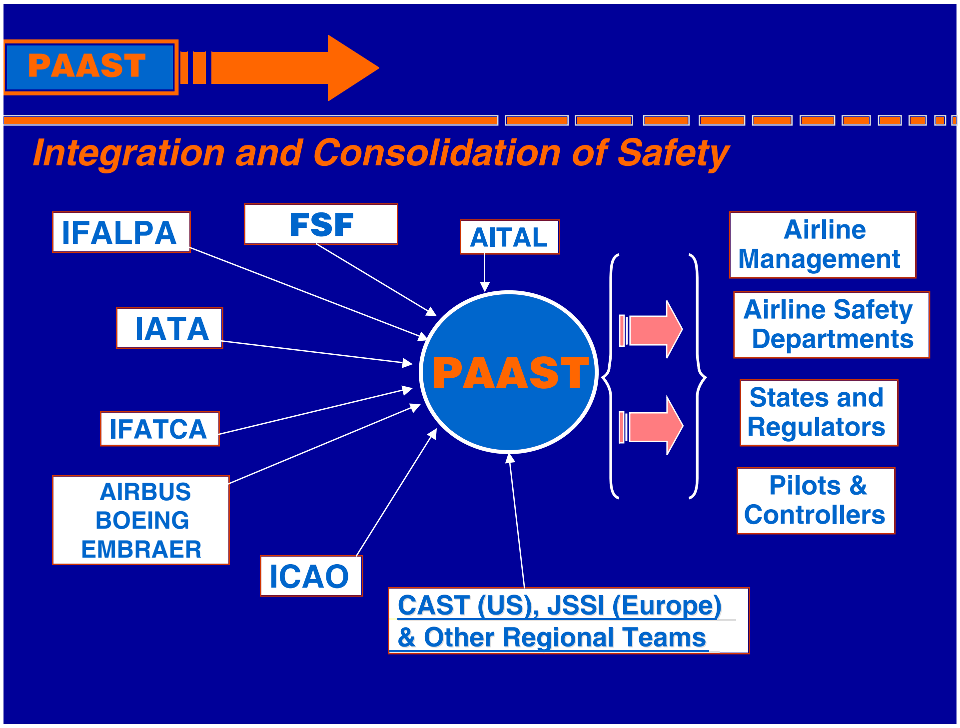
- Executive Committee
  - Joint chairmanship
- Sharing of organizational tasks
  - One permanent working group
    - Others established to perform a task
- Characteristics
  - Data driven
  - Multidiscipline
  - Open / Inclusive
- Promote objectives

PAAST membership comprises aviation organizations represented in the region, including government, airlines, ICAO Regional Offices and related organizations.

They work very closely with CAST, the JSSI and Flight Safety Foundation.

Elements of the following Safety Enhancements have been implemented:

- Safety Culture
- Flight Crew Training
- Uncontained Engine Failures
- Terrain Awareness and Warning System (TAWS)
- Standard Operating Procedures
- Regional Airline Safety Self-Evaluation Checklist



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- Standard Operating Procedures
- Regional Airline Safety Self-Evaluation Checklist

PAAST has established Action Team Leaders, based on the Regional Team Leader concept. These leaders understand the local conditions, legal systems, culture, etc., and are able to modify the information provided to them to effectively implement Safety Enhancements in their local region.

PAAST membership comprises aviation organizations represented in the region, including government, airlines and related organizations.

They work very closely with CAST, the JSSI and Flight Safety Foundation.

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- Safety Culture
- Flight Crew Training
- Uncontained Engine Failures
- Terrain Awareness and Warning System (TAWS)
- Standard Operating Procedures
- Regional Airline Safety Self Evaluation Checklist

Cooperative Development of Operational Safety and Continuing Airworthiness (COSCAP) is just getting started. Some of the regional teams are reviewing the CAST CFIT and Approach-and-Landing Safety Enhancements and are starting to implement safety enhancements.

Members include the national authorities and the operators in the particular region.

COSCAPs are sponsored under the ICAO Technical Cooperation Program.

COSCAP Objective

Enhance the safety and efficiency of air transport through the establishment of a self-sustaining sub-regional entity providing technical services in safety oversight to the Member States

Basic Features of a COSCAP Project

- **Implemented by ICAO and guided by a Programme Steering Committee, composed essentially of :**
  - **DGCAs of the participating States**
  - **ICAO representatives**
  - **Programme's Chief Technical Adviser**
  - **Representatives of the funding partners**
  - **Other participating organizations**

The South Asia Regional Aviation Safety Teams (SARAST) comprises airlines and civil aviation authorities from seven States: Bhutan, Bangladesh, India, Maldives, Nepal, Pakista, and Sri Lanka.

SARAST: www.coscap-sa.org

The South East Asia Regional Aviation Safety Team (SEARAST) comprises airlines and civil aviation authorities from 12 States: Brunei, Cambodia, Hong Kong, Macao, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam.

SEARAST: www.coscap-sea.com

The North Asia Regional Aviation Safety Team (NARAST) comprises airlines and civil aviation authorities from four States: China, Mongolia, Democratic Peoples Republic of Korea (DPRK) and Republic of Korea.

NARAST web site: www.coscap-na.org

CIS Steering Group has:

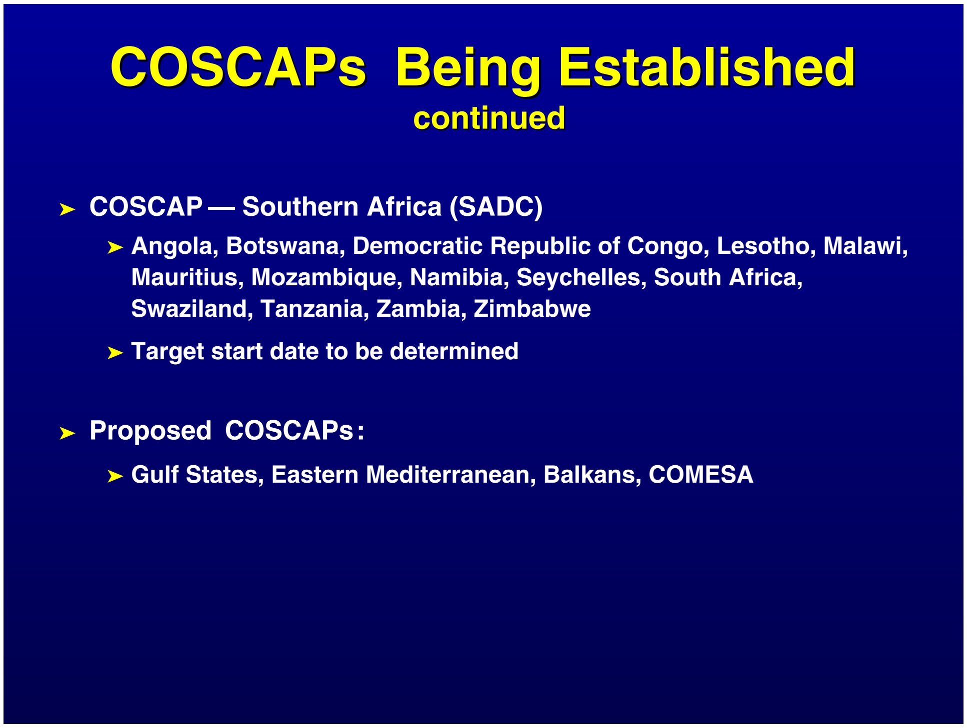
- Produced model rules of aeronautical licensing for CIS member states.
- Conducted a number of safety seminars.
- Begun development of an operations manual for airlines.

Union Économique et Monétaire Ouest Africaine (UEMOA)

Web page: http://www.uemoa.int/index.htm

Communauté Économique et Monétaire de l'Afrique Centrale (CEMAC)

Web page: http://www.izf.net/izf/FicheIdentite/CEMAC.htm



The Southern African Development Community (SADC)

Web page: http://www.asosh.org/SADC/sadc.htm

South Asia, South East Asia and North Asia Regional Aviation Safety Teams (SARAST, SEARAST and NARAST), have been established and have reviewed the CAST and JSSI work and agreed to implement 27 of the most effective CAST Safety Enhancements. They are providing support to each other as they track implementation.

The ICAO Global Aviation Safety Plan (GASP) encourages States to establish regional aviation safety teams.

COSCAP Safety Teams meet every six months to review implementation status and look for new areas to work on:

- Review outputs from CAST/JSSI
- Review Regional Aviation Safety Issues
- Recommend Accident Prevention Strategies to the respective Steering Committee
- Once approved by the Steering Committee implemented by coordinated efforts of regulatory authorities, air operators and service providers
- Participants from Member State CAAs, air operators, service providers, ICAO, FAA, JAA, Airbus, Boeing, IATA, AAPA

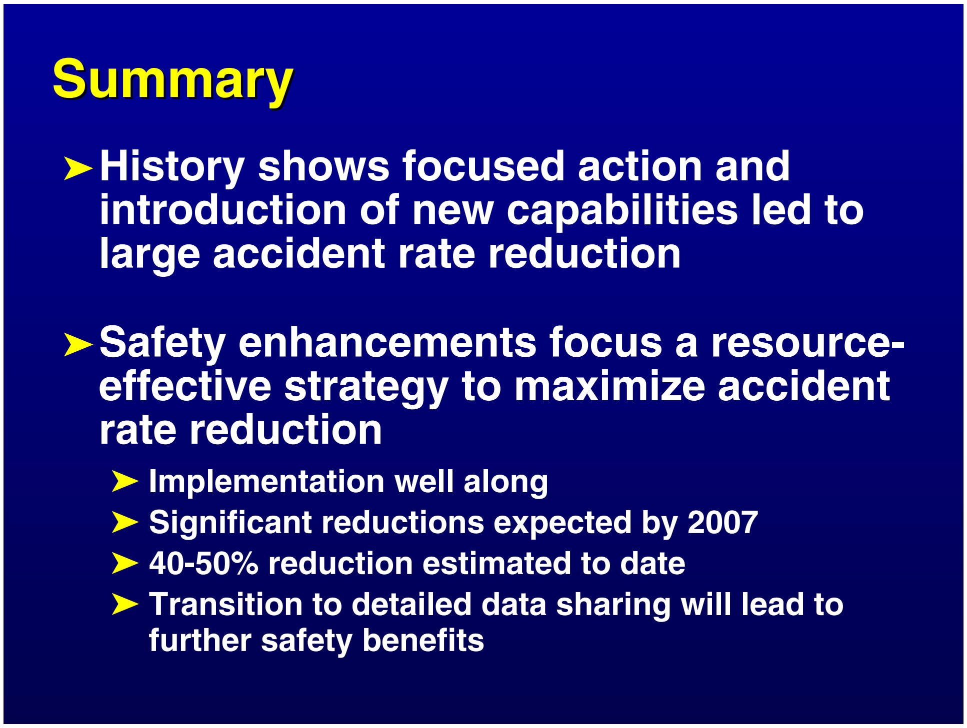
Web sites:

SARAST:	www.coscap-sa.org
SEARAST:	www.coscap-sea.com
NARAST:	www.coscap-na.org

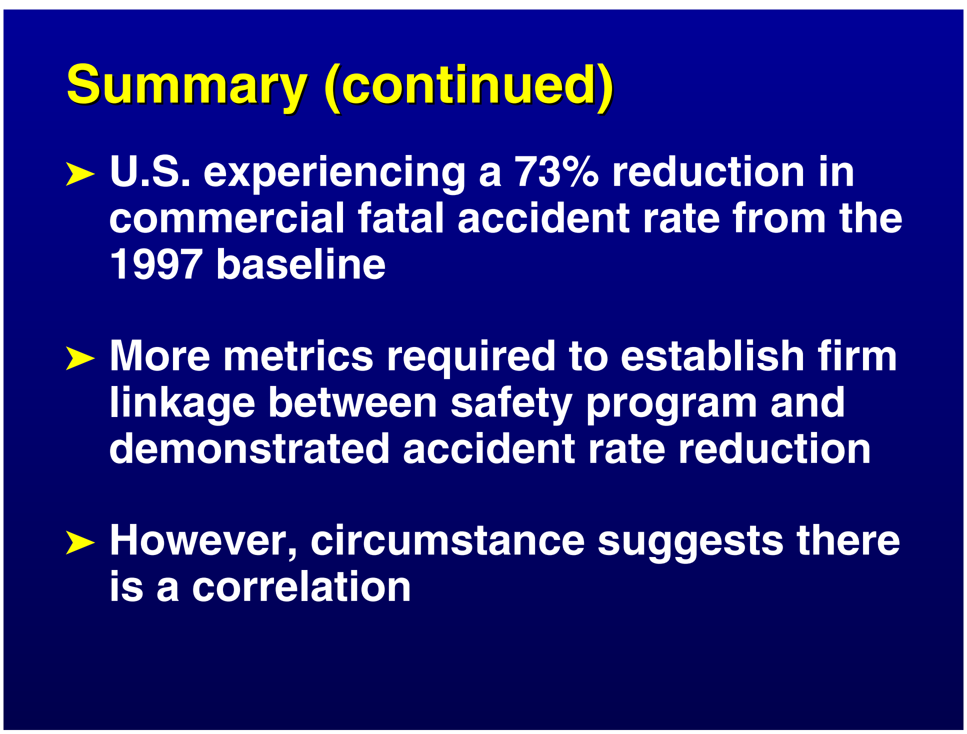
Selected COSCAP Safety Enhancements are:

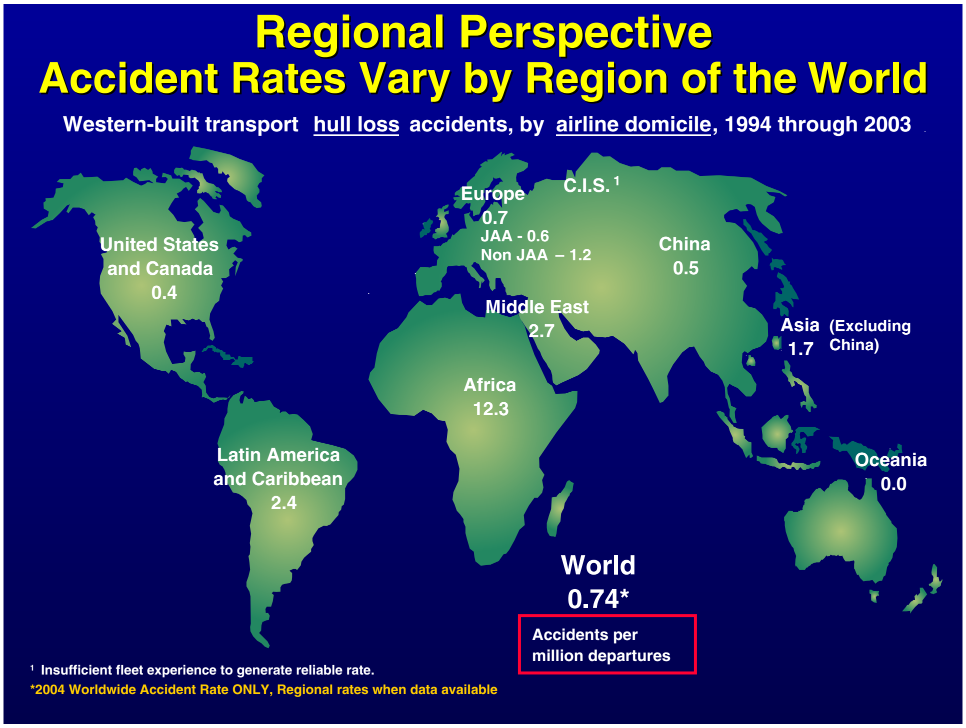
1. SE-1 TAWS installation
2. SE-2, CFIT Standard Operating Procedures (SOP)
3. SE-3, Precision-Like Approach Implementation (Vertical Angles)
4. SE-10, Airline Proactive Safety Programs (FOQA & ASAP)
5. SE-11, CRM Training
6. SE-12, CFIT — Training / CFIT Prevention
7. SE-14, ALAR Safety Culture CEO and Director of Safety more visible
8. SE-15, ALAR – Safety information in Manuals
9. SE-16, Distribution of essential safety information (Airplane Flight Manuals, etc.)
10. SE-23, Approach-and-Landing Flight Crew Training
11. SE-26, Loss of Control (SOPs)
12. SE-28, Loss of Control (Safety Information)

When these enhancements are in place we project a 60 percent accident risk reduction in the region.



We believe that the projected reduction is a conservative estimate. Validating implantation levels to get better estimate of expected results to date.

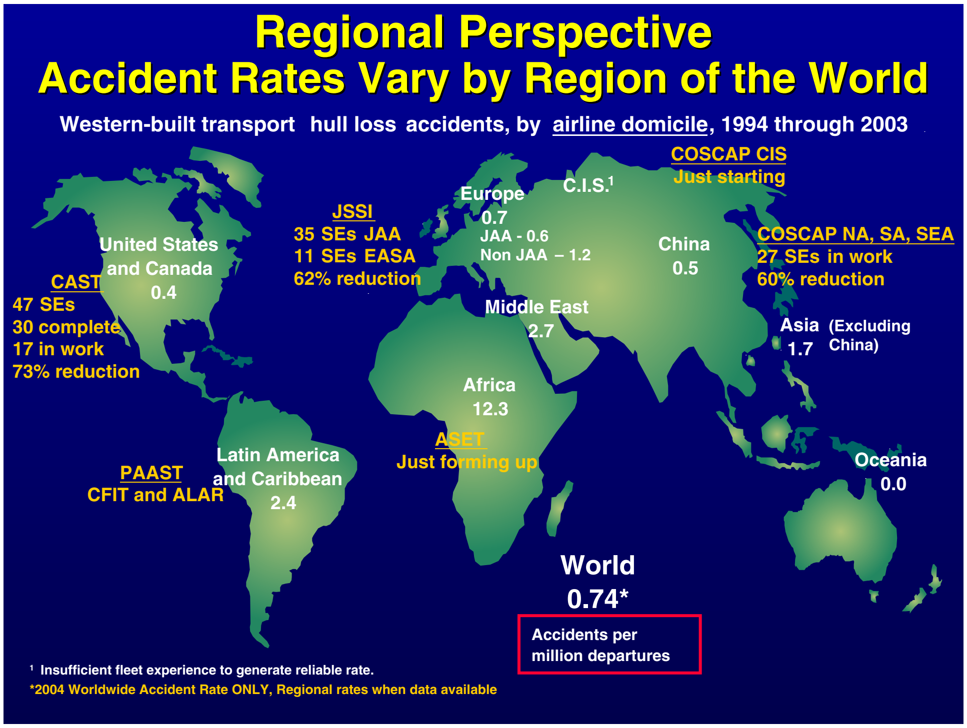




The accident rates shown here are of Western-built transport airplanes shown by airline domicile.

For example, if a U.S. airline had an accident in Africa the United States and Canada rate would change, not the rate in Africa.

We do not have the data (departure information, etc.) to establish rates for C.I.S.



Regional cooperative safety activities (ICAO and local regulators work together – COSCAPs) by region.

This chart shows two things.

- Accident rates by region of the world
- Regional cooperative safety activities (ICAO and local regulators working together – COSCAPs) by region.

The number of CAST Safety Enhancements adopted by the Asian COSCAPs and the European JSSI (Joint Safety Strategy Initiative) are also depicted.

COSCAP = Cooperative Development of Operational Safety and Continuing Airworthiness Programme

♦♦♦♦

Flight Safety Comparative Analysis of USSR/CIS-built And Western-built Jet and Turboprop Aircraft

Vladimir Kofman and Rudolf Teimurazov
Interstate Aviation Committee

Vladimir Poltavets
M. Gromov Flight Research Institute

For many years, Western countries have been of the opinion that the safety level of Soviet-built aircraft is inferior to those produced by their Western competitors. One of the reasons was a limited scope of safety-level information provided by Soviet aviation administrations to international organizations. Such information would not allow drawing accurate conclusions on the state of excellence of the domestic civil aviation equipment, which is mostly operated in the CIS Member States. Transparent information has become available since 1986.

At the beginning of this report, we would like to note that both the Soviet Union and later the CIS Member States have been paying a great deal of attention to aviation safety. The air transport system of the CIS Member States that was designed in the USSR to operate civil aviation has been modified lately and currently meets modern international requirements.

In this connection, we should also note that in 1992–1996, due to the transition to a market economy, we witnessed a considerable deterioration of flight safety. This period was marked by unprecedented reforms in all spheres of social life and the economy, including the civil aviation infrastructure.

This period of civil aviation activities in the CIS Member States was characterized by a significant downsizing of operations. First of all, we are talking about a decline of passenger and cargo traffic between regional cities and a considerable decline of agricultural and special operations. These volumes were suffering constant downsizing in all CIS Member States. Generally speaking, they dropped 4.5 times by 1999 and only from 1999–2000 have we observed an increase in air traffic.

Within several years, the CIS Member States were facing a redistribution of volumes of traffic between different aircraft.

At the time of the Soviet Union, 50 percent of special-purpose traffic on local airways was supported by helicopters and light aircraft. Immediate reduction led by 2000 to this share dropping two times due to the sharp reduction of operations by the above-mentioned aircraft in 1992.

We should mention another peculiarity of the transition period which affected the functioning of the aviation transport system — a significant increase in the number of airlines. This situation generated not only a direct conflict of interest between commercial development and flight safety in airlines, but also generated new accident factors related to redistribution of traffic in favor of charter operations (reaching 20 percent of total operations). Such developments in the economics of the aviation transport system had a negative effect on flight safety.

But starting in 1999, a trend to enhancing flight safety in the CIS Member States' civil aviation has become evident (Figure 1, page 78).

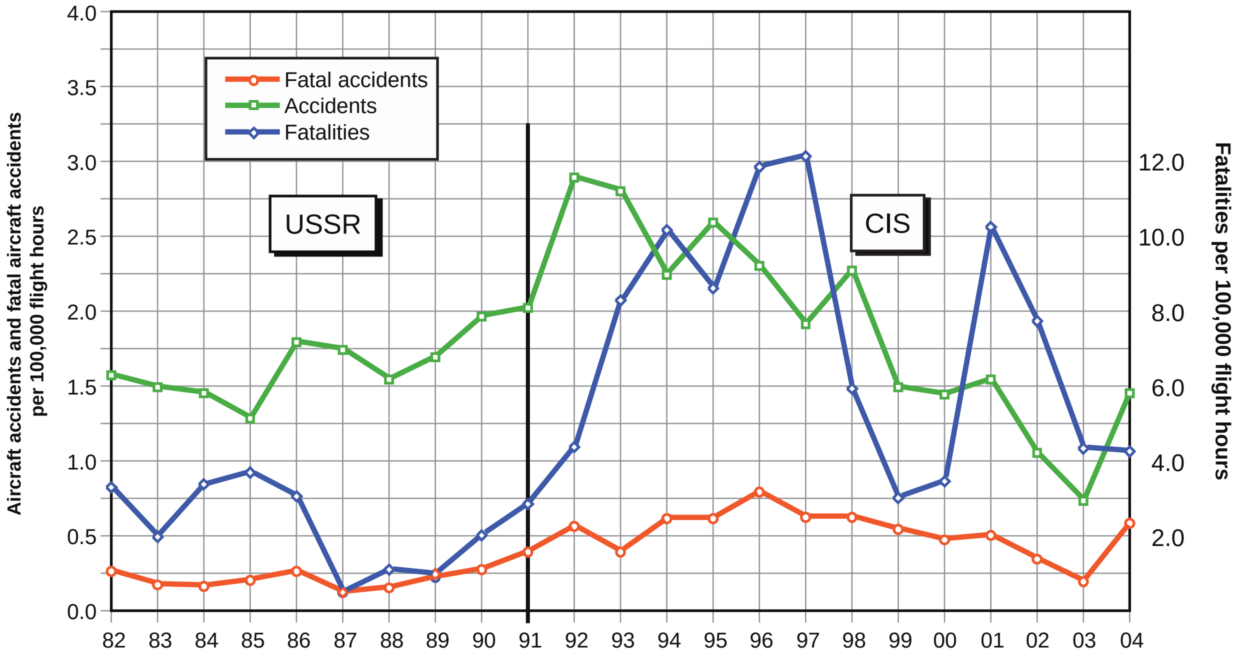


Figure 1. Aircraft accidents, fatal aircraft accidents and fatalities per 100,000 flight hours in civil aviation in the CIS countries. Whole fleet

The interesting feature of aviation transport in the CIS Member States is that flight safety of aircraft with takeoff weight more than 10 tons (1–3 class airplanes according to the CIS classification) in charter and cargo operations is considerably worse than that in regular operations (see Figure 2).

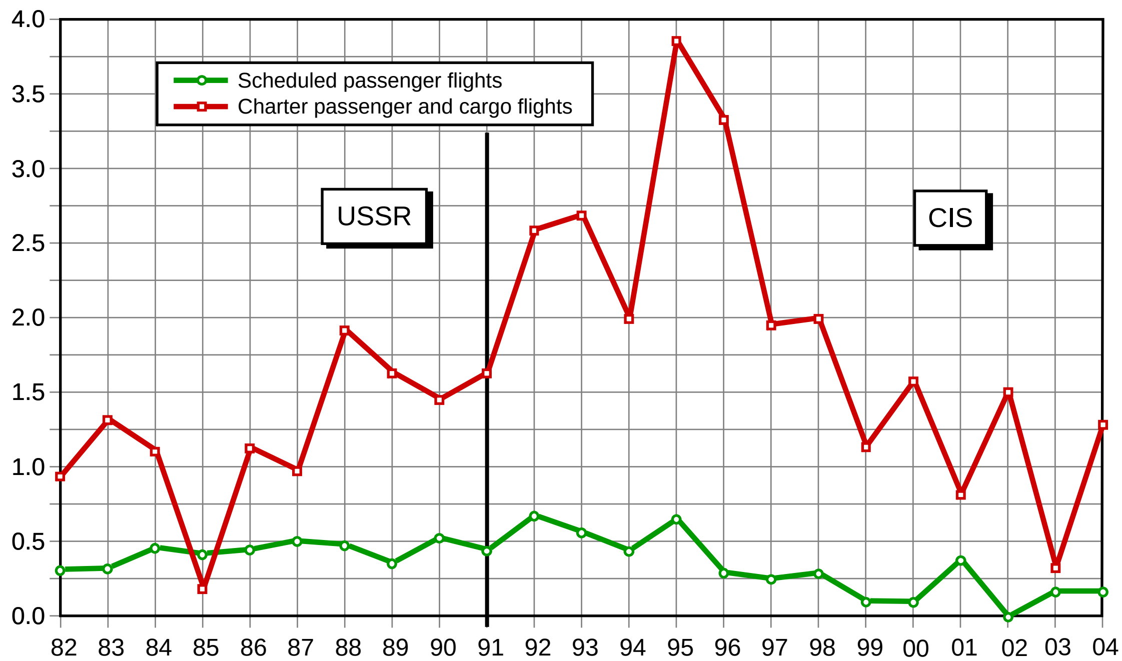


Figure 2. Aircraft accidents per 100,000 flight hours in civil aviation in the USSR/CIS. Takeoff weight over 10 tons.

At the same time, we should note that in spite of a general deterioration of the safety level in the CIS Member States at the time of aviation reforms, the safety level in the regular passenger segment actually did not drop.

It corresponds to the average international figures. In 1997, 1999, 2000, 2002 and 2003, there were no fatal accidents in scheduled operations.

Now, we will try to make an objective (based on operational data) comparative assessment of flight safety of the major similar types of USSR/CIS and Western jet and turboprop airplanes. For these purposes we have selected civil aviation aircraft operated longer than 30 years of the same generation, type, capacity and range.

The trustworthy comparison of domestic and foreign aircraft flight safety in the field of accidents is difficult to achieve since these events are categorized differently. Often the limited information on the events in question in the open Western media is not sufficient to assess the seriousness of hull damage, which in turn would not allow us to define an event as an accident or an incident in order to compare it with similar events involving our airplanes. Many events which in CIS countries are considered incidents or emergencies are called accidents according to foreign rules. That is why for the purposes of comparison we have selected fatal accidents only when at least one person was killed aboard an aircraft.

After this introduction, let us compare flight safety of different types of aircraft based on a relative number of fatal accidents. The assessment encompasses a specific fleet on condition that it consists of one or two generations of aircraft with a flight history long enough to be sure that the statistical information, including "geography" of operations, economic environment and political infrastructure is reliable.

1. Wide-body Airplanes (Twin-aisle)

Presently, there are more than 10 types of wide-body airplanes worldwide (about 3,200) produced by Airbus, Boeing, Lockheed Martin and Ilyushin. In order to provide the correct flight safety comparison, we have selected a group of airplanes with about the same life span: domestic Il-86 and western B-747 Classic, DC-10, L-1011 and A300B2/B4.

From the beginning of passenger operations up to 2004, there were 34 fatal accidents involving the B-747 Classic, DC-10, L-1011 and A300B2/B4. At that time, the average ratio (fatal accidents per 100,000 flight hours) for these airplanes was 0.034 (Figure 3, page 80). Within the same time frame, there was one fatal accident in 2002 involving an Il-86 on a ferry mission without passengers (14 crewmembers were killed). There were no fatal accidents involving a wide-body Il-86 since the time this airplane was put in service, meaning that no passengers were killed.

2. Long-range Narrow-body Airplanes (Single-aisle)

Comparison of flight safety levels of long-range narrow-body airplanes Il-62 and Il-62M with similar Western products DC-8 and B-707 during their total time of service has proved that their safety level is the same as of the DC-8 and a little better than the B-707 (Figure 4, page 80).

3. Middle-range Airplanes

Comparison of flight safety levels of middle-range Tu-154 and Tu-154M airplanes and short-range Tu-134, Yak-40 with their Western counterparts B-727, B-737-100/200 (JT8D), DC-9, F28 and BAC 1-11 during their total time of service has proved that their safety records are not worse than those of Western airplanes. Fokker F28 and BAC 1-11 flight safety records are inferior to USSR/CIS-built airplanes (Figure 4). B-727 airplanes are flight safety world champions in a group of narrow-body first- and second-generation airplanes and close to the high standards of fourth-generation wide-body airplanes. At the same time, it should be noted that presently the B-727 fleet of all models keeps the record for narrow-body jet flight hours — more than 100,000,000.

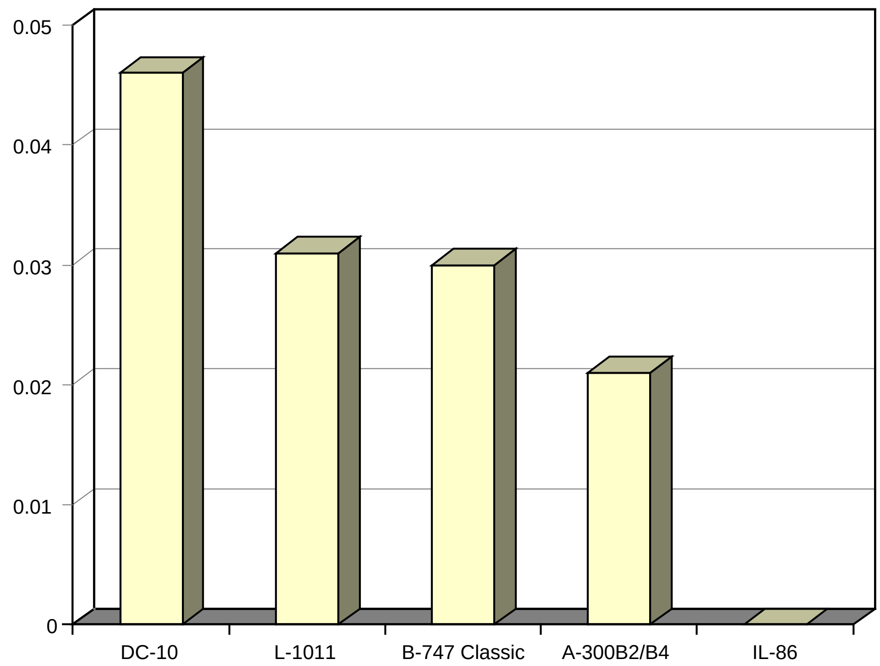


Figure 3. Accidents by Different Causes to One Generation Wide-body Passenger Airplanes per 100,000 Flight Hours From the Beginning of Their Service Worldwide

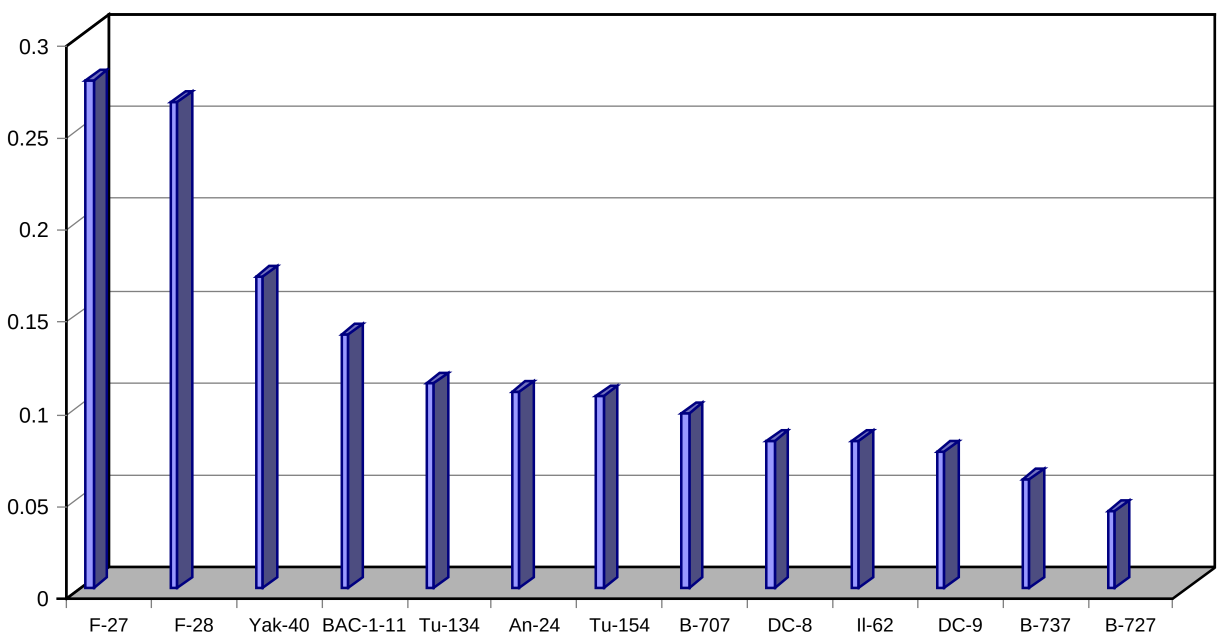


Figure 4. Accidents by Different Causes to First- and Second-generation Worldwide Narrow-body Jet and Turboprop Passenger Airplanes Presently in Service per 100,000 Flight Hours

4. Commuter Airplanes

Comparison of the flight safety level of the most popular domestic An-24 turboprop airplane with the similar Fokker F27 has proved that its record is better by 2.6 times than that of the F27 (Figure 4,).

Hence, judging by this comparative data we may assume that the flight safety record of the majority of types of domestic aircraft is not worse than their Western analogues.

It is important to note that the distribution of USSR/CIS and Western passenger jet and turboprop aircraft accident causes (Figure 5) generally agree. More than 70 percent of fatal accidents both on Soviet and Western-built airplanes are related to human factors.

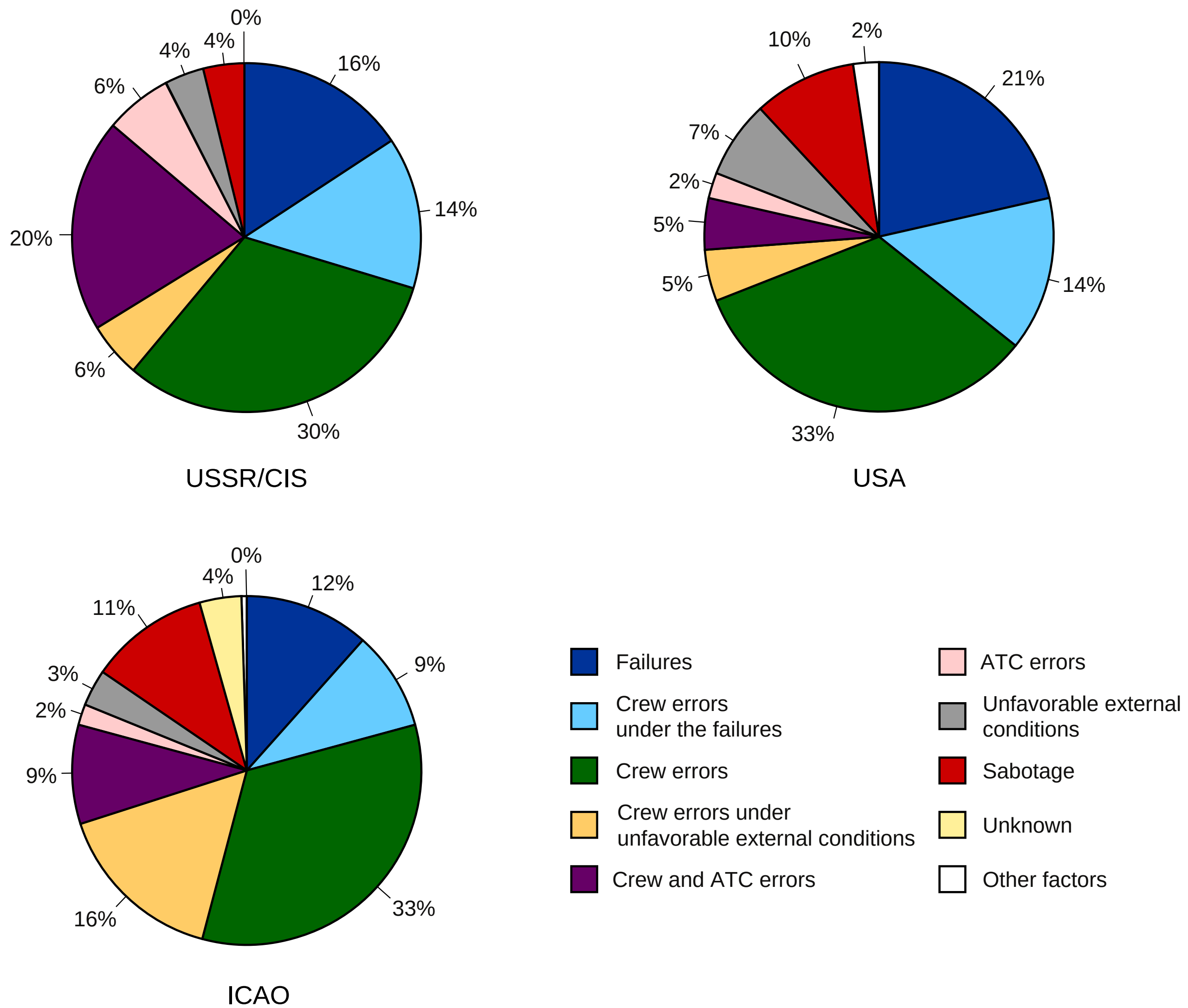


Figure 5. Accident Causal Factors for Passenger Jet and Turboprop Airplanes with Takeoff Weight More Than 10 tons

Causes of equipment failures on USSR/CIS-built and Western-built airplanes are actually the same. Table 1 (page 82) shows that through the lifetime of one of the most popular jets, TU-154, most of accidents caused by failures of functional systems took place when failures of two functional aircraft systems were evident: landing-gear (in 20 cases) and powerplant (in six cases). These two systems failures have caused 90 percent of accidents of a technical nature. On the B-727, which is similar to the TU-154, landing-gear failures caused 56 accidents, while engine failures caused 17 accidents, amounting to 91 percent of all technical failures. Types of functional system failures on the TU-154 and their influence on flight safety are actually the same as on the B-727 (Table 1). The percentage of functional systems failures at accidents involving the TU-154 and B-727 also coincides (Figure 6, page 82).

Table 1

Distribution of Accidents Caused by Equipment Failure on Tu-154 and B-727 per Functional Systems and Types of Failures From the Beginning of Operation Till 2004

System	Type of system failure	B-727	TU-154
Landing Gear	Non-deployment	43	15
	Folding	10	4
	Tire burst	3	0
	Nose wheel control failure	0	1
All failures within the system		**56**	**20**
Powerplant	Uncontained engine failure	13	5
	Engine starter failure	0	1
	In-flight shutdown	2	0
	Engine separation from aircraft	2	0
All failures within the system		**17**	**6**
Control System	Jamming of flaps	0	2
	Jamming of slats	2	0
All failures within the system		**2**	**2**
Other systems		5	1
Total failures within aircraft systems		**80**	**29**

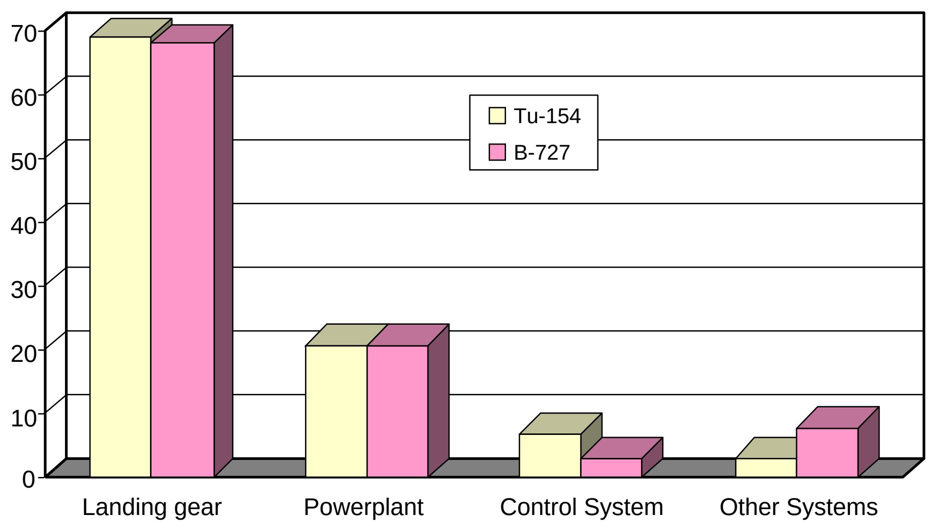


Figure 6. Distribution of Failure-related Accidents per Functional Systems of TU-154 and B-727 Airplanes Within Their Lifetimes

The main causes of TU-154 accidents are non-deployment of one of the landing gear on approach stage, causing considerable damage when aircraft wings touch the surface during the rollout (15 cases). In addition, during the period under review, there were TU-154 accidents caused by the folding of landing gear. Speaking about B-727 accidents, there were 43 cases of non-deployment of one of landing gear and 10 due to folding in the process of rolling.

All TU-154 powerplant-related accidents had to do with uncontained engine and engine systems failure. During the period of TU-154 operation there were six accidents caused by failure of powerplant components, while the B-727 suffered by 13 similar cases. Uncontained engine failures caused dangerous malfunctions of other functional systems and fires, leading to emergency situations.

The percentage of hardware failures on other types of aircraft is roughly the same. Eighty-eight percent of accidents to BAC 1-11 airplanes caused by systems malfunction were generated by problems in undercarriage and powerplants, while on Fokker F28 airplanes this percentage is 91 percent. Actually, the causes of accidents on USSR/CIS and similar Western-built airplanes coincide. The statistical information on the TU-154, TU-134, B-727, B-737, DC-9, BAC 1-11 and F28 proves that the accidents' casual factors are identical.

Hence, the analysis of accidents caused by equipment failures on domestic and similar Western-built airplanes has proved that these types of airplanes have the same technical weaknesses. It means that their state of the art is the same. The overwhelming majority of technical-related accidents are caused by failures of two functional systems: undercarriage (landing gear on the runway) and a powerplant (uncontained engine failure).

This situation may be explained by the fact that the contemporary level of aviation science and technology is not good enough to produce absolutely perfect technical systems. In foreign countries, USSR and the CIS Member States, new airplanes are designed using failure-proof methods including back-up and stand-by systems which duplicate other systems in case of malfunctions and provide for successful landing. The approaches and methods in the field of design of aviation products are in essence the same in the advanced Western countries, USSR and the CIS Member States.

The more experience we gain, the faster we eliminate shortcomings in aircraft design and production, improve airworthiness requirements, raise standards in crewmembers and ground personnel training. Both the USSR/CIS and Western countries have developed stable aviation transport systems providing for a relatively high level of aviation safety. From the beginning of civil jet operation up to the next 20 years the process of aircraft design and methods of operation has been under way. Technological advances have led us to a situation when the number of accidents caused by technical problems or aircraft performance dropped from 40 percent to 15 percent, while accidents related to personnel errors (mostly crewmembers) increased from 50 percent to 80 percent.

In conclusion, we should note that the improvements in aviation technology, ways and methods of flight and ground personnel training, flight management and operation in the USSR/CIS and advanced Western countries progressed at a similar pace and with due account of international experience in the field of aircraft manufacturing and operation. That is why the average flight safety rates of domestic jet and turboprop airplanes within our aviation transport system was and still is up to the mark of Western products of a similar type. These rates correspond to the international level of aviation science and technology achievements at the time these airplanes were designed and operated.♦

References

1. *Airliner Loss Rater*, Airclaims, London, 2001.

2. *World Aircraft Accident Summary* — CAA CAP479, Airclaims, London, 1963–2004.

3. Interstate Aviation Committee Reports on Flight Safety in the Civil Aviation of the CIS Member States, MAK, 1992–2004.

♦♦♦♦

Volga-Dnepr Airlines Flight Safety Assurance and Aviation Accident Prevention System

Yuri Malevinsky
Volga-Dnepr Airlines

The task of implementing a balanced scorecard system currently plays a vital part in strategic management.

The Balanced Scorecard System is an organizational framework for implementing and managing strategy at all levels of an enterprise by linking objectives, initiatives and measures to an organization's strategy.

The Balanced Scorecard provides an enterprise view of an organization's overall performance by integrating financial measures with other key performance indicators around customer perspectives, internal business processes and organizational growth, learning and innovation.

Evidently, along with the above indicators, the indicators of flight safety and aviation accident prevention should also be reflected in the scorecard for airlines. This implies that such indicators must be reasonable, measurable as far as possible and manageable.

The key goals of Volga-Dnepr Airlines in aviation accident prevention are:

1. To achieve controlled flight safety levels; and

2. To become the most safe charter cargo airline.

We believe that these strategic goals will be achieved as we become able to answer the following three questions with acceptable accuracy:

- When an aviation accident can occur;

- When and how to prevent it; and

- What resources will be required to prevent it.

Thereby we will continuously reduce aviation accident risks.

In our flight safety assurance and accident prevention activities we are first of all guided by recommendations set forth in the ICAO Accident Prevention Manual (Doc 9422-AN/923) and follow the principle of system approach that recommends considering any flight safety issues as the interrelation of three factors: "Man-Aircraft-Environment."

In our practical work on identifying causes of accidents or other significant shortcomings in flight safety assurance, we focus on the use of the SHELL concept that describes the three-factor model. By placing the "Man" in the center and consecutively analyzing pairs "Man-Document," "Man-Aircraft," "Man-Environment" and finally "Man-Man," answers to issues arising during investigation can be easily obtained. For example, whether the operational documentation is clearly and plainly written; whether it contains necessary and up-to-date safety information and provides it in an easy-to-find manner; whether the aircraft is ergonomic to a necessary extent; or whether, perhaps, the logic of management of certain units or systems is in conflict with common sense from the view of an operator's actions? These are just some of the many questions that can be formulated and systematized using the SHELL model. Moreover, answers to them play an important role in ensuring effective accident prevention.

Having studied the experience of leading airlines, Volga-Dnepr has adopted its Flight Safety Assurance and Accident Prevention Policy. It states that "the airline's management will succeed in providing the highest level of flight safety to ensure that the customers and personnel are confident at all times."

It is important to note that along with the policy, we have developed and adopted 14 principles of its implementation. Such principles constitute a type of code of conduct for all employees, from the general director to an ordinary employee.

These principles form the basis for practical activities, e.g., design and improvement of the flight safety system, design of internal regulations, application of disciplinary actions and other management functions. Please see our principles on Slide 5 (in the additional material following the text of this paper) for more detail.

Having adopted the above policy, we formed a structure of Corporate Safety Culture of Volga-Dnepr Group accordingly. This structure outlines basic tasks of the company's divisions directly involved in flight safety assurance processes and services of group companies that directly influence flight safety and accident prevention.

We consider the Flight Safety Assurance and Aviation Accident Prevention System as comprising three subsystems:

- Flight Safety Assurance System;
- Aviation Accident Prevention System; and
- Flight Safety Level Management System.

The Flight Safety Assurance System includes the activities undertaken by the airline's management and operational personnel to organize, implement and comply with requirements of flight safety regulations. In other words, this is the activity on ensuring a state in which the actual deviation from a norm stays within required containment limits.

As far as the Aviation Accident Prevention System is concerned, according to the ICAO Accident Prevention Manual (Doc 9422-AN/923) this is a combination of measures, which complement existing flight safety–related procedures accepted by states, manufacturers and operators. Obviously, such additional measures will be gradually integrated into traditional practice and become regular mandatory norms. Thus, we can say that *accident prevention is a perpetual process of improving the flight safety assurance system.*

The airline's existing accident prevention system consists of four elements:

- Data collection on deficiencies in the "Man-Aircraft-Environment";
- Deficiency identification and relevant decision-making process;
- Decision implementation; and
- Evaluation of effectiveness of preventative/corrective actions.

The deficiencies data collection element is the most important and complex in this system, as it is apparent that preventive actions, representing the final product of the system, will be much more effective if they are founded on complete and reliable information.

This structure has been currently employed for evaluation of risks and decision-making in respect of the airline's operations to politically unstable and war regions, i.e., high-risk areas. We used the structure for decision-making on operations to Afghanistan, Eritrea, Iraq and other regions.

The third and final component is the Flight Safety Level Management System. It is an in-house development of Volga-Dnepr Airlines that has been introduced in the company since 2000.

In designing this system we took a common “subject-object” management structure. Obviously, the company’s management staff represented the management subject. However, the question was what criteria should be taken to indicate the condition of the management object. We could take one of the common and generally accepted criteria, e.g., number of accidents per 100,000 flight hours or per 100,000 flights or other criteria. These criteria would be acceptable to characterize flight safety on a country scale but they were considered as inadequate for airlines because:

- First, an aviation accident for an airline is quite rare and sometimes vital;
- Second, it would take a long period for an airline to accumulate hundreds of thousands of hours or flights, meaning that such criteria would be out of date. Based on these assumptions, we selected the criteria describing a number of incidents per 1,000 hours and then, starting from 2005, moved to the number-of-flights criteria.

Furthermore, in order to manage the object, we should know in what condition this object should stay or what condition we should achieve. In our case, it was necessary to determine levels of safety, so that specific managerial actions could be applied in case of any deviation from them. Therefore, at the beginning of each year we set a safety level to be ensured throughout a year. This figure is discussed at the airline’s Flight Safety Committee meeting and included in main company objectives for a forthcoming period.

This fixed level of flight safety is put on the monitoring display as a red line. Furthermore, a specifically calculated reference level is also marked.

Now the task is to monitor the current safety level on a *weekly* basis throughout a year and, depending on its value, to make adequate control actions. Here we apply three rules of action:

- If the current safety level remains within the reference value (green field), then we work in a regular (planned) mode;
- If the current safety level exceeds the reference value (yellow field), then an extraordinary analysis of flight safety is carried out. Results of such analysis are reviewed at an extraordinary meeting of the Flight Safety Committee and decisions on improvement of the safety level with relevant corrective measures within the general director’s authority are developed.
- If such measures are insufficient and the current safety value is not improved, further exceeding the fixed safety level, then safety issues are brought to attention of and decision-making by the group president.

Slide 14 shows the monitoring display for the current year as of the date when the presentation was submitted for the Seminar. In addition to the diagram, you can see a table showing safety levels by aircraft types, incident allocation by factors and a brief summary about incidents.

As mentioned above, the “safety snapshot” is updated weekly, and every weekly operational meeting starts from its presentation.

Thereby, one of the most important underlying principles, i.e., involvement of the airline’s senior management into accident prevention work, is put into effect. Any of the senior managers of our company, i.e. its general director, finance director, HR director, etc., is always aware of the flight safety status and problems. This ensures that the company’s safety issues are handled deliberately and with full knowledge.

The Flight Safety Level Management System has been utilized in Volga-Dnepr Airlines for six years.

Slide 16 provides a combined monitoring for five previous years. It evidently shows the effect of its implementation. Thus, by our annual lowering of the fixed flight safety level cap, we purposively control the safety level.

We think that one of the main advantages of our system is that we do not wait until where the curve ends up at the year-end, as used before. Instead, we strive to control it throughout a year.

This system is certainly not perfect yet and does not guarantee a steady success. Nevertheless, we are confident in its indisputable effectiveness and are willing to proceed with its further perfection.

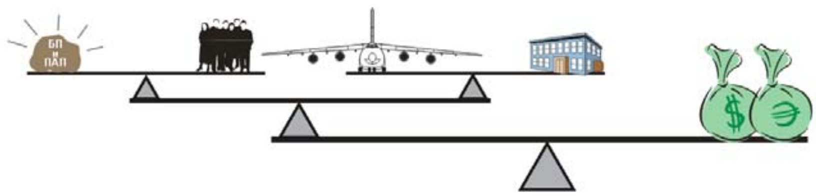
In conclusion, taking into account that this seminar is held in Russia, let me mention one of the "laws" of flight safety that was formulated by Prof. Nikolay Zhukovsky back at the beginning of the last century. The "law" is still, and likely will always be vital: "The airplane is a great creation of human genius and craft. It is beyond the authority of anyone other than those piously committed to laws of flying." Thank you for your attention.♦

Additional material follows on pages 88–97.

2

Flight Safety in Balanced Scorecard System

Balanced Scorecard System is an organizational framework for implementing and managing strategy at all levels of an enterprise by linking objectives, initiatives and measures to an organization's strategy.



The Balanced Scorecard System, as an instrument of strategic management, must include Flight Safety indicators

3

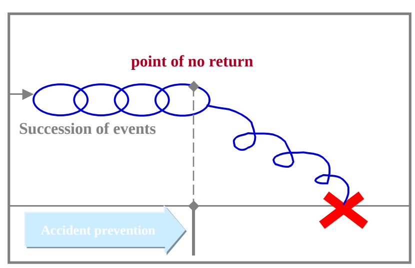
Strategic Goals in Aviation Accident Prevention

1. **Achieve controlled flight safety levels**
2. **Become the most safe charter cargo airline**

Evaluation criteria for the goal achievement:

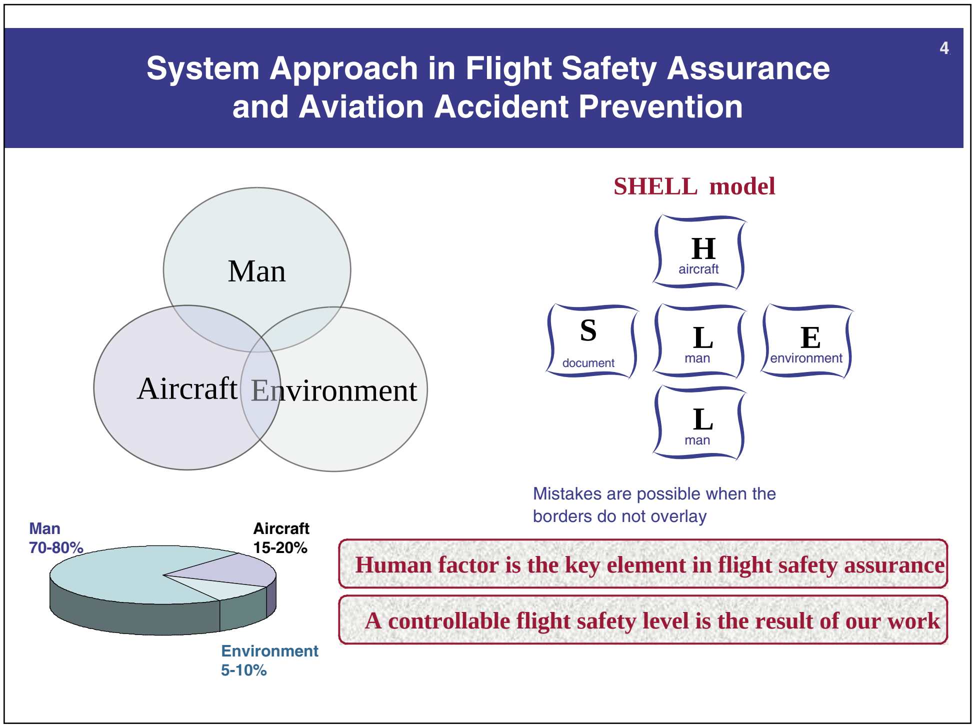
- We know when an aviation accident can occur
- We know when and how to prevent an accident
- We know how much it will cost to prevent an accident

We continuously reduce aviation accident risks

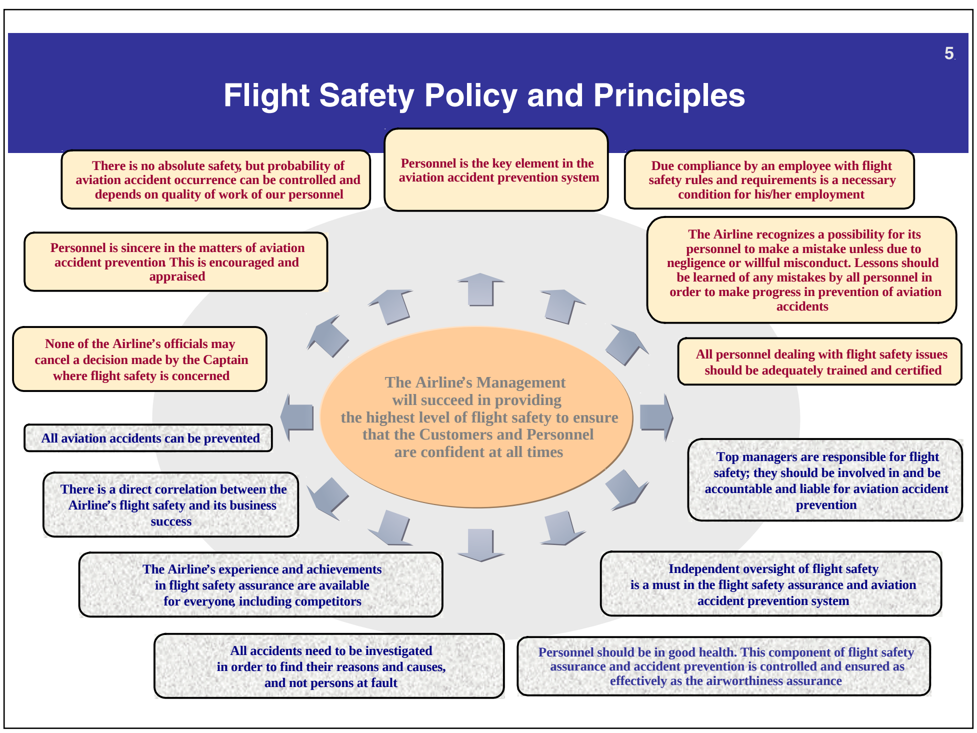


Succession of events

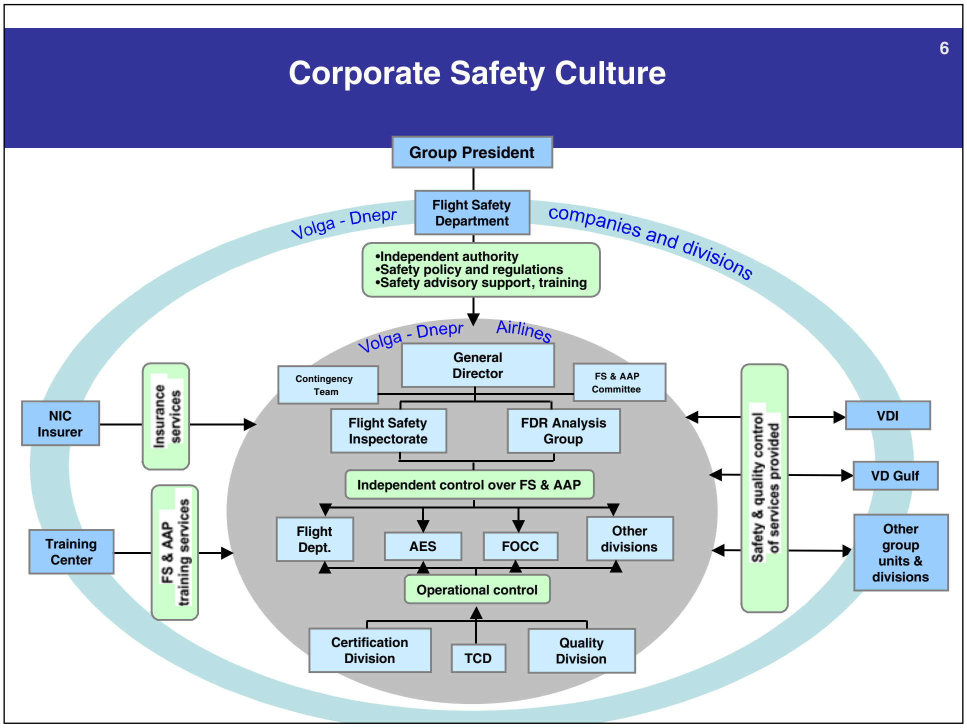
Eliminate one section – and the accident is prevented !

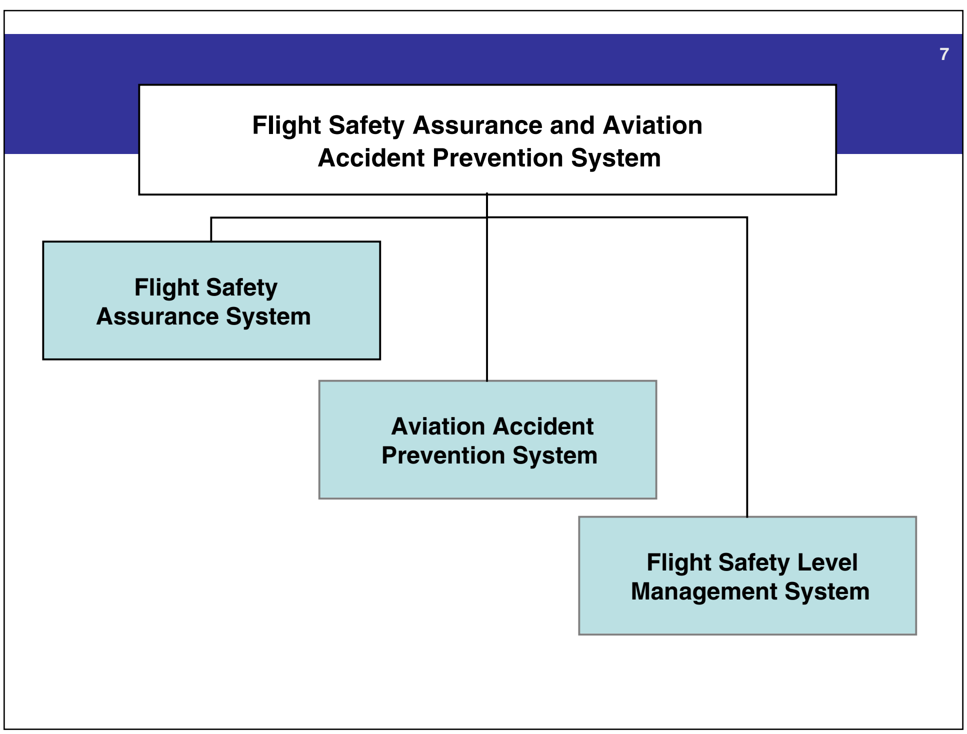


4
System Approach in Flight Safety Assurance and Aviation Accident Prevention
Man
Aircraft
Environment
SHELL model
H
aircraft
S
document
L
man
E
environment
L
man
Mistakes are possible when the borders do not overlay
Man 70-80%
Aircraft 15-20%
Environment 5-10%
Human factor is the key element in flight safety assurance
A controllable flight safety level is the result of our work



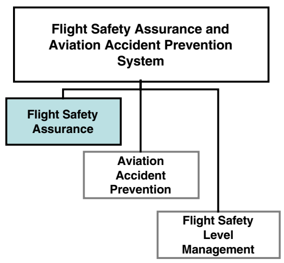
5
Flight Safety Policy and Principles
There is no absolute safety, but probability of aviation accident occurrence can be controlled and depends on quality of work of our personnel
Personnel is the key element in the aviation accident prevention system
Due compliance by an employee with flight safety rules and requirements is a necessary condition for his/her employment
Personnel is sincere in the matters of aviation accident prevention This is encouraged and appraised
The Airline recognizes a possibility for its personnel to make a mistake unless due to negligence or willful misconduct. Lessons should be learned of any mistakes by all personnel in order to make progress in prevention of aviation accidents
None of the Airline's officials may cancel a decision made by the Captain where flight safety is concerned
All personnel dealing with flight safety issues should be adequately trained and certified
The Airline's Management will succeed in providing the highest level of flight safety to ensure that the Customers and Personnel are confident at all times
All aviation accidents can be prevented
Top managers are responsible for flight safety; they should be involved in and be accountable and liable for aviation accident prevention
There is a direct correlation between the Airline's flight safety and its business success
The Airline's experience and achievements in flight safety assurance are available for everyone, including competitors
Independent oversight of flight safety is a must in the flight safety assurance and aviation accident prevention system
All accidents need to be investigated in order to find their reasons and causes, and not persons at fault
Personnel should be in good health. This component of flight safety assurance and accident prevention is controlled and ensured as effectively as the airworthiness assurance


6
Corporate Safety Culture
Group President
Flight Safety Department
Volga - Dnepr
companies and divisions
•Independent authority
•Safety policy and regulations
•Safety advisory support, training
Volga - Dnepr
Airlines
General Director
Contingency Team
FS & AAP Committee
Flight Safety Inspectorate
FDR Analysis Group
Independent control over FS & AAP
Flight Dept.
AES
FOCC
Other divisions
Operational control
Certification Division
TCD
Quality Division
NIC Insurer
Insurance services
Training Center
FS & AAP training services
Safety & quality control of services provided
VDI
VD Gulf
Other group units & divisions


7
Flight Safety Assurance and Aviation Accident Prevention System
Flight Safety Assurance System
Aviation Accident Prevention System
Flight Safety Level Management System

8

Flight Safety Assurance System

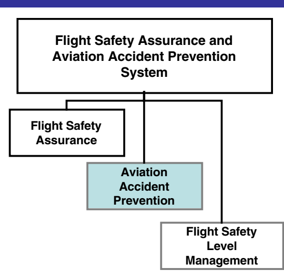


Flight Safety Assurance is the activities undertaken by the Airline's management and operational personnel to organize, implement and comply with requirements of flight safety regulations

$$\_N_{actual} \leq \_N_{norm}$$

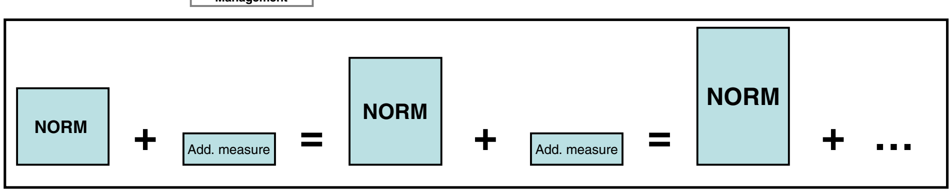
9

Aviation Accident Prevention System

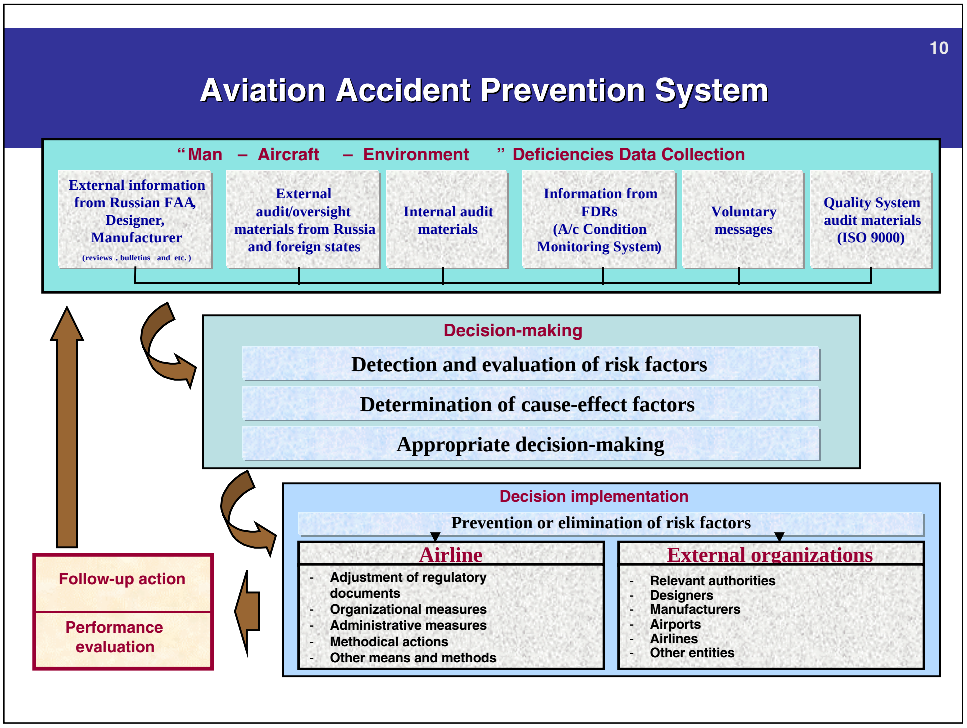


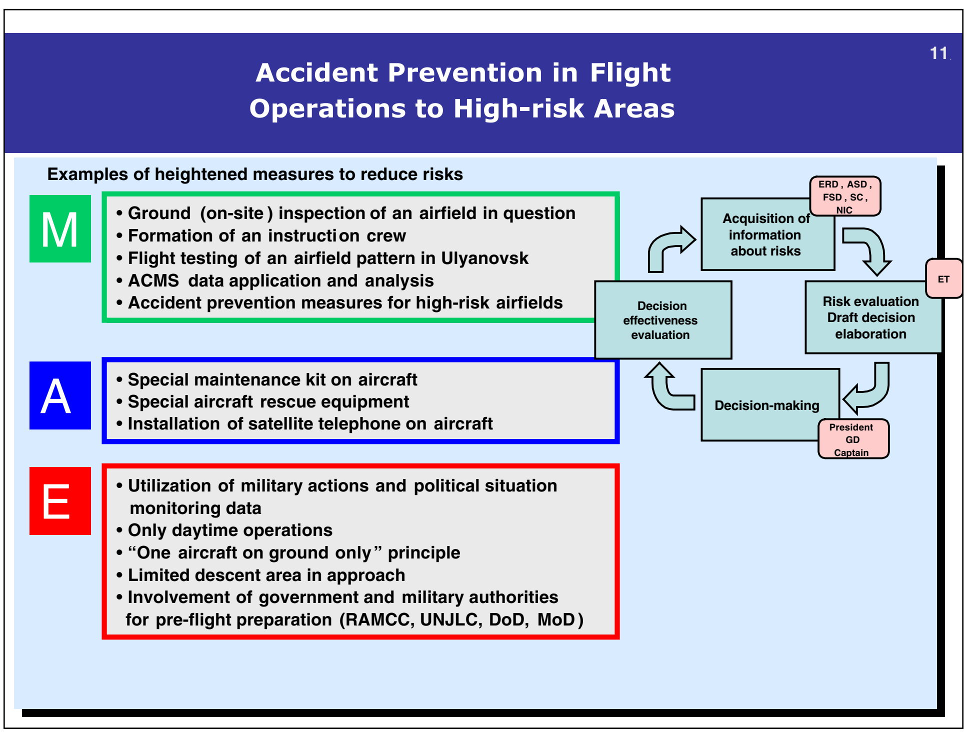
Aviation Accident Prevention is a combination of measures, which complement existing flight safety–related procedures accepted by states, manufacturers and operators

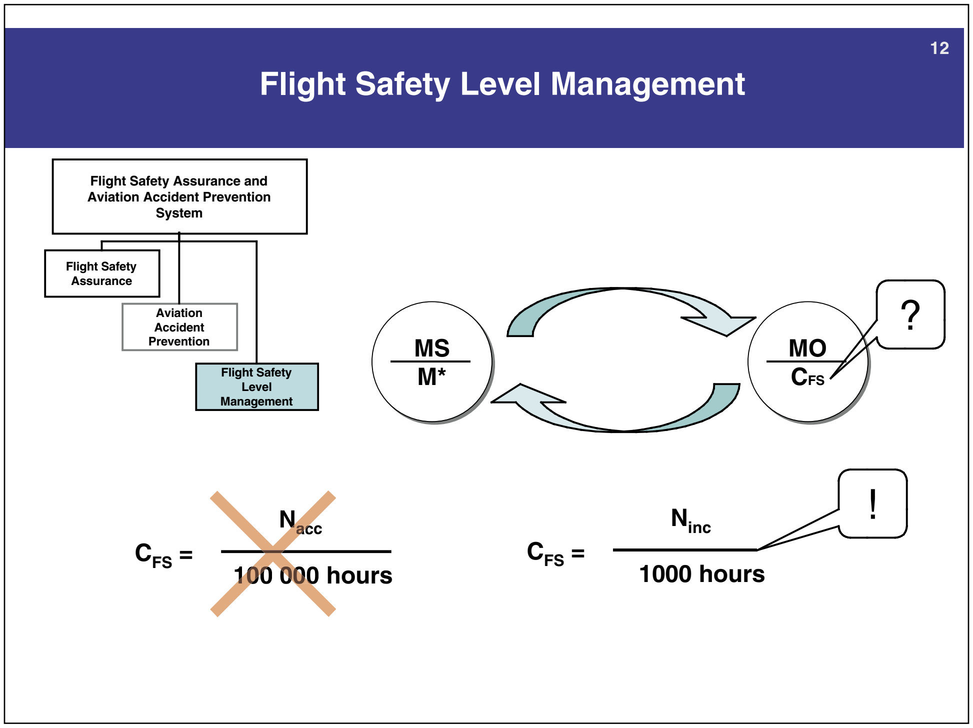
(ICAO Accident Prevention Manual)

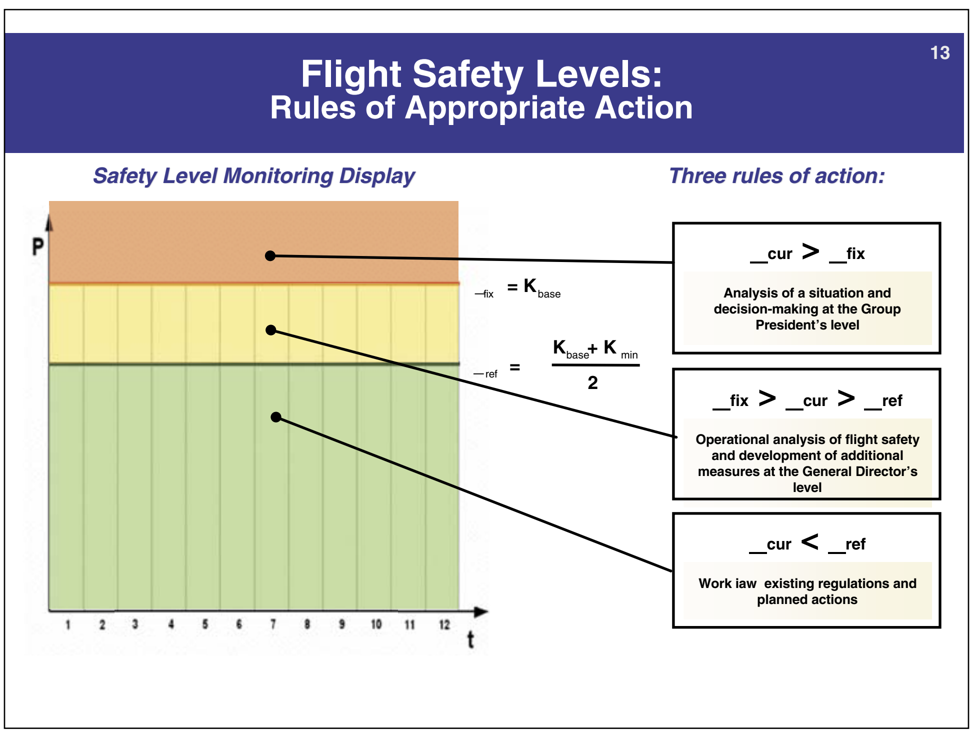


Accident prevention is a perpetual process of improving the flight safety assurance system


10
Aviation Accident Prevention System
"Man – Aircraft – Environment" Deficiencies Data Collection
External information from Russian FAA, Designer, Manufacturer
(reviews, bulletins and etc.)
External audit/oversight materials from Russia and foreign states
Internal audit materials
Information from FDRs (A/c Condition Monitoring System)
Voluntary messages
Quality System audit materials (ISO 9000)
Decision-making
Detection and evaluation of risk factors
Determination of cause-effect factors
Appropriate decision-making
Decision implementation
Prevention or elimination of risk factors
Airline
- Adjustment of regulatory documents
- Organizational measures
- Administrative measures
- Methodical actions
- Other means and methods
External organizations
- Relevant authorities
- Designers
- Manufacturers
- Airports
- Airlines
- Other entities
Follow-up action
Performance evaluation


11
Accident Prevention in Flight Operations to High-risk Areas
Examples of heightened measures to reduce risks
M
• Ground (on-site) inspection of an airfield in question
• Formation of an instruction crew
• Flight testing of an airfield pattern in Ulyanovsk
• ACMS data application and analysis
• Accident prevention measures for high-risk airfields
A
• Special maintenance kit on aircraft
• Special aircraft rescue equipment
• Installation of satellite telephone on aircraft
E
• Utilization of military actions and political situation monitoring data
• Only daytime operations
• "One aircraft on ground only" principle
• Limited descent area in approach
• Involvement of government and military authorities for pre-flight preparation (RAMCC, UNJLC, DoD, MoD)
Acquisition of information about risks
ERD, ASD, FSD, SC, NIC
Risk evaluation Draft decision elaboration
ET
Decision-making
President GD Captain
Decision effectiveness evaluation


12
Flight Safety Level Management
Flight Safety Assurance and Aviation Accident Prevention System
Flight Safety Assurance
Aviation Accident Prevention
Flight Safety Level Management
MS
M*
MO
CFS
?
CFS =
Nacc
100 000 hours
CFS =
Ninc
1000 hours
!


13
Flight Safety Levels:
Rules of Appropriate Action
Safety Level Monitoring Display
Three rules of action:
P
t
1 2 3 4 5 6 7 8 9 10 11 12
—fix = K base
—ref = K base + K min / 2
__cur > __fix
Analysis of a situation and decision-making at the Group President's level
__fix > __cur > __ref
Operational analysis of flight safety and development of additional measures at the General Director's level
__cur < __ref
Work iaw existing regulations and planned actions

Flight Safety Level Management

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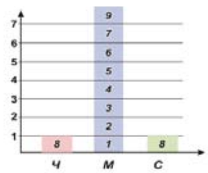
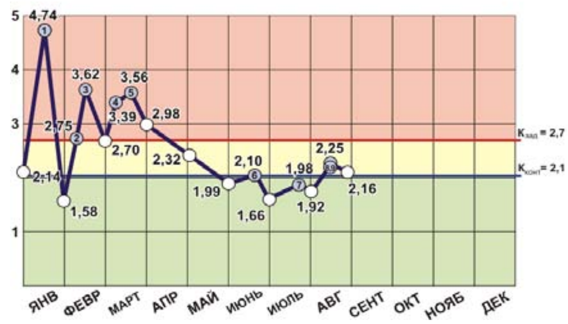
Тип ВС	Количество инцидентов	$K_{зад}$	$K_{факт}$
Ан-124-100	5	2,5	2,82
Ил-76	-	2,1	-
Як-40	3	1,0	2,33
Боинг-747	1	3,4	1,42
Парк ВС без Боинг-747	7	2,3	2,35
Весь парк ВС	9	2,7	2,19





1. 11 января, 82044, Энтебе, неуборка шасси
2. 7 февраля, 87981, Пенза, отказ управления ПОШ
3. 14 февраля, 82043, Кларкфилд - Тяньцзинь, неуборка 4-го ряда ООШ
4. 5 марта, 82043, Ницца, неуборка 5-го ряда ООШ при вылете из аэропорта
5. 18 марта, VP-BIA, Шанхай, выключение 2-го двигателя по загоранию табло "Клапан стартера открыт"
6. 18 июня, 82074, Новосибирск, отказ гидросистемы и выключение МДУ-3
7. 26 июля, 82043, Тяньцзинь - Новосибирск, отказ МДУ-4
8. 16 августа, 87484, Пенза, посадка на край ВПП
9. 16 августа, 87842, Внуково, возврат со старта из-за дыма в кабине

Flight Safety Level Management

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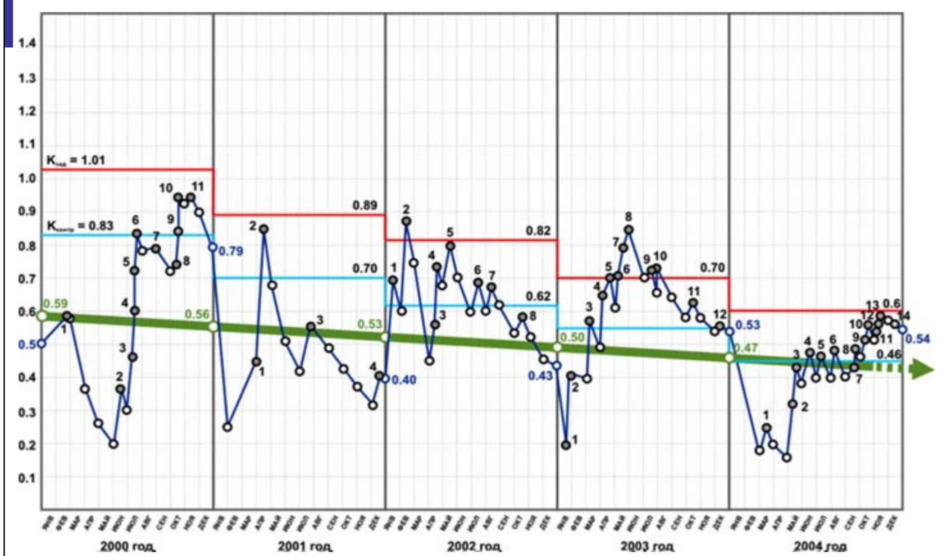
Flight Safety Level Management

16



Flight Safety Level Management

17

18

The airplane is a great creation of human genius and craft. It is beyond the authority of anyone other than those piously committed to laws of flying.

(Nikolay Zhukovsky)

♦♦♦♦

Survey on Cultural Factors Affecting Safety Management System Implementation in Latin America

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Boeing Research & Technology Europe

William L. Rankin, Ph.D., and Mike M. Moodi
Boeing Commercial Airplanes

1. Objective

While the worldwide accident rate for the Western-made commercial jet fleet was 0.73 per million departures in the 1995–2004 period (source: Boeing), it was at a level of 2.5 per million departures in Latin America. This compares unfavorably with a level of 0.4 in the United States and Canada and 0.7 in Europe (0.6 for JAA and 1.2 for non-JAA countries). While factors such as terrain, weather, regional conditions, infrastructure, airports, ATM support, operational conditions, regulatory oversight, and market and other economical factors can impact this rate, survey research performed by BR&TE examined whether the consideration of *cultural* or *inter-cultural factors*, including values, attitudes, social organization, communication and interactions, can provide additional elements of explanation.

This paper presents the results of a survey of 15 commercial airlines from the Latin American and Caribbean region performed as part of this research line. The survey was developed to provide more awareness for cultural factors and cultural differences with respect to difficulties Latin American airlines might face when implementing a safety management system (SMS) or safety programs and tools. Many airlines around the world, in particular in Latin America, are finding it hard to implement an SMS or to get the maximum benefits out of these programs. It is important to understand why this is happening. The purpose of this survey was to identify and understand which factors, especially cultural and inter-cultural factors, could relate to such difficulties. In order to account for the language preferences in the region, parallel English and Spanish questionnaire versions were sent to the airlines. A majority of respondents answered in Spanish and a minority in English or in Portuguese.[1]

2. Survey Pre-testing and Distribution

The questionnaire was pre-tested with two airlines and one pilot association in Spain in the second half of 2004. Objective, size and wording were optimized. Debriefing with the evaluators also allowed enriching those sections of the questionnaire specifically addressing SMS implementation, as well as contextual and cultural background aspects. The questionnaires were distributed with the help of Boeing field service representatives based in Latin America and representatives of IATA, IFALPA, ICAO and the Culture for Safety Network, an international network of industry, governmental and research organizations developed as an output of the First ICAO Iberoamerican Conference on Safety and Instruction in Civil Aviation, 2003, in Madrid, Spain. See for instance Hernán et al., 2003.

3. Participation and Response Rate

Fifteen of the 75 contacted airlines, representing 10 of 16 countries, completed the questionnaire. Therefore, the response rate is 20 percent for airlines and 62.5 percent for countries. Participation by country is as follows:

[1] Despite there being no Portuguese version. Translations by Rosa M. Rodríguez, Richard J. Kennedy and Michel A. Masson, BR&TE.

Argentina (1), Bolivia (1), Brazil (3), Colombia (1), Chile (1), El Salvador (1), Mexico (3), Panama (1), Uruguay (1), and two other Central American[2] (1) and Caribbean[2] countries (1), for a total of 15 airlines.

4. Questionnaire Structure and Survey Results

The questionnaire is divided into four sections as shown in Figure 1.

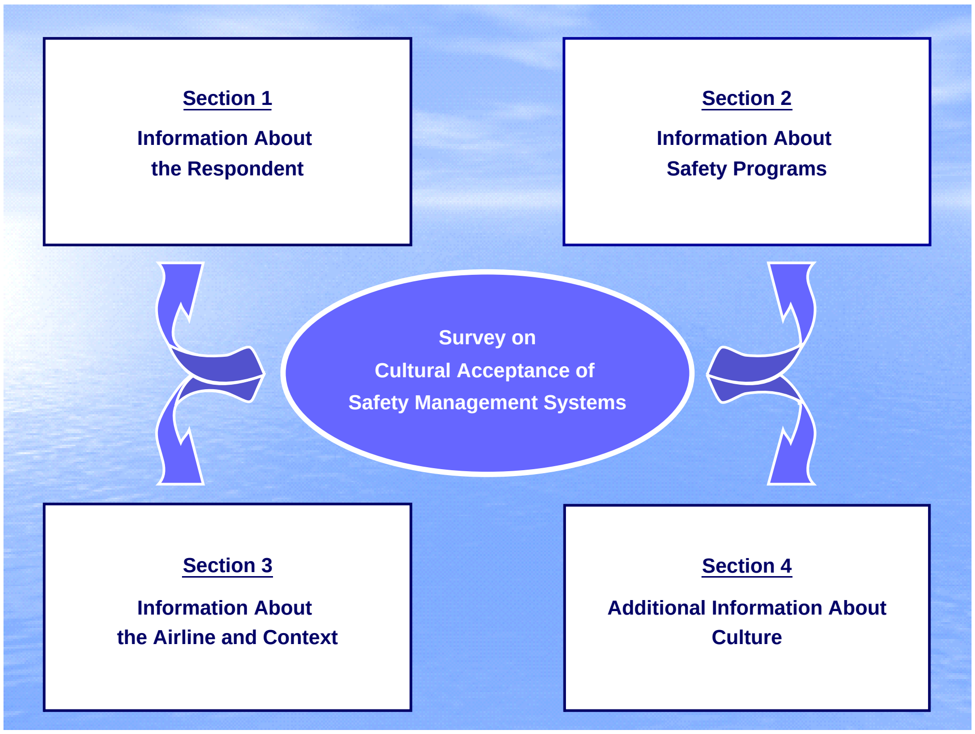

Figure 1. Questionnaire Structure

Results will be presented section by section, in the order defined above.

Section 1 — Information About the Respondent

The survey targeted *flight safety officers* because of their expert opinions. Answers were received from 16 respondents belonging to 15 airlines: 12 Spanish-speaking, three Portuguese-speaking and one English-speaking. Twelve respondents were flight safety managers or flight safety officers and four were flight safety directors at the time they completed this survey. Ten of them mentioned that they were captains in operation, one a retired captain and one a first officer. Six of them mentioned they were also working as flight, simulator or crew resource management instructor and two as accident or incident investigator.

Section 2 — Information About Safety Programs

Safety tools in use

This part of the questionnaire identifies which safety programs and tools are currently in use in the participating airlines.[3] They are classified in five groups: 1) mandatory occurrence reporting systems (MORs), 2) voluntary error and incident reporting, analysis and management systems (e.g., PEAT, MEDA, ASAP, BASIS, ASRS), 3) flight safety event reporting and analysis/information sharing systems (e.g.,

[2] These countries are not identified to keep the airlines anonymous.

[3] From now on, the results concern the airlines (15) and not the respondents (16), whereof two belong to the same airline.

AASES-ATA, AERO, ASI-NET, STEADES), 4) line operations audit systems (e.g., LOSA, LOAS, in-house) and 5) quality assurance based on flight data recording and analysis (e.g., FOQA, AQAS, BASIS, LOMS, SAFE). This structure and the different safety tools listed here have been directly adapted, with some additions, from GAIN's (GAIN, 2003).

National Mandatory Occurrence Reporting (MORs) Systems

	% Missing	% Used	% Not Used	% Total
National Mandatory Occurrence Reporting Systems (MORs)	20.0	80.0	.00	100.0

Voluntary Error or Incident Reporting, Analysis and Management Systems

	% Missing	% Used	% Not Used	% Total
CHIRP — Confidential Human Factors Incident Reporting Programme by U.K. CAA	0	13.3	86.7	100.0
ASAP — Aviation Safety Action Program by FAA	0	6.7	93.3	100.0
ASRS — Aviation Safety Reporting System by NASA for the U.S. FAA	0	13.3	86.7	100.0
PEAT — Procedural Event Analysis Tool by Boeing	0	20.0	80.0	100.0
MEDA — Maintenance Error Decision Aid by Boeing	0	26.7	73.3	100.0
BASIS — British Airways Safety Information System	0	20.0	80.0	100.0
AIRS — Aircrew Incident Reporting System by Airbus	0	6.7	93.3	100.0
HFACS — Human Factors Analysis and Classification System by U.S. Navy, Marine Corps, NASA and FAA	0	0.0	100.0	100.0

Percentages are typically under 25 percent. Note the relatively high percentages of users of MEDA and PEAT from the Boeing Safety Management Support[4] (BSMS) family and BASIS by British Airways. CHIRP by U.K. CAA and ASRS by U.S. FAA are used by more than 10 percent of the airlines having participated in this survey. Also, 26.7 percent (four airlines) reported use of an in-house system, in some cases Web-based. GAIN and a Union system were mentioned in 6.7 percent of the cases (one airline) respectively.

Flight Safety Event Reporting and Analysis / Information Sharing Systems

	% Missing	% Used	% Not Used	% Total
AASES — ATA Aviation Safety Exchange System	0	6.7	93.3	100.0
AERO — Aeronautical Events Reports Organizer	0	0	100.0	100.0
ASI-NET — Aviation Safety Information Network	0	6.7	93.3	100.0
ASDSS — Aviation Safety Data Sharing System	0	0	100.0	100.0
AQD — Aviation Quality Database by Superstructure, New Zealand	0	0	100.0	100.0
AVSiS — Aviation Safety Information System by AvSoft, U.K.	0	13.3	86.7	100.0
INDICATE — Safety Program by ATSB, Australia	0	0	100.0	100.0
SIE — Safety Information System by IATA	6.7	6.7	86.7	100.0
SRS — Safety Report System by First Launch, U.K.	0	0	100.0	100.0
STEADES — Safety Trend Evaluation, Analysis and Data Exchange System by IATA	0	26.7	73.3	100.0

[4] Formerly Boeing Safety Management System.

In this category of tools, STEADES by IATA and AVSiS by AvSoft, U.K., were used the most, with 26.7 percent (four airlines) and 13.3 percent (two airlines) respectively. Also BASIS, originally not in the questionnaire,[5] was mentioned by one airline.

Line Operations Audit Systems

	% In Progress	% Used	% Not Used	% Total
LOSA — Line Operations Safety Audit by the LOSA Collaborative	13.3	20.0	66.7	100.0

Interestingly, 33.3 percent of the participating airlines are using, or are in the process of introducing, LOSA. The majority (66.7 percent), however, are not using this safety program. In addition, 13.3 percent (two airlines) have reported using an in-house system and 6.7 percent (one airline) use LOAS by Airbus.

Quality Assurance Based on Flight Data Recording and Analysis

	% In Progress	% Used	% Not Used	% Total
FOQA — Flight Operational Quality Assurance	20.0	33.3	46.7	100.0
APMS — Aviation Performance Measuring System by NASA	0	0	100.0	100.0
AQAS — Airbus Quality Assurance System	0	0	100.0	100.0
BASIS Flight Data Tools	6.7	6.7	86.7	100.0
GRAF Vision — Flight Data Animator	0	6.7	93.3	100.0
LOMS — Line Operations Monitoring System by Airbus	0	6.7	93.3	100.0
RAFT Recovery, Analysis and Presentation System and Insight	0	0	100.0	100.0
SAFE — Software Analysis for Flight Exceedance	0	0	100.0	100.0

Of flight data recording and analysis tools, the most frequent ones are FOQA (33.3 percent) and BASIS (6.7 percent), plus 20 percent and 6.7 percent respectively are being implemented. GRAFS and LOMS have each been adopted by one airline. In addition, FIDRAS, RAW FDR and SAGEM, originally not in the questionnaire, were mentioned by one airline. These results are globally consistent with those revealed by the survey performed by Global Aviation Information Network (GAIN) four years ago (GAIN, 2001), Appendix B.

Degree of achievement of an SMS

Knowing what safety tools are used provides an objective indication of the degree of implementation of a safety program. In addition, the questionnaire also seeks to obtain subjective evaluations based on the safety officers' expert opinion of their airline's standing with regard to the main components of an SMS. Based on a literature review and on fruitful discussions with safety experts both in the context of the Culture for Safety Network and this survey's pre-testing phase, 10 dimensions were defined, of which nine were investigated in the survey. The Proactive Culture component was not investigated in this survey, but was introduced in the February 2005 questionnaire revision.

1. **Senior Management Commitment** — Airline management considers safety as a paramount corporate value, and has committed itself to adopting practices that will ensure safety and lead to continuous safety improvement.

2. **Safety Policy** — A safety policy that establishes safety as a paramount value, states safety objectives, highlights the importance of everyone's commitment and contribution and renders everyone accountable for achieving the stated safety objectives.

[5] BASIS has been integrated in a questionnaire revision dated February 2005.

3. **Safety Roles and Responsibilities** — Goals have been stated, staff and resources have been allocated, and accountabilities have been defined at all levels of the organization.
4. **Just Culture**[6] — The airline has a policy clearly stating which actions will and will not lead to disciplinary sanctions. The workforce knows and agrees on what is acceptable, such as unintentional errors, and what is not acceptable, such as violations, negligence or sabotage.
5. **Reporting Culture** — Staff is encouraged to report safety information. Everyone feels free to report and is willing to report, knowing that feedback is provided and that information leads to actual changes.
6. **Learning Culture** — All safety events, including errors and incidents, are considered opportunities to learn.
7. **Documented Processes** — Documented systems are in place to collect and process safety information regarding, for instance, accidents, incidents, errors, concerns and suggestions expressed by staff, safety audits, etc.
8. **Risk Management Process** — A risk management process is in place that uses reactive (for instance incident reporting) or proactive (for instance internal safety audit) safety approaches.
9. **Emergency Response Plan** — A plan has been defined to address emergency and crisis situations such as those resulting from an accident or a major incident.
10. **Proactive Culture** — The airline proactively seeks to improve safety even in absence of incidents or safety threatening events.

A Likert-type scale was used to assess the degree of achievement for these 10 components. The scale was defined as follows: 4 — Fully achieved; 3 — Almost achieved; 2 — Somewhat achieved; 1 — Slightly achieved; 0 — Not achieved at all. All participating airlines completed this part of the questionnaire.

Figure 2 below shows the mean degree of achievement for each component, ordered from least to most.

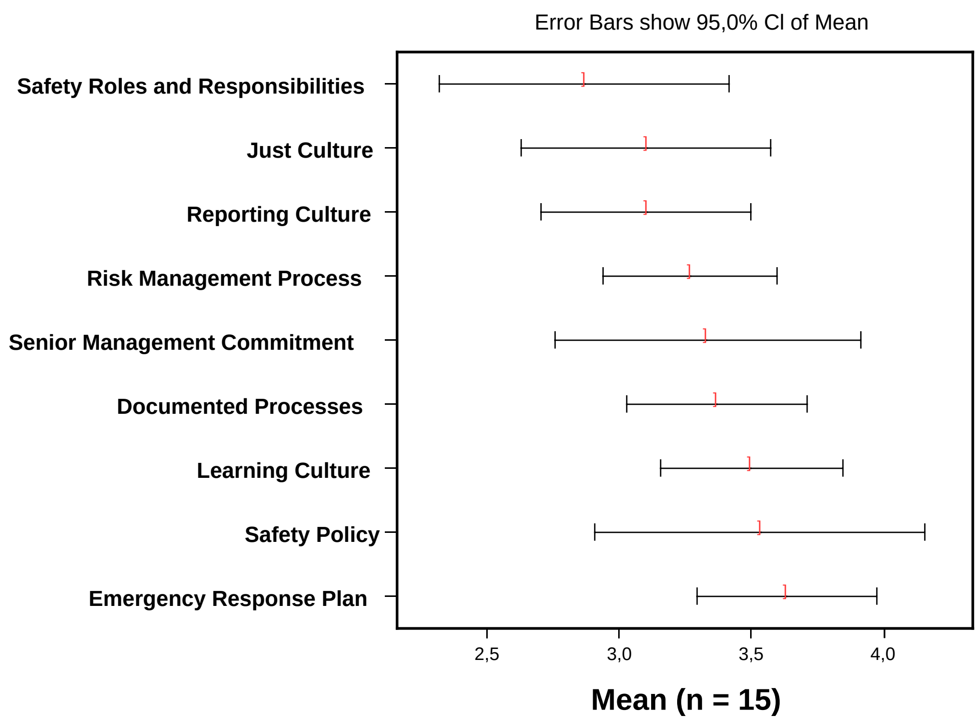

Figure 2. Degree of Achievement of Nine Components of an SMS

[6] See, for instance, GAIN, 2004.

Conditions favorable to the implementation of a SMS

Based on a literature review, the authors' professional experience and suggestions made by the participants during the pre-testing phase, a set of conditions that are favorable to the implementation and use of an SMS was developed. Respondents were asked to rate the degree to which their airline had achieved these conditions. A summary of these results is presented below. The rating scale was defined as follows: 4 — Fully achieved; 3 — Almost achieved; 2 — Somewhat achieved; 1 — Slightly achieved; 0 — Not achieved at all.

The following 10 conditions are the least achieved so far:

- In my airline, employees report all errors and incidents, including those that are not mandatory to report (mean score = 2.3).
- In my country, regulations truly encourage employees to freely report errors and incidents (2.4).
- The airline dedicates enough resources (personnel, budget, hardware and software, time) to run the safety reporting system (2.5).
- Management accepts that some errors or factors contributing to error are under their control (2.8).
- Results are shared with those individuals and organizations who may need to act upon the results, including airline employees, contracted staff, subcontracted organizations, other airlines (especially of the same alliance), suppliers, manufacturers and regulators (2.9).
- In my airline, employees report those errors and incidents that are mandatory to report (2.9).
- My airline has a disciplinary policy that fairly balances the need to favor free reporting of errors and the need to sanction other types of events involving negligent or deliberate safety threatening actions (2.9).
- Flight crews are convinced it is useful to report incidents and events because they know the information will be dealt with and lead to actual safety improvements (3.0).
- My airline has a reporting culture establishing why and how the event happened in order to learn about risk factors, manage risk and improve safety, not a culture of blame (3.1).

On the basis of the above average ratings, conceptually related items were grouped together to develop the following summary of findings: Regulations do not truly encourage free reporting, and airlines could dedicate more resources (personnel, budget, hardware and software, time) to run reporting systems. Management does not easily accept the concept that some errors or contributing factors to error are under their control. In addition, airlines rarely have a clear disciplinary policy that balances the need to favor free reporting of errors and to sanction negligent or reckless actions. Besides, collected information does not always lead to actual safety improvements, which also discourages reporting.

Conditions adverse to the implementation of an SMS

This section summarizes responses that indicate conditions adverse to the implementation of SMS.

The rating scale is defined as follows: 4 — Strongly agree; 3 — Agree; 2 — Neither agree nor disagree; 1 — Disagree; 0 — Strongly disagree.

The results are ordered from the most prevalent to the least prevalent adverse conditions:

- Flight crews prefer to keep information informal rather than writing official event reports (mean score = 2.8).

- Crews do not like to do the report paperwork (2.5).
- Crews do not report unless the captain decides to do so (2.2).
- Not enough resources (personnel, budget, hardware and software, time) are allocated to managing safety (2.0).
- There is no reason to report errors and incidents because this will not eventually change the flying environment (weather, terrain, traffic, etc.) (2.0).
- Since fixing problems can take time, pilots falsely assume they are not fixed (1.9).
- Most safety problems are *already* known (1.8).
- Most known safety problems are *not fixed* (1.7).
- The captain may want to protect the first officer by not reporting (1. 7).
- The airline is now struggling with objectives that are considered of higher priority than implementing a flight safety program, such as remaining in business or avoiding bankruptcy (1.6).
- Pilots at my airline fear direct airline sanctions: loss of bonus, fine, debarment, work termination, etc (1.6).
- Reporting goes against pilots' spirit and professional solidarity (1.5).
- In my airline, senior ex-military pilots are reluctant to report because reporting is not part of their military culture (reporting is conceived as criticizing the mission) (1.5).
- Pilots at my airline fear indirect airline sanctions: e.g., negative effects on career (1.5).
- Crews consider not being bothered with reporting as part of their privileges (1.4).
- Professional unions and airlines have different positions regarding the use of reporting systems and of the information collected (1.4).
- In my airline, younger ex-military pilots are reluctant to report because, when entering the civil domain, they are losing the juridical protection they were used to in the military environment (1.4).
- Reporting an event in which the captain is involved is not an accepted practice (1.3).
- Pilots at my airline fear, or know, that information about errors and incidents they might report can be used in court after an accident or an incident (1.3).
- Airline management fears direct airline sanctions: loss of bonus, fine, debarment, work termination, etc. (1.3).

In the respondents' expert opinion, the first type of barrier to reporting comes from the flight crews' preference for keeping information informal rather than for using an official channel. Flight crews also dislike doing the paperwork. A second type of barrier concerns professional identity: reporting goes against pilots' spirit and professional solidarity (caste structure). Crews may not report unless the captain decides to do so, and the captain may wish to protect the first officer by not reporting. Also, safety problems are difficult to correct: reporting won't eventually produce a change in the flying environment, most safety problems are already known and most of these known problems remain unsettled. Pilots also fear direct or indirect airline sanctions in a context in which reported information can be used in court, especially after an accident.

Section 3 — Information About the Airline and Context

One could argue that the difficulties airlines are facing with the implementation of safety programs are due to business pressure, especially after September 11, 2001. We wanted to examine this factor. First, we asked the respondents how much they agreed with the following statement: "The airline is now struggling with objectives that are considered of higher priority than implementing a flight safety program, such as remaining in business or avoiding bankruptcy." This statement was ranked in 10th position in the list above.

Then, we examined the consequences of September 11 on the airlines. The results are presented below:

Since September 11, 2001, the airlines have experienced:

In 2001–2004 — Event Type	Frequency	Percent
Cost Reduction or Stabilization	7	46.7
Code Sharing	6	40.0
Adhesion to an Alliance	4	26.7
Economic Risk*	2	13.4
Acquisition	1	6.7
Increase in Security Costs*	1	6.7
Bankruptcy	1	6.7
Growth*	1	6.7
Staff Cuts*	1	6.7
Merging	0	0

Expected in 2004–2007 — Event Type	Frequency	Percent
Restructuring of Activities or Routes	10	66.7
Code Sharing	7	46.7
Cost Reduction or Stabilization	6	40.0
Acquisition	6	40.0
Growth*	3	20.0
Merging	2	13.3
Fleet Upgrade*	1	6.7
Bankruptcy	1	6.7
Adhesion to an Alliance	0	0

* Mentioned by the respondents in addition to the lists presented in the questionnaire.

The most common strategies to remain in the business are restructuring of activities or routes, cost reduction or stabilization and code sharing. Interestingly, "growing the business" is the way by which commercially aggressive airlines have chosen to face these difficult market conditions.

These results are compatible with the IATA report summarizing the airline market evolution for 2004 (IATA, 2005) and previous years: Airlines are facing financial difficulties worldwide and the picture gets clearer when looking at Latin American regional characteristics. Consider the comments by G. Bisignani (2005), IATA, director general and CEO: "The crisis in our industry continues. Our fuel bill this year will be US$83 billion. Equal to the GNP of New Zealand. This is US$39 billion more than 2003. The fifth horseman of the Apocalypse — the extraordinary price of fuel — is destroying our profitability. Last year alone, the industry lost US$4.8 billion. But regional differences are astonishing … Latin American carriers were near break-even. The situation is changing fast. Some of the region's airlines are making money, but the majorities are technically bankrupt. And misguided airport privatization makes matters worse."

Section 4 — Additional Information About Culture

This last section of the questionnaire examines, in a free-text format, complementary information about three[7] basic components of culture:

- Regional Culture: What makes the culture of a given region (for instance, Latin America) unique, that is to say, different from the culture of any other region in the world;
- National Culture: What makes the culture of a particular country different from the culture of any other country in the region of interest; and
- Company Culture: What makes the culture of the airline different from the culture of any other airline in the region.

Regional Culture

Question: In the aviation domain, what makes *Latin American culture* unique, that is to say different, from the culture of any other region in the world?

Synthesis of answers:

The respondents' free-text comments are summarized below. This list was developed by grouping and synthesizing comments that were conceptually related. These findings are not prioritized and must be considered only as "remarkable results," describing salient characteristics and putting into context the quantitative results reported the previous sections.

- The region's young age and its cultural roots such as the love for its natural, historical, ethnic and social richness and the importance of the family concept, plus the use of a common language.
- Individualism but at the same time adaptation to other cultures of the different regions, since Latin America is basically a mix of races that are trying to unify.
- Reactive instead of proactive safety attitude, reinforced by the *rarity of accidents* and of incidents and by *market pressure*.
- Insufficient but developing safety culture, hampered by regulatory bodies that sometimes don't properly supervise safety regulation compliance when regulations do exist, by or the lack of such regulations.
- Reluctance to report to management and to the authorities because of fear of punishment (both direct and indirect), especially as airlines are trying to reduce costs to stay in the market. The situation is, however, improving.
- Fear of criticism, understood as a sanction. Feeling of guilt attached to error, nurtured by the society itself and by the authorities.
- Pilots lack trust in the reporting system and in the use authorities make of reported information. Consequently, the tendency is to report only what is mandatory.
- There have been some unfortunate instances of publishing and public use of reported information, without protection of the pilots involved.
- Aviation authorities sometimes depend directly on governments or on military structures, which is not compatible with private commercial interests and culture.

[7] A fourth category has been added in the February 2005 questionnaire revision: Professional Culture: What makes the culture of a given profession, for instance line pilots, different from the culture of any other professional group in the region of interest. See, for instance, Helmreich and Merritt, 1998.This dimension was not investigated in this survey.

- Many professional unions strongly influence the politics and culture in general; mixing labor interests with safety concerns.
- Lack of resources in some regions, which by the way reinforces solidarity (positive side effect).
- Lack of qualified personnel even if a substantial number of Latin American aviation personnel have been trained or acquired professional experience outside the region, especially in the United States.
- Personnel occupying administrative operational safety positions may not have all qualifications required in aviation safety or with SMS, and lack guidance.
- Ranks are very much respected, especially in case of clear difference in seniority.
- Risk taking is sometimes perceived as a way to put masculinity to the test.

Unfortunately, many of these responses indicate that implementing an SMS may be a challenge — e.g., reactive instead of proactive culture, reluctance to report for fear of punishment and lack of trust in a reporting system.

National Culture

Question: In the aviation domain, what makes your *airline's country culture different* from the culture of other countries in Latin America?

Synthesis of answers:

- The absence of accidents leads to overconfidence. Fortunately, safety programs (such as FOQA) have generated greater safety awareness among higher management.
- Budget constraints can impose limitations on safety programs. Aviation safety is seen as an expense, not as an investment, especially since its benefits can't be seen in a direct and immediate form. The work of those working in safety is not valuated and safety officers have a hard time convincing their management to do more for safety.
- Pilots have gradually gotten used to trusting safety programs, but still, setting up safety programs in an atmosphere of relative indifference is a titanic task.
- The pressures exercised by the powerful airlines, somehow subsidized or owned by the governments and their unions, mark in some cases the lines of authority. Smaller airlines may suffer from this situation.
- Some airlines are very aggressively and successfully growing their business.
- Flying in certain Latin American regions requires special piloting skills because of mountainous areas without radar coverage or precision approach systems.
- In small airlines, everybody knows everybody, which might create conflicts of interest in a context where the chances of career promotion are limited.
- A tendency to transgress norms is a particularity.
- Rest periods are perceived as a problem. In addition, pilots often have additional professional activities.
- Good historical contacts and exchanges with the United States (especially for northern Latin America).

- There is a real effort to change in line with the changes in the aviation world. Adoption of quality management systems and of the standards of the alliance to which the airline belongs is an example. Safety programs have also recently been introduced, in compliance with ICAO.

While some of these responses appear promising regarding SMS — e.g., good historical contacts with the United States and adoption of quality management systems — many responses indicate that implementation of an SMS will not be easy — e.g., overconfidence in safety, budget constraints and relative indifference to safety.

Question: In the aviation domain, what makes your *airline's country culture similar* to the culture of other countries in Latin America?

Synthesis of answers:

- Despite regional differences, Latin America is characterized by a similarity of languages and of races, the warmth and the kindness of its people and cultural and ethnic identification.
- Similarity of deficiencies, in particular in the civil aviation authority oversight.
- Apathy and a general difficulty in establishing a safety culture are found not only in aviation but also in life itself, and from the authorities down to the last employee of the smallest airline. A default way of thinking is "Don't worry, nothing will happen to me [this isn't my business]."
- Safety programs are being adopted but some of them are still not mandatory.
- Two opposite attitudes are reported regarding safety programs: skepticism, which hampers implementation, versus rapid implementation, with no guarantee that the basic principles have been clearly understood.
- Safety is often sacrificed for production and is rarely used to manage business.
- Some pilots have been very much influenced by military aviation.
- Operating in several countries leads to a mixing and merging of cultures. Airlines from countries occupying a central position in the American continent easily adopt cultural aspects and safety practices from other countries, especially from the U.S.

Lack of oversight by the authorities, apathy to establishing a safety culture, and lack of regulations regarding safety programs pose an obstacle to implementation of an SMS.

Company Culture

What makes your *airline's culture* different from the cultures of other airlines in Latin America?

Synthesis of answers:

Although this section is about airline differences, points of general interest can be mentioned. Most of them are *good practices*, worth being shared within the airline community.

- Merging, interchanges of aircraft and code sharing agreements have helped staying in the business.
- Other business strategies have been mentioned, such as hiring external consultants for improving service quality and growing the business, or creating a strategy and business development department.
- Familiarization with the competition from North American airlines has stimulated, and helped, for the central region.
- Presence and participation in international conventions and organizations are key.

- Participation in an alliance can provide benefits in terms of safety management and training programs.

- A great feeling of togetherness develops in small organizations, which survive in the industry despite all types of threats.

- Greater familiarity between crews is characteristic of smaller airlines.

- Some mid-size airlines find it easier to implement safety programs in a much faster way.

- Some airlines are also investing in technology and in personnel capable of auditing and operating safety programs.

- Keeping safety management separated from union or labor groups can reduce the political considerations regarding safety positions.

- Some airlines benefit from excellent safety awareness and are solidly adopting safety management and human resources processes.

- Selecting personnel following a strict and rigorous process, looking at competences in relation to job descriptions and avoiding favoritism (e.g., hiring airline employees' relatives) is an example of such a new approach. Career development based on the fulfillment of job requirements instead of seniority is another one.

- Some airlines now favor an "open doors" culture and policy, and labor protection is granted by an independent company union.

- For an accident or incident prevention program to be successful, providing relevant and direct information presented in simple terms, for instance in a Web site, is believed to be a good and recommendable approach. Transparency, clarity of information and *appropriation* will favor reporting and participation from the pilots. To be successful, a reporting system must be considered by the pilots as something they share, not as something that comes from management.

These differences in airline cultures indicate that some of the airlines may be more successful than others in implementing an SMS — e.g., some airlines' culture is more positive to safety, smaller airlines may find implementation of an SMS easier than larger airlines, and some have an "open door" policy.

5. Discussion and Conclusion

Although Western-designed safety programs and tools are considered universal or of universal benefit, some of their assumptions may be culturally sensitive. From the inter-cultural perspective advocated in the ICAO Circular on Cross-Cultural Factors in Aviation Safety (2004), one task for the manufacturers and safety program designers is to identify the assumptions behind these programs and to assess how many and how much of these assumptions are shared, or not, by operators worldwide. Many airlines around the world, in particular in Latin America, are indeed finding it hard to implement a U.S.- or European-like SMS. It is important to understand why this is the case. The purpose of this survey was to identify and understand which factors, especially cultural and inter-cultural factors, might contribute to such difficulties. More precisely, this survey assessed how many of the conditions needed for implementing a Western-designed SMS are currently achieved in Latin America, and for what reasons. *The main research hypothesis is that the more alien these requirements are to the local culture(s), the more efforts are required to properly implement such programs.*

The data collected in this survey provide some answer elements for the Latin American region. The questionnaire allowed us to assess the main dimensions defining an SMS and indicated where the major progress can be made. Safety goals should be better stated, staff and resources should be better allocated, and accountabilities defined at all levels of the organization. The airlines should also render clearer which actions will or won't lead to disciplinary sanctions. Airlines should also favor free reporting, providing feedback to the reporters and making sure that collected information leads to actual changes and is protected. In order to do so, regulations could better protect collected information.

Major improvements are also expected to come from the airlines with more resources to manage safety, although the current economic context does not really favor it, and from management accepting that contributing factors to error are sometimes under their own control. To be effective, any reporting system must also acknowledge that flight crews prefer keeping information informal and that they do not like to do the report paperwork. As suggested by one respondent, providing relevant and direct information presented in simple terms, for instance, in a Web site, is a recommendable approach: transparency, clarity of information and appropriation will favor reporting and participation from the pilots.

The reader familiar with SMS might argue that this pattern does not differ much from the situation in the Western world or in other regions of the world. Indeed, this pattern could well be shared by *all* airlines worldwide that are currently implementing an SMS or that have had recent experience with SMS, due to the change of values and practices that such a program often requires. What truly differentiates Latin America from other regions can only be identified by *comparison*, which would require extending this type of research to other regions as well. In the absence of such a comparative study, some aspects reported in Section 4 can be suggested, or hypothesized, as specific to Latin America:

- Despite regional differences, Latin America is probably unique by the similarity of languages and of races, the warmth of its people and their strong cultural and ethnic identification. Latin America is also a mosaic featuring a mixing and merging of cultures. A great feeling of corporate, national, regional and cultural pride is vivid in the region, and a great feeling of togetherness develops in small organizations, which survive despite demanding business conditions.

- Latin America seems to suffer from a similarity of deficiencies, in particular the lack of civil aviation authority guidance and oversight. Also, powerful airlines, somehow subsidized or owned by the governments and their unions, mark in some cases the lines of authority. Smaller airlines may suffer from this situation. Union and labor interests also sometimes interfere with airline and safety management.

- Certain apathy towards safety is found not only in aviation but also in the life itself, and from the authorities to the industry. For management, safety is still considered more an expense than an investment. Also, two opposite attitudes were reported regarding safety programs: skepticism, which hampers implementation, versus rapid implementation or quick fix, with no guarantee that the basic principles are really understood or put into practice.

- However, Latin America is *moving*. Airline mergers, interchanges of aircraft, code sharing agreements and accession to alliances have helped airlines stay in business. Other strategies were mentioned, such as hiring external consultants for improving service quality and for growing the business. Familiarization with the competition from North American airlines has stimulated and helped the central region to develop its business. Some airlines are also investing in technology and in personnel capable of auditing and operating safety programs and are adopting new types of recruitment and career development systems. Participation in international business and safety groups is considered key to success and the progressive implementation of safety programs has started generating safety data, which improves safety awareness among airline management.

From a customer support point of view, this type of questionnaire can be used with airlines as a diagnostic and coaching tool because it indicates where efforts are the most needed and puts the information in context. Cultural assessment can be used as a guide to implement changes. Cultural assessment can provide a more comprehensive view of current conditions (corporate, staff and regional values and practices and contextual aspects) influencing

SMS implementation. Effective cultural assessment relies on the employees' perspective of how the organization is conducting its business and caring about safety. The implementation of SMS calls for assessment of gaps in current safety and quality programs. A questionnaire like this one can be used for facilitating gap assessment within airlines that are committed to implementing an SMS program.

Working on the cultural and contextual factors that potentially hamper, or facilitate, the utilization of such safety programs will eventually facilitate the collection of data of safety interest for the airlines and the manufacturers, and increase the knowledge of regional safety aspects. This wider objective can be shared with other organizations involved in regional safety, such as, for Latin America, IATA through its Latam/Car regional safety strategy, PAAST, the IATA Pan-American Aviation Safety Team, IFALPA/ASPA, the International Federation of Airline Pilots' Associations/Association of South Pacific Airlines and ICAO through its North American, Central American and Caribbean Offices.

Over the last decade, Boeing has been strongly advocating cooperation with the industry (for instance Graeber, 1998; Hutchins, Holder and Pérez, 2002; Castaño, 2003; Castaño and Graeber, 2003), taking into account cultural diversity and offering tools such as the BSMS to help airlines managing safety take into account local aspects. The importance of having all stakeholders *working together* has also recently been emphasized in the ICAO Circular on Inter-Cultural Factors (2004). The airlines that participated in this survey just took up this collaboration challenge. The authors wish to thank them for their contribution.♦

Acknowledgement

The authors gratefully acknowledge the contributions of the 15 Latin American and Caribbean airlines that participated in this survey and the Spanish airlines and Pilot Association that helped to improve the questionnaire during its pre-testing. Special thanks also go to Curt Graeber, BCA, for his guidance throughout all the stages of this research and for his review of this paper.

References

1. Hernán, Miguel, Hörmann, Hans-Jürgen, Kennedy, Richard, Orti, Fortunato, Swanson, Douglas E. and Masson, Michel (2003). "Investigaciones en medio ambiente, seguridad y gestión de tráfico aéreo. Areas de trabajo del Centro Internacional de Investigación y Tecnología de Boeing-Madrid." Paper presented at the First ICAO Iberoamerican Conference on Safety and Instruction in Civil Aviation, Madrid, Spain, July 2003.

2. Global Aviation Safety Network (GAIN). <http://204.108.6.79/products/documents/Guide_Analytical_Methods_and_Tools.pdf>. June 2003.

3. Global Aviation Safety Network (GAIN). *Survey of Analytical Processes & Requirement for Airline Flight Safety Management*. December 2001.

4. Global Aviation Safety Network (GAIN). *A Roadmap to a Just Culture: Enhancing the Safety Environment*. September 2004.

5. International Air Transport Association (IATA). *International Air Transport Association Annual Report 04. Looking at the Industry a New Way*. 2005.

6. Bisignani, Giovanni (2005). "State of the Air Transport Industry." Paper presented at the 61st IATA Annual Meeting and World Air Transport Summit, Tokyo, May 30, 2005.

7. Helmreich, Robert L. and Merritt, Ashleigh C. *Culture at Work in Aviation and Medicine, National, Organizational and Professional Influences*. Ashgate: Aldershot, England, 1998.

8. International Civil Aviation Organization (ICAO). Circular 302-AN/175. *Cross-Cultural Factors in Aviation Safety*. Prepared by Daniel Mauriño and Ashleigh C. Merritt. 2004.

9. Graeber, Curtis (1998). “Airplanes, Safety and Culture, a Manufacturer’s Perspective.” In *Proceedings of the First ICAO Regional Seminar & Workshop on Cross-Cultural Issues in Aviation Safety, Bangkok, Thailand, August 12–14, 1998*. Montreal, Canada: ICAO, 1998.

10. Hutchins, Edwin; Holder, Barbara E.; and Pérez, Alejandro E. *Culture and Flight Deck Operations*, sponsored research agreement 22-5003. Prepared for the Boeing Company. June 2002.

11. Castaño, Diego J. (2003). “El Valor de la Colaboración.” *Aviador* no. 17 (Julio-Agosto 2003): 39–42. Colegio Oficial de Pilotos de la Aviación Comercial (COPAC): Madrid, Spain.

12. Castaño, Diego J. and Graeber, Curtis (2003). “Boeing y la introducción del Factor Humano en la educación de seguridad aérea.” Paper presented at the First ICAO Iberoamerican Conference on Safety and Instruction in Civil Aviation, Madrid, Spain, July 2003.

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♦♦♦♦

Maintenance Error Management — The Next Step at Continental Airlines

Randy Ramdass
Continental Airlines

In the ever-changing aviation industry, at Continental Airlines safety has remained the number one priority in every phase of our operation. However, the challenges that we face daily sometimes overshadow the importance of continuing our safety culture. At IAH/South Central Maintenance region, we continue to build on our safety culture foundation — the involvement of both management and employees working together to build a positive safety culture.

Both employees and management are very proactive regarding safety violations, corrective actions and follow-up. In addition, engineering improvements combined with training and education have proven very successful in reducing on-the-job injuries. Original equipment manufacturer (OEM) training for our technicians with in-depth focus on what could happen have proven successful compared to training that demonstrated how a piece of equipment operates.

Despite our success, we need to continue to find ways to continue to focus and to improve the safety awareness in our work areas. Recent ground damage investigation revealed that employees were too self-assured with operating equipment around company aircraft. Complacency has seeped in on many occasions and has led to the operating of lift devices without safety harness and fall restraint or moving equipment around aircraft without a guide man in place.

We can do better. We owe it to ourselves and our employees to provide guidance for improvement. We have introduced Maintenance Threat Error Management (MTEM) principles in our safety training for our management personnel and technicians. We are using MTEM for accident investigations. MTEM will succeed if both management and technicians apply it and believe that it will give them the added safety margin in the current operating environment. We need to be proactive. We need to recognize threats and errors and, more important, teach our management and technicians how to effectively manage them by recognizing, evaluating and taking steps to neutralize them.

We have introduced Aviation Safety Action Program (ASAP) in Continental Airlines Maintenance. This program is a partnership with the International Brotherhood of Teamsters (IBT) and Federal Aviation Administration (FAA) to foster and improve safety. The intent is to identify and resolve safety issues through cooperation and corrective action rather that through punitive action. Incentives are designed into the program to encourage voluntary information that can benefit our maintenance organization. In addition, employees can identify and report safety-related issues for resolution without fear of disciplinary action. ♦

Additional material follows on pages 116–124.

Maintenance Error Management

by

Randy Ramdass

58th Annual International Air Safety Seminar (IASS 2005)

Joint Meeting of Flight Safety Foundation,
International Federation of Airworthiness
and
International Air Transport Association

Theme : *Safety Is Everybody's Business*

Moscow, Russia

November 7–10, 2005

Objective

- **To study** the root causes of violations by maintenance technicians so that appropriate guidance materials could be developed, thereby minimizing rule violations errors.
- **To understand** the Human Factor errors which have contributed to maintenance errors at Intercontinental Airport-Houston (IAH) (Continental Airlines).
- **To implement** procedures as part of a larger effort to help our managers, supervisors and technicians understand, evaluate, and minimize maintenance errors.

Continental Airlines, IAH Region

Mission-Vision-Values

Mission: To provide clean, safe and reliable transportation for our passengers.

Vision: To create an environment where our employees look forward to coming to work. To be the preferred airline carrier of the flying public.

Values:
1) Personal Safety
2) Safety of Aircraft and Equipment
3) Dignity and Respect
4) Performance and Goals

Our mission is defined.
Our vision is clear.
Our values are prioritized.

We need to work together to live the vision, adhere to our values, and accomplish the mission.

Challenges

- ✱ Recognize both **positive and negative** human factors play a crucial role in aircraft maintenance safety.
- ✱ **Identify** and dealing with Human Factor issues are the key elements to performing safe and efficiently aviation maintenance.
- ✱ **Creating a safety culture** to allow the free flow of safety concerns, issues and information without repercussion was the most important step in Continental's transformation – which laid the foundation for our maintenance team to build upon.

Challenges

- ✱ It is important for Continental Airlines and aviation safety, that errors, incidents and accidents be **investigated thoroughly to learn the correct lessons** to prevent future incidents and accidents.
- ✱ While much effort has been focused on analysis of the causes of errors, these analyses ultimately depend for their validity on whether or not the appropriate set of facts was collected by personnel that perform the investigation.
- ✱ In reviewing past incidents, this project established that only a fraction of the available facts were collected and our efforts fell short in communicating follow up and preventative action.

Human Factors

- Our team realized **technology and know-how** have helped reduce human error and accident rate of aviation to low levels.
- We realized that our **past and current accomplishment** is just that and recognized that new approaches will be needed to lower the rates further.
- We also realized that regardless of the marvelous innovations in technology and procedures, we're not going to reduce the accident rate until we get our front-line employees in the mindset to give us the information we need.

- Maintenance Human Factors is crucial and a very important safety issue. Continental Airlines and the FAA spend and devote time and effort on this topic.
- The challenges of Human Factors in maintenance are equally important as safety, security, proper tools and parts.

Setting the Environment

- ✱ The importance of continually striving to ensure good working relationship and communications between airline management and the labor force.
- ✱ Morale of the workforce can be influenced positively by letting workers know when a job has been well done.
- ✱ Also, the workforce should have some insight into the problems being faced by management, because the only effective way for comprehensive solution to the issues is by working together and raising the awareness with our entire team.

FAA Performance Goals

- ✱ By 2007, reduce the commercial aviation fatal accident rate per 100,000 departures by 80 percent, from a three-year average baseline (1994 through 1996 — 0.051 fatal accidents per 100,000 departures).

Fatal Aviation Accidents (US Commercial Air Carriers per 100,000 departures)					
Targets					
1999	2000	2001	2001	2003	2004
.048	.045	.043	.038	.033	.028

Aviation Safety Action Program ~ASAP~

- ASAP is a safety based partnership and cooperation between Continental Airlines, FAA and the International Brotherhood of Teamsters – representative body for our technicians.
- ASAP was launched June 2004 and after a period of 18 months will be reviewed and evaluated to measure success.
- The goal of the Aviation Safety Action Program at Continental Airlines is to **enhance aviation safety through the prevention of accidents and incidents**. Its focus is to encourage voluntary reporting of safety issues and events that come to the attention of maintenance and related employees.

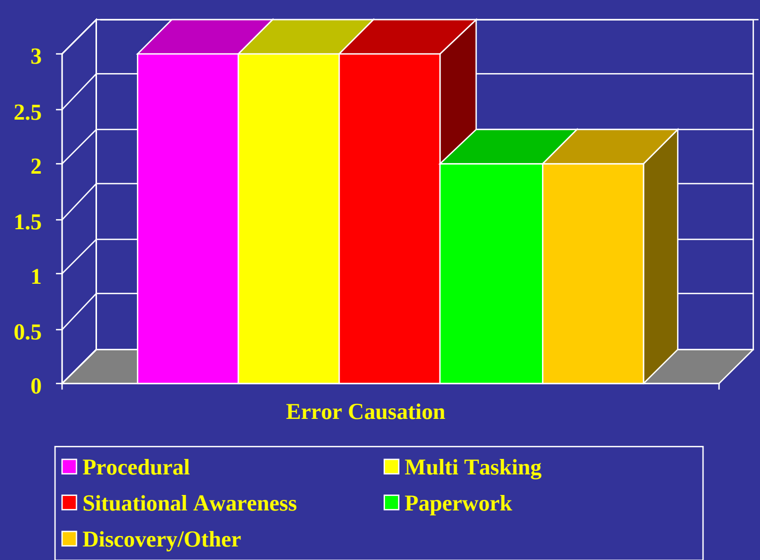
Continental ASAP Results

Total Reports		
Received to Date	69	
Sole Source	42	61%
Non-Sole Source	27	39%
Reviewed by ERC	68	99%
Waiting ERC Review	1	1%
Accepted	64	94%
Excluded	3	4%
Pending Employee/Company Action	8	12%
Open for Additional information	2	3%
Closed	58	85%
Dispositions to Date	66	96%
Waiting ERC Review/Open	3	4%
Excluded	3	5%
ERC Letter of No Action	29	44%
ERC Corrective Action Letter	13	20%
FAA Letter - No Action	2	3%

Ground Incidents and Accidents

- Ground incidents and accidents represent a major cost to Continental Airlines and the aviation industry. Safety measures have tended to focus mainly on aircraft safety in flight.
- Flight Safety Foundation launched Ground Accident Prevention (GAP) program in 2003 and one focus is the **collection and analysis of data**.
- **Human Factors** is the primary contributing factor in ground accidents and incidents. More importantly, how thoroughly we investigate each errors or incidents and measure the effectiveness of Human Factors interventions using an error-investigation methodology in just as critical.

Review of Incidents for 2004



Analysis of Investigation

- ✱ We have done a great job gathering information, fact finding, and completing the Incident Analysis regards to the initial investigation.
- ✱ We have done a great job identifying the error causation factors that have contributed to the incidents and accidents, however fell short in sharing the information and raising the awareness.

Moving Forward

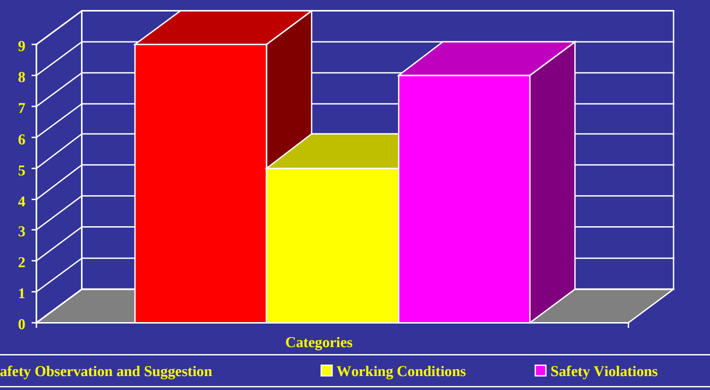
2 Issues to Focus our Attention on:

- Indoctrinate our supervisors, managers and investigation teams on investigation analysis methodology.
- Document and map the error forcing conditions — human, technical, procedural, and environmental aspects — that may have contributed to the error.

This will provide a very detailed and comprehensive model to analyze error causation, and empower to implement the optimum intervention.

Safety Feedback

- Through our Safety Committee web site on the Houston IAH Hub Tech Ops link, we have created the avenue where anyone can send a safety concern, observation and recommendation.



Conclusion

- In aviation, **accidents are usually highly visible,** and as a result, aviation has developed standardized methods of investigating, documenting, and disseminating errors and their lessons.

- Errors generally fall into 2 categories: (1) systematic or organizational and (2) individual.

- Thirdly, the error management strategies can be broken down further into reactive and proactive. In general, we are reactive, completing the investigation and corrective action after an incident occurs. We need be more on the proactive trend – recognize the potential error inducing situations and to prevent the error in real time.

♦♦♦♦

Passenger Safety Information, Past and Future

Professor Helen Muir and Lauren Thomas
Cranfield University

Abstract

The paper will include a review of recent research into passenger attention to safety information together with future safety briefing challenges. Issues associated with future very large transport airframes (VLTAs) and new technology options will also be included.

1. Introduction

The requirement for passenger briefing and safety cards was introduced in an attempt to improve passenger safety and survival rates in the event of an accident. In the majority of survivable accidents in which loss of life occurs, the fatalities will have arisen either as a consequence of a fire or as a result of the aircraft crashing on takeoff or landing. In both of these situations, if passengers have correct information about how to behave, their probability of survival will improve.

2. Accidents Involving Fire

In an accident involving fire, there are frequently only two minutes between the onset of the fire and the conditions in the cabin becoming non-survivable due to the presence of smoke and toxic fumes. It is therefore essential that passengers be given every possible assistance to evacuate down escape slides as rapidly as possible. A great deal of effort has been expended by the industry in order to ensure that all of the passengers are able to evacuate quickly in the event of an emergency. This has included:

a. 90-Second Evacuation Demonstration

   For any new airframe, a demonstration for the regulatory authority has to be conducted by the manufacturers to show that all of the passengers can be evacuated through half the available exits in 90 seconds or less. Considerable efforts are made to introduce some realism into these tests in that they use a representative cross-section of the population, there is baggage in the aisle, professional cabin crew are used and the test takes place in darkness (on the assumption that the evacuation of passengers would be more difficult in accidents which happen at night).

b. Cabin Configuration

   The configuration of the cabin interior is strictly regulated with requirements for numbers and types of exits, maximum numbers of seats and minimum distances between seat rows. There are requirements for maximum distances between exits and minimum dimensions for aisles, cross-aisles and access to exits. A large amount of independent testing work has been undertaken to ensure that the distances specified in these regulations are adequate (Ref.1). Over time, as more knowledge has been gained, some of the distances have been modified.

c. Performance of Cabin Crew

There is considerable evidence from accidents (Ref.2) and from research that the performance of the cabin crew will be the most important determinant of the speed of an evacuation. The regulations require a minimum of one trained member of cabin crew for every 50 passengers. However, what is also of importance is not only the number of crew but also their emergency procedures and their ability to act assertively.

Experimental research has shown that the behavior of the cabin crew is critical in ensuring a smooth and efficient evacuation (Ref.3). Assertive cabin crew who provided concise, positive commands and instruction, and used physical gestures and contact when appropriate, achieved significantly faster passenger evacuation rates than non-assertive cabin crew. When the cabin crew left the cabin at the start of the evacuation, to simulate situations where the cabin crew are incapacitated, the passenger evacuation rates obtained were similar to those achieved by non-assertive crew.

d. Passenger Education

There is evidence from accidents that passengers who know what to do in an emergency and who follow the directions of the cabin crew have a greater probability of survival (Refs.4 & 5).

3. Accidents Involving Impact

In alternate accident scenario of the aircraft crashing on takeoff or landing, a great deal of effort has also been expended to take steps to improve the survival probability of passengers. This has included:

a. Cabin configuration. Changes to the strength and design of aircraft seats have been made (16g seats are now a requirement) and airbags to protect passengers from hurting themselves against bulkheads have been introduced.

b. Passenger education. Detailed information is included on the safety card and on some video briefings about how to adopt the “brace for impact position” in the event of an aircraft coming into land with possible difficulties.

4. Safety Regulations

The regulatory authorities require all operators to brief passengers on emergency procedures. In the United Kingdom, the Air Navigation Order requires operators to provide a briefing to passengers on the position and method of use of emergency exits, safety belts, oxygen equipment, life jackets, floor path lighting systems and any other equipment intended for use by passengers in the event of an emergency (ANO, 1997). Similarly, in the United States, Federal Aviation Regulations (FARs) require passengers to receive a briefing on smoking, emergency exits, seat belts and flotation devices (FARs Part 121).

Although the operators are required to provide this safety information, it is frequently disregarded by passengers. The reasons why passengers fail to pay attention to potentially lifesaving information are many and varied. For example, passengers may believe that the probability of survival in the event of a crash is so low that paying attention to the safety information is a waste of time. In fact, the vast majority of accidents are survivable. The NTSB recently showed that, of all accidents to Part 121 carriers during the period 1983 to 2000, the overall survivability rate was 95.7 percent (Ref.6).

There are no regulations which state the methods to be used in providing the most effective pre-departure briefing, although guidance supplied by the Federal Aviation Administration may be regarded as best practice (Ref.11). Cabin crew who conduct live briefings and demonstrations should use their own initiative to attract passenger attention, making eye contact with passengers, being animated, and using clear and distinct diction. They should also ensure that they and their colleagues are distributed evenly throughout the cabin, and that their briefings and demonstrations can be clearly seen and heard by all passengers.

The FAA also acknowledge that some operators may opt to use video recorded pre-departure safety briefings, to ensure consistency of delivery on every flight. Video recordings allow passengers to be shown safety tasks where a live demonstration is not possible, such as the correct manner of using the evacuation slide. Video technology also means that the pre-departure briefing can be given in multiple languages, including, for example, sign language. Video recorded briefings may also increase the variety and the novelty value of the briefing, by using different faces and voiceovers. Rapidly changing images may also assist in attracting, and keeping, passenger attention.

5. Passenger Attention to Safety Briefings

Several research studies have been conducted to examine why passengers do not pay attention to the safety information provided. In 1979 Johnson investigated the differences between people who paid attention to passenger safety information, and those who did not (Ref.7). Using a structured interview schedule, researchers conducted telephone interviews with a selection of 231 people who had flown on commercial aircraft at least twice in the previous two years. The researchers defined “attenders” as people who had said that they had previously paid attention to safety briefings, and who also said that they intended to pay attention to the information on future flights. The “non-attenders” were defined as people who said that they did not pay attention to the safety information, and who expressed no intention to do so in the future. The results indicated that the non-attenders were likely to be male, younger and more highly educated. They were also more likely to have flown more often, usually flying alone and on business trips. In contrast, those who paid attention to the safety information were more likely to fly in the company of someone they knew and were more likely to fly for pleasure.

The National Transportation Safety Board investigated 21 accidents that occurred between 1962 and 1984 (Ref.8). They found that “passengers’ risk of injury or death in these accidents could have been reduced had they: (1) paid attention to the flight attendant’s oral safety briefings and demonstrations, (2) read the safety card to familiarize themselves with the location and operation of safety equipment; and (3) been better motivated and thus better prepared to act correctly during an emergency situation” (Ref.6). In some of these cases, not only were passengers generally very poorly prepared, but sometimes they behaved inappropriately, or even contrary to cabin crew instructions.

In 1992 Fennell and Muir conducted a survey of passengers arriving at Gatwick Airport in the U.K. (Ref.9). They asked passengers how frequently they traveled, whether they had listened to the pre-flight briefing and then some questions about items which had either been covered in the safety briefing or were on the safety cards. The results indicated that frequent fliers (typically businessmen) frequently admitted to not having attended to the safety briefing or read the safety card. The non-frequent fliers (typically families and holiday passengers), in the majority, had listened to the safety briefing and sometimes read the safety card. However, when the responses to the questions about information in the briefings were analyzed, frequent fliers (the majority of whom had not attended to the briefing) got many more of the answers right than non-frequent fliers (the majority of whom had listened to the briefing).

The National Transportation Safety Board recently completed a study of 46 evacuations that occurred between September 1997 and June 1999 (Ref.10). As part of this study, questionnaires were sent to all passengers involved in the 30 most serious evacuations, which were defined as those involving suspected fire, actual fire or use of the evacuation slides. Of the 457 passengers who returned their questionnaires, 54 percent said that they had not watched the entire safety briefing because they had seen it before. Another 15 percent said that they had not watched the entire briefing because the information it contained was common knowledge. Passengers were also divided on how effective the briefing had been. Over half of the respondents said that the briefing had not contained information specific to their evacuation. They reported that they would have liked more information on exit routes, how to use the slides and how to get off the wing after leaving the cabin via an over-wing exit.

These last two pieces of research suggest that in an attempt to provide passengers with all of the relevant information, we may, ironically, be failing by providing them with too much information. The business travelers, or frequent fliers find them long and repetitive, while for the infrequent flier there is a huge amount of information, far more than any one individual can be expected to absorb and retain following one presentation.

One important issue with regard to pre-departure briefings is that they should present information which is consistent both with passenger expectations, and with what will actually occur in a given emergency situation. In a study conducted by Johnson (Ref.12) airlines were first asked what commands the crew would use in the event of an emergency or crash landing, where passengers would be required to assume the brace position. Common responses were that the crew would instruct passengers to "brace," "grab your ankles" or "go head down and stay down." Later, passengers were asked which commands they would expect to hear, they said that they would expect to hear commands such as "get into an emergency/crash position," "head down," "lean forward" or "we're going to crash." Approximately 30 percent of the research participants would not have realized that a crash was about to occur if they had heard the command "brace, brace." Hence, the information provided in pre-departure briefings should be consistent with passenger expectations, and with the commands and procedures that will actually be used in a given emergency situation.

6. Safety Cards

As well as the pre-departure briefing, passenger safety information can be imparted via a safety card. Safety cards are used to supplement the information provided in the pre-departure briefing. A card should be available for every passenger seat, thus, unlike the information contained within a pre-departure briefing, the information on the safety card remains available for reference throughout the duration of the flight.

The NTSB (Ref.10) safety study found that, 68 percent said that they did not read the safety card. A large proportion (89 percent) of these passengers said that the reason was they had read the card provided on previous flights. It is of concern that 44 percent of passengers said that they had not paid attention to either the safety briefing or the safety card. However, most passengers who did read the safety cards said that they found them useful, particularly with regard to identifying the location of exits. Passengers also reported that the safety cards had provided information on which exits had slides, how to use the slides and the location of emergency lighting.

Safety cards often use pictorials to convey safety information to passengers. A series of related pictorials is known as a pictogram. The underlying assumption is that pictorials and pictograms, unlike text, will be universally understood. This is of course important considering that air travel is international in nature. Safety cards ideally need to be understood by everybody, regardless of their language, culture or country of origin. Published standards are available which provide methodologies for assessing the comprehension level of such information. For example, there is an international standard for judging the comprehensibility of graphical symbols (Ref.13). The use of such methods is likely to assist in ensuring consistent levels of passenger comprehension, so that safety cards will be understood by the widest possible audience.

In 1997 Caird et al. reported a study of safety card pictorials in which participants were asked to discuss which safety cards, from a sample of 50, were most likely to aid or hinder comprehension (Ref.14). Thirty-six pictorials from nine safety cards were used in comprehension tests, where 113 participants were asked the meaning of the pictorials. The responses were rated as incorrect, partially correct or correct. Only 16 of the pictorials had comprehension scores of above 50 percent. The authors concluded that "safety card pictorials appear to represent a less than optimal universal safety language." This is of concern given that all pictorials would need to be understood before a pictogram could be interpreted correctly.

Johnson and Altman manipulated the phrases that were used on safety cards, in order to investigate the effect that this had on passenger behavior on the evacuation slide (Ref.15). To use the slide effectively, passengers should jump onto it; passengers who sit on the sill take longer to evacuate. The researchers found that safety cards that included the instruction to "Jump — don't sit" resulted in 73.5 percent of passengers using the slide correctly. When the cards included the instruction to "jump," 67.8 percent of passengers used the slide correctly. When passengers received no briefing card, only 59.9 percent of the passengers used the slide correctly. A passenger who sits takes approximately one-third of a second longer to evacuate than a passenger who jumps. This time differential could have a significant impact on the evacuation of two or three hundred passengers.

There are some general principles or guidelines for the presentation of information on safety cards. For instance, it has been suggested by Johnson that the information should integrate words with diagrams, and present pictograms in meaningful sequences. Pictorials are preferable to photographs, as they reduce visual clutter (Ref.16). Schmidt and Kysor suggested that the safety cards that receive poor effectiveness ratings tended to be those containing more text than pictorial information, and which were somewhat disorganized in their presentation of information (Ref.17). However, because the design and information content of safety cards is known to vary so widely, the only way to be sure that a safety card will be easily understood is to conduct comprehension tests.

7. Passenger Safety Duties

The issue of passenger attention to safety information is particularly important where passengers are expected to perform specific duties in the event of an emergency situation. For example, passengers seated in exit rows may be required to open the Type III exit if an evacuation of the aircraft is necessary. Such a situation occurred at Manchester in 1985 (Ref.5). A Boeing 737 with 131 passengers and six crew on board was departing for Corfu. On takeoff, the left engine suffered an uncontained failure, and a wing fuel tank access panel was penetrated. Leaking fuel rapidly ignited, and by the time the aircraft came to a complete stop, the cabin was filled with black, acrid smoke, which rapidly instilled fear and alarm among passengers.

At the instigation of other passengers, the passenger seated adjacent to the right-hand Type III exit attempted to open it as the aircraft came to a stop. She pulled on the armrest that was mounted on the hatch, in the mistaken belief that it was the hatch handle. The passenger seated next to her reached over and pulled the operating handle, and the hatch, weighing 48 pounds, fell inwards, trapping them both in their seats. They were released by a male passenger in the row behind, who lifted the hatch, and placed it on a vacant seat. It took approximately 45 seconds to make the Type III exit available, by which time many passengers had been overcome by the toxic smoke and fumes. The evacuation delays contributed to 55 fatalities (Ref.5).

The Type III exit hatch is not usually attached or hinged to the airframe. The hatch, once released, has to be brought back into the cabin, rotated and disposed of. This mode of operation is counterintuitive in a self-help exit, since the hatch is intended to be operated by passengers. The hatches may weigh as much as 65 pounds, and this makes handling particularly cumbersome. Many passengers have reported great difficulty in making Type III exits available in emergency situations. In one case reported by the NTSB (Ref.10), a passenger who attempted to open the Type III exit pulled the operating handle, and put his shoulder to the hatch to push. He had not realized that the design of the hatch meant that it had to be brought into the cabin first. In another case, a passenger operated the hatch, and then had to jump through fire to get away from the airplane. Passengers do not always check conditions outside the aircraft before operating the exit.

Although passengers seated in the exit row are screened for their suitability to sit adjacent to the exit, screening provides no guarantee that passengers will pay attention to the safety information. At most, passengers seated in the exit row may be instructed by the cabin crew to read the safety card and ensure that they are familiar with the manner in which the exit operates. However, the type of briefing and the level of detail provided can have a significant influence on the time it takes to make the exit available, and on the way in which passengers dispose of the hatch. If the hatch is left inside the cabin, it becomes an obstacle in the passageway to the exit, and this creates delays for evacuating passengers.

Cobbett, Liston and Muir investigated the influence of four different types of briefing on the performance of Type III exit operators (Ref.18). Fifty-six groups of three participants were recruited to evacuate a Boeing 737 cabin simulator. All groups received a pre-flight safety briefing and safety card. Fourteen groups received no additional information, while fourteen groups received a minimum Type III exit briefing. The minimum briefing informed the participants that they were seated next to an emergency exit that they may be required to open, and that they should therefore read the instructions on the safety card and seat-back placards.

The last two groups of fourteen received detailed briefings, which included the information in the minimum briefing. Additionally, these briefings instructed passengers on when and how to operate the exit. Participants in these conditions were explicitly told the weight of the hatch, and were informed that the hatch was not hinged or attached to the airframe. The operating handles were also pointed out by cabin crew, and participants were told that the hatch should be disposed of outside the cabin. These detailed briefings were presented orally to fourteen groups, and in writing to the remaining participants.

The results indicated that passengers who had received the detailed oral or written briefings reacted to the call to evacuate significantly more quickly than participants in the no–Type III briefing or minimum briefing conditions. The overall time taken to make the exit available for evacuation was significantly quicker for participants who had received the detailed written briefing than it was for participants in the other three groups. In addition, a disproportionately high number of participants from the no–Type III briefing condition left the Type III exit hatch inside the cabin. Providing the participants with such detailed briefings did take significantly more time, but the evidence suggests that if cabin crew are able to comprehensively explain safety duties to exit row passengers, then this would be time well spent.

8. Future Opportunities

New technology may provide us with the opportunity to address some of the issues and problems discussed in the previous sections. Aircraft seats on almost all new airframes have individually controlled television screens. In time these could be made interactive. As the technology improves and the overwhelming majority of the passengers become computer literate, it could be possible to make briefings interactive (the research literature on human memory clearly indicates that active learning is far more successful than passive learning). There could be the opportunity to provide different briefings for different scenarios and for passengers to select their preferred language. There is also the potential for the briefing to form part of a learning game on aircraft safety. The objectors will no doubt claim that there will always be some (possibly older) passengers who cannot cope with computers. In this event they could simply be shown a video which is equivalent to the one used today and perhaps given a little extra briefing from the cabin crew. There is no doubt that developments in computer technology will offer new options for educating passengers in safety information.

In addition to new computer technologies, there are also new airframes being developed which because of their novel configurations will offer their own unique challenges for the provision of safety information for passengers. The Airbus A380 has twin decks each potentially capable of holding up to 400 passengers. The Blended Wing Aircraft proposed by the Boeing Co. will include six bays of passengers, each containing a central aisle and with rows of three seats either side. For both of these VLTA airframes the challenge for passenger education will be to enable all passengers to have situational awareness of their seat location within these complex airframes, together with knowledge of their nearest available exits. In airframes with twin decks, the circumstances in which passengers may or may not make sure of the stairs in an emergency will require careful consideration, as will the procedures for cabin crew to use for the appropriate direction of passengers. In the blended wing airframes, the evacuation of passengers through exits in the forward section of the cabin will require carefully designed procedures and management, in order to ensure that contra-flows do not occur and that the behavior of passengers remains orderly.

9. Conclusion

We know that providing passengers with safety education does improve their probability of survival in an emergency. We know that the information required for use by passengers in an emergency must be specific, unambiguous and able to be fully understood and remembered. Furthermore, we know that it is important that all passengers understand that they have a high probability of surviving an accident and that their attention to the instructions from the flight attendants, together with their knowledge of the safety information, will significantly improve their chances of survival.♦

References

1. Muir, H., Marrison, C. and Evans, A. (1989) *Aircraft evacuations: The effect of passengers motivation and cabin configuration adjacent to the exit.* CAA Paper 89019, Civil Aviation Authority, London.
2. NTSB (1996) *Report on the accident to Boeing 747-131 N93119 at New York on 17th July 1996.* NTSB, Washington, D.C.
3. Cobbett, A.M. and Muir, H.C. (1996) *The influence of cabin crew during emergency evacuations at floor level exits*. CAA Paper 95006, Civil Aviation Authority, London.
4. ICAO Summary 1984-2, *Report on the accident to Boeing 737 C-GQPW at Calgary Airport on 22nd March 1984.* ICAO, Montreal, Canada.
5. U.K. Air Accidents Investigation Branch, Department of Transport (1985) *Report on the accident to Boeing 737-236 Series 1 G-BGJL at Manchester International Airport on 22 August 1985.* Aircraft Accident Report 8/88.
6. NTSB (2001) *Survivability of accidents involving Part 121 US air carrier operations, 1983 through 2000.* NTSB/SR-01/01, PB2001-917001. Washington, D.C.
7. Johnson, D.A. (1979) *An investigation of factors affecting aircraft passenger attention to safety information presentations*. Report IRC-79-1, for the Federal Aviation Administration, Contract DOT-FA78WA-4095.
8. NTSB (1985) *Airline passenger safety education: a review of methods used to present safety information*. NTSB/SS-85/09, PB85-917014. Washington, D.C.
9. Fennell, P.J. and Muir, H.C. (1992) *Passenger attitudes towards airline safety information and comprehension of safety briefings and cards*. CAA Paper 92015, Civil Aviation Authority, London.
10. NTSB (2000) *Emergency evacuation of commercial airplanes*. NTSB/SS-00/01, PB2000-917002. Washington, D.C.
11. FAA (1999) *Passenger safety information briefing and briefing cards*. Federal Aviation Administration Advisory Circular 121-24B. Issue 2/1/99.
12. Johnson, D.A. (1998) Studies reveal passenger misconceptions about brace commands and brace positions. *Cabin Crew Safety*, 33 (3), 1–6.
13. ISO (2001) *Graphical symbols — test methods for judged comprehensibility and for comprehension*. International Standard 9186, 2nd ed., 2001-04-01. ISO, Switzerland.
14. Caird, J.K., Wheat, B., McIntosh, K.R. and Dewar, R.E. (1997) The comprehensibility of airline safety card pictorials. *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, Human Factors Society, Santa Monica, California, U.S., 801–805.
15. Johnson, D.A. and Altman, H.B. (1973) Effects of briefing card information on passenger behavior during aircraft evacuation demonstrations. *Proceedings of the Human Factors Society Convention, Human Factors Society*, Santa Monica, California, U.S., 215–221.
16. Johnson, D.A. (1980) The design of effective safety information displays. In Poyday, H.R. (ed.) *Proceedings of the Symposium: Human Factors and Industrial Design in Consumer Products*. Tufts University, Medford, Massachusetts, U.S., 314–328.
17. Schmidt, J.K. and Kysor, K.P. (1987) Designing airline passenger safety cards. *Proceedings of the Human Factors Society 31st Annual Meeting*, Santa Monica, CA, 51–55.
18. Cobbett, A.M., Liston, P. and Muir, H.C. (2001) *An investigation into methods of briefing passengers at Type III exits*. CAA Paper 2001/6, Civil Aviation Authority, London.

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Rejected Takeoffs Won't Go Away

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Abstract

From preflight through takeoff roll, many factors enter into the decision every pilot makes on every takeoff — whether to continue as planned or abandon the attempt. Fortunately, in almost every case, the decision is easy. However, when circumstances arise that put the successful takeoff in question, the pilot's decision becomes critical and must be made correctly. If all factors that might affect the aircraft are known, the pilot theoretically has the information necessary to make the right decision. However, if any of those factors remain unknown, the safety of the rejected takeoff (RTO) maneuver may be in jeopardy.

The RTO accident and incident problem is not limited to a single operator or any one country. Clearly, this is an international problem in need of an international solution. In terms of the number of runway overruns as a function of phase of flight, those that occur during the landing phase will outnumber those occurring during the takeoff phase. Exposure to a possible overrun exists on every landing but, since the RTO is an abnormal maneuver, the exposure during takeoff exists only if an RTO is initiated. Because of increased traffic levels, during recent years, the number of RTOs may have increased, and with each RTO there is a risk of an overrun incident or accident. There are at least three areas of improvement that would significantly reduce this risk: 1) readily available aircraft performance information on contaminated runways, 2) training and 3) aircraft system technology.

In August 1989, a LADE Fokker F-28 lost directional control during a takeoff from San Carlos de Bariloche, Argentina. The takeoff was aborted, but the aircraft ran off the end of the runway. Reportedly, the runway was contaminated with slush and snow.[1]

The event mentioned above shows that contaminated runways continue to be problematic for both takeoff and landing. Each winter, aircrews experience problems such as inadequate removal of contamination, the lack of timely and accurate runway condition reports, and the lack of performance data for operations on contaminated runways. Although much attention has been focused on the landing phase, the rejected takeoff situation is similar because of the reduction in aircraft braking coefficient of friction due to runway contamination.

In July 1988, an Air France B-747, departing Delhi at close to maximum takeoff weight, experienced a no. 4 engine fire warning during the takeoff roll. The alert came 2.5 seconds after the captain called "V_1." The first officer, who was the flying pilot, aborted the takeoff after he noticed the captain's hand was moving towards the throttles. Maximum speed reached was 172 knots (V_1 was 156 knots). The airplane overran the 1,000-foot overrun area, tearing off the landing gear. Had the first officer better understood the importance of V_1, he would not have initiated the abort at a speed higher than the V_1 callout.

The event mentioned above, as well as previous data, indicate that a statistically significant number of RTO accidents were the result of pilots initiating the RTO at speeds greater than the maximum safe abort speed. This indicates a misunderstanding of the critical takeoff speeds, which would be remedied through flight crew and operator education on the certification criteria for transport category airplanes. In the early 1990's, industry and government developed the Takeoff Safety Training Aid in an effort to reduce the number of RTO accidents. However, not all operators have included the elements of the Training Aid in their training programs. Understanding of certain certification requirements is essential to aircrews to aid them in their decision making. In addition, improving the understanding of certification requirements will assist training departments in their development of flight procedures.

In January 2000, a Kenya Airways Airbus A310 crashed on takeoff from Runway 21 at Abidjan. On takeoff, the aircraft used more runway than normal and was “still very low” as it passed over a sea wall 500 meters beyond the runway end. The aircraft failed to gain height and struck water one mile off shore in darkness.[1]

As a potential remedy to events like the Kenya A310 accident, current technology exists that could be used to develop a takeoff monitoring system to assist pilots in making that critical go/no-go decision. In 1994, the U.S. National Aeronautics and Space Administration (NASA) published a technical paper on their research in developing a Takeoff Performance Monitoring System (TOPMS). This is a software and hardware system that visually displays aircraft runway position, acceleration, engine status and other situation advisory information. Alternatively, an aural alert system may be more appropriate, allowing the pilot to “watch the road” while monitoring the takeoff. A system such as this would improve reaction time and be more economically feasible.

For older generation aircraft still in service, implementation of “takeoff line speeds” could provide the necessary information about that aircraft’s acceleration characteristics against predicted values for the runway in use.

In November 1992, an Aerolineas Argentina B-737 ran off the end of the runway following an aborted takeoff. The abort was initiated because of poor acceleration during the takeoff roll due to failure of two main gear tires. If this crew had at their disposal a set of predictive line speeds, they would have been able to detect the poor acceleration earlier in the takeoff run.[1]

This paper will present a summary of RTO issues from the pilot’s perspective. Improvements in delivering timely, accurate, standardized information to flight crews will be outlined and their practicality discussed. The author will discuss possible training advancements, including greater use of existing tools that will serve to increase the level of knowledge of the RTO maneuver among flight crews. Feasibility of employing emerging technology on new aircraft, and potential means to improve the operation of older aircraft will also be discussed.

Introduction

In late 1990, an industry/government working group was formed to study rejected takeoff (RTO) accidents and incidents and the related human factors issues. This working group ultimately consisted of 35 airlines, 10 manufacturers, seven government agencies, five industry associations and three pilot associations.[2] The result of this working group’s efforts is found in the development of the Takeoff Safety Training Aid.[3]

According to data obtained by Boeing for the Western jet transport fleet, there were 46 RTO overrun accidents and an additional 28 serious incidents between 1959 and the end of 1990.[4] In a special report by the U.S. National Transportation Safety Board (NTSB), the Board stated, “Pilots faced with unusual or unique situations may perform high-speed RTOs unnecessarily or may perform them improperly.”[5] This was the issue that the Takeoff Safety Training Aid sought to address by improving the flight crew’s knowledge and understanding of the takeoff problem.

An online search of the NTSB accident database[6] conducted by the author, and summarized in Appendix A, revealed 47 reports of RTOs in scheduled air carrier operations conducted in the United States since 1990. Of these, 15 resulted in an unplanned exit of the runway, with two aircraft being destroyed, four receiving substantial damage, seven receiving minor damage and two receiving no damage. With the significant increase in the number of takeoffs over the last 15 years, it would appear that the goals of the Takeoff Safety Training Aid have been largely realized. However, RTO accidents continue to occur. Accident/incident data suggest that slippery runways, flight crew decision-making, and the lack of a takeoff monitoring system are still causal factors.

Slippery Runways

Contaminants on the runway, such as standing water, slush, snow or ice, can affect both the ability of the aircraft to accelerate to liftoff speed or decelerate to a stop, should a rejected takeoff be initiated.

On March 16, 2003, an Embraer EMB-120 sustained minor damage during the takeoff roll, when the aircraft departed the left side of the 7,802 foot long runway.[7] The airport manager reported that at the time of the incident, the runway was covered with 1 to 1-1/2 inches of snow over a 1/4 inch layer of slush. Shortly after initiating the takeoff the aircraft began tracking left of the runway centerline. Differential power and rudder were used in an attempt to regain control, but the aircraft continued drifting left. A rejected takeoff was initiated after the left main wheels entered the soft earth at the edge of the runway. The NTSB determined the probable cause of this incident as the failure to maintain directional control with the snow and slush covered runway as a contributing factor. This rejected takeoff incident could have been avoided if the runway had been cleared of contaminants, or if the crew had a clear description of the contaminant, indicating that they should have delayed their takeoff attempt.

On Dec. 20, 1995, a Boeing B-747 sustained substantial damage following an aborted takeoff from John F. Kennedy International Airport.[8] The runway had been plowed and sanded about an hour and a half prior to this accident, but there was still packed snow covering portions of the runway. Shortly after beginning the takeoff roll the aircraft drifted to the left of the runway centerline. Recovery was attempted by use of the rudder and steering tiller but when it was apparent the left drift could not be arrested, a rejected takeoff was initiated. Despite using maximum braking the aircraft exited the left side of the runway, at which point the no. 4 engine struck a concrete structure tearing the entire pylon from the wing. The right wing landing gear and nose gear collapsed before the aircraft came to rest. There was one serious injury and 16 minor injuries. The NTSB determined the probable cause of this accident to be the failure to reject the takeoff in a timely manner. Contributing factors were inadequate B-747 slippery-runway operating procedures provided by the airline and the aircraft manufacturer. No amount of aircrew training is going to improve runway friction but runway maintenance, accurate reporting of runway conditions and aircraft performance data related to runway conditions might have prevented this accident.

Transport Canada commissioned a survey of Canadian pilots in an effort to better understand how slippery-runway guidance material is being used. The survey was distributed to 3,450 commercial pilots in Canada, of which 393 pilots responded. Following are some of the summary of findings taken from the TP 13941E report:[9]

- "Most of the pilots are aware of guidance material of operating on slippery runways."
- "Most pilots have guidance material available to determine landing distances and crosswind limits when operating on slippery runways."
- "Many pilots lack guidance material for determining accelerate-stop distances and adjustments to V_1/V_R, and would like to have this material available to them."
- "The current format of the guidance material makes it confusing and difficult to use. The material should be presented in simple, easy-to-use lookup charts specific for each aircraft type."
- "The quality of runway friction information provided by airports varies between airports, with quality being better at large airports."
- "Friction values need to be updated more frequently, particularly at small airports, and out-of-date values need to be removed. There need to be improvements in the methods of distributing the information quickly and alerting pilots of low runway friction, possibly through the use of the Automatic Terminal Information Service."
- "Over 20 percent of pilots of large jet aircraft have not received any formal training on the use of runway friction information. Of those that received training, 20 percent indicated that training on the

use of runway friction values was covered 'poorly.' Many indicated that the format of the material is too complicated to be covered in the short time allotted."

- "Despite the low number of accidents in recent years due to slippery runways, pilots report frequent occurrences of safety concerns such as significantly reduced braking, slipping sideways due to crosswinds, and being close to not stopping on the runway."

Additional findings in the TP 13941E report describe landing technique and estimating landing distances based on friction reports. The report also found that reductions in weight prior to takeoff were not common. This is not surprising given the lack of performance information provided to pilots concerning contaminated runway takeoffs.

The U.S. Federal Aviation Administration (FAA), in its Airport Winter Safety and Operations Advisory Circular, states:

> *Snow, ice and slush should be removed as expeditiously as possible to maintain runways, high-speed turnoffs, and taxiways in a "no worse than wet" condition. Surface friction can be improved by application of abrasive material when unusual conditions prevent prompt and complete removal of slush, snow or ice.*[10]

This is a challenging task for the airport operator in active winter conditions. In addition, the tempo of flight operations on a particular runway may result in the touchdown zone being in better condition than the rollout end because of jet blast from departing aircraft. Airline pilots have reported instances where the rollout end had not been cleared as well as the touchdown zone. Due to the potential for a rejected takeoff, special emphasis must be placed on maintaining the entire runway length, including the rollout end.

There is a misconception among airport operators that all transport category aircraft must have performance data in their airplane flight manual (AFM) to account for wet or contaminated runways. In fact, airplanes with type designs approved under U.S. Federal Aviation Regulations (FARs) Part 25 prior to March 1998 (Amendment 92) were only required to determine accelerate-stop distances on a dry runway. For these aircraft wet runway accountability was not a requirement under U.S. regulations. However, some manufacturers included wet runway accountability, voluntarily, by Special Condition. Aircraft with type designs approved after the incorporation of Amendment 92 are required to have wet runway performance data contained in the AFM, but this doesn't include runway contamination (i.e., snow, slush, ice).

The European Aviation Safety Agency (EASA) is ahead of the FAA in this regard. The certification regulation, CS 25.1591, requires the manufacturer to provide guidance material to assist operators in developing suitable procedures for use by flight crews when operating on contaminated runway surface conditions. In addition, JAR-OPS 1.485 requires the operator to ensure that the approved performance data in the AFM is supplemented to account for takeoff and landing on contaminated runways. It is interesting to note that an aircraft certified under EASA CS-25 is required to have guidance material for wet and contaminated runway operations, but that same aircraft certified under FARs Part 25 is not. This safety material should be made available to all pilots.

When contaminant removal is not possible, an assessment of the friction potential of the surface is necessary. There are two components to determining friction potential: the surface condition and its effect on aircraft braking coefficient. Both of these have been the subject of much research over the last 40 years.

As the TP 13941E report found, pilots see a need to improve surface condition reporting. This issue was echoed at the 3rd International Meeting on Aircraft Performance on Contaminated Runways (IMAPCR 04),[11] but exactly how to do this was not discussed. In the United States, airport conditions are reported via the Notice to Airmen (NOTAM) system as stipulated by the regulations governing airports certified for commercial aviation.[12] The regulation requires airport certificate holders to collect and disseminate airport condition information but does not specify the format or issuance times. Guidance is available through Advisory Circular (AC) 150/5200-28, *NOTAMs for Airport Operators*, but again, the format is rather loose and no specified time interval is suggested.

The process for NOTAM issuance is not conducive to quick dissemination of the surface condition information necessary during rapidly changing conditions.

Other systems in use include the Snow Warning to Airman (SNOTAM) and the Meteorological Operational Telecommunication Network Europe (MOTNE). The SNOTAM is issued each day and is valid for 24 hours, with requirements that a new SNOTAM be issued if significant changes occur. A SNOTAM for a particular runway includes information about the cleared runway length and width, contaminants observed on each third of the runway, mean depth, friction measurement on each third of the runway and the type of measuring device, critical snow banks, obscured runway lights, planned further runway maintenance with the expected time of completion, next planned observation or measurement time, and plain-language remarks. The format is better defined than for the NOTAM but, again, issue times may be inconsistent. There is much information included in a SNOTAM which may not lend itself to inclusion in an Automatic Terminal Information Service (ATIS) broadcast.

The MOTNE is an eight-digit group appended to the METAR. The digits describe the runway, the type of deposit, the extent of coverage, the depth, and braking conditions. Because it is appended to the METAR, information should be available at least hourly and could be added to Automatic Terminal Information Service broadcasts. However, the braking conditions are an average over the entire runway rather than in thirds. Averaging can introduce a bias that indicates the runway has better friction potential than really exists. A shortened form of the SNOTAM coded in a format like the MOTNE and appended to METAR and ATIS is one possible solution. This, of course, requires trained personnel to make the required observations and/or measurements in a timely fashion for inclusion in the report. At a minimum the following items should be reported: 1) runway designator, 2) date and time of observation, 3) contaminants on each third of the runway, 4) mean depth for each third, 5) friction measurement on each third, 6) further maintenance time, and 7) next planned observation/measurement time.

The Air Line Pilots Association, International (ALPA) has a program in place that has the potential to improve the level of awareness of airport winter operations. The Airport Liaison Representative (ALR) program seeks to identify volunteer line pilots willing to establish an active partnership with a particular airport, maintain a dialogue with airport operators and participate in their local airport meetings. Many ALRs present a pre–winter season briefing to the airport operator and participate on that airport's snow committee, if one is established.

How the information is reported won't matter much if the information contained in the report is inaccurate. Runway friction measurement has been the subject of dedicated research for many years, and continues to this day. In January 1996 the Joint Winter Runway Friction Measurement Program (JWRFMP)[13] began as a result of a fatal crash in Dryden, Ontario, in March 1989. That accident involved a Fokker F-28 that crashed off the end of the runway on departure. The objective of the JWRFMP was to study methods for measuring friction and to define an International Runway Friction Index (IRFI) that could be related to aircraft performance and used worldwide. One disturbing observation made by the author during the IMAPCR 04 meeting was the apparent inconsistent nature of the measured friction data.

The JWRFMP 2003 Testing and Data Analysis executive summary states:

> *International research of friction measurement confirmed that friction measurement devices measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types.*[14]

Reproducibility is an indication of the degree to which multiple devices of a given design return the same friction value when measuring the same surface. Figure 3 on page 15 of the JWFMP 2003 Testing and Data Analysis report illustrates the reproducibility problem. The figure is a plot of average friction values versus eight different asphalt surface types. Twenty-five friction measuring devices of the same design were compared on each of the eight surface types. The results show an average difference of 0.18, in friction value, between devices. For example, one device may return a friction value of 0.40 while another device, of the same design, on the same surface, returns a value of 0.22. This is a 45 percent difference in friction value for the same surface. Using a popular comparison between friction values and braking action, this difference is similar to “good” braking action suddenly being “poor” braking action without any change is surface condition.

Clearly more work is needed in the area of friction measurement and perhaps the IRFI is the answer. According to the current ASTM International Standard E2100-04, “The IRFI is intended to provide an international unified friction index for use in harmonizing the output of devices used to measure the friction of airport movement areas during winter operations.”[15] The data collected by the JWRFMP was used in the development of this standard. However, an ASTM International Standard for relating IRFI to aircraft braking coefficient has yet to be developed.

Relating the runway condition to aircraft performance has proven to be a challenging task and is one of the objectives of the JWRFMP, as well as work done by the Canadian National Research Council (NRC). The Canadian Runway Friction Index (CRFI) was developed as an improvement to the James Brake Index (JBI). The NRC conducted tests to relate CRFI to aircraft landing performance using a Dash 8 and Falcon 20.[16] This testing resulted in the CRFI tables currently presented in the Canadian Aeronautical Information Publication (AIP).[17] These tables provide flight crews with recommended runway lengths for landing as a function of CRFI. This is a move in the right direction. With the CRFI tables a flight crew now has something by which to make real-time operational decisions. Also, it must be mentioned that a single value of runway friction for the entire runway is inappropriate. Averaging the values measured in the first, middle and last third of the runway may give a false sense of security or unwarranted concern. Therefore, it is important that runway friction be measured and reported in thirds of the total runway length.

Because of reproducibility issues with friction measurements and the subjective nature of braking action reports, an alternative would be to relate aircraft takeoff performance to runway contaminant type and depth. Each aircraft type would require accelerate-stop testing on various surface types to determine aircraft braking coefficient and the effects of impingement and displacement drag, as a function of contaminant type and depth. One possible source for some of this data is through the Flight Operations Quality Assurance (FOQA) program in place at many airlines. As described in FAA Advisory Circular AC 120-82, a FOQA program acquires and analyzes data collected from an aircraft’s digital data bus and analog inputs. This use of FOQA data is another reason to pursue FOQA data sharing among all stakeholders.

With respect to contaminated runways, the small number of RTO overruns versus landing overruns may lead one to think RTOs pose less risk than landings. Every takeoff must be followed by a landing but not every takeoff results in an RTO. Rejected takeoff accidents are rare compared to the number of takeoffs conducted each year worldwide. To have an RTO event on a contaminated runway is highly improbable. But should it occur under current operational practices, in a runway limited scenario, an accident or incident is a strong possibility. The flight crew must have some guidance material concerning the effect of runway contaminants on aircraft takeoff performance to make an informed decision as to the suitability of a particular runway for a safe takeoff.

In addition, a systems approach towards eliminating RTO overrun accidents has to include airport design as well. Every runway that’s to be used in commercial operation must have an adequate runway safety area (RSA). Consider Air France Flight 358 that overran its landing runway, on Aug. 3, 2005, at Toronto’s Pearson International Airport. Having an RSA, and strategic use of Engineered Materials Arresting Systems (EMAS), might have prevented the complete destruction of the Airbus A340-300 aircraft. Also, consider that an RSA would allow much better access to the aircraft by aircraft rescue and fire fighting (ARFF) personnel. It was very fortunate that no one was killed in that accident, but a similar event in the future could have a very different outcome.

What can be done now? Establish and maintain a dialogue between airport operators, airline operators and pilots, specifically geared toward airport operations on contaminated runways with the goal of sharing “best practices.” Ensure that pilots have guidance material readily available to them to account for contaminated runways for takeoff and landing. A safety partnership must be established, and maintained, among airport operators, the airlines and the pilots that operate out of that airport. Research must continue towards refining the International Runway Friction Index and getting “buy-in” by the aviation community. Until reliable methods exist for measuring surface friction and relating those values to aircraft takeoff performance, airport operators must come to terms with the fact that aggressive winter contaminant removal is a necessary price that must be paid in order to show "due diligence" in the safe operation of their airport. Close collaboration between all stakeholders will improve airport operations on contaminated surfaces.

Flight Crew Decision Making

On July 8, 1996, a Boeing B-737 received minor damage, and one passenger received serious injury, after the airplane ran off the end of Runway 20C at Nashville's Metropolitan Airport following a rejected takeoff. The investigation revealed that the no. 1 engine had ingested a bird estimated to weigh four ounces. Data from the flight data recorder (FDR) and cockpit voice recorder (CVR) indicated that "V_1" was called at 142 knots with a loud bang heard one second later. The aircraft began to yaw left. One second after the "bang" is heard "rotate" is called at 150 knots. A rejected takeoff was initiated with peak airspeed reaching 153 knots. Once the aircraft was stopped, a brake fire erupted which was quickly extinguished by ARFF personnel, but not before the cabin crew initiated an evacuation without the captain's approval. The NTSB determined the probable cause of this accident to be the initiation of a rejected takeoff above V_1.[18]

On May 12, 1994, a Saab SF340B sustained minor damage following an aborted takeoff from Runway 22 at Texarkana Regional Airport in Arkansas. At approximately 95 knots the configuration warning sounded, prompting the first officer to state, "Configuration light, abort." The captain immediately initiated the abort but encountered some difficulty in getting the power levers back beyond the flight-idle gate. The crew was not certain the propellers were in reverse. The aircraft rolled 205 feet beyond the runway end, despite using maximum braking.

The investigation found that if the beta range power lever latches are lifted prior to retarding the power levers to idle, the power levers will jam, preventing propeller reverse. The cause of the configuration light was the result of too much rebound on the right condition lever while in the full forward position.[19] Positioning the right condition lever full forward for takeoff closes a microswitch. Occasionally, the acceleration of takeoff causes the condition lever to move just enough to open the micro switch without affecting propeller speed. This is a well-known characteristic of the SF340. If the first officer had simply applied pressure against the condition levers, the configuration light would have extinguished. In fact, at least one operator requires the first officer to hold the condition levers against their forward stops for takeoff. Had this crew been exposed to this scenario during simulator training, this accident might have been avoided.

In order to make good decisions, the flight crew must be knowledgeable, and that is why training is so important. The government/industry group that developed the Takeoff Safety Training Aid understood this. Airline training ensures that flight crews are knowledgeable about their aircraft systems, standard operating procedures, emergency/abnormal procedures and flight characteristics. What's not covered very well, if at all, is an understanding of how their aircraft were certified. As certification regulations changed over the years, some misconceptions began to appear, not only among line pilots but in training departments as well. The Training Aid was made available in 1990, and although not mandatory, Air Carrier Operations Inspectors were directed to encourage its use in airline training departments.[20] While this may have occurred, many pilots are not aware of the Takeoff Safety Training Aid, or the essential information it contains. This may be a consequence of the rapid expansion that took place in the 1990's and is reason enough to re-emphasize the use of the Training Aid and to make it accessible to all pilots. It's been 15 years since its introduction and there is interest in updating the Training Aid to reflect current accident/incident data and include recent regulatory changes. Advisory Circular AC 120-62 announces the availability of the Takeoff Safety Training Aid and how to obtain copies.

The Training Aid includes an Overview for Management, a Pilot Guide to Takeoff Safety, an example Takeoff Safety Training Program and Takeoff Safety Background Data. A video was also developed. The Management Overview summarizes the factors pointing to the need for improved training. According to the Training Aid, half of the RTO accidents and incidents studied were initiated at speeds above V_1, one-third occurred on runways that were wet or contaminated with snow or ice, a little over one-fourth of the events actually had any loss of engine thrust, and nearly one-fourth were due to tire failure. The conclusion was that over 80 percent of the overrun events were avoidable.

Every pilot should know, or at least have a basic understanding of, the certification rules that pertain to the takeoff phase of flight. In this way the pilot will have a clear understanding of the meaning of V_1 and a "feel" for the assumptions used in developing the performance data. It is important for pilots to understand their aircraft's certification basis, since the performance data is determined with respect to the rules under which that type design was initially approved, and are not necessarily the current version of the rules. Prior to Amendment 25-92, V_1 was called the takeoff decision speed. This name for V_1 may have been the cause for confusion among pilots who thought this was the speed at which a decision to stop or continue was made. This is not the case. The decision to stop or go must have already been made upon reaching V_1. In other words, there is not a "decision point" but rather a decision continuum that begins with the setting of takeoff thrust and ends at V_1.

Prior to March 1978 V_1 was called the "critical engine failure speed" and was selected to permit a safe takeoff with an engine failure occurring at that V_1 speed. The accelerate-stop distance was determined by accelerating the airplane to this V_1 speed, failing an engine at that speed, and then stopping the airplane. V_1 was defined at the same point the critical engine was assumed to fail. Although the regulations required allowance for time delays in accomplishing the RTO procedure they were not explicit as to where time delays should be introduced in relation to V_1. Additionally, there was no provision that the go/no-go decision by the pilot could be due to problems other than engine failure, such as cockpit smoke.

Adoption of Amendment 25-42 (March 1, 1978) to FARs Part 25 introduced V_{EF} and defined that speed as the critical engine failure speed. The speed V_1 cannot be less than V_{EF} plus the speed gained between engine failure and the point when the pilot takes the first action to stop the aircraft. According to AC 25-7A[21] on page 80-7, the time between V_{EF} and V_1 cannot be less than one second. V_1 is no longer coincident with engine failure. Determination of accelerate-stop distance was changed by requiring a two-second delay after V_1, during which the aircraft continued to accelerate, before the pilot took any action to stop the airplane. To account for RTOs initiated for reasons other than engine failure, determination of the all-engine operating accelerate-stop distance was added. The one-engine-inoperative takeoff distance is based on engine failure occurring prior to V_1 (at V_{EF}) and continuing with the takeoff. With typical acceleration rates for jet transports, this event occurs about five knots before V_1. Initiating the "V_1" call slightly early may be safer than calling "V_1" crisply but late. One technique is to initiate the "V_1" call five knots early, which is done by some airline operators. Another technique is to lengthen the call such that it is completed no later than V_1 (i.e., "veeeee one"). In this way the pilot flying is given time to change from the "abort" mindset to a "go" mindset.

Amendment 25-92 (March 20, 1998) revised the accelerate-stop requirements by replacing the two seconds of continued acceleration with a distance equivalent of two seconds at V_1 speed. Accelerate-stop distances must be based on fully worn brakes and include wet runway accountability. Also, the term "takeoff decision speed" was removed, reinforcing the idea that V_1 is not a decision point but the end of the decision continuum.

The speed V_1 is the maximum speed at which a rejected takeoff may be *initiated* or the minimum speed to continue the takeoff. *If the takeoff weight is equal to the Field Length Limit Weight, an overrun is virtually guaranteed should a decision to abort be made such that initiation of the stopping procedure occurs after V_1*. However, the vast majority of takeoffs are conducted with airplane weights below the Field Length Limit Weight. This means that extra margin exists for stopping the airplane and implies that the RTO procedure could be less aggressive. Flight crews are not, typically, given information regarding the amount of excess runway available in these cases.

So how far below Field Length Limit Weight does an airplane have to be for the crew to modify the RTO procedure? There is no way for an airline crew to know. Therefore, regardless of how much runway remains upon reaching V_1, the RTO must be conducted as if the airplane was at the Runway Limit Weight. This is especially true when runway friction may be lower than expected at the far end of the runway due to rubber deposits or contamination.

In the development of the Airplane Flight Manual (AFM) data presentation, time delays are introduced to ensure that enough time exists for the line pilot to achieve the full stopping airplane configuration. Various time-delay methods have been used over the years, and some pilots may have thought these provided additional time in deciding whether to stop or continue the takeoff. This was never the case. The time delays are applied to ensure sufficient time to configure the airplane, not to expand the time available to make a decision. The AFM transition times are transparent to the line pilot in terms of operational procedure.

Figure 1 shows an example of AFM transition times taken from the Takeoff Safety Training Aid (Section 2, page 2.14). In addition, automated systems in many aircraft such as auto-brakes and spoiler deployment shorten the time necessary to achieve the full stopping configuration, once the crew initiates the RTO.

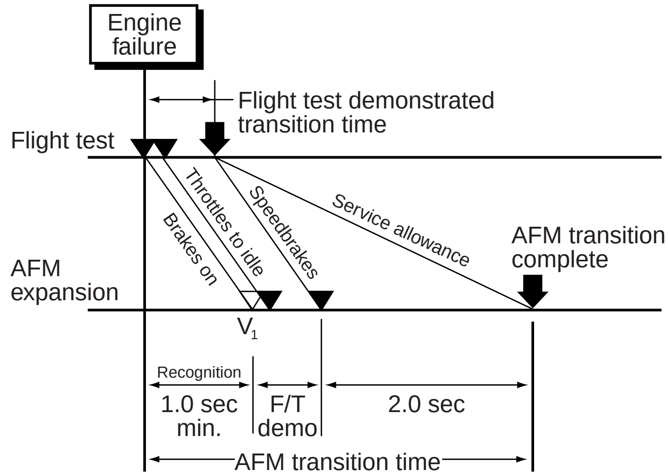

Figure 1

As previously discussed, the accelerate-stop distances were based on a smooth, dry runway. Wet runway accountability was introduced after March 20, 1998, with Amendment 25-92, and is currently reflected in EASA CS-25 regulations. There is no accountability for winter contaminated runway conditions in the current U.S. regulations, although advisory information is required for those operators subject to JAR-OPS rules. The current situation is that EASA CS-25 regulations require advisory information be provided to allow operators to develop procedures for takeoff and landing on contaminated surfaces; U.S. regulations have no such provision. This means that an aircraft model sold to an operator subject to JAR-OPS has this safety information, but the same aircraft model sold to a U.S. operator does not.

Not every airplane anomaly occurring prior to V_1 requires an RTO. In fact, some problems such as tire failure would adversely affect the accelerate-stop distance while having little impact on the accelerate-go distance. Unless there is a loss of engine thrust, smoke in the cockpit or flight control problems making the airplane unflyable, it may be better to continue the takeoff. By continuing the takeoff the subsequent landing can utilize the full runway length available. Additional benefits are that the airplane is a bit lighter and there's an increase in aerodynamic drag from landing flaps. For aircraft certified under Amendment 25-42 and after, an engine failure occurring two seconds prior to V_1 would allow continued takeoff and still provide 15 feet or more of screen height.

Because of the criticality of aborting a takeoff at speeds near V_1, it is imperative that good crew coordination be exercised. Both pilots must be aware, as the airplane accelerates along the runway, that the events for which an RTO would be initiated become fewer and fewer. To assist in this "event shedding," operators establish low speed and high speed regimes. Although the NTSB identified 100 knots as the division between "low" and "high" speed regimes in their Special Report, many operators and some manufacturers use a lower speed, such as 80 knots. When in the low speed range any abnormal event could be cause for an RTO. But upon entering the high speed range, the risk of stopping must be weighed against the risk of continuing. Close to V_1 only the direst of events should precipitate an RTO, especially if the aircraft is at Field Length Limit Weight.

In summary, training is an area that can be rapidly improved by auditing an existing training program with the concepts and suggestions discussed in the Takeoff Safety Training Aid. All commercial pilots ought to have their own copy of Section 2 of the Training Aid, "A Pilot Guide to Takeoff Safety." Section 4 of the Training Aid contains an example of a takeoff safety training program and is a good place to start. Additional academic topics should include flight crew procedures for dealing with wet and contaminated runways. Additional simulator training topics should include unique and/or unusual events occurring near V_1 (other than engine failure), slippery runway RTOs, and the effects of being early and late on the V_1 call.

Takeoff Monitoring System

On March 2, 1994, a McDonnell Douglas MD-80 sustained substantial damage following an aborted takeoff at LaGuardia, New York. There were seven minor injuries. During the attempted takeoff, the crew observed the airspeed not increasing normally and elected to abort. Data from the FDR confirmed that the pitot heat had not been selected "ON" by the flight crew. A build-up of snow and/or ice in the pitot/static system tubes and ports resulted in erroneous airspeed readings. The NTSB determined the probable cause of this accident to be failure to turn on an operable pitot/static heat system and untimely response to anomalous airspeed indications, with the consequent rejection of the takeoff at an actual speed of five knots above V_1.[22] Although the crew failed to follow proper procedure, an acceleration monitor might have kept that error from being compounded, and this accident would have been avoided.

Some may assume that pilots always know the required runway length necessary to stop from any point in the takeoff roll. However, the pilot only has an indirect measure of runway remaining based on V_1 speed. Thus, if the airplane exhibits poor acceleration due to inefficient engines or runway contamination, the point at which V_1 is reached may be much further down the runway than takeoff performance calculations assume. If an RTO were conducted in this case there might not be enough runway remaining to stop, despite the pilot having initiated the RTO below indicated V_1 speed. Basically, the pilot needs to know if V_1 will be reached within the distance determined in the AFM prior to reaching this speed. Having some means to gauge the airplane's actual acceleration against a predicted value (an acceleration monitor) is not a new idea.

In 1985, a study was done at the University of Kansas, on the design of a Takeoff Performance Monitoring System (TOPMS).[23] This system was further developed at NASA's Langley Research Center and integrated into their Transport System Research Vehicle (TSRV), a B737-100. The system was flight tested between March 1987 and November 1989.[24] The TOPMS calculates and graphically displays aircraft acceleration, runway position, engine performance and other situation advisory information. Basically, the system compares actual performance to a calculated predicted nominal performance level. If the difference between predicted and actual exceeded a specified level, alerts were given to the pilot in the form of graphical situation advisory flags (SAFs). The algorithm used airplane body-mounted accelerometers and a gimbaled inertial measurement unit to obtain the acceleration data necessary for the calculations. The algorithm included mathematical models for engine thrust and airplane aerodynamic characteristics.

The TOPMS incorporated a pre-takeoff module and a real-time module. The pre-takeoff module accepted information about the airplane's center of gravity, weight, flap position, pressure altitude, wind and temperature. Although not explicitly stated in the Flight Test Report,[21] it appears that available runway length was also entered. The algorithm determined the required Engine Pressure Ratio (EPR), V_1, V_R and V_2, from AFM data tables stored in memory, and calculated a predicted nominal acceleration and where along the runway V_1 and V_R should occur. The real-time module used measured values of EPR, throttle lever angle, flap position, acceleration, groundspeed and calibrated airspeed to compare against the predicted values. The airplane's position on the runway was calculated using a double integration of acceleration. During post-flight analysis, a single integration of groundspeed appeared to be more accurate. However, the initial position was taken at a surveyed point on the runway, something that wouldn't be available in airline operations.

However, a Global Positioning System (GPS) could be the source of position information. In fact, this was investigated by Pinder, Crowe and Nikiforuk in their study of a takeoff performance monitor for turboprop aircraft.[25] This study used a GPS as the sole source of kinematic information and was tested in a British Aerospace 3112 aircraft. Their conclusion was that a projection of displacement can be determined within the length of the test airplane in time to alert the crew of a problem. This is consistent with the results of the NASA tests using filtered accelerometers. Much higher position accuracy is available by using ground-based GPS augmentation systems such as the Wide Area (WAAS) and Local Area (LAAS) Augmentation Systems.

The NASA TOPMS presents a graphical interface to the crew. Initially this interface was presented on a Head-Down Display (HDD) but later was incorporated into a Head-Up Display (HUD). This allowed the pilot flying

(PF) to evaluate the TOPMS information while still maintaining visual contact with the runway environment. But not all aircraft are equipped with a HUD. The flight test report stated that the SAFs weren't intended to remove the captain's authority but to prompt scanning the supporting information to determine or verify that a problem exists and quickly decide what to do. This is a potential flaw in the system. If a problem arises near V_1, by the time the crew visually examines the display and reacts, V_1 speed will have been exceeded.

A similar problem exists in airplanes equipped with a crew alerting system (i.e., ECAMS or EICAS) which displays system messages to the crew. It takes time for the crew to read the message, comprehend its meaning and then react. Inhibiting all but the most critical messages during the takeoff helps to avoid this problem. During takeoff, the PF should be looking outside the aircraft to maintain alignment and for collision avoidance. The pilot monitoring (PM) divides his/her time between visual information sources outside and inside the cockpit. One sensory input that may be underutilized is the crew's sense of hearing. The fire bell means one thing — an engine fire. The crew doesn't have to look at anything to know an engine fire is being detected. Similarly, a unique aural alert sound for poor acceleration or any system failures that suggest an RTO, such as detected thrust reverser deployment, would improve the pilot's reaction time. It must be emphasized, however, that the final decision to abort must remain with the Captain.

But what's to be done with older aircraft that may not have the on-board sensor system that would allow the implementation of TOPMS? Some type of acceleration check is needed. The TOPMS compares what the actual acceleration is to what would be considered "normal" airplane acceleration under the existing conditions. An operator's performance engineers could calculate the minimum acceleration curve necessary to ensure a safe takeoff for a given runway length, temperature, pressure altitude and aircraft weight. This curve could be used to calculate a maximum time between specified speeds such as 40 to 100 knots, with corrections for runway slope, contamination and wind. During takeoff, the crew would start the clock at 40 knots and confirm that the elapsed time to 100 knots is under the maximum time. Of course this method would be invalid if the air data system was in error. It would, however, provide a check on acceleration in the majority of cases for airplanes with no other systems available for determining acceleration.

Conclusion

High speed rejected takeoffs pose a significant risk of an accident or incident. Completely eliminating rejected takeoffs is not realistic. Our goal should be to control the adverse effects that RTOs potentially pose. This goes beyond the statistical and procedural view provided by the Takeoff Safety Training Aid. The following are just some examples of means to mitigate the likelihood of a RTO related accident:

- Timely and complete removal of winter contamination from runways to at least as good as wet condition.
- Timely, accurate, and standardized reports of runway conditions to the flight crew.
- Continued research to harmonize friction measurements on wet or contaminated runways and establish a relationship with aircraft braking coefficient.
- Wet or contaminated runway performance information readily available to all flight crewmembers.
- Improved training through the use of the Takeoff Safety Training Aid and by incorporating unique and/or unusual events occurring near V_1 during simulator training. This training should also include experience in conducting rejected takeoffs at various aircraft weights, including Field Length Limit Weight, on dry and slippery runways.
- Implementation of a Takeoff Monitoring System or development of an acceleration check methodology.
- Including Runway Safety Areas and/or Engineered Materials Arresting Systems for all runways.♦

Notes

1. Commercial Aviation Safety Team (CAST), Joint Implementation Modeling Data Analysis Team (JIMDAT). *JIMDAT Accident Evaluation Tool & Part 121 2001-2004 Listing.* 2005.

2. Eckstrand, C.L. *Takeoff Safety Training Aid*. Boeing Memorandum, M-7670-CLE-492-065. Boeing Commercial Airplane Group, 2 September 1992.

3. U.S. Dept. of Transportation. Federal Aviation Administration. *Takeoff Safety Training Aid, Announcement of Availability.* Advisory Circular, AC120-62. Washington, D.C., United States: U.S. Government Printing Office, 1994.

4. U.S. Dept. of Transportation. Federal Aviation Administration. *Takeoff Safety Training Aid*. Springfield, Virginia, United States: National Technical Information Service (NTIS), 1994. NTIS Reference No. PB93780013.

5. U.S. National Transportation Safety Board (NTSB). *Special Investigation Report – Runway Overruns Following High Speed Rejected Takeoffs.* NTSB Report No. NTSB/SIR-90/02. Washington, D.C., United States: National Transportation Safety Board, Public Inquiries Branch, 1990.

6. NTSB. *Accident Database & Synopsis*. 2005. National Transportation Safety Board, Washington, D.C. Accessed on 20 June 2005. <http://www.ntsb.gov> Path: Aviation; Accident Database & Synopsis; Database Query.

7. NTSB report DEN03IA054, 16 March 2003, scheduled 14 CFR Part 121 air carrier flight.

8. NTSB report DCA96MA029, 20 December 1995, scheduled 14 CFR Part 121 air carrier flight.

9. Biggs, D.C., and Hamilton, G.B. *Runway Friction Accountability Risk Assessment Results of a Survey of Canadian Airline Pilots*. Transportation Development Centre. Transport Canada, TP 13941E. June 2002. <http://www.tc.gc.ca/tdc/publication/pdf/13900/13941e.pdf>.

10. U.S. Dept. of Transportation. Federal Aviation Administration. *Airport Winter Safety and Operations.* Advisory Circular, AC150/5200-30A, thru Change 8. Chap. 2, Para. 7, page 5. Washington, D.C., United States: U.S. Government Printing Office, 2005.

11. 3rd International Meeting on Aircraft Performance on Contaminated Runways held at ICAO Headquarters, Montreal, Canada, 3-5 November 2004.

12. U.S. Dept. of Transportation. Federal Aviation Administration. *Part 139 Certification of Airports.* Title 14 Code of Federal Regulations. 2005. Federal Aviation Administration, Washington, D.C. Accessed on 09 July 2005. <http://www.faa.gov/>. Path: Regulations & Policies; Regulatory & Guidance Library; Federal Aviation Regulations; Current FAR by Part; Part 139; Sec. 139.339.

13. Transport Canada. Transportation Development Center. *Joint Winter Runway Friction Measurement Program*. Accessed on 9 July 2005. <http://www.tc.gc.ca/tdc/projects/air/f/9048.htm>.

14. Wambold, J.C., Henry, J.J. *Joint Winter Runway Friction Measurement Program (JWRFMP) 2003 Testing and Data Analysis.* Transportation Development Centre, Transport Canada, TP 14194E, June 2003. <http://www.tc.gc.ca/tdc/publication/pdf/14100/14194e.pdf>.

15. ASTM E2100-04, "Standard Method for Calculating the International Runway Friction Index," ASTM International. For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at <service@astm.org>. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

16. Croll, J.B., Bastian, M., Martin, J.C.T., and Carson, P. *Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the Canadian Runway Friction Index*. National Research Council Canada. LTR-FR-183, Transport Canada Publication TP13943E, June 2002. Accessed 09 July 2005. <http://www.tc.gc.ca/tdc/publication/pdf/13900/13943e.pdf>.

17. Transport Canada. Aeronautical Information Publication. *CRFI Application to Aircraft Performance.* July 11, 2002. <http://www.tc.gc.ca/civilaviation/commerce/operationalstandards/crfi/CRFI.pdf>.

18. NTSB report ATL96FA101, 08 July 1996, scheduled 14 CFR Part 121 air carrier flight.

19. NTSB report FTW94IA154, 12 May 1994, scheduled 14 CFR Part 121 air carrier flight.

20. U.S. Dept. of Transportation. Federal Aviation Administration. *Flight Standards Information Bulletin for Air Transportation (FSAT)*. FSAT 96-05. 08 May 1996.

21. U.S. Dept. of Transportation. Federal Aviation Administration. *Flight Test Guide For Certification of Transport Category Airplanes*. Advisory Circular, AC25-7A, Chap. 2, Section 2, Para. 11(c)(3)(iii), page 80-7. Washington, D.C., United States: U.S. Government Printing Office, 2005.

22. NTSB report DCA94MA038, 02 March 1994, scheduled 14 CFR Part 121 air carrier flight.

23. Srivatsan, R. *Design of a Takeoff Performance Monitoring System.* Ph.D. thesis, University of Kansas, 1985.

24. Middleton, D.B., Srivatsan, R. and Person, L.H., Jr. *Flight Test of Takeoff Performance Monitoring System*. NASA TP-3403, May 1994.

25. Pinder, Shane D., Crowe, Trever G. and Nikiforuk, Peter N. *A Practical Investigation of a Takeoff Performance Monitor for Turboprop Aircraft.* University of Saskatchewan, Canada. American Institute of Aeronautics and Astronautics, AIAA 2001-4170.

About the Author

In 1986, Capt. William de Groh joined McDonnell Aircraft Company in the Flight Test department as a flight test engineer. He was involved with systems testing on the AV-8B Harrier II and F/A-18 Hornet programs, as well as the first TAV-8B two-seat Harrier. He was test conductor during Advanced Tactical Air Reconnaissance System integration testing on the F/A-18.

In conjunction with his engineering work, Capt. de Groh has worked as a flight instructor, glider tow pilot and parachute jump pilot. He served as the chief flight instructor at the Patuxent River Navy Flying Club in Maryland and has flown approximately 25 different types of aircraft in his more than 7,200 flight hours.

Capt. de Groh holds an Airline Transport Pilot certificate with a SF340 type rating and is currently serving as First Officer on the Embraer 145. He also holds a commercial glider pilot certificate, single and multiengine instrument airplane flight instructor certificates, and advanced and instrument ground instructor certificates.

In addition to flying the line for American Eagle Airlines, Capt. de Groh volunteers as a safety representative for the Air Line Pilots Association, International (ALPA) both on the local and national level. Based at the Dallas/Fort Worth International Airport, he is the vice-chairman for the ALPA Central Air Safety Committee. On the national level, he is currently the Aircraft Design and Operations Group vice-chairman for domestic operations and the director of aircraft performance programs.

Additional material follows on pages 146–147.

Appendix A

U.S. NTSB RTO Reports, 1991 to March 2005, for FARs Part 121 Operations

	NTSB NO.	DATE	A/C TYPE	LOCATION	Damage	RTO INIT SPEED	CAUSE	Off Runway ?	RWY COND
1	DCA05WA043	3/14/05	B767	Buenos Aires, Argentina	?	?	Engine surge/pax evacuation	?	?
2	DCA05WA042	3/11/05	B777	Buenos Aires, Argentina	?	110 kts	Engine fire/pax evacuation	?	?
3	DEN04IA124	8/7/04	B737	Denver, CO	M	?	ATC	No	?
4	DEN04IA012	10/12/03	DC-10	Denver, CO	M	>V1	Leading edge slat disagreement	No	dry
5	DEN03IA054	3/16/03	EMB120	Cedar City, UT	M	<V1	Blown off rwy	Yes	Slush, snow covered asphalt
6	DCA02MA026	3/9/02	CL600	Dulles, VA	M	<V1	Bird strike	No	?
7	DCA01WA061	9/24/01	DC-8	Mexico City, Mexico	M	100 kts	Rwy incursion by a B777	Yes	?
8	CHI01FA104	3/17/01	A320	Detroit, MI	S	>V1	PIO & improper trim settings	Yes	Slush covered
9	ANC01IA007	10/15/00	B747	Anchorage, AK	M	Init 148 Max 166	MLG tire failure	Yes	dry
10	NYC00IA250	9/5/00	DC-10	Newark, NJ	M	<V1	Uncontained engine failure	No	dry
11	DEN00FA085	5/5/00	DHC-6	Monument Valley, UT	S	?	Windshear	Yes	dry dirt
12	CHI00LA124	4/25/00	SF34	Hancock, MI	S	<V1	Struck deer	No	dry
13	MIA99FA005	10/7/98	B727	Miami, FL	S	?	Uncontained engine failure	No	Wet
14	DCA98WA089	9/28/98	A300	Paris, France	M	?	ECAM trim msg	No	?
15	SEA98WA086	6/4/98	MD-80	Yuzhno, Russia	M	?	Compressor stall	No	?
16	LAX98IA085	2/9/98	DC-9	Honolulu, HI	M	<V1	Engine failure	?	dry
17	LAX97IA300	8/24/97	A300	Los Angeles, CA	M	<V1	Tire failure	No	dry
18	LAX97FA276	8/7/97	L1011	Honolulu, HI	M	>V1	Tire failure	No	dry
19	CHI97IA117	4/28/97	B737	Chicago, IL	M	<V1	Engine failure	?	dry
20	MIA97IA050	12/30/96	DC-8	Orlando, FL	M	<V1	Overserviced nose gear strut	Yes	dry
21	FTW97IA045	11/23/96	MD82	Dallas-Fort Worth	M	?	Uncontained engine failure	No	dry
22	ATL96FA101	7/8/96	B737	Nashville, TN	M	>V1	Bird Strike	Yes	dry
23	DCA96MA068	7/6/96	MD88	Pensacola, FL	S	< V1	Uncontained engine failure	No	dry
24	DCA96MA029	12/20/95	B747	Jamaica, NY	S	<V1	Loss of directional cntrl	Yes	Compacted Snow
25	ATL95MA106	6/8/95	DC-9	Atlanta	S	?	Uncontained engine failure	No	dry
26	CHI95IA142	5/1/95	DC-10	Chicago, IL	M	?	Uncontained engine failure	?	dry
27	FTW94IA154	5/12/94	SF340	Texarkana, AR	M	<V1	CL caused TO config. warn.	Yes	dry
28	DCA94MA038	3/2/94	MD-82	Flushing, NY	S	>V1	Erroneous airspd not pitot heat	Yes	snow covered

U.S. NTSB RTO Reports, 1991 to March 2005, for FARs Part 121 Operations *(continued)*

	NTSB NO.	DATE	A/C TYPE	LOCATION	Damage	RTO INIT SPEED	CAUSE	Off Runway ?	RWY COND
29	DCA94IA032	1/28/94	DC-9	Chantilly, VA	M	?	Loss of directional cntrl.	Yes	wet
30	ANC93IA188	9/25/93	B747	Anchorage, AK	M	?	Bird Ingestion	?	dry
31	NYC93IA017	10/12/92	B737	Pittsburgh, PA	N		Engine failure	No	dry
32	FTW92IA208	8/14/92	MD-88	Dallas/Fort Worth, TX	M	~ 90	Engine failure	No	dry
33	DCA92MA044	7/30/92	L-1011	Jamaica, NY	D	>V1	False stall warning	Yes	dry
34	LAX92IA209	5/13/92	B767	Los Angeles, CA	M	?	Air duct rupture	No	dry
35	ATL92IA080	4/15/92	F28	Charlotte, NC	N	>V1	Apparent deceleration	Yes	dry
36	ATL92IA030	12/18/91	A310	Covington, KY	N	?	False TR warning	No	dry
37	DEN92IA007	10/30/91	DC-10	Colorado Springs, CO	M	?	directional control loss	Yes	ice; compacted snow
38	LAX91IA376	8/29/91	B767	Los Angeles, CA	M	?	Engine failure	No	dry
39	NYC91FA125	5/3/91	B727	Windsor Locks, CT	D	?	Engine failure	No	dry
40	NYC91FA086	3/12/91	DC-8	Jamaica, NY	D	?	Improper Trim	Yes	dry
41	CHI91IA062	1/7/91	B737	Kansas City, MO	N	?	Loss of directional control	Yes	ice
42	ATL90FA146	7/22/90	B737	Kinston, NC	S	?	Fuel pump failure	?	dry
43	DEN90IA154	7/4/90	A300	Denver, CO	M	?	Engine Failure	No	dry
44	MKC90IA070	3/17/90	B737	Wichita, KS	M	?	Engine failure	No	dry
45	LAX90LA116	3/13/90	B727	Phoenix, AZ	M	?	Struck a pedestrian	No	wet
46	LAX90IA101	2/18/90	L1011	Los Angeles, CA	M	?	Pneumatic sys failure	No	dry
47	CHI90IA070	1/20/90	B737	Cedar Rapids, IA	M	?	Tire failure	?	compacted snow

NTSB = U.S. National Transportation Safety Board

Damage code:

N = none M = minor S = substantial D = destroyed

Methodology: Accessed the NTSB Data Base Query page through the NTSB home page at <http://www.ntsb.gov>. Path: Aviation; Accident Database & Synopsis; Database Query. Entered date range of 1/1/1999 and 6/20/2005. Selected "Part 121: Air Carrier" under the pull-down menu labeled "Operation." All other fields left at default settings. "Submit Query" button selected. The author then reviewed each report looking for any mention of rejected/aborted takeoff.

The author found 47 reports of RTOs. In 16 cases the aircraft exited the runway as a result of the RTO, with 15 unplanned exits, one deliberate (DCA01WA061). Reports that did not explicitly indicate an exit of the runway are not included in these numbers. Of the 15 unplanned exits, two aircraft were destroyed, four suffered substantial damage, seven experienced minor damage and two had no damage.♦

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Running Out of Runway:
Analysis of 35 Years of Landing-overrun Accidents

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1 Introduction

1.1 Background

> *On February 28, 1984, the first officer flying a DC-10 was making a manual CAT II ILS approach to Runway 04R at New York JFK airport. The captain noted that the airspeed was high and informed the first officer. The approach bug speed was 168 knots. However, when the aircraft crossed the threshold the speed was 204 knots. The aircraft touched down about 4,700 feet. beyond the threshold of the 8,400-foot runway and could not be stopped on the runway. The captain steered the aircraft to the right to avoid an approach light pier as it overran, and it came to rest on the waters of Thurston Basin some 600 feet beyond the end of the runway. The accident happened on a wet runway. The National Transportation Safety Board (NTSB) determined that the probable cause of the accident was the crew's disregard for prescribed procedures for monitoring and controlling airspeed during the final stages of the approach, their decision to continue the landing rather than execute a missed approach and their over-reliance on the autothrottle speed control system, which had a history of recent malfunctions. The 163 passengers and 14 crewmembers evacuated the aircraft safely, but a few received minor injuries. The nose and lower forward fuselage sections, wing engines, flaps, and leading edge devices were substantially damaged at impact.* (Source: NTSB accident investigation report AAR-84/15.)

This is a typical example of an accident in which the pilot was not able to stop the aircraft before the end of the runway. This event is called an *overrun*. Overruns can occur during both takeoffs and landings. However, the vast majority took place during landing. Takeoff overruns normally occur after high-speed rejected takeoffs. Although rejected takeoffs are not uncommon, the majority happen at relatively low speeds, explaining the lower number of takeoff overruns. Most aircraft land on runways that are longer than the minimum required distance. Still, each year landing overruns are reported worldwide. Landing overruns belong to the group of most frequently reported accident types in the world. Fortunately, landing overruns do not often result in casualties among passengers and crew. The landing-overrun accident with an Airbus A340 that occurred recently at Toronto–Lester B. Pearson International Airport clearly illustrates this. Despite this fact, landing overruns can still be considered a major threat to aviation safety. It is therefore interesting to have an overview of factors that increase the landing overrun risk, the trends in statistics and in the influence of safety initiatives. This paper presents a safety study on landing overruns of commercial transport aircraft. For this purpose, landing-overrun accidents that took place during the last 35 years were analyzed.

1.2 Objective and scope

The objectives of the study are to identify and quantify the most important risk factors associated with landing overruns; to see if there are any trends in landing overruns during the last 35 years of flying; and to try to see what influence safety initiatives possibly have had on landing overruns. This study was limited to commercial transport aircraft.

1.3 Organization of the paper

Section 2 of this paper presents an overview of the factors that influence landing performance. Section 3 discusses the methodology applied in this study. The findings are presented in Section 4 and are discussed in Section 5. Section 6 gives some final remarks. The conclusions and recommendations are presented in Section 7.

2 Factors influencing landing performance

There are a number of factors that influence landing performance. For the present study, it is important to have a basic understanding of these factors without going into much detail. This section presents a brief overview of those landing performance factors.

2.1 What is a 'good' landing?

In short, a "good" landing has the following characteristics. It starts with a stabilized approach on speed, in trim and on glide path. During the approach, the aircraft is positioned to land in the touchdown zone. When the aircraft crosses the threshold, it is at the correct height and speed. The approach is ended by a flare without any rapid control column movements, which is followed by a positive touchdown without floating. Immediately after touchdown of the main gear, the spoilers (if available) are raised (manually or automatically), the brakes are applied (manually or automatically), (if available) reverse thrust or propeller reverse is selected and the nose is lowered. These actions are all conducted without delay and according to standard operating procedures. This is the landing as it can be found in flight crew training manuals. However, not many landings are conducted exactly like this every day. Deviations from this good practice occur often without any serious consequences. However, when there are large deviations from "good" practice, it can become more difficult to stop the aircraft on the runway. These deviations are discussed in the next sections.

A good landing is one that you can walk away from.
A great landing is one where you can use the aircraft again.

2.2 Approach speed

The approach speed is determined by a number of factors, such as flap setting, weight of the aircraft, the headwind, turbulence and the handling of the pilots. Based on a number of these factors, the pilot calculates a target approach speed (bug speed) which the pilot tries to fly during the approach. In the example presented in the introduction of this paper, the DC-10 was flying 36 knots too fast when crossing the threshold. Excess approach speed increases the tendency that the aircraft floats during the flare. Some aircraft have a higher tendency to float than others. This is mainly affected by aerodynamic ground effect, which varies among different aircraft types. In case of floating, the pilot often tries to bleed off the excess speed. This action takes a significant part of the amount of runway remaining on which to stop the aircraft. The effect of the excess speed on the ground roll distance is usually less than the increase of the flare distance due to floating. This is explained by the fact that the deceleration of the aircraft during the flare is only a fraction of what can be achieved during braking on the ground, even on slippery runways. Therefore, putting down the aircraft with an excess in speed is important instead of bleeding off the excess speed in the air. Excess-approach-speed landings are more often associated with nonprecision and visual approaches than with precision approaches. Precision approaches are inherently related with a procedure in which a constant descent gradient from the final approach altitude to touchdown is defined. The descent gradient can be verified during the flight. Nonprecision approaches can be designed to be a stabilized approach procedure. However, this is not always the case, which makes such approaches more vulnerable to excess speed.

2.3 Approach path

Atmospheric turbulence, guidance errors and inaccurate control by the pilot can result in deviations from the nominal glide path. It is important that the aircraft crosses the threshold at the correct height and with the intended glideslope. Excess height at the threshold can increase the landing distance. The same applies when the glideslope is shallower. For example, the increase in landing distance for an aircraft on a three-degree glideslope approach with excess height of 30 feet at the threshold is approximately 700 feet. In combination with a one degree shallower glideslope, this increases to approximately 1,000 feet. Some pilots tend to make a so-called duck-under maneuver when crossing the runway threshold. In this situation, the pilot is flying the aircraft below the nominal path with a shallower glideslope. The tendency to do so varies among the pilots, aircraft type flown and visual conditions. Such a flying technique can also result in longer landings.

Excess-height landings are more often associated with nonprecision and visual approaches than with precision approaches. Precision approaches are inherently related with a procedure in which a constant descent gradient from the final approach altitude to touchdown is defined. This descent gradient can be verified during the flight. Nonprecision approaches can be designed to be a stabilized approach procedure. However, this is not always the case, which makes such approaches more vulnerable to excess height.

2.4 Flare and touchdown

During the flare maneuver, the pilot reduces the rate of descent so that an excessively hard touchdown is avoided. In the execution of the flare, the pilot relies on his/her experience and judgment. The pilot decides on the moment to initiate the flare and on the amount of elevator input during the flare. The touchdown should follow immediately upon the completion of the flare. However, often the aircraft floats for some time before touchdown. This can take a considerable amount of runway. In the example presented in the introduction of this paper, the DC-10 landed some 4,700 feet beyond the threshold. In the example, the aircraft floated for some distance after the initial landing flare. The 20-feet callout was made three times. Thereafter, the captain (PNF) told the First Officer (PF) to put the aircraft down. The tendency to float depends on a number of factors which are difficult to generalize. For instance, ground effect appears to play an important role. Ground effect is the aerodynamic influence of the ground on the flow around an aircraft. It increases the lift, reduces the aerodynamic drag and generates a nose-down pitching moment as the ground is approached. The nature of and magnitude of ground effect are strongly affected by the aircraft configuration. Ground effect provides a landing cushion that feels very comfortable to the pilot. This could explain to some extent the influence of ground effect on the tendency to float. As explained already, excess approach speed can also result in floating of the aircraft after the flare as the pilot tries to bleed off the excess speed.

The touchdown should be done positively without being excessively hard. When the touchdown is too smooth, spin-up of the tires could be delayed when the runway is slippery. As explained later, this can affect the deployment of ground spoilers and the proper functioning of the anti-skid system.

After touchdown of the main wheels, the nose should be lowered without delay in order to maximize the load on the tires. On some fighter jets, the pilots tend to keep the nose up as long as possible in order to increase drag and shorten the needed runway length. This technique is called *aerodynamic braking* and is an acceptable technique on some fighter jets. However, for commercial transport aircraft, it is not a recommended technique. The stopping forces associated with this technique are only a fraction of those forces when the aircraft is braked with the nose down. The aerodynamic-braking technique has resulted in landing overruns with commercial transport jets in the past. Therefore, it should never be used during landings with commercial transport aircraft.

2.5 Rollout

The prompt use of all available stopping systems helps to minimize the rollout distance. As soon as the aircraft has touched down, these devices should be utilized without any delay. There are a number of stopping devices used:

ground spoilers, reverse thrust and wheel brakes. Ground spoilers are installed on a large number of commercial transport aircraft. In particular, jet transport aircraft are equipped with ground spoilers. Reverse thrust is available on a number of jet and propeller aircraft. This system provides an effective means of stopping the aircraft. Wheel brakes are the stopping device that every aircraft has installed. Another stopping force that comes for free during the ground roll with any aircraft is airframe aerodynamic drag. Problems with the stopping devices and/or any delay in using them can make it difficult for the pilot to stop the aircraft on the runway. Some of the issues with the mentioned stopping devices will be briefly discussed next.

Wheel braking is one of the primary means of generating stopping forces on an aircraft. The tire has to slip to generate a braking force. Maximum braking force is achieved at a tire slip in the order of 10–15 percent. The braking force on a tire is proportional with the vertical load on the tire. Runway conditions also influence the amount of braking force a tire can generate. The highest braking forces are obtained on dry surfaces. Whenever the runway is wet, flooded or covered with snow, ice or slush, lower braking forces are obtained than on a dry runway. In case of wet runways, the texture of the surface is also important. On a wet, rough surface, higher braking forces are achievable than on a wet, smooth surface. Most commercial transport aircraft are equipped with an anti-skid system. This system prevents tires from lockups and automatically optimizes tire slip for maximum braking forces by controlling the braking pressure. The pilot can therefore apply maximum brake pedal input without being concerned about possible tire lockups and optimum braking. The anti-skid needs a reference wheel speed to function. This speed is initially generated by the wheel itself just after touchdown. However, wheel spin-up can be delayed when landing on flooded runways. On such runways, the aircraft tires can hydroplane. The footprint of the tire is then separated from the surface by a film of water. Frictional forces between the tire and the ground are then very low as water cannot develop significant friction forces. Friction forces are needed to get the tire spinning. The speed at which a tire starts to hydroplane depends on a number of factors, such as tire inflation pressure, forward speed of the tire, tire design (radial or cross-ply), etc. (see Van Es, 2001, for more information on hydroplaning). The tires can become locked if the pilot applies braking before the tires are spinning. As a result, the braking forces are significantly lower.

Jet transports can be equipped with an automatic braking system. The autobrake system was introduced in the early and mid–1970s. The autobrake system automatically controls the braking of the aircraft after touchdown. An autobrake selector switch allows the pilot to select from several deceleration levels for landing. During the landing roll, pressure is automatically applied to the brakes after touchdown. The system regulates brake pressure to compensate for the effects of aircraft drag, thrust reversers and spoilers to maintain the selected deceleration level. The autobrake system disarms immediately when the pilot applies manual braking. The autobrake system is a very efficient system, which is not always recognized as such by pilots. Compared to manual braking, the deceleration generated by the autobrake system is usually more consistent. Furthermore, pilots tend to limit their brake input. In case of the need to stop the aircraft when only limited runway is available, this behavior can be critical. Flight simulators do a great job in simulating the flight characteristics of an aircraft. However, they are not good in simulating ground forces. The sensation of a truly maximum braking effort cannot be simulated correctly. The noises, the vibrations, the deceleration associated with a maximum braking effort are not similar to the real situation. Whenever the pilot applies maximum manual braking, the pilot's reaction will often be to reduce the brake pedal input. The use of autobrakes for landing on slippery runways instead of manual braking has been recommended in the past by accident investigation agencies. For instance, the National Transportation Safety Board (NTSB) and FAA gave the following recommendation after examining the MD-82 overrun accident at Little Rock (June 1999):

> *Autobrake systems, when available and operative, should be armed and confirmed armed by both pilots, in accordance with manufacturers' recommended procedures for the airplane and autobrake system regarding landing on a wet or slippery runway, or landing in a high crosswind, or in accordance with equivalent approved company procedures. Those procedures should be reflected in the respective flight manual, checklists and training program used by the pilot, or when recommended procedures are not specified by the applicable manufacturers regarding landing on a wet or slippery runway, or landing in a high crosswind. Autobrake systems, when available and operative, should be armed and confirmed armed by both pilots when preparing to land in any of those conditions. Those procedures should be reflected in the respective flight manual, checklist, and training program used by the pilot.*

Ground spoilers (also known as lift dumpers) are located on the top of the wing. When deployed, they increase aerodynamic drag. They also decrease the aerodynamic lift significantly, resulting in a higher load on the tires. Ground spoilers are most effective at high speeds. Aircraft can be equipped with wing-mounted ground spoilers that can raise automatically right after main gear touchdown. For this, the ground spoilers need to be armed prior to touchdown. Ground contact sensors are installed on the aircraft in order to prevent the ground spoilers from deploying automatically in the air. There are different types of contact sensors in use. Wheel spin-up of the main gear tires can be used as an indication of ground contact. Main landing gear oleo compression can also be used (often in combination with wheel spin-up). On aircraft equipped with bogie main landing gears, the tilt angle can be used as an indication of ground contact. As discussed earlier in this section, wheel spin-up can be delayed when landing on flooded runways. As the friction force on a tire is proportional with the load on the tire, it is important to get as much load on the tires right after touchdown. Ground spoilers are designed to do just that. However, if the ground spoilers are waiting for the tires to spin up, a major problem has occurred. The ground spoilers need then to be deployed manually. On many aircraft, the ground spoilers can also deploy upon activation of thrust reversers. For this, the spoilers do not need to be armed before touchdown. However, it is always better to arm the ground spoilers before touchdown in the event of inoperative reversers or no use of the reversers. It can also take some time to select the reversers, which delays the deployment of the spoilers.

Thrust reversers are stopping devices which do not depend on runway condition. They are very effective in generating stopping forces, especially on slippery runways. Thrust reversers on jet transports generate the highest stopping forces at high speeds. Below a certain speed, maximum reverse thrust is often not allowed. The reverse thrust is modulated to idle reverse between 80–60 knots IAS on a jet transport in order to avoid foreign object damage to the engine and to avoid ingestion of turbulent air from the reverse thrust into the main engine inlet, possibly leading to an engine surge or stall. On turboprop aircraft, the propellers are normally moved out of reverse at lower speeds than on jet transports. On some turboprop aircraft, full reverse cannot be selected at high speeds due to the possibility of asymmetric reserve thrust. Another issue is that the reversers on jet transports can produce a lot of noise. This sometimes restricts their use on airports to idle thrust only. If thrust reversers are available and the conditions are marginal (e.g., wet/contaminated runway, wind conditions, short runway, etc.), they should always be used, regardless of environmental restrictions. Thrust reversers can also give directional controllability problems in some cases. For instance, tail-mounted engines can affect the flow around the vertical tail, reducing rudder effectiveness. Also, the use of thrust reversers in heavy crosswind conditions can give controllability problems. These controllability problems can be solved by reducing reverse thrust. However, the pilot then loses a valuable stopping force.

2.6 Automatic versus manual landing

Aircraft that can land during low visibility and/or cloud ceilings (CAT III conditions) are equipped with a system that allows the aircraft to make a fully automatic landing. The majority of aircraft that have these systems installed can only conduct a fully automatic landing up to touchdown (autoland with no roll-out guidance). After touchdown, the crew must disengage the autopilot and take control of the aircraft. Although the autoland system is very accurate, it is not able to get the aircraft to touchdown on the exact same spot on the runway every time. However, compared to manual instrument landings, the touchdown scatter of an automatic landing is much less. Unpublished flight data showed that the mean distance from the threshold to the touchdown point is about 30 percent higher during a manual instrument landing. The scatter in this distance (in terms of standard deviation) is about 130 percent higher during a manual landing. These facts are not a big surprise, as the manual instrument landing is strongly influenced by pilot flight handling. Touching down far on the runway, flying fast and/or flying high above the flight path are things that are less likely to occur during automatic landings.

Normally, autolands are conducted when the visibility or cloud ceiling is too low to make a safe manual landing. However, this does not rule out the use of autoland systems during better weather conditions. Indeed, autoland operations are conducted during fine weather conditions with excellent visibility (although not many). Full protection of the ILS is not required for that case. It is also expected that the crew will have sufficient visual references to detect and correct any deviations from the expected flight path. However, there are some risks of performing autoland operations on runways not meeting CAT II/III standards. Protection of the ILS sensitive area is not assured, and other aircraft and vehicles may cause disturbance to the localizer signal. Unexpected flight control movements may occur at a very low altitude when the autopilot attempts to follow the disturbed beam bends. The crews should therefore be alert to the possibility of abnormal autopilot behavior and guard the flight controls throughout the automatic landing. The crew should also be prepared to disconnect the autopilot and manually land or go around. However, during significant crosswind landings, disconnecting the autopilot at low altitudes can be risky. The operator should always include the appropriate instructions in the flight operations manual for autoland landings under good visibility conditions. The crew should also inform ATC about the intention to conduct an autoland under the above mentioned scenario. In that case, ATC can inform the flight crew of any known or anticipated disturbance of the ILS beam due to other aircraft and vehicles.

> *On February 21, 1986, a DC-9 landed on Runway 24 at Erie international airport. The aircraft touched down some 2,000 feet beyond the displaced threshold. Although the pilots armed the spoilers, they did not automatically deploy, so the captain armed them manually. Reverse thrust was selected and the brakes activated. The brakes were not effective. Subsequently, the aircraft could not be brought to a halt before the end of the runway. The aircraft overran through a fence, eventually coming to rest partly across a road. The runway was covered with snow, with a reported braking action of fair-to-poor. The approach was flown with a tail wind and approximately 10 knots above reference speed. Tailwind landings on Runway 24 were not authorized in wet or slippery conditions.* (Source: NTSB report DCA86AA018.)

3 Data analysis methodology

3.1 Approach

The overall data analysis approach employed in this study was to:

- Develop a taxonomy for the collation and analysis of the data;
- Identify a sample of landing-overrun accidents; and,
- Analyze the data to determine what factors and to what degree they were associated with landing-overrun accidents.

3.2 Data inclusion criteria

The following criteria were used to establish the data sample:

- Only occurrences that were classified as "accidents" according to ICAO Annex 13 definition were included;
- Both fatal and nonfatal accidents were included;
- The accidents involved a landing overrun. An overrun is an event in which the aircraft departed the end of the runway. Also included are those events in which the pilots noticed that the aircraft could not be stopped on the remaining runway and decided to deliberately steer the aircraft off the runway to avoid a collision with objects placed near the runway end. Not included are those events in which the pilots lost directional control of the aircraft on the ground resulting in a veer-off;
- Accidents related to unlawful or military action were excluded;
- The accidents involved fixed-wing aircraft with a maximum takeoff weight of 5,500 kilograms or higher that were used in a commercial operation (passenger or cargo), excluding training and ferry flights. There was no restriction to the geographic location; and,

- The accidents occurred during 1970 through 2004.

3.3 Data sources

The primary data source used in this study was the NLR Air Safety Database. For many years, National Aerospace Laboratory (NLR)–Netherlands has maintained a large database with aviation safety related data called the NLR Air Safety Database. The NLR Air Safety Database is a collection of databases containing different types of data. The NLR Air Safety Database contains detailed information on accidents and incidents of fixed-wing aircraft from 1960. Currently, the NLR Air Safety Database contains detailed information on more than 40,000 accidents and serious incidents that occurred worldwide. For each occurrence, a wide variety of factual information is available. For a large number of occurrences, the causal and contributing factors are also available. Besides data on accidents and incidents, the NLR Air Safety Database also contains a large collection of non-accident-related data. These data include the following: airport data, flight exposure data (hours and flights at the level of airlines, aircraft type and airports), weather data, fleet data, and more. The NLR Air Safety Database is updated frequently using reliable sources, including data from official reporting systems, insurance claims, accident investigation boards, aircraft manufacturers, civil aviation authorities and more. Queries were conducted in the NLR Air Safety Database using the data-inclusion criteria. The level of detail of the information available for each individual accident varied. For a large number of accidents, detailed reports were available. However, for some accidents there was only limited information.

3.4 Taxonomy

The accident data were analyzed using a taxonomy that was developed for this study. The taxonomy was based on the factors that influence landing performance. as discussed in Section 2, extended with some additional elements such as aircraft type and location. The taxonomy is listed in Table 1.

Table 1: Taxonomy

Aircraft type
Approach type (precision, nonprecision, visual)
Autoland
Date
Excess approach speed
Failure of stopping device
High on approach
Hydroplaning of the tires
Late or no application of available stopping devices (reversers, brakes, spoilers)
Location
Long landing (touching down far beyond the threshold)
Propulsion type
Runway condition (dry, wet, flooded, icy, snow-covered)
Tailwind

3.5 Analytical process employed

The major steps included in the analysis are listed below:

1. The data were evaluated through a straightforward single-variable analysis. This included developing frequency distributions of each risk factor considered. It also included an exploratory analysis that provided a general understanding of the landing-overrun accident data.

2. A central objective of this study was to estimate the risk associated with the various landing factors (excess speed, tailwind, runway condition, etc.). It was therefore essential to understand the prevalence of these individual factors during landings which did *not* end up in a landing overrun. For instance, to estimate the risk associated with long landings, it should be known how many long landings took place without resulting in an overrun. These data were obtained in various ways. First of all, the NLR Air Safety Database contains data which allows making fairly accurate estimations of the prevalence of a number of risk factors in non-accident landings. Examples are the number of landings conducted on the different runway surface conditions. For other risk factors, data obtained from Flight Data Monitoring systems from a limited number of operators were used. These data were used to estimate prevalence of a number of risk factors in non-accident landings. Examples are excess approach speed, long landings and high approaches. It is realized that this only gives a rough order of magnitude of the prevalence of those risk factors for operations worldwide. This should be considered when analyzing the results. An estimate of the risk of having a landing-overrun accident with a particular risk factor present was accomplished by calculating a risk ratio. This risk ratio provides insight on the association of a factor on the risk in a landing-overrun accident. The risk ratio is the rate of the accident probability with the factor present over the accident probability without the factor present. The risk ratio is given by the following formula:

$$\textit{Risk Ratio} = \frac{\left(\dfrac{\text{accidents with presence of a risk factor}}{\text{normal landings with presence of a risk factor}}\right)}{\left(\dfrac{\text{accidents without presence of a risk factor}}{\text{normal landings without presence of a risk factor}}\right)}$$

   Risk ratio values greater than one indicate an increased level of risk due to the presence of a particular factor. A risk ratio of four means that the probability of an accident with the risk factor present is four times higher than without its presence. Positive associations between a risk factor and landing-overrun accidents show that a demonstrated association exists. However, it does not prove causation.

3. Finally, trends in the accident data were analyzed. In particular, changes over time were considered.

4 Findings

4.1 Univariate analysis

A total of 400 landing-overrun accidents were found that met the data-inclusion criteria. During the study period (1970–2004), approximately 796 million landings were conducted worldwide with passenger and cargo aircraft with a takeoff weight of 5,500 kilograms or higher. The estimated landing-overrun accident rate for the study period was 0.5 per million landings worldwide. Table 2 presents the accident distribution by region. The landing accident overrun rate per million landings is also given. Table 2 clearly shows the differences in landing overrun rates among the world regions.

Table 2: Landing-overrun accident distribution by region

Region	Landings (millions)	Accidents	Rate (per million landings)
Africa	31.84	86	2.70
Asia	71.64	74	1.03
Australasia	31.84	8	0.25
Central/South America	55.72	75	1.35
Europe	191.04	91	0.48
North America	397.99	61	0.15
Middle East	15.92	5	0.31
All	795.99	400	0.50

The distribution of accidents by aircraft category is shown in Table 3. The difference in landing accident overrun rate between jet and turboprop aircraft was not statistically significant at the 5 percent level. This means that the probability of a landing-overrun accident of a jet aircraft is not different from a turboprop aircraft.

Table 3: Landing-overrun accident distribution by aircraft category

Aircraft type	Landings (millions)	Accidents	Rate (per million landings)
Transport jet	527.22	250	0.47
Transport turboprop	268.76	150	0.56

Table 4 shows the distributions of the landing overrun risk factors for the complete data sample. The values shown in Table 4 are raw values only. They are not corrected for the number of landings conducted, which is done in the next section of the paper.

Table 4: Landing overrun risk factors distribution

Factor	Number of Accidents	Percent
Nonprecision approach	289	72.3%
Long landing	211	52.8%
Excess approach speed	111	27.8%
Hydroplaning of the tires	60	15.0%
Late or no application of available stopping devices	60	15.0%
Visual approach	56	14.0%
Tailwind present	49	12.3%
High on approach	29	7.3%
Brakes inoperative	21	5.3%
Reverser inoperative	10	2.5%
Ground spoilers inoperative	2	0.5%

The different types of runway surface conditions in the landing-overrun accidents are shown in Figure 1. Often, the surface condition varied along the runway. For instance part of the runway can be icy and another part covered with snow. Also in the case of flooded runways it was often only a part of the runway that had pools of standing water with the remaining part of the runway being wet. For this reason the different surface conditions that can exist are grouped in Figure 1 (page 158). The values shown in Figure 1 are raw values only. They are not corrected for the number of landings conducted on under such runway conditions which is done in the next section of the paper.

4.2 Bivariate analysis

In order to estimate risk ratios as defined in Section 3.5, the number of landings with or without a factor absent should be known. Different approaches were followed to obtain these data. For instance, data from airline flight data monitoring programs were used to estimate the number of long, fast and high landings for the complete data set. The approach type flown was estimated from the NLR Air Safety Database, which contains information regarding precision, nonprecision and visual approaches by airport (see also Khatwa et al., 1996). The actual runway conditions at airports (e.g., wet, snow-covered, etc.) are not well recorded in databases. Therefore,

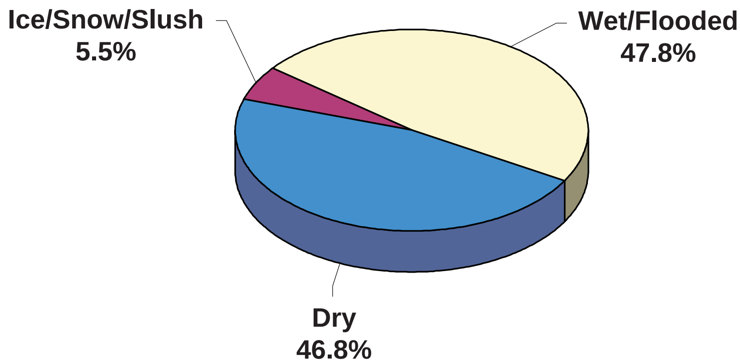

Figure 1: Runway condition distribution

the number of landings conducted on the different runway conditions were estimated from historical hourly precipitation observations at airports. The fact that it, for instance, rains does not automatically mean that the runway is wet. This depends on the drainage characteristics of the runway, the wind, the amount of rain that is falling and some other factors. With precipitation like snow, the runway can be made clear of it when large amounts accumulate on the surface. Therefore, adjustments were made on the calculated number of landings on wet/contaminated runways based on hourly precipitation observations. These adjustments were done by using engineering judgment. Although it is realized that this approach can introduce errors in the results, it is believed that the errors will be small enough just to fulfill the basic objectives of this study.

Calculation of risk ratios could not be accomplished for all variables that were considered. Denominator data for the late or non-use of stopping devices and the failure of stopping devices were not available. There were data available on the failure of stopping devices for a number of countries with a high safety standard. However, it was felt that these data were not applicable to the overall sample.

Table 5 presents the association of landing overrun related risk factors, adjusted for the number of landings involved in each factor. A value greater than one indicates a greater risk. The larger the risk ratio value, the stronger the association between the factor and the landing-overrun accident risk. All risk ratios presented in Table 5 are statistically significant at the 5 percent level. The landing-overrun accident risk while flying a nonprecision approach was 25 times greater than that associated with a precision approach. The risk ratio was 27 when flying a visual approach compared to a precision approach. If the landing was long, the landing-overrun accident risk was 55 times greater than when it was not long. The landing overrun risk is 38 times greater when there was excess approach speed. A tailwind of five knots or more increases the landing overrun risk by a factor of five. Finally, being high on approach increases the risk by a factor of 26. The results presented in Table 5 treat the long landing (touching down far beyond the threshold), excess approach speed, high approach and approach type variables as independent. However, in some cases these variables were related. For instance, high and fast landings often resulted in long landings.

Table 5: Risk ratio for landing overrun–related risk factors

Landing overrun related risk factor	Risk Ratio	Risk-factor accidents	Risk-factor absent accidents	Risk factor landings (millions)	Risk factor absent landings (millions)
Nonprecision approach	25	289	55	135.32	636.79
Long landing	55	211	189	15.92	780.07
Excess approach speed	38	111	289	7.96	788.03
Visual approach	27	56	55	23.88	636.79
Significant tailwind present	5	49	351	23.88	772.11
High on approach	26	29	371	2.35	793.63

Table 6 shows the risk ratios associated with runway condition. All risk ratios presented in Table 6 are statistically significant at the 5 percent level. The landing-overrun accident risk increases by a factor of 10 when the landing was conducted on a wet or flooded runway. If the runway was covered with snow, ice or slush, the landing-overrun accident risk is 14 times greater than when landing on a dry surface.

Table 6: Risk ratio for runway surface conditions

Runway condition	Risk Ratio	Risk-factor accidents	Risk-factor absent accidents*	Risk factor landings (millions)	Risk factor absent landings* (millions)
Wet/flooded	10	191	187	73.71	716.42
Snow/ice/slush	14	22	187	5.86	716.42

* Dry runway condition

4.3 Trend analysis

Figure 2 shows the variation in the landing-overrun accident rate for the period 1970 through 2004. The data were grouped in five-year blocks in order to increase the statistical robustness of the data. Figure 3 (page 160) shows the share of landing-overrun accidents in the overall number of approach and landing accidents that occurred worldwide. Again the data were grouped in five-year blocks.

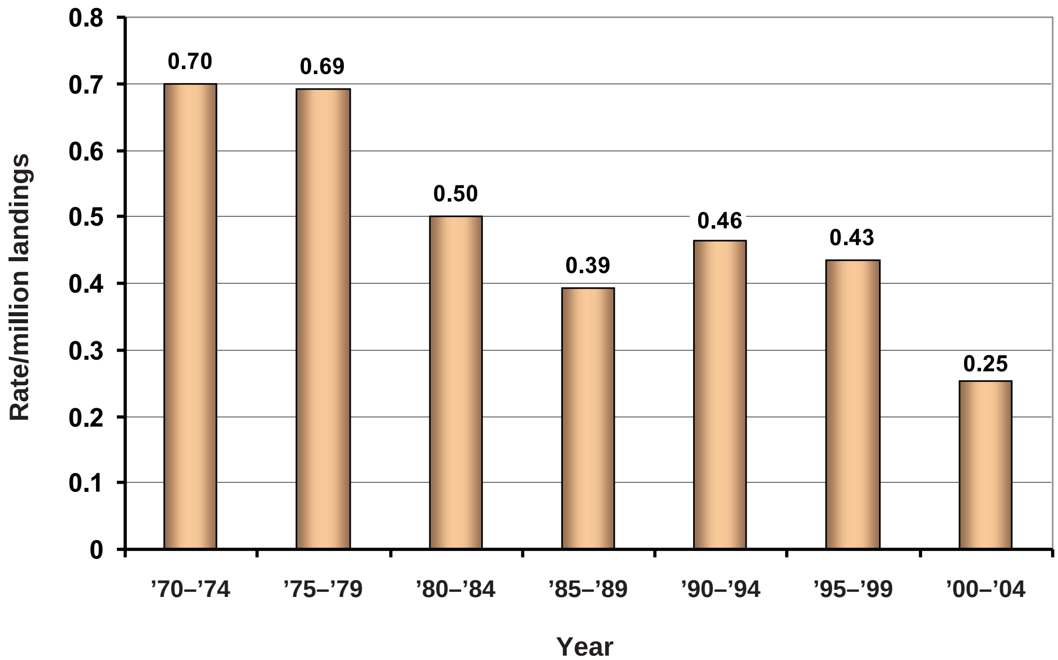

Figure 2: Landing-overrun accident rate trend

5 Discussion

In this study, 400 landing-overrun accidents were analyzed that occurred worldwide in the period 1970–2004. Based on the findings of the analysis of these accidents, a discussion of the results is presented in this section.

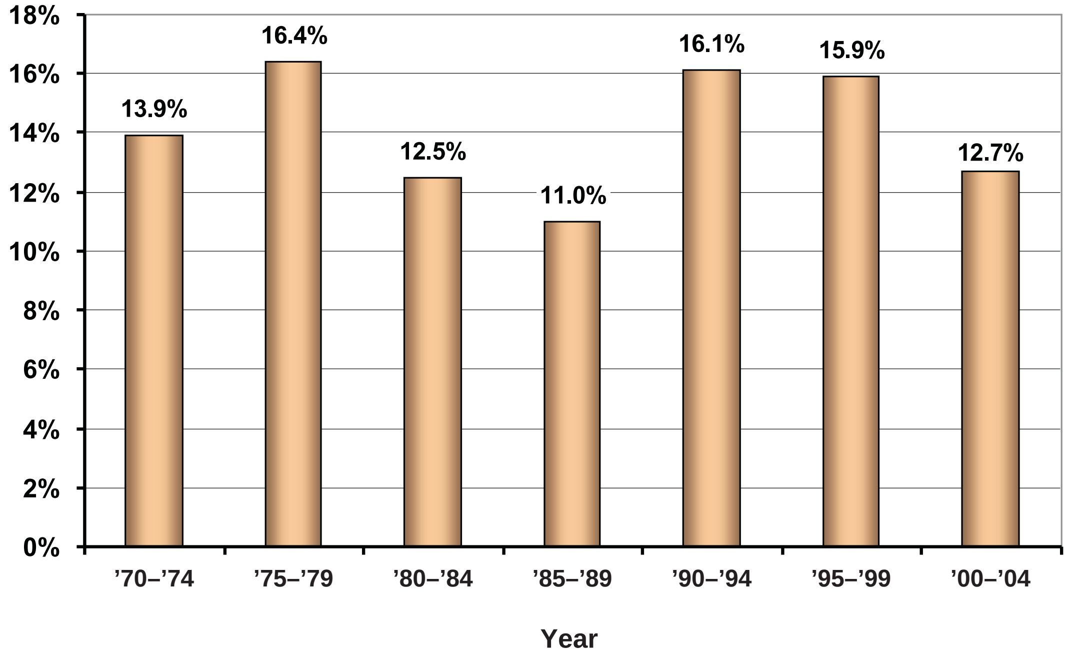

Figure 3: Trend in share of landing-overrun accidents in approach-and-landing accidents

5.1 Aircraft accident distribution by region

It was found that the landing overrun risk varies for the different world regions (Table 2). There are several explanations for this finding. There exists a difference in the level of aviation safety between the different regions in general. This could also affect the landing overrun risk. Note that an almost similar regional distribution in accident rates was found for landing accidents in general — that is, not limited to overruns (see Khatwa et al., 1996).

The highest landing overrun rate was found for Africa. The lowest rate was for North America. However, when comparing the rates for the different regions, it should be realized that not all differences in accident rates are statistically significant (at the 5 percent level). Although North America seems to have the lowest rate, it was not found to be statistically different from the rates estimated for the Middle East and Australasia regions. The low rate for North America was statistically different from the rate for Europe and the remaining regions.

5.2 Long, fast and high landings

In more than half of all accidents, the landing was long, meaning that the aircraft contacted the runway far beyond the threshold. Landing far beyond the threshold showed the highest landing overrun risk increase. A long landing itself is not always hazardous. For instance, when a small turboprop aircraft lands on a very long runway, landing long will not automatically result in difficulties stopping the aircraft on the remaining runway. However, long landings can become more hazardous when the available runway to stop the aircraft becomes shorter and/or the runway is slippery. The estimated number of long landings used to derive the risk ratio contained landings on all kinds of runways with different lengths. In that respect, the derived risk ratio for long landings represents an average risk value. Landing fast and/or high also increased the landing overrun risk significantly. Long landings are often associated with fast, high landings and/or tailwind landings. Excess approach speed is often a reason for a pilot to float the aircraft after the landing flare, during which the pilot tries to get rid of the excess speed. Excess approach speed was mentioned in 37.4 percent (79 out of 211) of all long landings. Being high on approach can also lead to longer landings. High on approach was mentioned in 12.8 percent (27 out of 211) of all long landings. In only two high approach cases, there was no long landing reported. Pilots clearly need to follow their procedures for monitoring and controlling airspeed and height during the final stages of the approach. Tailwind can also increase the tendency to float. A tailwind condition existed in 15.2 percent (32 out of 211) of all long landings. Long landing cannot be explained by excess speed, high approaches, etc., only. Clearly, pilot flying technique plays a significant role in the occurrence of a long landing. More study is required to get a better understanding of this.

5.3 Approach type

The landing overrun risk is much higher when a nonprecision or visual approach is flown. These approach types are more likely to become unstabilized (e.g., flying too fast and too high) than precision approaches. Indeed, the vast majority of overruns in which there was an excess approach speed occurred during a nonprecision or visual approach (81 percent). In 80 percent of all landing-overrun accidents that were high over the threshold, the approach type was nonprecision or visual. Similarly, in 82 percent of all overruns in which a long landing was reported, the approach type was a nonprecision or visual approach.

5.4 Runway condition

Slippery runway conditions were associated with higher risk of a landing-overrun accident (Table 6). This finding is not a surprise and is well known in the aviation community. However, the quantitative increase in risk was not known. Runway condition affects the braking forces the aircraft tires can generate. Furthermore, wheel spin-up can be delayed on slippery runways, which affects the proper functioning of the anti-skid system and the deployment of ground spoilers. On wet/flooded or slush-covered runways, the tire may hydroplane, which reduces the braking forces between the tire and runway significantly. On snow and ice-covered runways, the braking friction levels are very low, making it difficult to stop the aircraft. During the last 35 years, there have been many initiatives to get a better understanding of runway traction. Numerous studies have been conducted for instance in the United States by NASA, USAF and FAA, and in the United Kingdom to understand the impact of runway condition on the stopping capabilities of an aircraft. These studies examined the influence of runway texture on braking friction, analyzed the hydroplaning of tires and showed what impact snow and ice had on braking friction. Several studies also looked at measuring runway friction using ground vehicles and the correlation of the outcome of these vehicles with the friction of an aircraft. This could be valuable for the pilot when making an assessment of landing performance. Unfortunately, despite the great effort made so far, an acceptable solution to this problem of measuring runway friction and correlating it to aircraft landing performance is still to be found.

5.5 Tailwind landings

Tailwind landing are associated with higher risk of landing overruns (Table 5). Tailwind increases the groundspeed and therefore the landing distance (see Van Es and Karwal, 2001). Typically, aircraft are certified to make landings with a maximum tailwind component. For most commercial aircraft, this is 10 knots on a dry runway. Some aircraft are certified for higher tailwinds. However, this is usually not more than 15 knots. On slippery runways, lower tailwinds are allowed during the landing, varying from five knots to no tailwind at all. A more detailed discussion on tailwind operations is provided by Van Es and Karwal, 2001.

5.6 Application of available stopping devices

In 8.3 percent of the landing-overrun accidents, one or more stopping devices did not function (Table 4). This was mainly due to problems with the hydraulic systems. This sometimes also prevented the use of flaps, which resulted automatically in excess approach speed landings. More concerning is the fact the in 15 percent of the accidents, there was late or no application of the available stopping devices (Table 4). In many of these accidents, an overrun was avoidable if the available stopping devices would have been properly used. The problems were mainly caused by the fact that the ground spoilers were not armed (52 percent of all cases with late or no application of the available stopping devices). In these cases, the pilots often failed to notice that the spoilers did not deploy. Also, late or no application of thrust reversers was often found in the accidents (67 percent of all cases with late or no application of the available stopping devices). In some cases, reverse thrust was selected initially; however, shortly afterwards it was deselected again. It did not become clear from the analyzed data that insufficient manual braking was often a factor. However, to identify that fact, detailed flight data recordings need to be analyzed. Unfortunately, in many of the analyzed accidents, such information was not available to the author. It can be assumed that this lack of information also often applied to the people that originally investigated the accident, as pedal input is recorded on only a limited number of aircraft types (assuming that an FDR was installed and functioning on the aircraft).

5.7 Autolands

None of the analyzed landing-overrun accidents was reported to be attributable to malfunctioning or improper functioning of the autoland system. In one accident from the data sample, the crew initially conducted an autoland but then took manual control over the aircraft again just after passing the threshold. In only a very few cases, it was suspected that an autoland was most likely conducted due to the visibility conditions at the time of landing. However, not enough details were reported to be absolutely sure. This made it difficult to estimate a reliable risk ratio for manual landings.

5.8 Trend analysis

Figure 2 shows the trend in the landing-overrun accident rate worldwide. It is shown that in the 1970s, the rate was the highest for the period considered in this study (1970–2004). During the 1980s, the rate significantly improved. However, this improvement did not continue in the 1990s. The first five years of the 21st century finally showed a reduction in the landing-overrun accident rate again. It is difficult to say what exactly caused the reduction in the accident rate during the period 1970–2004. However, there are a number of initiatives that could have contributed to the safety improvement. Some of the more important ones will be discussed now.

The efficiency of anti-skid systems has improved over the years. The early anti-skid systems were simple on-off systems that produced braking efficiencies of 60 percent and were introduced in the 1950s. Later (1960s), modulated anti-skid systems were introduced that had braking efficiencies in the 70–85 percent range. During the 1970s, braking efficiencies of consistently over 90 percent were achieved for the first time with the newer anti-skid systems. The commercial aircraft that were operated in the analyzed period in this study were equipped with one of the anti-skid systems described here. As time progresses, older aircraft equipped with less sophisticated anti-skid systems were replaced with newer models having more efficient anti-skid systems.

Autobrake systems were introduced during the 1970s. They are found on many jet transport aircraft today. It was estimated that autobrakes were used in 30 percent of all landings in the study period. In 2004, this share was estimated to be nearly 50 percent of all landings.

Since the 1960s, research on tire braking friction was conducted. These studies provided insight into runway friction and how it could be improved. This has led to the introduction of, for instance, grooved and porous friction course runways. Although these surfaces often gave an improvement in runway friction on wet runways, they do not rule out the possibility of an overrun on such a runway. Indeed, there were a number of landing-overrun accidents that took place on grooved runways. Also, many studies were conducted to measure runway friction using ground vehicles. The objective was often to correlate the braking friction of these ground vehicles with that of an aircraft. Unfortunately, despite the enormous effort a lot of work is still to be done in this area to arrive at a useful way to correlate ground vehicles with full-scale aircraft.

During the late 1990s, different safety studies were initiated with the aim to improve the level of flight safety. Special attention was given to accidents that occurred during approach and landing, including landing overruns.

Studies include those conducted by the Commercial Aviation Safety Team (CAST) on approach-and-landing accidents, the Flight Safety Foundation task force on approach-and-landing accidents (FSF, 2001) and the joint study into landing aids (Khatwa, 1996). These studies provided the aviation community with a set of mitigating measures. Especially, the FSF Approach-and-landing Accident Reduction (ALAR) Briefing Notes are of great importance. Several briefing notes are devoted to issues that affect the possibility of landing overruns. However, it is too early to conclude that these initiatives had a major influence on the reduction of the landing-overrun accident rate during the first five years of the 21st century.

Another interesting technology that is worthwhile to mention here is the application of a ground arrestor system which is located beyond the end of the runway and centered on the extended runway centerline. A ground arrestor system is designed to stop an overrunning aircraft by exerting deceleration forces on its landing gear Although this technology (as explained later) cannot prevent overruns from happening, its application can mean the difference between an accident and a minor incident. Different types of ground arrestor systems were studied in the U.K. in the 1970s and later in the United States. An example of a soft ground arrestor system is the Engineered Material Arresting System (EMAS). A soft ground arrestor system like EMAS deforms under the weight of an aircraft tire that runs over it. As the tires crush the material, the drag forces decelerate the aircraft, bringing it to a safe stop. In recent years, EMAS has become popular in the United States at airports that have difficulties complying with the rules on runway safety areas defined by the FAA. There have been at least three reported overruns in which EMAS stopped the aircraft. These occurrences took place in the United States with a Saab 340 (May 1999; see photo), an MD-11 (May 2003) and, most recently, in January 2005 with a B-747. Clearly, no soft ground arrestor system can prevent overruns. However, it seems evident that such a system can reduce the consequences. Other arrestor systems were also studied the past. Examples are loose gravel, water ponds and arrestor cables. Application of these systems to commercial airports has been limited.

6 Final remarks

The variables that increase the risk of a landing overrun were discussed in the previous sections. Each of the investigated variables played an important role in the chain of events leading to an overrun. Typically, a landing overrun was not characterized by the presence of only one variable. It is often the combination of factors that finally made the aircraft overrun the runway. The quantified risk ratios in this study demonstrate that associations exist between a number of landing-related factors and the risk of a landing-overrun accident. Such associations do not prove any causation and only suggest that an increase in risk for a landing-overrun accident appears when the factor is present. The present study did not try to identify the underlying causal factors related to landing overruns. There have been many studies conducted in the past in which these underlying causal factors have been identified (see, e.g., FSF, 2001).

On September 19, 1972, a Fokker F28 made an NDB approach to Runway 22 in conditions of heavy rain and poor visibility at Port Harcourt, Nigeria. The final approach to touchdown was steep. Finally, the aircraft touched down smoothly with a speed 20 knots in excess of the recommended touchdown speed at 3,300 feet beyond the threshold. During flare the pilot added power. The remaining runway length after touchdown was some 3,700 feet. After touchdown, there was no appreciable deceleration of the aircraft. The ground spoilers did not deploy due to the lack of wheel spin-up. This was caused by hydroplaning of the main gear tires. The pilot did not select ground spoilers manually. The aircraft was not stopped on the runway, and it overran across an area of soft ground before impacting an embankment, breaking off the left wing. The aircraft eventually came to rest some 750 feet beyond the end of the runway. In the final part of the approach, the controller informed the crew that the runway was wet. However, in actual fact, the runway was flooded. This was due to the heavy rain in combination with the fact that the runway contained undulations in the surface which favoured the flooding of the runway. (Source: Accident Investigation Report published by the Dutch Civil Aviation Authorities and Nigerian Government, 1973.)

7 Conclusions and Recommendations

7.1 Conclusions

The following conclusions can be drawn from the landing-overrun accident data studied in this paper:

- The Africa region demonstrated the highest landing-overrun accident rate, followed by Central/South America and Asia. All these regions had rates of more than one accident per million landings. The rest of the world demonstrated rates below one accident per two million landings, which was less than half of the rate of the previous mentioned regions. North America had the lowest rate of all regions.

- No statistically significant difference in the estimated landing-overrun accident rate between commercial transport jet and turboprop aircraft was found.

- On a worldwide basis, there appears to be a significant increase in landing overrun risk when one of the fallowing factors is present during a landing: nonprecision approach, touching down far beyond the threshold (long landing), excess approach speed, visual approach, significant tailwind present, high on approach, wet/flooded runway, and/or snow/ice/slush-covered runway. The highest risk increase occurred when the aircraft touched down far beyond the threshold (long landing), followed by excess approach speed.

- On a worldwide basis, the landing-overrun accident rate has decreased by a factor of three over a period of 35 years. This reduction is most likely the result of a numbers of factors, including improvement in braking devices (anti-skid, autobrakes, etc.), better understanding of runway friction issues and safety awareness campaigns.

- Late or no application of available stopping devices was often found to be a factor in landing-overrun accidents. These overrun accidents were all avoidable if the crew had used the available stopping devices without any delay.

7.2 Recommendations

- It is recommended to disseminate the results of this study to all interested parties, including airlines, regulators and pilot unions.
- It is recommended to analyze in detail the characteristics associated with long landings using recorded flight data of normal day-to-day landings.♦

8 References

- Khatwa, R.; Roelen, A.; Karwal, A.; Enders, J.H.; Dodd, R.; Tarrel, R. "An evaluation of approach and landing factors influencing airport safety." National Aerospace Laboratory (NLR)–Netherlands, Technical Paper TP-96221, 1996.
- Van Es, G.W.H.; Karwal, A.K. "Safety aspects of tailwind operations." National Aerospace Laboratory (NLR)–Netherlands, Technical Paper TP-2001-003, 2001.
- Van Es, G.W.H. "Hydroplaning of modern aircraft tires." National Aerospace Laboratory (NLR)–Netherlands, Technical Paper TP-2001-242, 2001
- Flight Safety Foundation. Approach-and-Landing Accident Reduction (ALAR) Tool Kit. 2001.

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Innovative Training With Promising Results — Runway Incursion Update

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Introduction

Reducing the risks of runway incursions and runway collisions is a top priority of the U.S. Federal Aviation Administration (FAA). Runway safety management is a dynamic process that involves analyzing runway incursions, understanding the factors that contribute to runway collision risks and taking actions to reduce these risks. The following runway incursion data from the United States is shared with the intent of stimulating discussion about global risk management. Characteristics of runway incursions in the United States are described by how they are defined, categorized, distributed and most commonly experienced within the U.S. National Airspace System (NAS). Background is also provided about why the reduction of runway incursions is a significant management challenge. Finally, the paper will discuss safety measures that are working well along with future runway incursion mitigation strategies.

U.S. Runway Incursion History

In the United States, a runway incursion is defined as "any occurrence in the airport runway environment involving an aircraft, vehicle, person or object on the ground that creates a collision hazard, or results in a loss of required separation with an aircraft taking off, intending to take off, landing or intending to land."

Categorization by Error Type

Runway incursions are attributed to one of three human errors in the United States: Air Traffic Controller Operational Errors (OEs), Pilot Deviations (PDs) and Vehicle/Pedestrian Deviations (V/PDs). Figure 1 (page 168) describes the three error types. Each type of runway incursion falls under the regulatory or management authority of a separate FAA line of business; i.e., OEs fall under the regulatory/management responsibility of the air traffic organization, PDs fall under the regulatory/management responsibility of flight standards, and V/PDs fall under the regulatory/management responsibility of airports.

Typically, an incursion is assigned to the person (e.g., air traffic controller, pilot or vehicle driver) who made the most recent error prior to the actual event. In the operational environment, however, these (human) errors are part of an unfolding scenario, like a chain of events leading to a collision, where the links are likely to fall into all three categories. For example, a pilot deviation may be influenced by actions of the controller, design of the airport infrastructure, and previous training and certification requirements.

Categorization by Severity of Risk

To better understand the nature of runway incursion risk at towered airports in the U.S. NAS, runway incursions are further categorized into the four severity categories illustrated in Figure 2 (page 168). Category A is the most

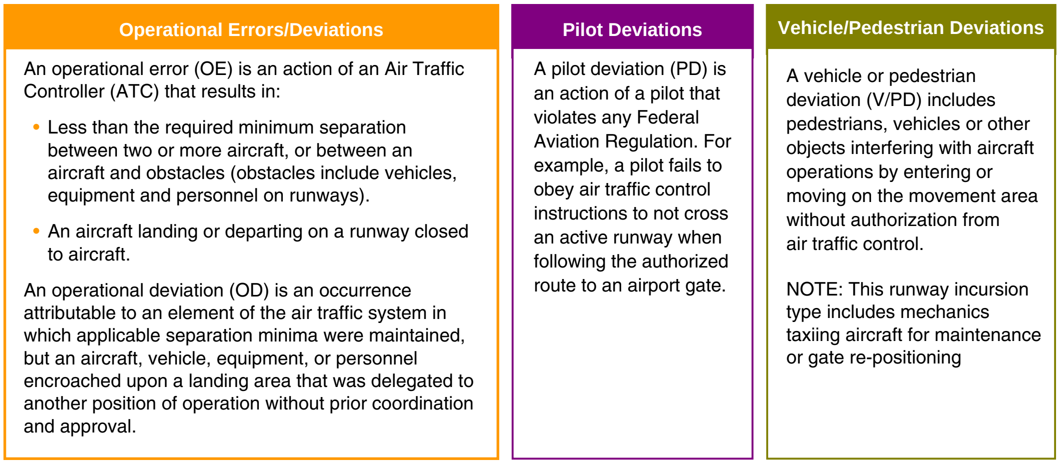


Figure 1. Runway incursion error categories.

serious and Category D is the least serious. Severity classifications are assigned to runway incursions through evaluation by a panel of experts with backgrounds in air traffic, airports and pilot operations. One of the U.S. Government Performance and Results Act (GPRA) sub-goals for FAA requires the reduction of Category A and Category B runway incursions over time.

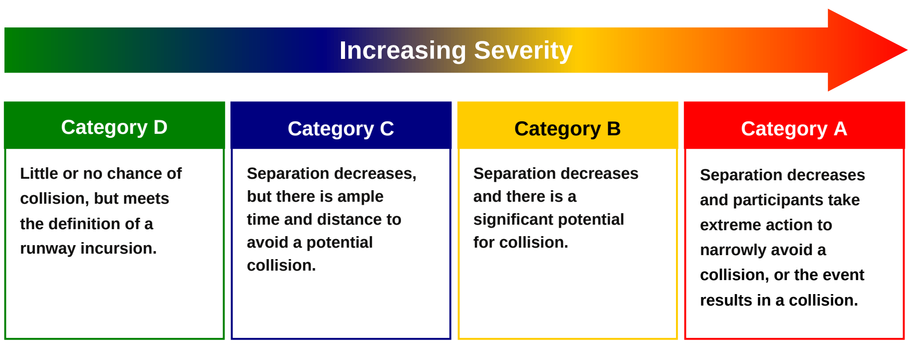


Figure 2. Runway incursion severity categories.

Distribution of Runway Incursions in the U.S. NAS

Between fiscal year (FY) 2001 and FY 2004, there were a total of 1,395 runway incursions at nearly 500 towered airports in the U.S. NAS. Figure 3 (page 169) and Figure 4 (page 169) illustrate the distribution by error type and severity.

Runway incursions are relatively rare events. On average, a runway incursion happened approximately once in every 176,000 operations (defined as either a takeoff or a landing) during the last four fiscal years at nearly 500 towered airports in the U.S. NAS. Figure 3 illustrates that over half of all runway incursions are assigned to PDs, with the remainder being split between OEs and V/PDs. Figure 4 illustrates the risk categories by percentage assigned to runway incursions. Category A and Category B runway incursions together average 11 percent over the four-year period. This average represents an important decrease from 19 percent for the same calculation made with data from calendar year (CY) 1997 to CY 2000. (Note: As required by the GPRA, U.S. federal agencies have established standards for measuring performance on a fiscal year basis. Calendar year data is used in the above comparison, because runway incursions that occurred in the first quarter of FY 1997 were not being categorized by severity.)

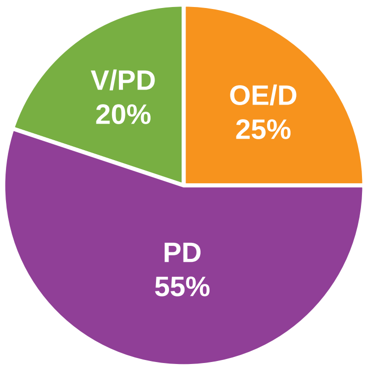


Figure 3. Distribution of runway incursions by error category (FY 2001 to FY 2004).

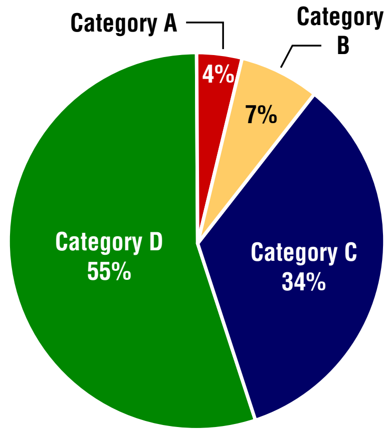
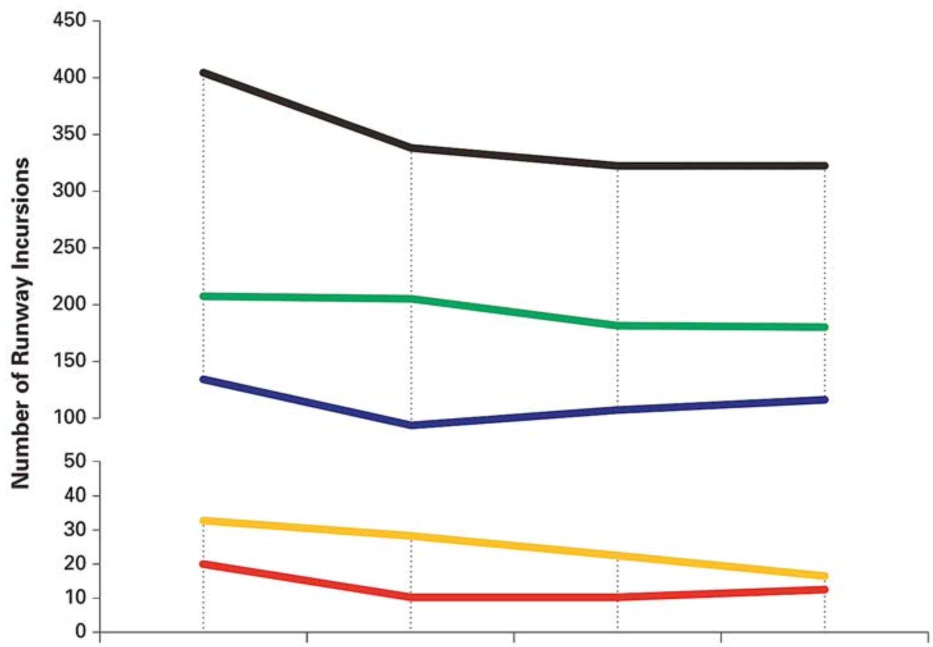


Figure 4. Distribution of runway incursions by severity of risk (FY 2001 to FY 2004).



	FY 2001		FY 2002		FY 2003		FY 2004		Total	
	Number	Rate per Million Ops	Number	Rate per Million Ops	Number	Rate per Million Ops	Number	Rate per Million Ops	Number	Rate per Million Ops
Category D	210	3.2	208	3.2	181	2.9	178	2.8	777	3.0
Category C	143	2.2	94	1.4	110	1.8	120	1.9	467	1.8
Category B	33	0.5	27	0.4	22	0.4	16	0.3	98	0.4
Category A	20	0.3	10	0.2	10	0.2	12	0.2	52	0.2
Insufficient Data*	1	0.0	0	0.0	0	0.0	0	0.0	1	0.0
Total	407	6.1	339	5.2	323	5.1	327	5.2	1,395	5.4

Figure 5. Annual frequency of runway incursions by severity category (FY 2001 to FY 2004).

Figure 5 illustrates the annual severity distribution of runway incursions year by year from FY 2001 to FY 2004. Over the four-year period, the majority (89 percent) of runway incursions — 1,244 of the 1,395 — were Category C and D events that involved little or no risk of a collision. Serious incursions, Category A and B events, represented 11 percent. Five Category A runway incursions resulted in collisions during the four-year period. Four of these collisions involved two general aviation aircraft. The other collision involved a commercial cargo aircraft colliding with construction cones on a closed runway at night. No fatalities resulted from any of the collisions.

Figure 6 and Figure 7 (page 171) illustrate how runway incursions are distributed by severity and error type at the 35 airports identified in the FAA Operational Evolution Plan (OEP) — the OEP-35 airports. FAA considers these airports to be the primary drivers of NAS performance in terms of system capacity. Most of the OEP-35 airports handled a mix of traffic that consisted of more than 80 percent of commercial aircraft operations (takeoffs and landings).

Of note here is the wide variation in runway incursions between airports that would appear to be relatively similar in operations (for example, highly trained air traffic controllers moving traffic with predominately commercial pilot crews flying well-equipped commercial aircraft). From this depiction, it can be deduced that airfield design has a significant impact on the difference of runway incursion performance between airports. It is important to note that the OEP-35 airports experience a higher percentage of OEs and a lower percentage of PDs than the NAS averages (illustrated in Figure 7). The percentage of V/PDs that occurred at the OEP-35 was essentially the same as the NAS average.

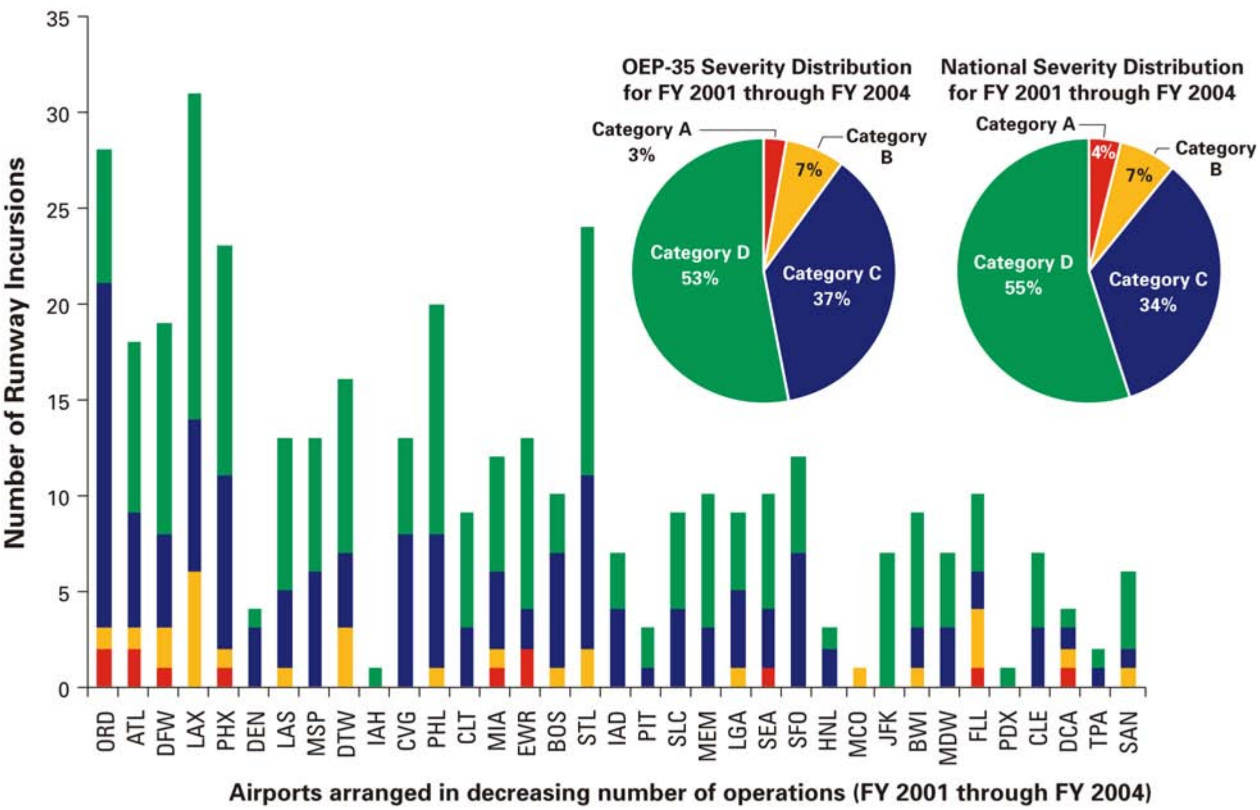


Figure 6. Runway incursions by severity at the OEP-35 airports (FY 2001 to FY 2004).

State and local governments in the United States typically own civil airports, runways, taxiways and facilities, with ATC control towers and varied air traffic equipment owned/operated (sometimes contracted, leased, etc.) by the U.S. federal government. Private enterprises or individuals typically own aircraft. These relationships come into play as changes are contemplated to reduce runway incursion risk.

Figure 7 shows the safety-related decision support tools for ATC controllers — Airport Movement Area Safety System (AMASS) and Airport Surface Detection Equipment-Model X (ASDE-X) — that are already implemented or slated for deployment at the OEP-35 airports.

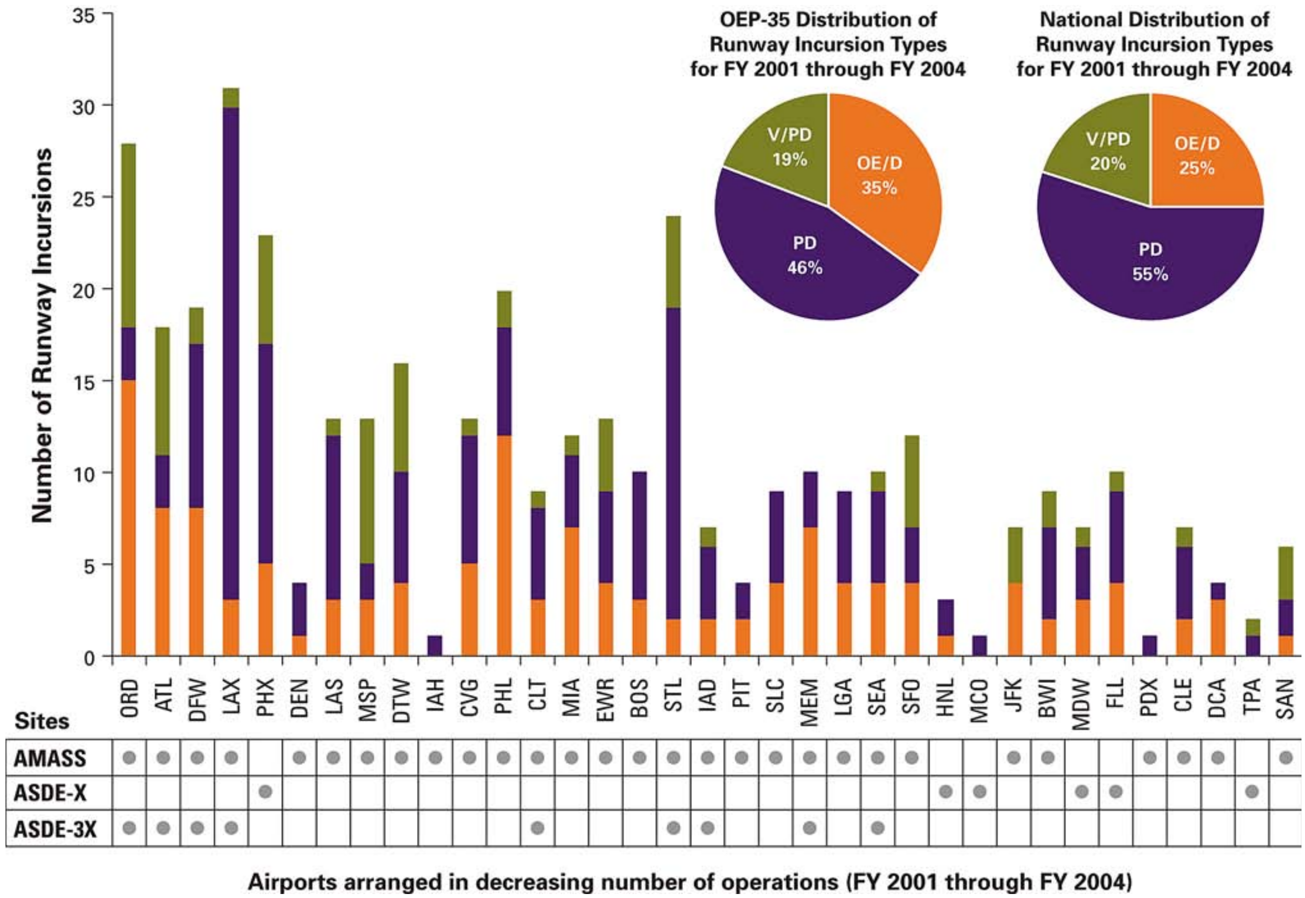


Figure 7. Runway incursions by error category at the OEP-35 airports (FY 2001 to FY 2004).

Factors Associated With Runway Incursions

There are several general characteristics that can be attributed to the runway incursions that occurred in the United States from FY 2001 through FY 2004. Of the 1,395 runway incursions, approximately 83 percent occurred during daylight hours in visual meteorological conditions (VMC). The majority of runway incursions (55 percent) were PDs, and general aviation pilots were responsible for 74 percent of the PDs. Twenty-five percent of the runway incursions were attributed to OE/Ds, and V/PDs accounted for the other 20 percent. Fifty-five percent of all runway incursions during this period were Category D events. Four percent of all runway incursions were Category A events. Of the nearly 500 FAA towered airports, 317 airports reported at least one runway incursion during this four-year period.

Runway Incursion Findings, 2002 Through 2004 (Preliminary Data)

Analysis of all runway incursions from 2002 through 2004 (preliminary data) showed that 45 percent of the incursions involved aircraft entering the runway safety area in front of an aircraft landing (69 percent of the landing aircraft went around). In addition, 32 percent of all runway incursions involved aircraft entering the runway safety area in front of an aircraft taking off (38 percent of the aircraft taking off aborted; 45 percent rotated before reaching the intersection; 17 percent rotated after reaching the intersection).

Pilot Deviations (Pilot Errors)

The causes of PDs that result in runway incursions cannot be determined from the limited information currently available. However, the reports of PDs do contain information on the types of errors that resulted in pilot deviation runway incursions.

Common pilot errors that resulted in runway incursions are:

- Pilot reading back the air traffic controller's instruction correctly and then doing something else.
- Pilot misidentifying their location.
- Pilot "heads down" programming FMC or conducting checklists.

Findings from common pilot errors:

- Twenty-three percent involve pilots completely crossing the runway in front of a takeoff or landing.
- Thirty-seven percent involve pilots entering the runway (includes partially crossing the runway edge and lining up and waiting for takeoff).
- Forty percent involve pilots crossing the hold-short lines, but not crossing the runway edge.

What can pilots do to reduce risk?

- Minimize "heads down" activity while taxiing.
- Use airport diagrams during taxi operations.
- Listen for clearances to land, taxi and take off, and for all clearances involving their runway.
- Look out for conflicting traffic.
- When in doubt about their position or their clearance, ask air traffic control.
- For air carriers: Turn landing lights on when takeoff clearance is received (this is a signal that the aircraft is moving).

Operational Errors (ATC Errors)

While the information as to what causes ATC errors is limited, the factors that are most often cited as contributing to OEs are:

- Air traffic controllers forgetting (about a closed runway, a clearance that they issued, an aircraft waiting to take off or cleared to land).
- Lack of (or inadequate) coordination between controllers.
- Air traffic controllers misidentifying aircraft.
- Readback/Hearback errors.

Findings from common ATC errors:

- Fifty-four percent involve pilots completely crossing the runway in front of a takeoff or landing.
- Twenty-seven percent involve pilots entering the runway (includes partially crossing the runway edge and lining up and waiting for takeoff).
- Nineteen percent involve pilots crossing the hold-short lines, but not crossing the runway edge.

What can controllers do to reduce risk?

- Recognize limitations of human memory and attention, and protect against this.

- Optimize teamwork.
- Never “assume” — Keep up their scan and check.
- Practice good communication techniques.

Vehicle/Pedestrian Deviations

The information as to what causes vehicle/pedestrian errors is also limited. The factors that are most often cited as contributing to V/PDs are:

- Drivers getting lost on the airport surface.
- Drivers being unfamiliar with airport signs and markings.
- Drivers being unfamiliar with air traffic control terminology.
- Drivers misunderstanding air traffic controller instructions.
- Drivers misreporting the location of vehicles to air traffic control.

Findings from common vehicle errors:

- In seventy-seven percent of the vehicle deviations, the vehicle completely crossed the runway (63 percent involved an aircraft taking off, and 37 percent involved an aircraft landing).

Approximately 20 percent of the reported V/PDs involve people who do not belong on the airfield — some of these people have inadvertently entered the airfield due to the lack of adequate fencing and other deterrents while the others represent intentional circumvention of deterrent measures, such as hopping a fence. As airport security measures increase, these unauthorized entries on the airfield are expected to decrease.

What can be done to reduce the risk of V/PDs?

- Greater emphasis should be placed on airfield driver training (for example, non-pilots who taxi or tow aircraft, such as mechanics).
- For those persons authorized to be on the airfield, greater emphasis is needed on limiting runway access to those vehicles and personnel that have an operational necessity.
- Whenever possible, vehicle traffic should be directed to use airfield perimeter roads. When such roads do not exist, vehicles should be encouraged to cross at the departure ends of runways.

Current Situation

The United States has made some headway in reducing the total number of runway incursions and in the number of serious runway incursions, Category A and Category B, during the four-year period. Furthermore, the reduction in both the total number of pilot deviations and those that resulted in serious incursions represents substantial progress. But the problem is not solved.

Recently, there have been serious incursions at three international airports: Boston Logan International Airport (BOS) in Massachusetts, Los Angeles International Airport (LAX) in California and John F. Kennedy International Airport (JFK) in New York. Each involved U.S. domestic and international air carriers. At BOS, an ATC error resulted in two aircraft receiving takeoff clearances on intersecting runways. At LAX, an ATC error resulted in an aircraft receiving instructions to land on an occupied runway. At JFK, a pilot error resulted in an aircraft flying over another aircraft inadvertently crossing a runway.

We need to work together globally to help mitigate the problem. Below are some items the United States is implementing to reduce risk in the future.

Commercial Aviation Safety Team and Standard Operating Procedures

The Commercial Aviation Safety Team's (CAST's) goal is to reduce the U.S. commercial aviation fatal accident rate by 80 percent by the end of 2007. CAST, along with the General Aviation Joint Steering Committee, chartered the Runway Incursion Joint Safety Implementation Team to develop a plan to help accomplish this goal. Expert representatives from across the aviation community, including the International Civil Aviation Organization, JAA (now EASA), International Air Transport Association, Flight Safety Foundation, IFALPA, airlines, other international organizations and appropriate regulatory/government authorities were brought together to help reduce the worldwide commercial aviation fatal accident rate.

A data-driven, consensus-based, integrated strategic safety plan was developed that includes 47 prioritized safety enhancements, eight research and development projects and two studies. Industry-wide, standard operating procedures (SOPs) have been among the highest scoring safety enhancements across five accident categories, including controlled flight into terrain, approach and landing, loss of control, runway incursions and turbulence. Not surprisingly, the implementation of SOPs for surface operations is one of the most powerful near-term interventions in mitigating the risk of runway incursions. Although most airlines have detailed procedures for airborne operations, relatively few airlines had standard procedures for operating in the increasingly complex surface environment. The Federal Aviation Administration revised Advisory Circular 120-74, "Flight Crew Procedures During Taxi Operations," to recommend that all FARs Parts 91, 121, 125 and 135 operators establish, document, train to and follow standard operating procedures ("best practices" developed from a survey of industry) for conducting safe aircraft operations during taxi operations.

Landing Lights

One of the "best practices" outlined in the revised Advisory Circular (AC) 120-74A is about the use of landing lights. Until relatively recently, there was no consistent practice among air carrier pilots concerning the use of landing lights while lined up on the runway waiting for takeoff, or when cleared for takeoff. Some pilots would illuminate all of the landing lights as they lined up on the runway with the expectation that this would make the aircraft more visible to aircraft on approach and it would help prevent "landovers" (that is, an aircraft landing over the aircraft holding on the runway). Other pilots would illuminate the landing lights (along with the strobe light, if not automatically controlled) once the takeoff clearance had been received. Thus, they used the landing light as a signal that the aircraft was rolling.

It should be noted that it is extremely difficult to detect motion of a plane that is moving forward at a 90-degree angle to the viewer. All of the cues that our visual system uses to indicate motion are difficult to detect under these circumstances, until the aircraft is relatively close to the viewer.

Based on analysis, the following recommendation was added to the air carrier Standard Operating Procedures (FAA AC 120-74A):

> When holding in position for takeoff, the landing lights should be off until takeoff clearance is received; in this way, it provides an indication to ATC and other aircraft that the aircraft is rolling.

Since the publication of the Advisory Circular and the implementation of this procedure, the incidence of serious runway incursions resulting from crossing in front of a takeoff has decreased (from 47 percent for 2000–2002 to 26 percent for 2004).

Enhanced Airfield Paint Markings

The FAA has changed its standard for taxiway centerlines to provide for an enhanced taxiway centerline that will alert pilots that they are approaching a runway holding position. The operators of the 72 airports that have the most passenger enplanements are required to install the new markings at all taxiways with runway holding positions by June 30, 2008. Other airport operators may also install these markings on their airfields at their option; if an operator decides to exercise this option, the enhanced markings must be installed at every holding position on the airfield.

Description of the modified taxiway centerline: Dashed yellow lines are to be placed on both sides of the taxiway centerline. The modified centerline will be implemented approximately 150 feet prior to the runway holding position marking (if sufficient space is available). The enhanced centerline may or may not be supplemented by surface painted holding-position signs. A more detailed description of this enhancement can be found in Advisory Circular AC 150/5340-1J, which can be found at <www.faa.gov/arp>.

When pilots encounter the enhanced centerline while taxiing, the new paint markings will make them aware that they are approaching a runway holding position. It is recommended that pilots go into a "heads up" mode until they determine the exact location of the holding position, and cross-check their taxiing instructions to determine whether or not they are required to hold short.

Future Technologies

The FAA has identified and deployed advanced technologies to reduce the risks of runway collisions at commercial airports. Runway surface surveillance systems use ground surveillance radar to provide tower controllers with information on the position and identification of aircraft and vehicles.

Runway Status Lights

A technology that is in research and development is the Runway Status Light System (RWSL), an all-weather automatic system that provides an additional layer of safety to controllers, pilots and vehicle operators. RWSL improves situational awareness via a visual alert indication to the pilots and vehicle operators in the runway environment. RWSL works in concert with existing pilot procedures to enhance runway safety and does not increase controller workload nor decrease airport capacity. The lights are driven automatically using computer processing of integrated surface and terminal surveillance information. Surface and terminal surveillance systems, such as Airport Surface Detection Equipment Model X (ASDE-X) and Airport Movement Area Safety System (AMASS), detect the presence and motion of aircraft and vehicles on or near the runways. The RWSL safety logic then assesses any possible conflicts with other surface traffic, illuminates red runway entrance lights (RELs) if the runway is unsafe for entry or crossing, and illuminates red takeoff hold lights (THLs) if the runway is unsafe for departure. RELs are in-pavement fixtures situated at selected runway-taxiway intersections and face the taxiways that intersect runways. THLs are also in-pavement fixtures situated at selected full-length and intersection takeoff-hold positions, and are installed alongside the runway centerline for approximately 1,000 feet facing aircraft in the takeoff hold position.

The Operational Evaluation (OpEval) of the REL using the ASDE-X surface surveillance was completed in June 2005 at Dallas/Fort Worth International Airport (DFW), and the system performance was found acceptable and compatible with normal ATC operations. The OpEval of the THL is scheduled to begin at DFW in early 2006. The evaluation of the RWSL with AMASS is scheduled to begin in summer of 2006 at San Diego International Airport.

Cockpit Moving Map Displays

When the Commercial Aviation Safety Team studied more than 800 runway incursion accidents and incidents, they concluded that the most powerful runway incursion prevention tool was the cockpit moving map display with own-ship position. Data revealed that this safety enhancement alone would reduce pilot deviations by more than 40 percent. Additionally, it was found that when Automatic Dependent Surveillance Broadcast (ADS-B) is added to the moving map display to show other aircraft and ground vehicles, an overall reduction in runway incursions of approximately 65 percent would result.

Cockpit moving map displays will increase pilot situational awareness when own-ship position is displayed. When ADS-B, runway occupancy status and data linked air traffic control sequences are added, CAST data revealed that 95 percent of all runway incursions could be prevented. In this environment, pilots, controllers and vehicle operators see the “big picture” of airport operations. We remain committed to fielding cockpit moving map displays with these technology enhancements because they will save lives.

It should be noted that moving map usage has led to significant capacity enhancement as well in the testing thus far. Equipage should lead to significant safety and capacity gains.

Runway Safety Online Course

The FAA Office of Runway Safety, the Air Line Pilots Association, International (ALPA) and the Aircraft Owners and Pilots Association’s Air Safety Foundation have collaborated to produce a new runway incursion prevention education web site. This site was put online in mid-September and is already being used by a number of major U.S. carriers in their recurrent training programs. The Air Transport Association of America has embraced the site and is encouraging use of it by its members. The web site provides challenging segments on airfield signage and markings. It also includes practical pilot standard operating procedures (SOPs) and best practices to avoid runway incursions. As part of the education, pilots are tested before and after the training, and upon successful completion receive a certificate of accomplishment. We intend to update the online course on an annual basis, and if there is international interest, we would participate in producing an online equivalent that would highlight any differences between U.S./Canada and ICAO procedures.

Runway Safety DVD for Commercial Pilots

The FAA and ALPA have collaborated on a DVD for distribution to all FARs Part 121/135 carriers in the United States. A copy of that DVD is available to all the Moscow IASS attendees. The DVD was produced in conjunction with United Airlines’ training department and ALPA. Although its content is similar to that contained on the ALPA web site, its format is more scenario-based and provides an alternate means of bolstering the effectiveness of runway incursion prevention training. This is the first DVD produced that specifically targets commercial pilots. To date, there have also been two DVDs produced that focus on the general aviation community. Together, we believe, these education materials will increase pilot knowledge and situational awareness, and reduce the risk of fatal runway incursions.

ICAO Runway Safety Toolkit

ICAO and Embry-Riddle Aeronautical University, Florida, United States, produced a Runway Safety Toolkit (on CD-ROM) as part of a continuing effort to assist States in the implementation of runway incursion prevention programs. This interactive toolkit is a compilation of the best educational material available, acquired over a several-year period, and also makes use of information and knowledge obtained during a series of ICAO seminars on the subject of runway safety held between December 2003 and October 2004. The toolkit is meant to be used with other runway safety tools and to support other runway safety program initiatives.

The toolkit also contains the ICAO Standards and Recommended Practices (SARPs) relevant to runway safety, important safety messages, quizzes, videos, electronic versions of posters, ICAO awareness presentations, references and links, and a glossary of terms. A copy is available to all the Moscow IASS attendees.

The Next Step

Despite high levels of proficiency, errors that result in runway incursions still occur. Participating in efforts with global partners and industry to develop innovative methods and tools for collecting, analyzing and sharing runway safety information is essential. Advancing international cooperation in the prevention of runway incursions will enhance the safety and confidence of the flying public around the world. ♦

Additional material follows on pages 177–198.

INNOVATIVE TRAINING WITH PROMISING RESULTS –

RUNWAY INCURSION UPDATE

Presented to: IASS

By: **William S. Davis**,
Vice President, FAA ATO-Safety

Charlie Bergman,
Manager, ALPA Air Safety and Operations

Date: November 2005

Overview

- **UNDERSTANDING THE PROBLEM**
- **CAST PROGRESS**
- **“BEST PRACTICES”**
- **WHAT’S WORKING**
- **LET’S WORK TOGETHER**

2

The Runway Incursion Challenge

- **Millions of aircraft operations**
- **Catastrophic events occur infrequently**
  - Risk = Severity x Frequency
- **Human error is a certainty**
- **Technology has limitations**
- **Consequences are global**
- **Global risk management required**

3

Types of Runway Incursions

➢ **The FAA investigates runway incursions and attributes the occurrence to one or more of the following error types:**

Operational Errors

• An operational error (OE) is an action of an Air Traffic Controller (ATC) that results in:

- **Less than the required minimum separation between two or more aircraft, or between an aircraft and obstacles (obstacles include vehicles, equipment, and personnel on runways).**
- **An aircraft landing or departing on a runway closed to aircraft.**

Pilot Deviations

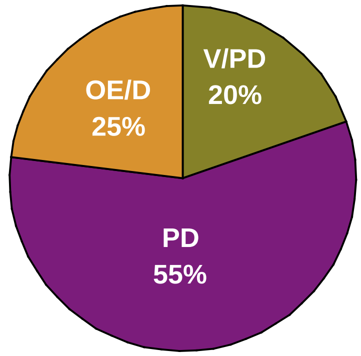
• A pilot deviation (PD) is an action of a pilot that violates any Federal Aviation Regulation. For example, a pilot fails to obey air traffic control instructions to not cross an active runway when following the authorized route to an airport gate.

Vehicle/Pedestrian Deviations

• A vehicle or pedestrian deviation (V/PD) includes pedestrians, vehicles or other objects interfering with aircraft operations by entering or moving on the runway movement area without authorization from air traffic control.

4

Runway Incursion Reduction Requires Partnership

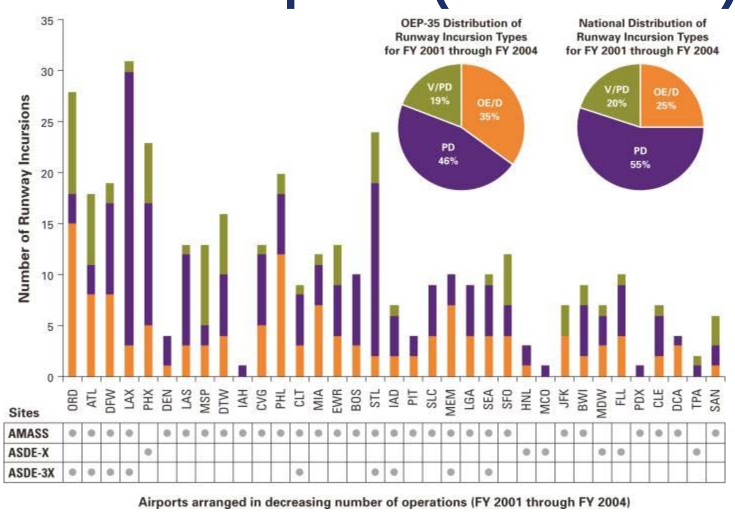


FY 2001-FY 2004

OE/D = Operational Error/Deviation
PD = Pilot Deviation
V/PD = Vehicle/Pedestrian Deviation

5

Error Type Distribution at 35 U.S. Towered Airports (FY01-FY04)



6

Runway Incursion Severity Categories

Operational dimensions affecting runway incursion severity:

Available Reaction Time	Evasive or Corrective Action	Environmental Conditions	Speed of Aircraft and/or Vehicle	Proximity of Aircraft and/or Vehicle

Increasing Severity →

Category D	Category C	Category B	Category A
Little or no chance of collision, but meets the definition of a runway incursion.	Separation decreases, but there is ample time and distance to avoid a potential collision.	Separation decreases and there is a significant potential for collision.	Separation decreases and participants take extreme action to narrowly avoid a collision, or the event results in a collision.

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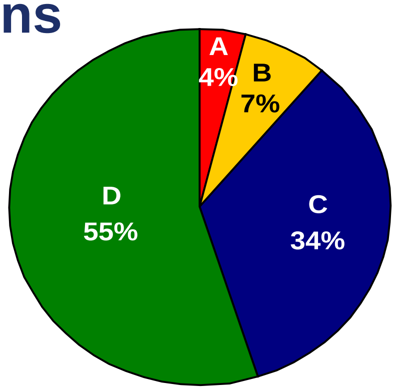
Severity Distribution of Runway Incursions

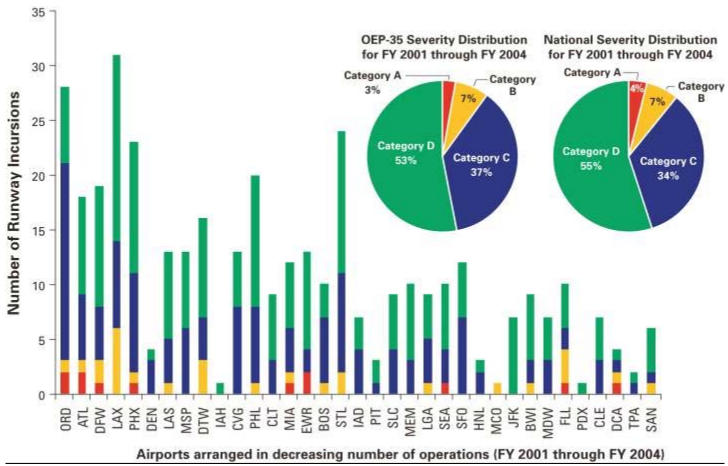


FY 2001 – FY 2004

Data are preliminary and subject to change

8

Severity of Runway Incursions at 35 U.S. Towered Airports (FY01-FY04)



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CAST Goals

- Reduce the U.S. commercial aviation fatal accident rate by 80% by 2007
- Work together across the aviation industry to reduce risk
- Data-driven safety plan

10

Data-Driven Safety Plan

- 47 Prioritized Safety Enhancements
- 8 R&D Projects and 2 Studies
- Projected 73% Risk Reduction by 2007 (75% by 2020)
- Foundation for U.S.-driven, continuous improvements in aviation safety

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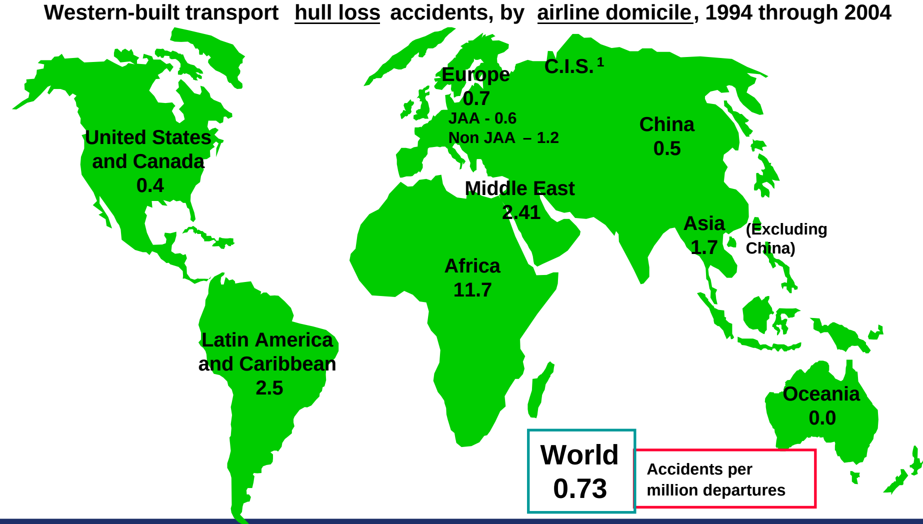
Regional Overview

Accident Rates Vary by Region of the World

Western-built transport hull loss accidents, by airline domicile, 1994 through 2004



[1]Insufficient fleet experience to generate reliable rate.

12

Boeing 3-22-05 REG-106

Safety Plan Benefits

- **Prediction of a 73% fatality risk reduction that also results in approximately $620 million annual savings to the industry**
  - ➤ Current accident cost per flight is approximately $76 per flight cycle
  - ➤ Implementation of the 47 selected safety enhancements reduces this cost by $56 per flight cycle

Safety is Good for Business

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CAST- & JSSI-Driven International Safety Activities

ICAO

- **COSCAP** **(Cooperative Development of Operational Safety and Continuing Airworthiness)**

Europe

- **JSSI: Joint Safety Strategy Initiative**

Central and South America

- **PAAST: Pan American Aviation Safety Team**

East Africa

- **African Airlines Safety Council, AFRASCO**
- **African Safety Enhancement Team**

West Africa

- **Flight Safety Foundation**

Asia/Pacific

- **Association of Asia Pacific Airlines**

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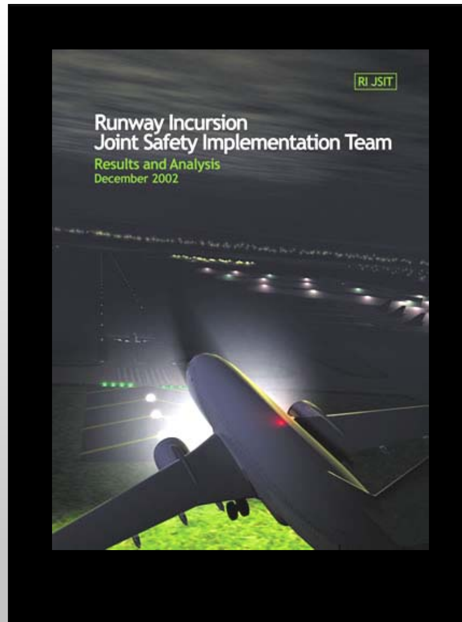

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RI JSIT — Seven Project Areas

- Standard Operating Procedures
- Air Traffic Control Training
- Air Traffic Control Procedures
- Visual Aids Enhancement & Automation Technology
- Situation Awareness Tech for ATC
- Pilot Training
- Aircraft/Vehicle Upgrade

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Our Process to Develop SOPs

- Included FAA staff, captains from 10 U.S. airlines, trade associations, unions and airport staff
- Collected existing runway incursion SOPs
- Compiled FAA Advisory Circulars

17

Key Revisions to Advisory Circular 120-74A

- Integration of "best practice" runway procedures into cockpit checklist
- Cleared for takeoff = Turn on landing lights
- Unexpected delay on runway = Contact ATC
- Focus on active listening to clearances and readback procedures

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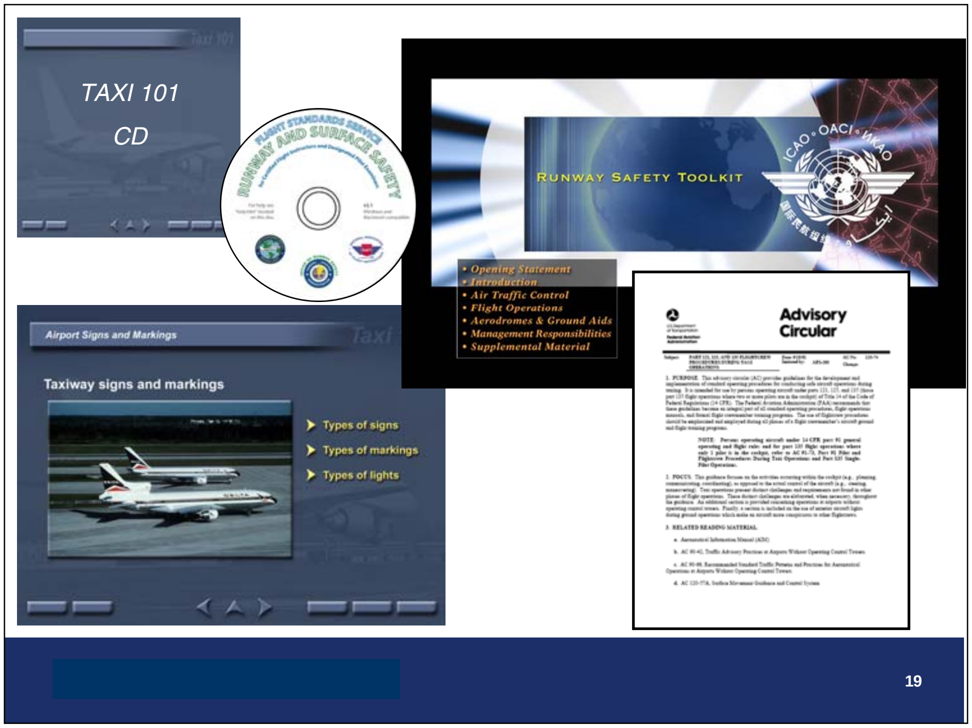

Recent Runway Incursion Findings at 35 U.S. Towered Airports

- **From 2000–2002, 47% of serious runway incursions involved aircraft crossing in front of a takeoff**
- **After publication of Advisory Circular 120-74A in 2004, 26% of serious runway incursions involved aircraft crossing in front of a takeoff**

20

Runway Incursion Findings, 2002–2004 (Preliminary Data)

- **Aircraft entering runway safety area in front of an aircraft landing — 45% of all runway incursions**
  – 69% of landing aircraft went around
- **Aircraft entering runway safety area in front of an aircraft taking off — 32% of all runway incursions**
  – 38% of aircraft aborted
  – 45% rotated before reaching the intersection
  – 17% rotated after reaching the intersection

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Common ATC Errors in Runway Incursions

- **Forget (about a closed runway, a clearance that they issued, an aircraft waiting to take off or cleared to land)**
- **Lack of (or inadequate) coordination between controllers**
  – Most often ground and local on a crossing
- **Misidentify aircraft**
- **Readback/Hearback errors**

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Findings from Common ATC Errors

- Most (54%) involve pilots <u>completely crossing</u> the runway in front of a takeoff or landing
- 27% involve pilots <u>entering</u> the runway (includes crossing the runway edge and lining up and waiting for takeoff)
- 19% involve pilots <u>crossing the hold-short lines</u>, but not crossing the runway edge

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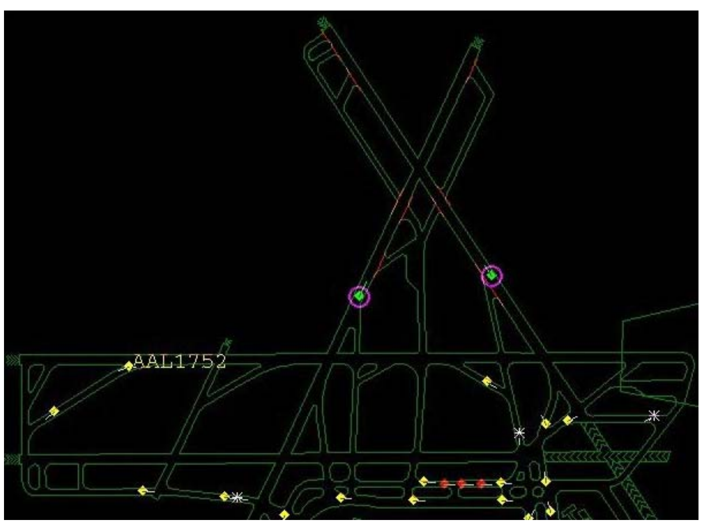
Category A Incursion – Snapshot 1



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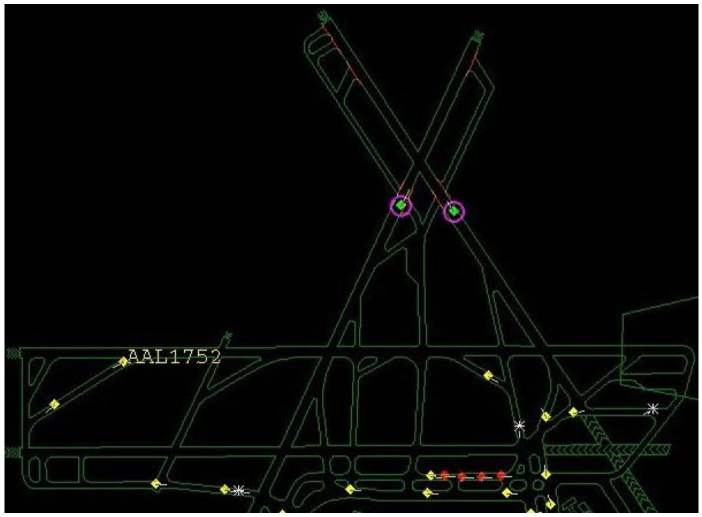
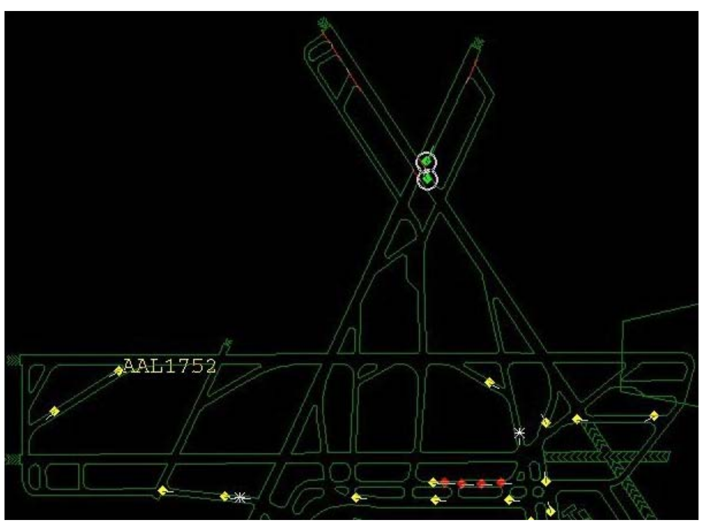
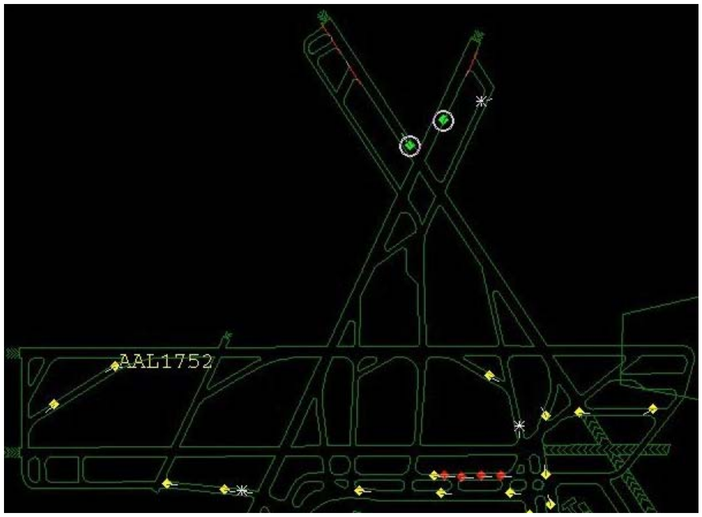
Category A Incursion – Snapshot 2



Category A Incursion – Snapshot 3



Category A Incursion – Snapshot 4



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What Controllers Can Do

- **Recognize limitations of human memory and attention (protect against)**
  - Don't clear an aircraft to "line up and wait" if you plan on it being there for more than a minute
- **Optimize teamwork**
- **Never "assume" — keep up your scan and check**
  - Recall number one pilot error follows a correct readback
- **Good communication techniques**
  - Always inform pilots of similar call signs

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Common Pilot Errors in Runway Incursions

- Most common pilot error in runway incursions is reading back the air traffic instruction (for example, to "hold short") correctly and then doing something else
- Most common reason for the error is that pilots lose track of where they are (misidentifying their location)
- Most common factor cited for losing track of location is that one pilot is "head down" programming FMC or conducting checklists

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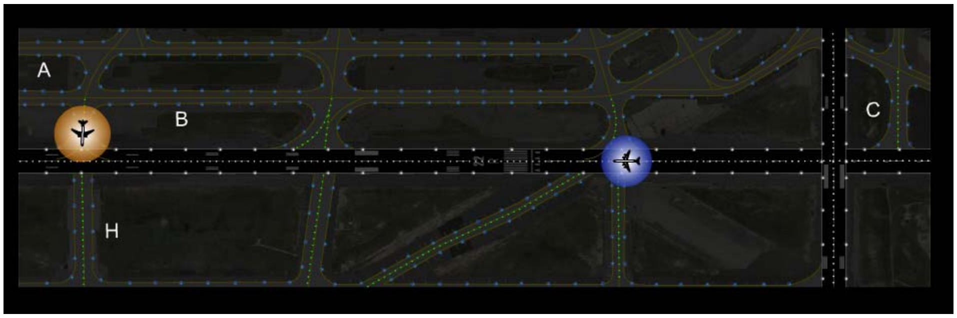
Findings from Common Pilot Errors

- 23% involve pilots completely crossing the runway in front of a takeoff or landing
- 37% involve pilots entering the runway (includes partially crossing the runway edge and lining up and waiting for takeoff)
- 40% involve pilots crossing the hold-short lines, but not crossing the runway edge

30

Category A Incursion – Snapshot 1



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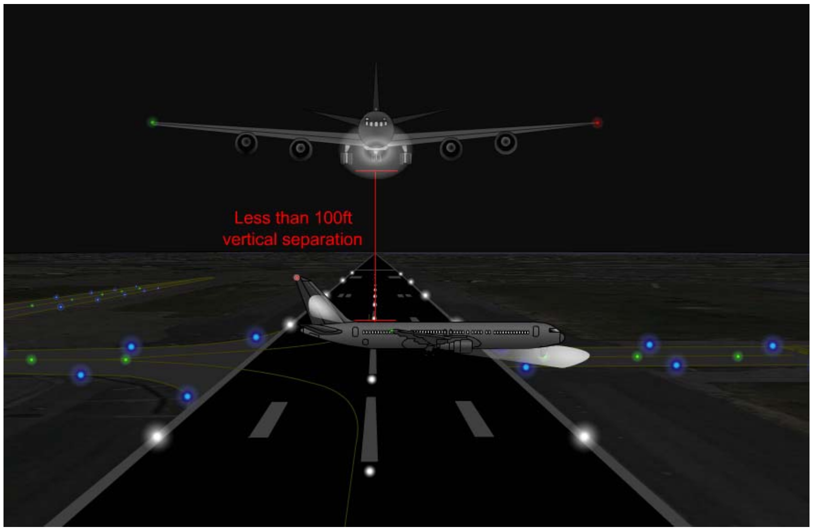
Category A Incursion – Snapshot 2

32

Category A Incursion – Snapshot 3



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What Pilots Can Do

- **Minimize "heads down" activity while taxiing**
  - Is there a runway between you and your departure runway or between you and the gate?
- **Use of airport diagrams during taxi**
- **Both pilots should listen up for clearances to land, taxi and take off, and for all clearances involving your runway**
  - Is there an aircraft on final?
  - This method worked for USAir altitude busts

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What Pilots Can Do (continued)

- Look out for conflicting traffic
- When is doubt about your position or your clearance, ask.
- (For air carriers) Turn landing lights on when takeoff clearance is received (this is a signal that aircraft is moving)

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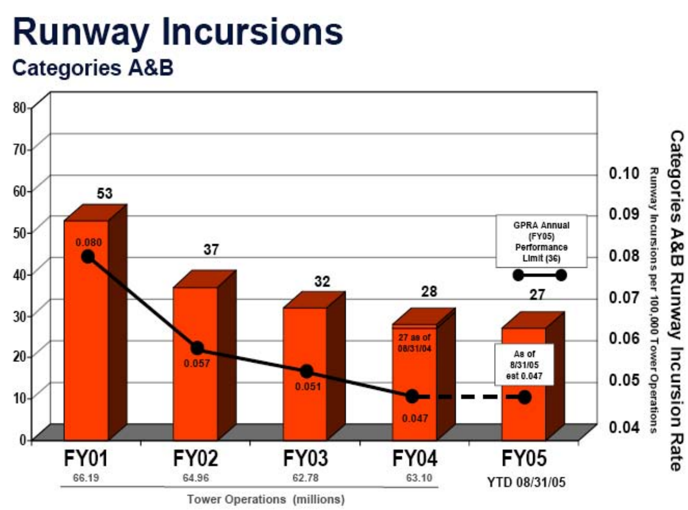
What's Working



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Additional U.S. Actions to Reduce Risk

- Advisory Circulars have been published to encourage pilots to standardize surface operations
- Enhanced markings are being implemented to alert pilots that they are approaching hold-short lines
- Awareness tools have been created for diverse audiences (pilots, controllers, drivers) such as publications, infrastructure, web sites, DVDs, evaluations (RSATs) and professional meetings

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Description of the Enhanced Taxiway Centerline:

- Dashed yellow lines are placed on both sides of the taxiway centerline
- The modified centerline will be implemented approximately 150 feet prior to the runway holding position marking (if sufficient space is available)
- The enhanced centerline may or may not be supplemented by surface painted holding-position signs

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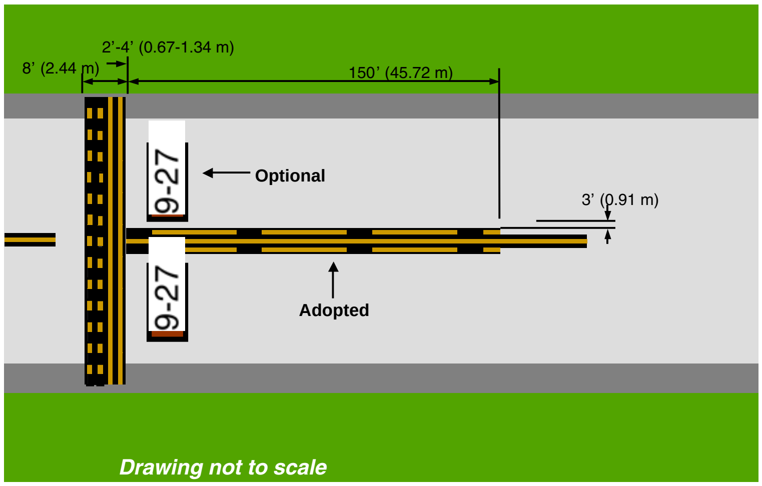
Enhanced Taxiway Centerline



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FAA Runway Safety Web Site

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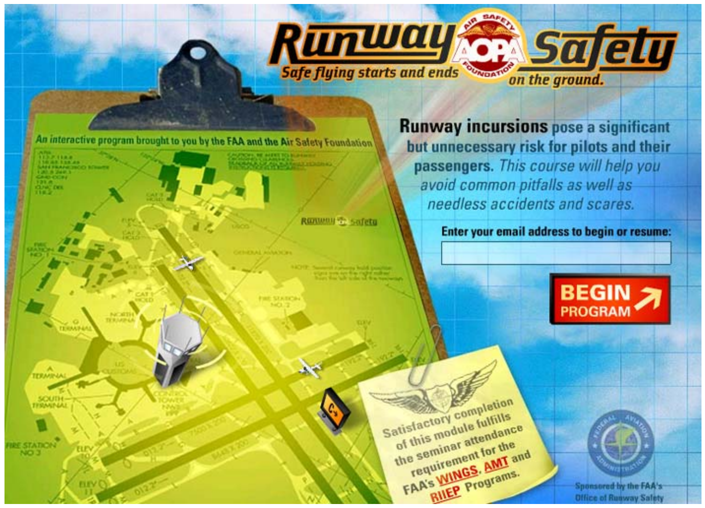
AOPA Runway Safety Course



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New ALPA Runway Safety Course

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Let’s Work Together

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www.ato.faa.gov

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Helicopter Controlled Flight Into Terrain (CFIT) Accidents: When and Where

Yasuo Ishihara
Honeywell International

1 Introduction

The number of Controlled Flight Into Terrain/Obstacle/Water (CFIT) accidents during Part 135 operations in the U.S. has increased in the last few years. In 2003 and 2004, there were eight helicopter accidents involving emergency medical service (EMS) helicopters which are believed to be CFIT accidents. In offshore operations, an S-76 went down in the Gulf of Mexico in early 2004, which is also believed to be a CFIT accident. Some helicopter operators and helicopter safety committee members are considering night vision goggles (NVGs) as a solution to prevent helicopter CFIT accidents in Part 135 operations. However, the industry needs to understand the effectiveness of NVGs in the historical helicopter CFIT accidents. Although NVGs are great tools to enhance flight safety at night, it is important to know many of the CFIT accidents occur in an environment where NVGs may not provide any help.

The Enhanced Ground Proximity Warning System (EGPWS), specifically designed for helicopters, can provide a Terrain Awareness Display and Terrain Alerting System customized for helicopter operations. EGPWS monitors conflicting terrain/water/obstacles along the flight path that may not be seen by the pilots by using a high-resolution terrain/obstacle database included in the system. The Helicopter EGPWS provides visual and aural alerts to the pilots when a conflicting terrain or obstacle is detected in front of or below the aircraft. Because the Helicopter EGPWS uses an internal terrain/obstacle database, it provides protection in all weather conditions (rain, fog, day or night).

2 Helicopter EGPWS

The helicopter EGPWS uses the present 3-D position, speed and track of the aircraft, together with a stored terrain/obstacle database, to predict a potential threat ahead of the aircraft. The system is designed to be tolerant to moderate position errors, altitude errors and/or terrain and obstacle database errors. It is important to note that the "look ahead" algorithm is independent from radio altitude based functions (known as classic GPWS functions).

2.1 Look-Ahead Algorithm

The "look ahead" algorithms have a caution envelope and a warning envelope as shown in Figure 1. The voice message "Caution Terrain (or Obstacle)" or "Warning Terrain (or Obstacle)" is given when the look-ahead Caution Envelope or Warning Envelope touches terrain or obstacles defined in the database. The Helicopter EGPWS look-ahead algorithm is designed so that no nuisance alerts are issued during normal operations, including takeoff and landing at an off-airport location.

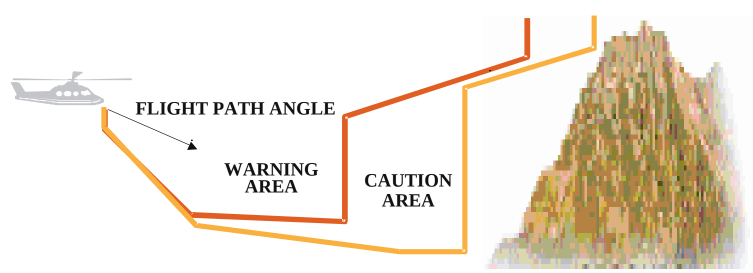

Figure 1 - Look-Ahead Envelope

The Helicopter EGPWS provides two operating modes: "normal mode" and "low altitude mode." The "low altitude mode" is suitable for day VFR operations where the aircraft is operated intentionally in close proximity to terrain. The "normal mode" provides a longer alert time than the "low altitude mode" and is recommended during other operations such as at night or in IMC. The desired mode can be selected by the pilots using a switch in the cockpit.

2.2 Terrain Awareness Display

In addition to the Look-Ahead algorithm, the Helicopter EGPWS shows surrounding terrain and obstacle information on an available display, such as an EFIS Navigation Display, Weather Radar indicator or Multi Function Display (MFD). The color definition of the terrain awareness display is explained in Figure 2.

The terrain display color is defined relative to the aircraft altitude. Pilots do not need to calculate the difference between the present aircraft altitude and the terrain/obstacle elevation to assess their relationship to the threat.

Figure 3 shows sample Terrain Awareness Displays. Two numbers at the lower right-hand corner of the display are called PEAKS numbers. The upper value represents the elevation of the highest terrain/obstacle shown on the display in 100s of feet MSL. In this example, the highest terrain/obstacle elevation is 4,400 feet. The lower value indicates the elevation between black and low density green in 100s of feet MSL.

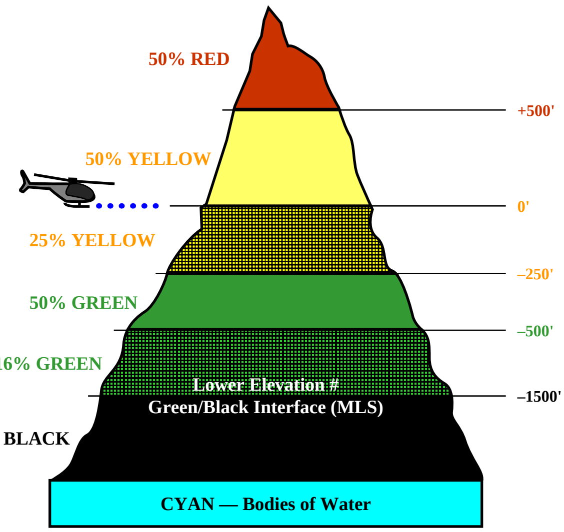

Figure 2 – Terrain Display Color Definition

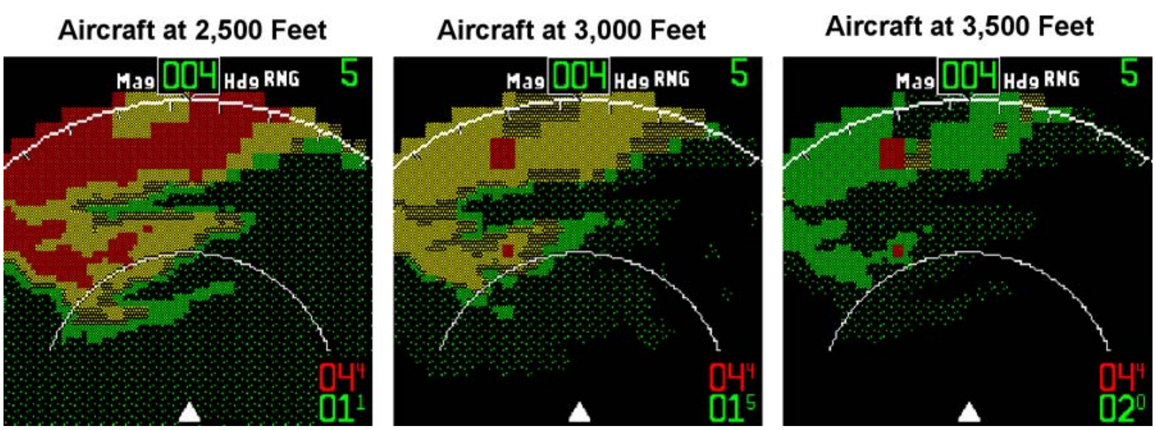

Figure 3 - Sample Terrain Awareness Display

When the terrain threat is within the "Caution Terrain/Obstacle" range, the conflicting terrain/obstacle on the display turns solid yellow. When the terrain threat reaches the warning level ("Warning Terrain/Obstacle"), the conflicting terrain/obstacle is painted in solid red.

Figure 4 (page 201) shows the terrain awareness display on a navigation display installed in an S-76B cockpit.

2.3 Geometric Altitude

Geometric Altitude is the best composite aircraft altitude derived from barometric altitude, temperature (SAT), runway elevation, corrected barometric altitude, radio altitude, terrain elevation and GPS altitude. Geometric Altitude is designed to help ensure optimal operation of the EGPWS Terrain Awareness and Display functions through all phases of flight and atmospheric conditions. Geometric Altitude reduces or eliminates errors potentially induced in Corrected Barometric Altitude by non-standard temperature, non-standard altitude conditions, altimeter miss-sets and altimeter setting standards/procedures (such as QFE).

Figure 4 - Terrain Awareness Display (S-76B)

With the Geometric Altitude function, EGPWS can operate reliably throughout extreme local pressure or temperature variations from standard, is not susceptible to altimeter miss-sets by the flight crew and will not require any custom inputs or special procedures by the flight crew when operating in a QFE environment.

An overview of Geometric Altitude function is shown in Figure 5.

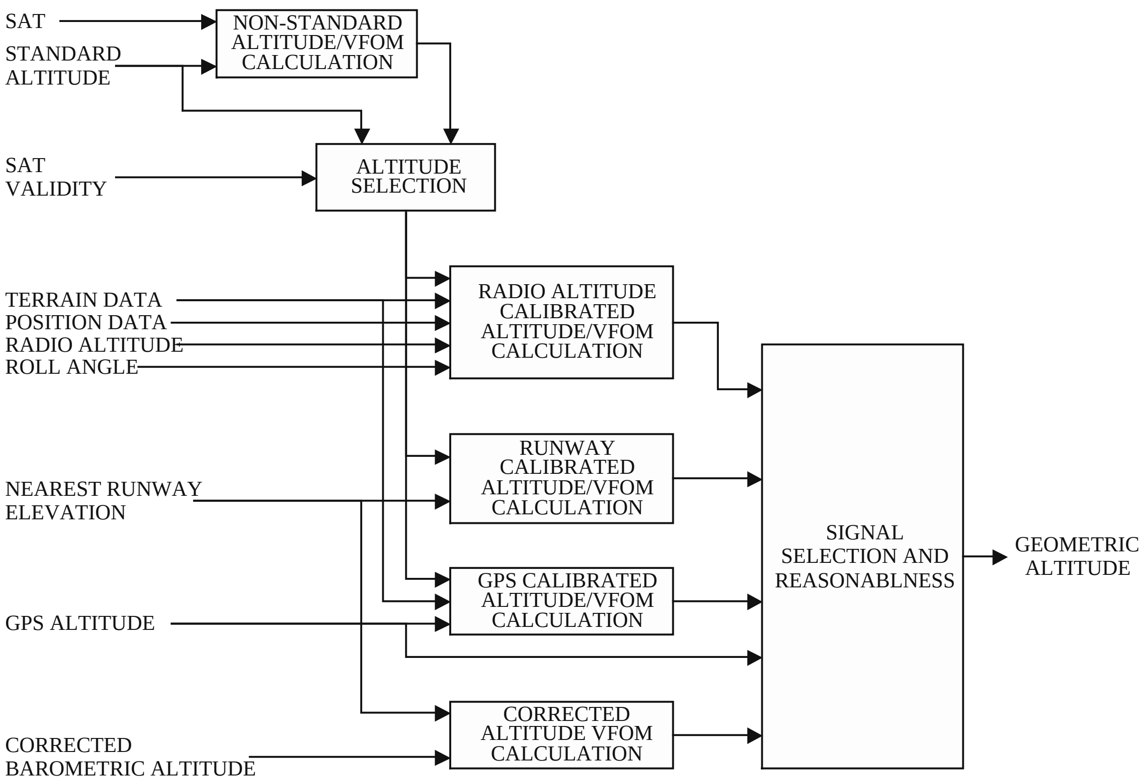

Figure 5 - Geometric Altitude

2.4 Terrain Database

The helicopter EGPWS stores the terrain database in a non-volatile memory. The database is divided into 11 regions of the world. The terrain database is compiled by Honeywell using the best available terrain data for each area. The terrain data is stored in the non-volatile memory at 6 arc-second resolution. The terrain data in helicopter EGPWS is registered in WGS-84 datum and the elevation is referenced to Mean Sea Level (MSL). As Figure 1 shows, the Look-Ahead envelope monitors threats below and ahead of the aircraft. Therefore, the Look-Ahead algorithm is not affected by the effect of ocean tide and waves.

2.5 Other EGPWS Modes

The helicopter EGPWS has additional modes that are independent from the Terrain Awareness function (Figure 6). Most of those modes use a radio altitude instead of Geometric Altitude. All modes are designed and configured specifically for helicopter operations.

The basic modes are:

- Mode 1 – Excessive descent rate
- Mode 2 – Excessive terrain closure rate
- Mode 3 – Descent after takeoff
- Mode 4 – Unsafe terrain clearance
- Mode 5 – Descent below glideslope
- Mode 6 – Advisories (Excessive bank angle, Radio altitude callout, Tail-strike, etc.)

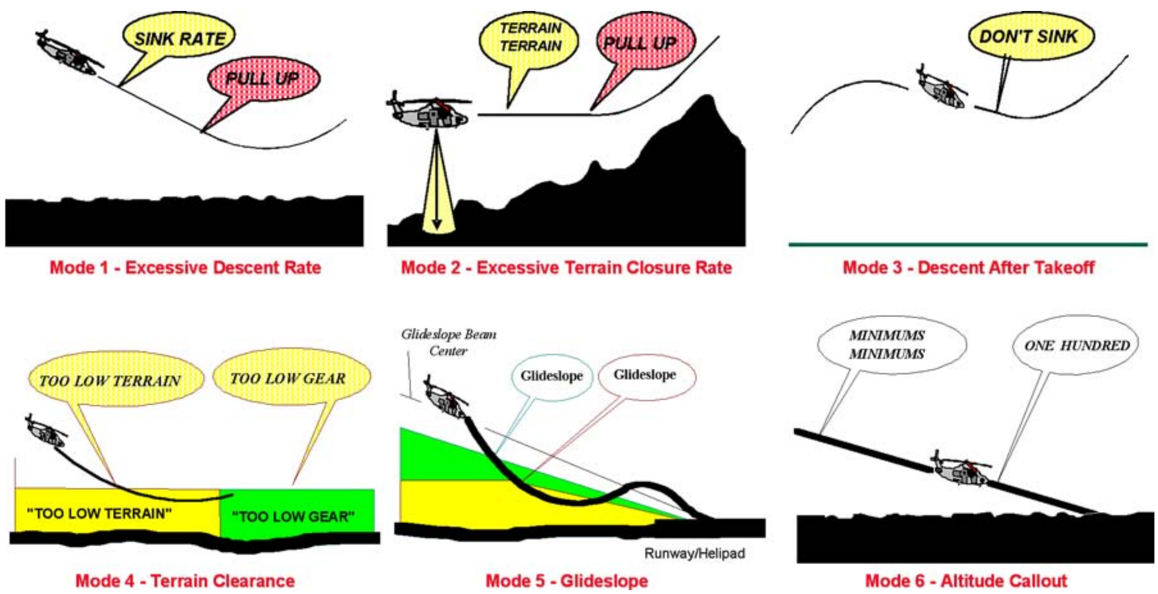

Figure 6 – Other Basic Modes

3 Helicopter CFIT Accidents

Controlled Flight Into Terrain (CFIT) is a type of accident in which a perfectly working aircraft is flown inadvertently into the ground, man-made obstacles or water. For the purpose of this study, wire strike accidents are excluded.

Based on NTSB preliminary accident reports, between 1992 and 2004, there were 66 turbine-powered helicopter accidents which can be classified as CFIT accidents involving Part 91 and 135 operators in the U.S., and 124 lives were lost in the accidents. Some of the helicopter CFIT accidents are shown in Table 1 (page 203).

DATE	LOCATION	MODEL	FATALITIES	Op	Op Type
04/22/94	Bluefield, VA	Bell 412SP	4	91	EMS
09/11/95	Winslow, WA	Agusta A109A	3	91	EMS
12/12/96	Penn Yan, NY	BO-105	3	135	EMS
06/25/98	Mt. Waialeale, HI	AS-350BA	6	135	Tour
06/09/99	Juneau, AK	AS-350BA	7	135	Tour
04/25/00	St. Petersburg, FL	BK117-A3	3	91	EMS
07/21/00	Kahului, HI	AS-355	7	135	Tour
03/23/03	Gulf of Mexico	Sikorsky S-76A	10	135	Offshore
08/21/04	Battle Mountain, NV	Bell 407	5	135	EMS

Table 1 – Some U.S. Turbine Helicopter CFIT Accidents

Figure 7 shows the number of helicopter CFIT accidents between 1992 and 2004.

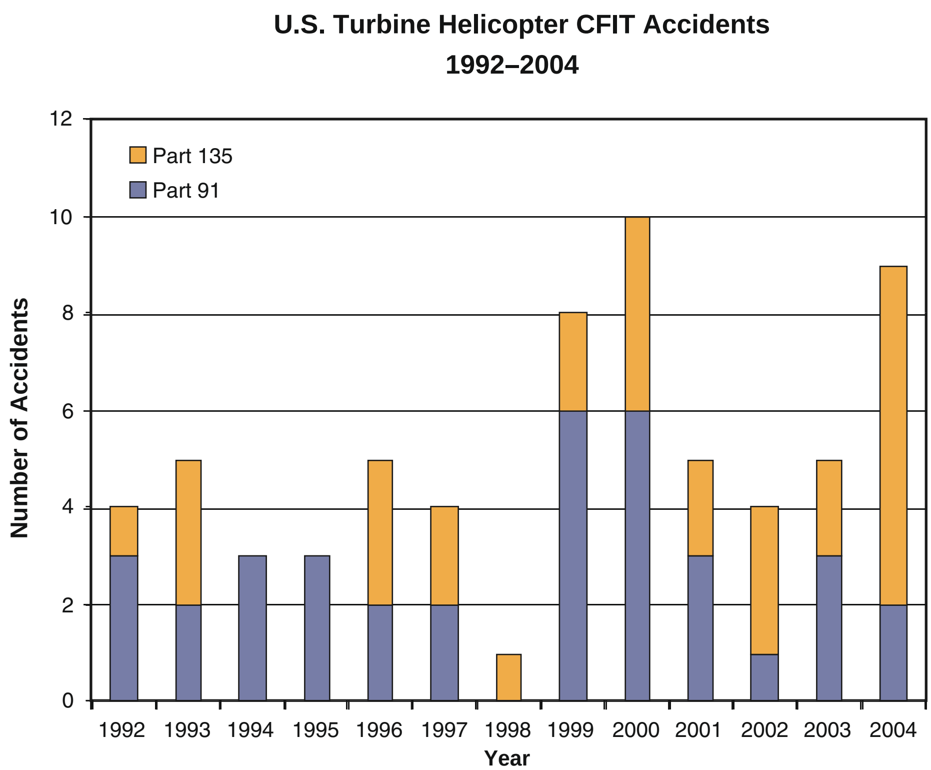

Figure 7 – Number of U.S. Turbine Helicopter CFIT Accidents (1992–2004)

52 percent of the overall helicopter CFIT accidents happened during daytime, and 61 percent of the CFIT accidents happened in VMC condition as shown in Figure 8 (page 204).

In significant contrast, when only the EMS helicopter CFIT accidents are reviewed, 84 percent of the accidents occurred during nighttime Part 91/135 operations during the same 12-year period as shown in Figure 9 (page 204), although only about 38 percent of all helicopter EMS flights are conducted at night, according to the Air Medical Physician Association (AMPA).

In all helicopter operations, approximately 40 percent of the CFIT accidents occurred in IMC.

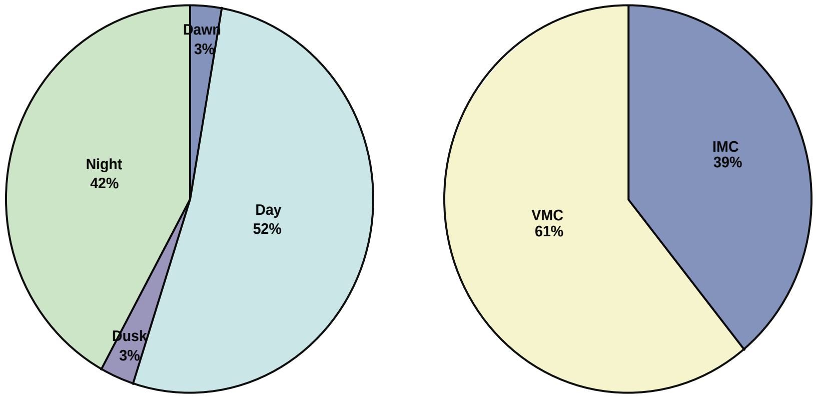

Figure 8 - Time of Day and Meteorological Condition (All U.S. Turbine Helicopters)

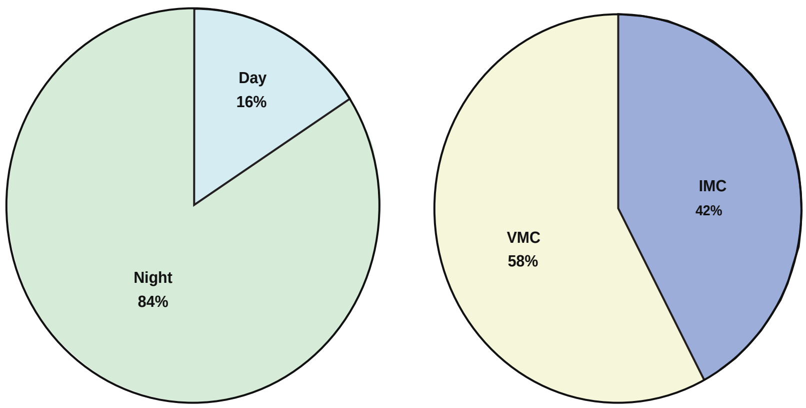

Figure 9 - Time of Day and Meteorological Condition (U.S. EMS Helicopters)

The EMS and offshore industries, as well as NTSB, are currently studying the effectiveness of helicopter Enhanced Ground Proximity Warning System (EGPWS) or commonly known as Helicopter Terrain Awareness and Warning System (Helicopter TAWS) as a tool to enhance flight safety. In fact, there are some proactive operators who are already operating with a helicopter EGPWS. Some positive outcomes have been reported by these EGPWS equipped operators.

As pointed out in many accident statistics, the majority of the helicopter CFIT accidents occur during cruise phase (Figure 10).

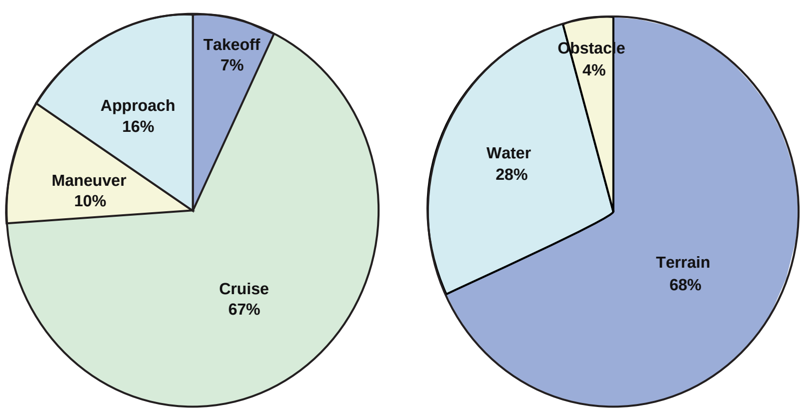

Figure 10 - Phase of Flight and Threat Type (All U.S. Turbine Helicopters)

4 Effectivity Analysis of Helicopter EGPWS

Some of the helicopter accidents were analyzed to study how effective the Helicopter EGPWS could have been. The accident scenario was created primarily from the information available in the accident report published by the accident investigation Bureaus.

Results of four accidents are provided below covering the following scenarios:

- Night, VMC, Flown into Mountain
- Night, VMC, Flew into Ocean
- Day, VFC, Flew into Man-made Obstacle
- Day, IMC, Flew into Mountain

4.1 Accident 1 - Flight Into Mountain at Night, VMC

On August 21, 2004, about 11:50 p.m. PST, a Bell 407 helicopter, operating as an air ambulance flight, impacted mountainous terrain in cruise flight and was destroyed near Battle Mountain, Nevada. All five persons on board were killed. According to preliminary information, the helicopter crashed shortly after picking up an infant patient and the infant's mother for a flight to a Reno hospital. Dark night, visual meteorological conditions prevailed. The accident site was along the direct course line from Battle Mountain Hospital to Derby Field Airport in Lovelock. The helicopter impacted rugged mountainous terrain on the eastern slope of the Tobin Range in Pershing County at a Global Positioning System (GPS) location of 40 degrees 27.147 minutes North, 117 degrees 29.517 minutes West, and an elevation of 8,644 feet. The debris path was along a magnetic bearing of 230 degrees. Evidence of a high-speed impact and a fire has been reported. The flight was being operated as a commercial 14 CFR Part 135.

The simulated aircraft track is plotted on a sectional map in Figure 11. The profile plot in Figure 12 shows the simulated aircraft altitude in blue and the profile of the mountain in brown.

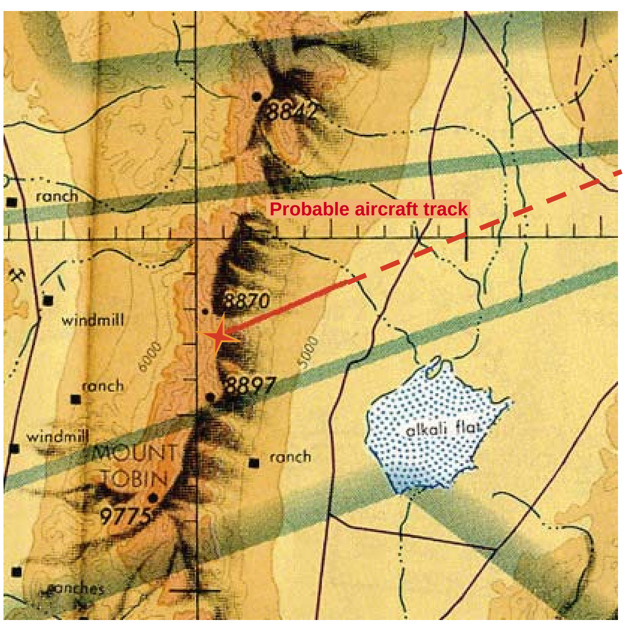

Figure 11 - Probable Accident Aircraft Track

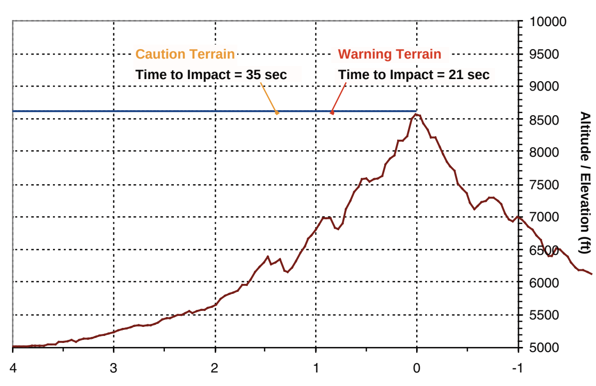

Figure 12 - Probable Accident Profile

The pilot would have seen a terrain picture shown in Figure 13 approximately 90 seconds prior to impact if EGPWS was installed. The terrain display clearly shows a terrain conflict ahead of the aircraft in yellow, indicating the terrain is at or above the aircraft's present altitude. The upper PEAKS number indicates the maximum terrain elevation in the area is 9,700 feet.

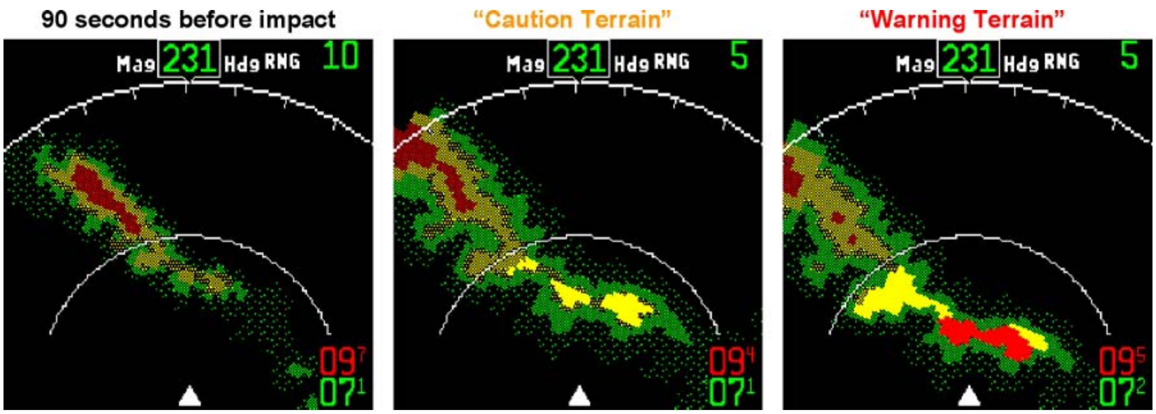

Figure 13 – Terrain Awareness Display (Accident 1)

35 seconds from impact, EGPWS would have given the first aural alert "Caution Terrain". The conflicting terrain detected by the EGPWS look-ahead algorithms are now depicted in solid yellow as shown in Figure 13. Also note that the display range is automatically set to 5 NM.

An aural warning "Warning Terrain" would have been given approximately 21 seconds from impact. The conflicting terrain detected by the EGPWS look-ahead warning algorithms are now depicted in solid red as shown in Figure 13.

Although the EGPWS terrain display cannot be used for navigation, the display provides pilots a much higher level of situational awareness.

It should be clear from information depicted on the terrain display shown in Figure 13 that there is conflicting terrain three miles ahead of the aircraft. This information is available long before EGPWS gives the aural alerts and warnings.

4.2 Accident 2 - Flight Into Ocean at Night, VMC

On March 23, 2004, at about 1918 Central Standard Time, a Sikorsky S-76A helicopter crashed about 30 minutes after takeoff from Galveston International–Scholes Airport, Galveston, Texas. The 2 crewmembers and 8 passengers on-board were killed. The helicopter was destroyed due to impact forces with the water. No emergency or distress calls from the aircraft were reported before the accident. The wreckage was located about 70 miles southeast of the departure airport. The flight was being operated as a commercial 14 CFR Part 135.

The probable accident scenario in Figure 14 (page 207) was simulated using a helicopter EGPWS. The simulation result is described below. This aircraft most likely impacted the ocean with very small vertical speed, something like 150 feet per minute. Although many people think EGPWS is designed only for flight into a "mountain," the fact is that EGPWS can provide good protection from an inadvertent descent over flat terrain/water accident scenario. As described in a previous section, EGPWS, not only looks ahead of the aircraft, it also looks below the aircraft for safe terrain clearance appropriate for a given phase of flight. When the aircraft descends below the safe terrain clearance, EGPWS will issue a "Caution Terrain" alert. If the descent continues, the message changes to a "Warning Terrain" warning. EGPWS can also provide an "Altitude Callout" (Mode 6). It can be configured so that EGPWS gives an aural message "Altitude Altitude" as the aircraft descend through a certain radio altitude threshold set by a bug on the radio altimeter.

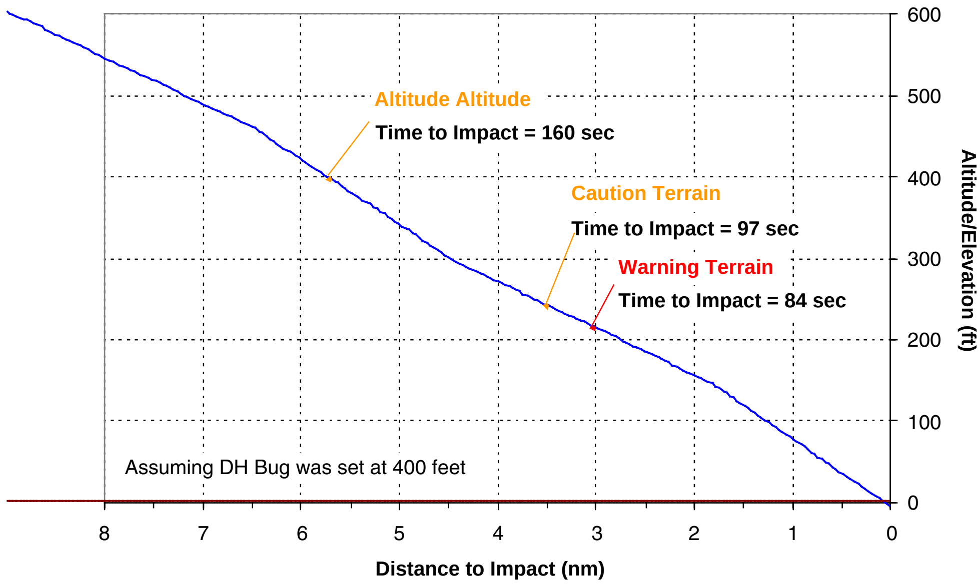

Figure 14 - Probable Accident Profile

Assuming a shallow rate of descent of 150 feet per minute and that the DH bug was set at 400 feet, the EGPWS simulation result shows that an "Altitude Altitude" advisory callout would have been given 160 seconds prior to impact. A "Caution Terrain" alert would have been given at approximately 240 feet, 97 seconds before impact. At approximately 200 feet, 84 seconds prior to impact, the alert would have switched to "Warning Terrain" warning.

4.3 Accident 3 - Flight Into Obstacle in Day VMC

On April 25, 2000, at 1216 eastern daylight time, an Eurocopter BK117 collided with a radio transmission tower located on the Weedon Island State Preserve in St. Petersburg, Florida. The air medical flight was operated under the provisions of Title 14 CFR Part 91 positioning flight with no flight plan filed. Visual weather conditions prevailed at the time of the accident. The medical evacuation helicopter was destroyed; the commercial pilot and his passengers were fatally injured. The local flight departed Bayfront Medical Center, in St. Petersburg, Florida, at 1212, and was en route to the Bayflite operations at St. Joseph Hospital in Tampa, Florida.

According to the operator, the crew had completed a patient drop-off and was en route to the Bayflite operation in Tampa, Florida. The operator also stated that the flight was flying a newly established route from the Bayfront Medical Center to St. Joseph Hospital. The new routing was in response to noise complaints from neighborhoods along the previously direct route. According to an eyewitness, the helicopter was flying northeast at about 500 feet above the ground. As the eyewitness approached the radio transmission tower in the preserves, he noticed the helicopter as it collided with the radio transmission tower guy wire and the steel tower structure 480 feet above the ground. The helicopter continued several hundred feet northeast and crashed into a mangrove.

The pilot would have seen the terrain picture shown in Figure 15 (page 208) approximately 60 seconds prior to impact if EGPWS was installed. The terrain display clearly shows a conflict ahead of the aircraft in yellow, indicating the obstacle is at or above the aircraft's present altitude (Depicted in high density yellow.)

34 seconds from impact, EGPWS would have given the first aural alert "Caution Obstacle." The conflicting obstacle detected by the EGPWS look-ahead algorithms are now depicted in solid yellow as shown in Figure 15.

An aural warning, "Warning Obstacle," would have been given approximately 21 seconds from impact. The conflicting terrain detected by the EGPWS look-ahead warning algorithms are now depicted in solid red as shown in Figure 15.

Figure 15 – Terrain Awareness Display (Accident 3)

The EGPWS alert would have been a good "attention getter" for the crew to be able to look out the window and identify the threat visually, and execute a recovery maneuver in timely manner.

4.4 Accident 4 - Flight Into Mountain in Day IMC

On April 21, 1999, about 1030 local time, a Kawasaki BK-117B-1 helicopter impacted mountainous terrain during cruise flight approximately 5 kilometers south-southeast of the city of Keelung, Taiwan, China. The non-scheduled positioning flight was operating under the civil aviation rules of the ROC. Aboard the helicopter were the captain, first officer and a company maintenance engineer. A VFR flight plan was filed for the flight that departed Sungshan Airport in Taipei at 1017 with an intended destination of Fengnien Airport in Taitung. Visual meteorological conditions prevailed for the takeoff from Taipei, and instrument meteorological conditions prevailed at the accident site. The helicopter was destroyed by impact forces and fire, and the three occupants were fatally injured.

The simulated aircraft track is plotted on a sectional map in Figure 16.

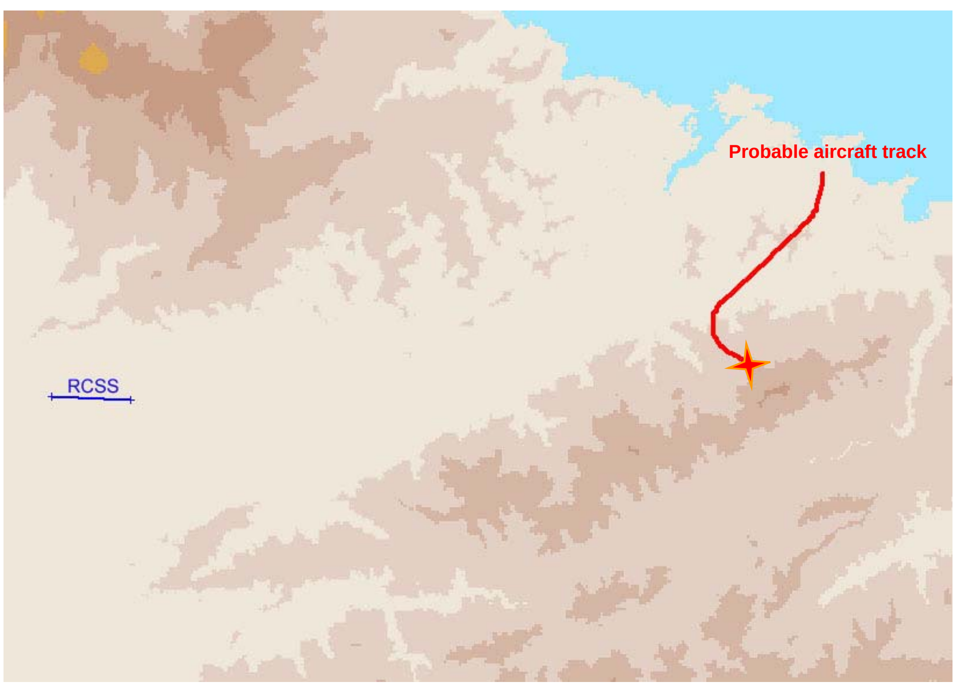

Figure 16 - Probable Accident Aircraft Track

The pilot would have seen a terrain picture shown in Figure 17 approximately 50 seconds prior to impact (right before the final left turn was made) if EGPWS was installed. The terrain display clearly shows a terrain conflict to the left of the aircraft in yellow and red, indicating the terrain is at or above the aircraft's present altitude.

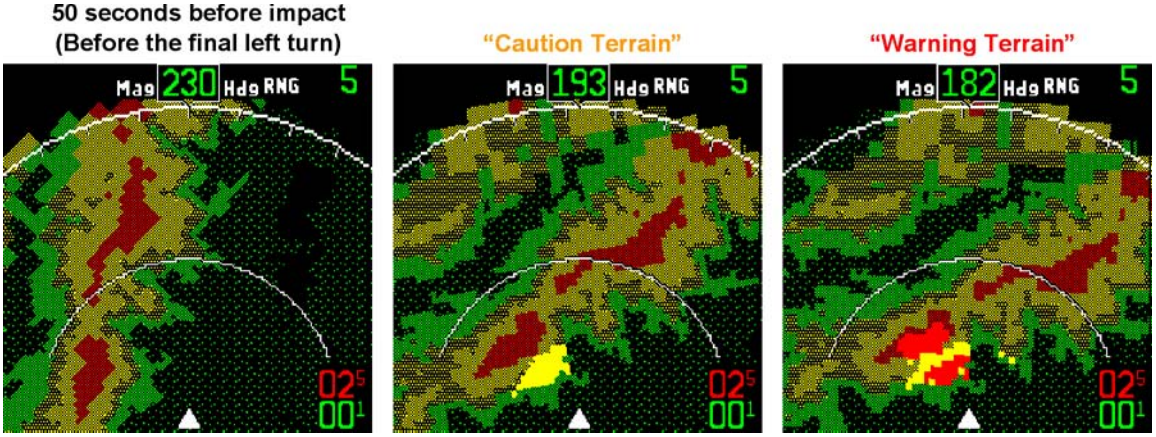

Figure 17 – Terrain Awareness Display (Accident 4)

42 seconds from impact, EGPWS would have given the first aural alert, "Caution Terrain". The conflicting terrain detected by the EGPWS look-ahead algorithms are now depicted in solid yellow as shown in Figure 17.

An aural warning "Warning Terrain" would have been given approximately 40 seconds from impact. The conflicting terrain detected by the EGPWS look-ahead warning algorithms are now depicted in solid red as shown in Figure 17.

Although the EGPWS terrain display cannot be used for navigation, the display can provide pilots a much higher level of situational awareness. It should be clear from information depicted on the terrain display shown in Figure 17 that there is conflicting terrain to the left of the aircraft before the final left turn was made. This information is available a long time before EGPWS gives the aural alerts and warnings.

5 Conclusions and Recommendations

Based on the helicopter accident analysis, Controlled Flight Into Terrain accidents can occur during day and night, in VMC and IMC, regardless of the pilots' experience levels. Although it is not intuitive, CFIT accidents do happen during day VFR flight. It is also important to realize that a CFIT accident does not happen only in mountainous environment. CFIT risks even exist over flat terrain or water, especially at night or in poor weather.

The EGPWS Terrain Awareness Display provides a high level of situational awareness to helicopter pilots in day or night, and in VMC or IMC. Many CFIT accident situations can be avoided long before the "Look Ahead" algorithms detect a threat and issue aural alerts by simply "seeing" terrain on the display. In accident situations over flat terrain or water, EGPWS provides "radio altitude callout" in addition to aural alert and warning when a helicopter descends below safe altitude. The EGPWS can help in significantly reducing the CFIT risk. However, proper pilot training on CFIT risk awareness is equally important to reduce the CFIT risk.

It is also important to know that the Helicopter EGPWS presented above is designed specifically for helicopter operations. All "modes," "Look-Ahead" algorithm and terrain/obstacle database are tailored for helicopter operation. EGPWS/TAWS designed for fixed-wing airplane operations should not be used in helicopters as it will give an excessive number of nuisance alerts by their system design.♦

6 Reference

Don Bateman, “The Introduction of Enhanced Ground-proximity Warning Systems (EGPWS) Into Civil Aviation Operations Around the World,” paper presented at 11th annual European Aviation Safety Seminar (FSF), Amsterdam, March 8-10, 1999.

Ira J. Blumen, M.D., “A Safety Review and Risk Assessment in Air Medical Transport,” Air Medical Physician Association, November 2002.

National Transportation Safety Board, NTSB Preliminary Accident Report: NTSB Identification SEA04MA167.

National Transportation Safety Board, NTSB Preliminary Accident Report: NTSB Identification DCA04MA030.

National Transportation Safety Board, NTSB Preliminary Accident Report: NTSB Identification ATL00FA048.

National Transportation Safety Board, NTSB Preliminary Accident Report: NTSB Identification FTW99RA122.

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Outsourcing Component Support: The Component Solution Provider's Input to Improving Flight Safety

Mike Humphreys
SR Technics UK

Overview

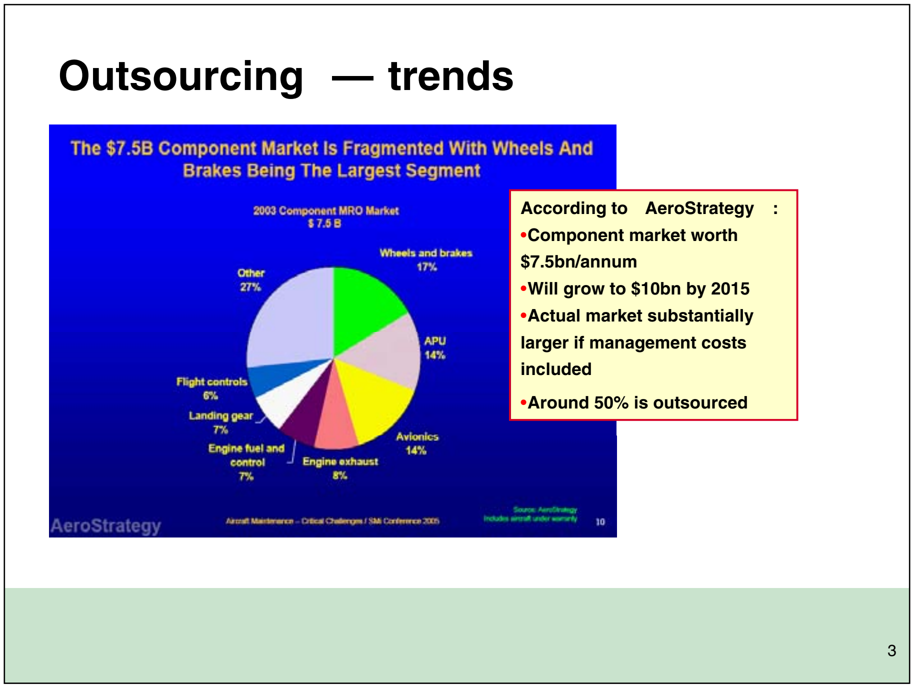
_ Outsourcing — The future ?
_ The business drivers
_ Regulatory requirements
_ Managing for safety
_ Safety factors to consider when outsourcing
_ Conclusions

2

In recent years there has been a dramatic increase in the trend for airlines to outsouce their component support requirements to third party suppliers. While there is no standard business model for such arrangements, a number of suppliers now offer a total care package including the purchase of an airline's rotable components, access to their rotable inventory, provisioning of component stocks of the airline's operating bases, managed logistics and repair cycle processes.

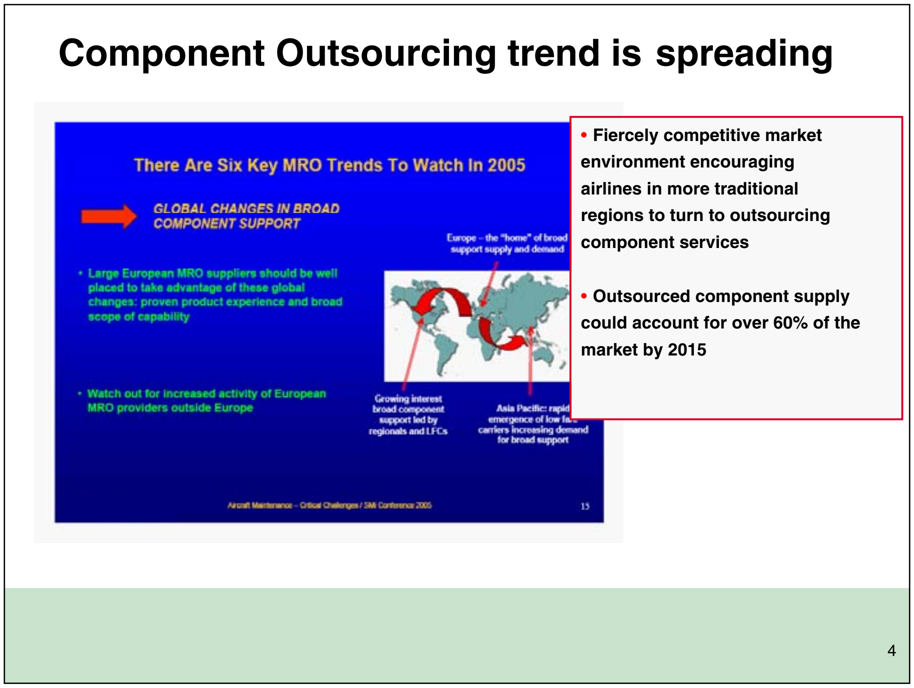
This trend in outsourcing has been driven by the significant cash and operational benefits seen by the airlines. However, how does outsourcing these key elements of an airline's technical operations need to be managed to ensure continued and improving airworthiness? What are the features that need to be considered when outsourcing component support from a safety persepective, and what regulations govern this type of arrangement?

I will attempt to address these questions by first looking at the drive for outsourcing and what's behind it, assess the current requirements governing this type operation and try to give some steers for the future.



Why is the understanding of the current market in component repair and overhaul important for flight safety? There are two real reasons. First, the size of the activity globally and second, the rapid growth in the outsourcing of not only component repair but the outsourcing of the entire component supply chain.

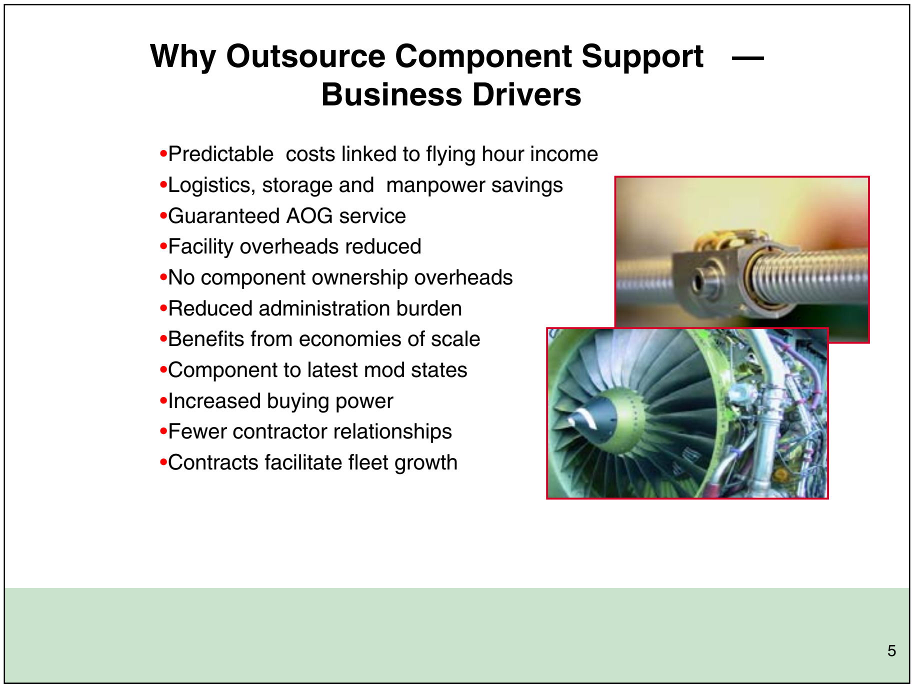
Let's first look at the size of the market. Currently, according to AeroStrategy, an independent aviation consultancy, the component market is valued at $7.5 billion per annum, which with expected growth will reach $10 billion by 2015. Of this activity AeroStrategy estimates that 50 percent is outsourced. This outsourcing is made up of a combination of traditional component repair activity to OEMs, airline shops and independents. There are already strong regulatory controls on the accomplishment of this activity through EASA and FAA 145 approvals. Increasingly, however, airlines are not simply outsourcing the repair activity but also the total supply chain relating to component support, including provisioning, access to pooled stocks, logistics, warehousing and repair cycle management. The regulatory regime governing this activity is less straightforward.



Again, independent consultants AeroStrategy indicate that the trend to exploiting outsourcing solutions is increasing and that this business model will migrate from its traditional "home" in Western Europe to other parts of the world.

Airlines are facing an ever more competitive environment. The growth of low cost carriers, increasing fuel costs, etc., have forced the traditionally structured airlines to review their business models. For reasons that I will address shortly, the whole business of outsourcing the component supply chain has increasing attractiveness in this competitive and changing environment.

The challenge for the industry is to ensure this growth is properly regulated and all the participants in this emerging global business model address fundamental issues of continuing airworthiness standards and improving flight safety.



Low cost airlines have consistently recognized the benefits of outsourcing maintenance, and particularly component support, preferring to concentrate their management time and resources on their core business — flying passengers. The benefits that this brings will vary from airline to airline according to their specific business environment and extent of the outsourced services.

Service improvements and savings can be made in all the following areas:

Predictable costs linked to flying hour income

Logistics, storage and manpower savings

Guaranteed AOG service

Facility overheads reduced

No component ownership overheads

Reduced administration burden

Benefits from economies of scale

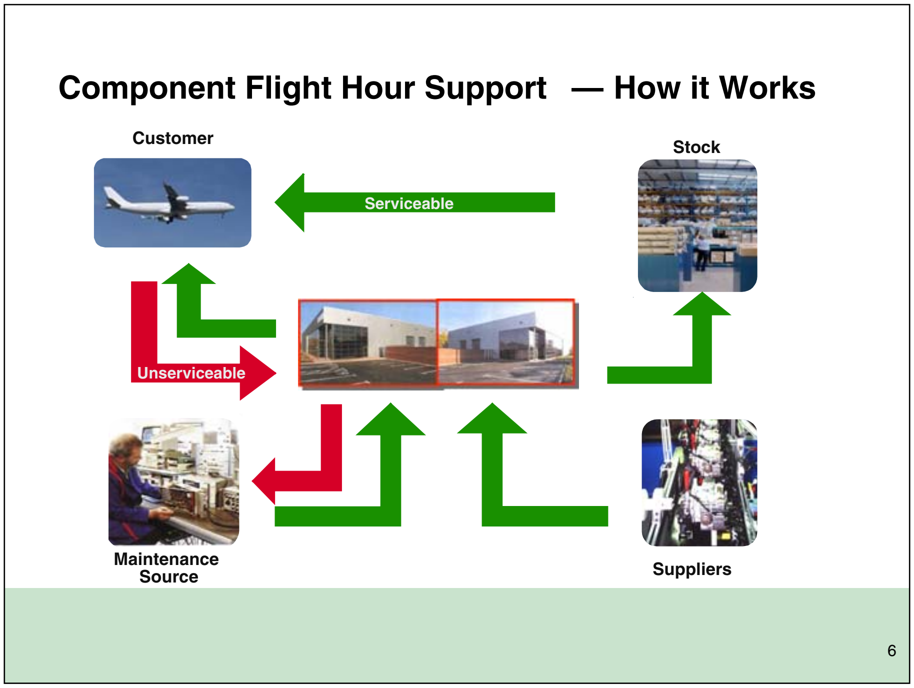
Component to latest mod states

Increased buying power

Fewer contractor relationships

Contracts facilitate growth — economies of scale

Savings of up to 25 percent over the traditional in-house component support business model can be made.



So how does an outsourced component supply chain work and what are the steps in the process that need attention from an airworthiness perspective?

The purpose of the process is the delivery of approved serviceable components to the operator of the aircraft. This can come from primarily two sources:

1. Typically flight safety components (no-go/go-if) are located close to the operator's hub of operations in a "consignment stock." Clearly these stocks have to be held in a suitable location and have to be regularly audited to ensure they are within shelf life and properly documented.

2. The second primary source will be from the supply chain provider's "pool" of rotables which are usually located at a suitable central location which can ensure speed of delivery and predictability of cost.

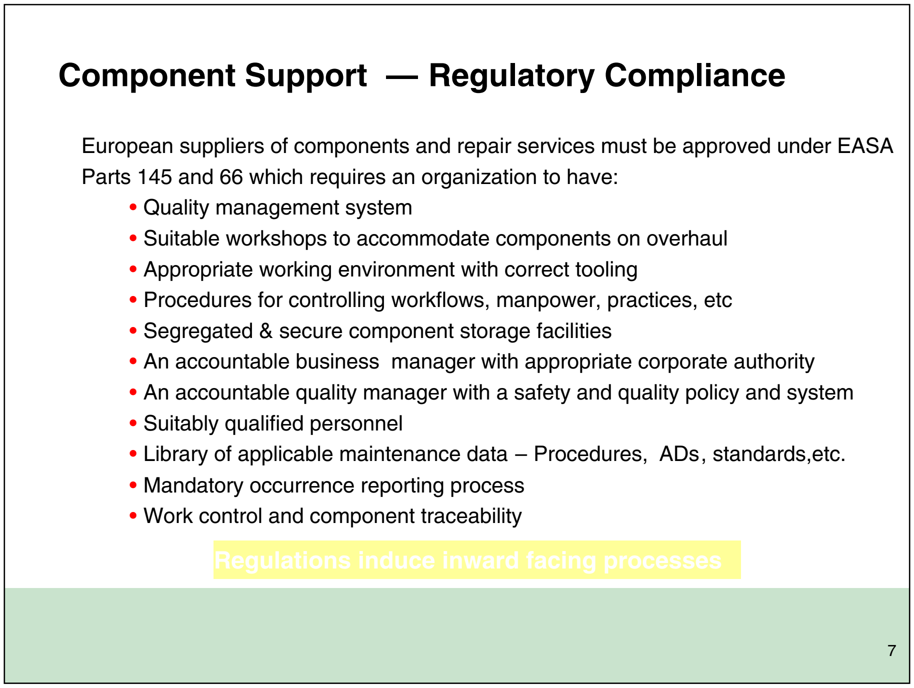
Replenishment of the operator's consignment stocks will also be provided from the supplier's pool of rotables.

Unserviceable components, once removed, are returned to the supplier and then sent to an approved maintenance supplier, either internal workshops or external vendors. The repair cycle is managed and serviceable components returned to the pool for future use.

The final part of the supply chain is the procurement of new or used rotable components to add to the system to ensure delivery to the customer.

Bonding all of this together is a logistics and transportation system which has to work 24/7 to deliver the right parts at the right time with the right standards.

As you can imagine this process demands constant focus on systematic quality management. One breach in the chain can have very serious consequences.



European suppliers of component and repair services must be approved under EASA Parts 145 (for all repairs) and 66 (for on-wing repairs), which require an MRO to demonstrate compliance with the following requirements:

Quality management system

Suitable workshops to accommodate components on overhaul

Appropriate working environment

Segregated and secure component storage facilities

An accountable business manager with appropriate corporate authority

An accountable quality manager with a safety and quality policy and system

Suitably qualified personnel

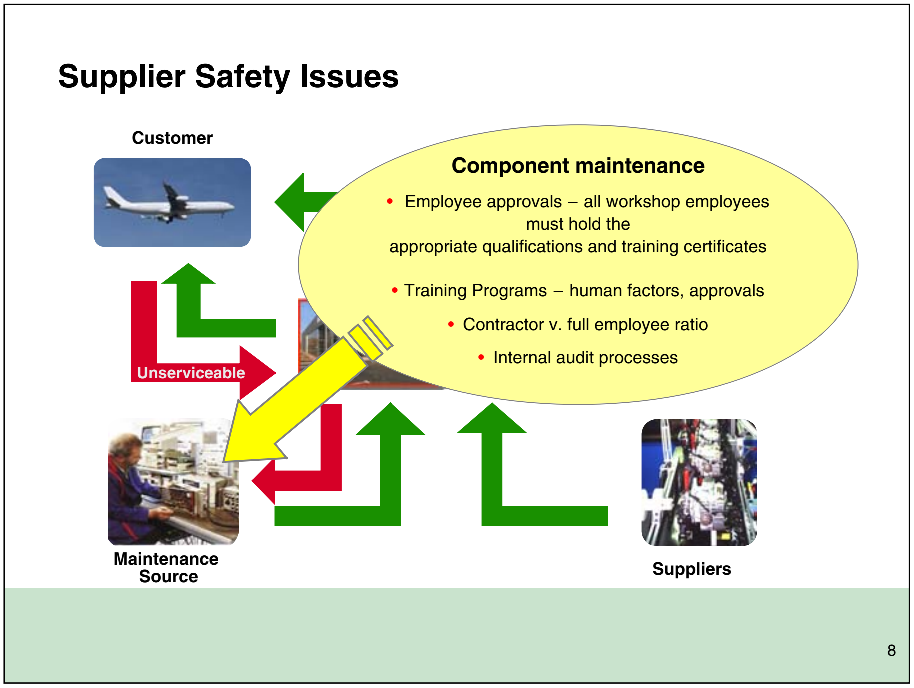
Library of applicable maintenance data — Procedures, ADs, standards, etc.

Procedures for controlling workflows, manpower, practices, etc.

Mandatory occurrence reporting process

Work control and component traceability

Each approved organization has a quality management system that will focus on ensuring that internal processes are in place to deliver outputs that meet specific criteria. These QMS are usually implemented as a means of demonstrating compliance with minimum requirements and tend to be inward facing, with a specific focus on the most recent "occurrence." Some enlightened MROs have internal safety management systems that take a holistic view of managing airworthiness risk. However, most of these tend to be inward focusing, as they are also driven by minimum "regulation" or regulator codes.

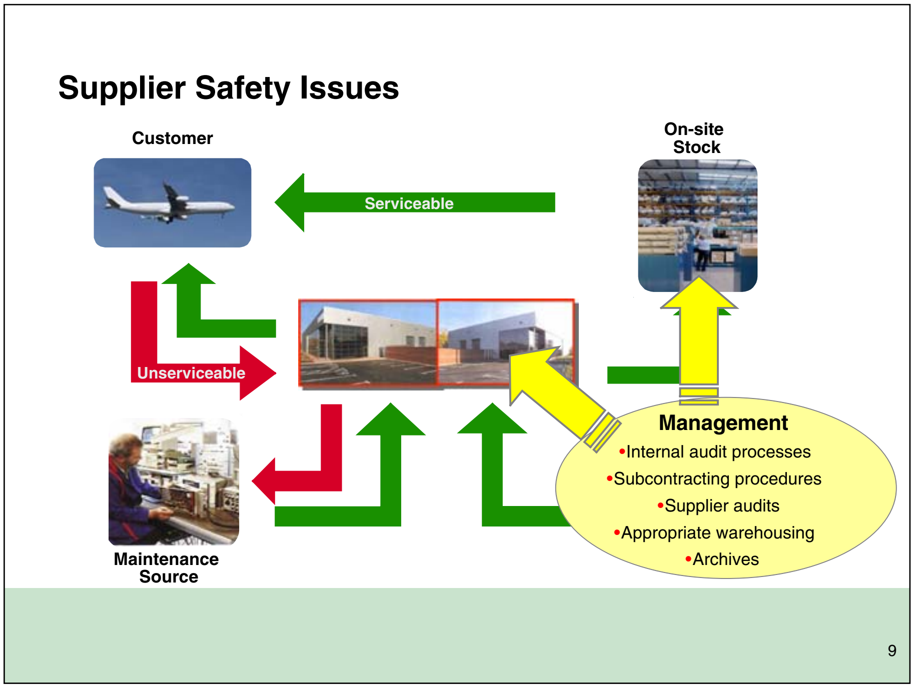


Let's now look at how and where safety issues can impact on the component supply process. At some point in the cycle, all components will be returned to the workshops for inspection and repair if necessary. This could be in the supplier's own workshops or those of a subcontractor.

The MRO must ensure that all employees hold the appropriate approvals to allow them to perform the work on that particular component, that relevant training has been received and is up to date, and that the most recent manuals are available with which to undertake the repair. Furthermore, it is essential that any equipment used has been properly calibrated and maintained.

As important is the use of the correct spares to undertake the repair. These must have been sourced from the appropriate supplier, be to the correct specification and be fit for the purpose.

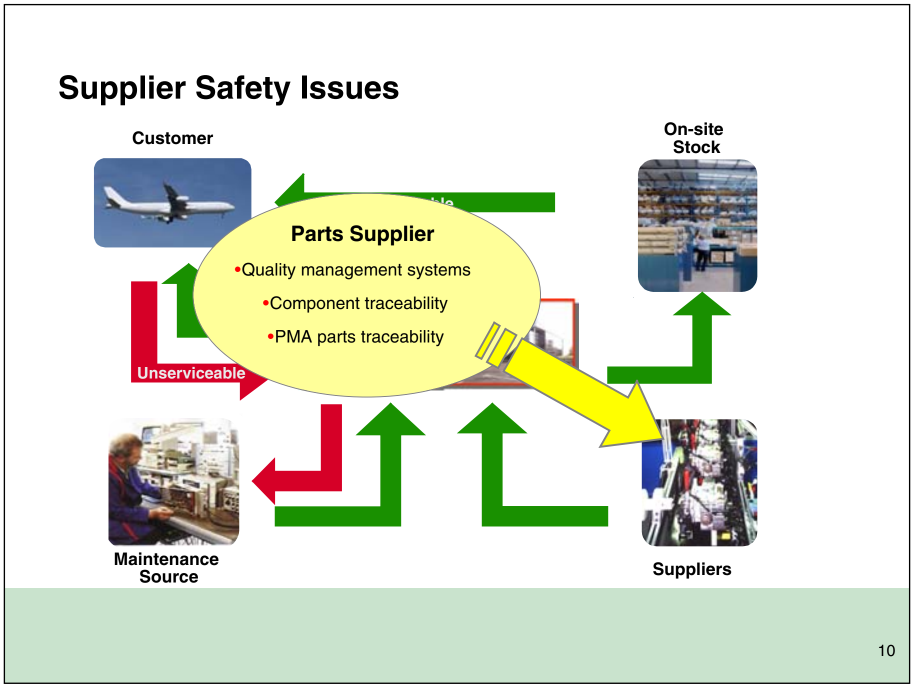
To meet these requirements it is important that the repair source has its own audit processes which are open and involve the MRO. This is of course easier to accomplish when the repair source is in house. Where it is an outsourced supply, the MRO must ensure that the selected source meets all these requirements and continues to do so.



As we have already seen, components can be held prior to use either in centrally located stores or at the airline's local sites in consignment stocks, which can be in a warehouse or close to the gate at the airport. These stocks must be held in suitably constructed buildings which are dry, heated and accessible. Appropriate racking is equally important, as are the containers in which components are stored and transported. Certain items require secure caging, access to which is restricted and controlled.

This process usually requires the use of a comprehensive and all-encompassing computer system that allows the supplier to track the location, approvals and condition of all components in the system. The authorities also require the supplier to maintain an archive system of information, tracking each component in his system so as to allow investigations should any safety issues arise.

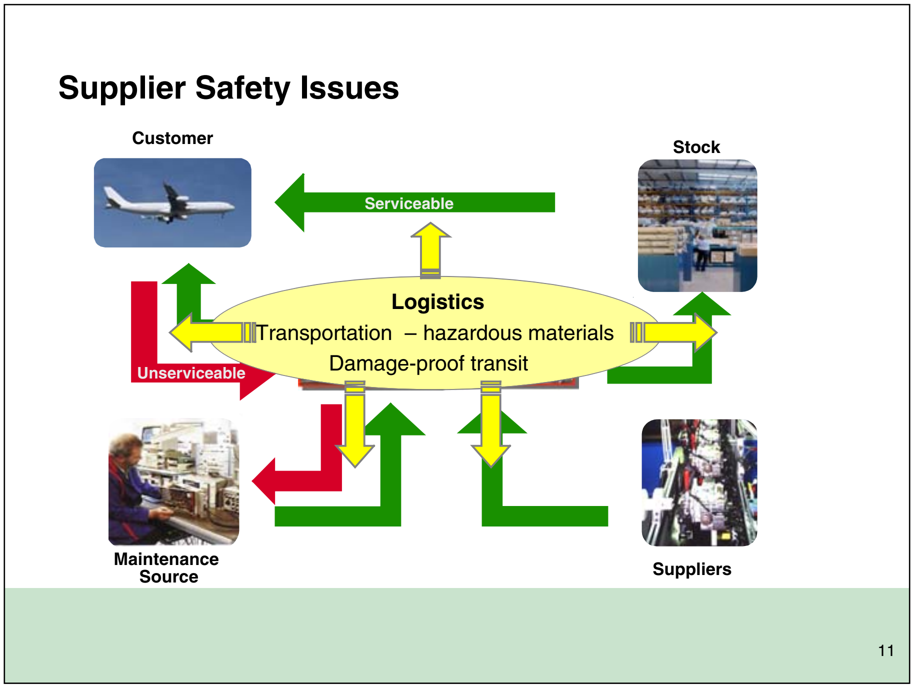
The MRO will be required to demonstrate to both the airworthiness authorities and his customers that he has the appropriate quality and safety audits in place to ensure that both his internal processes and those of his suppliers are working and up to date. Regular supplier audits are as essential as those of any new suppliers prior to contract.



At some point in the cycle, the supplier will be required to either replace or increase his stock of components. These can be new items sourced direct from the OEM or used items which have been removed from other aircraft. The onus is again on the MRO to ensure that his source can provide the necessary component history allowing traceability, stored in the appropriate environmental conditions and transported in the correct containers.

The issue of PMA parts is one that is currently taking a high profile across the industry. The MRO must ensure that if he is using a PMA supplier, the parts are appropriately marked and segregated in his system. Many airlines prohibit the use of such parts and the MRO's processes must ensure that these parts do not get used on the wrong aircraft.

The MRO must once again ensure that his quality systems address the processes of his suppliers to ensure that he isn't contravening any of the airworthiness requirements under his approvals.



Bonding the supply chain together is a robust logistics network which ensures parts are delivered to the right location at the right time but, most important, in a fit-for-purpose state, undamaged and with the appropriate certifications and approvals.

An obvious example here is the transportation of hazardous materials or oxygen bottles which require special attention and transportation.

Again, components must be transported in the correct containers to avoid damage, which is both costly and potentially dangerous. The logistics process must be adequately documented and allow traceability within the logistics system.

As can be seen from the last four slides, the possibilities for safety issues exist throughout the component supply process. The need for proactive quality management systems is important. However, do the current systems fully cater for the evolving and growing industry? Let's now examine how they could be improved.

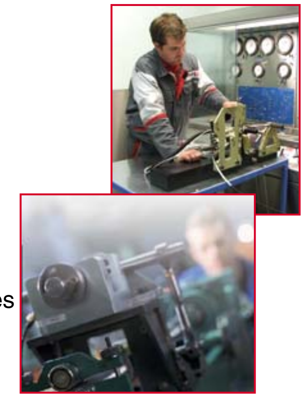
Safety Considerations When Outsourcing

Traditional

- Approvals
- Financial stability
- Audit procedures
- Tools & equipment
- Contractors v. Employee ratio

Emerging

- Quality procedures & systems
- Open book processes
- Customer involvement in safety processes
- Training programs
- Management oversight (KPI's)
- Reputation



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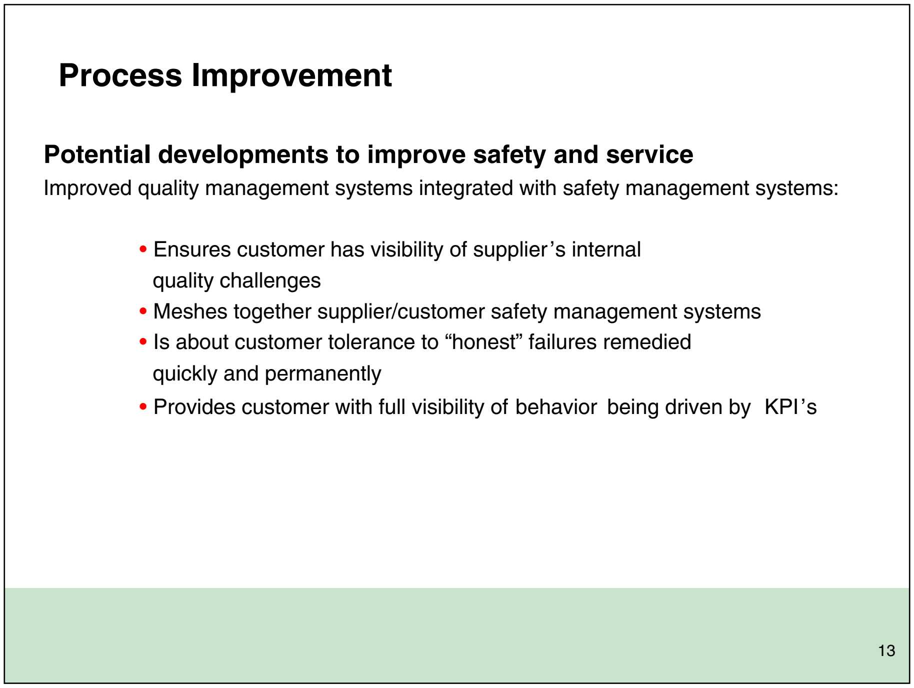
As the popularity of outsourcing component support increases, more airlines will be redefining the criteria surrounding the factors affecting the continued flight safety of their operation.

We have seen that traditional approaches and regulations focus on established component maintenance and repair or workshop activities. They do not necessarily cover the more holistic approach now required, bearing in mind the complexity and changing scope of the outsourcing model now being offered and operated.

A systematic approach is now called for, with emphasis on open book processes with the customer at the center and fully involved. We see much more value in improving safety from this environment. Key performance indicators should be developed, shared and jointly applied to ensure all elements of the supply system are continuously improved.

When selecting a supplier, among regulatory approvals, financial due diligence and audit of the management and organizational attitude towards airworthiness and personal safety should also be examined and measured. A good framework to do this is the EFQM model.

It should not be assumed that just because regulatory compliance is certified an acceptable level of quality and safety will be practiced. JAR 145 can be interpreted in many different ways, especially across national boundaries.



A key development for the future is for suppliers to improve their quality management systems (QMS) and adopt an integrated safety management system (SMS) that ensures the airline has visibility of the supplier's internal quality challenges and meshes together the supplier and customer SMS's. While the boundaries for the SMS may well be clear (for regulatory purposes), the supplier and customer need to engage in each others SMS's. While a customer can establish KPI's and leave the supplier to meet these KPI's, enlightened customers will examine and assist the supplier into developing behaviors/cultures that support the customer and have a more holistic safety driven system.

An example follows:

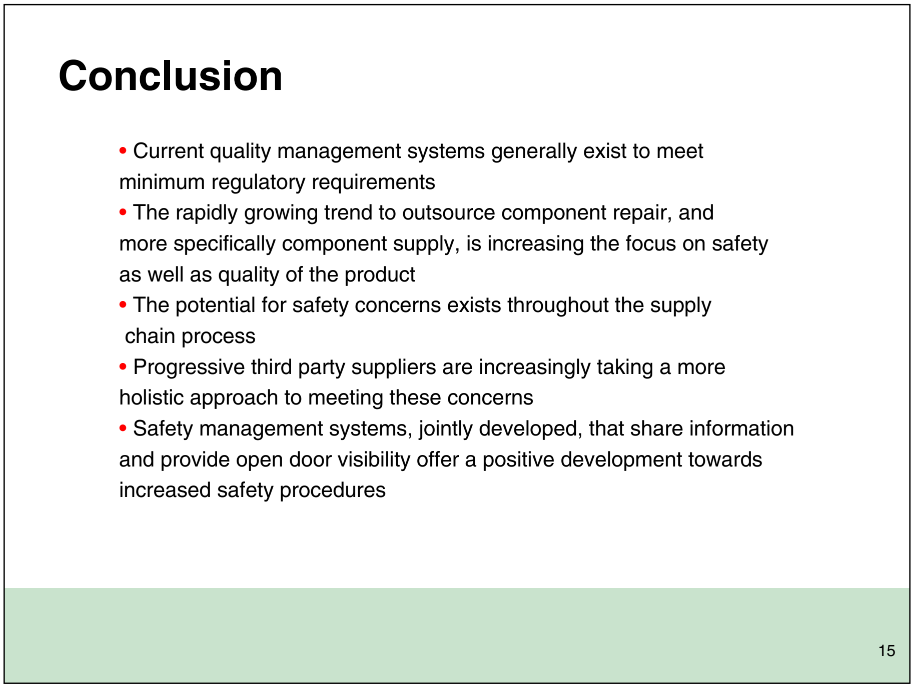
An airline may insist that the supplier provide any component that suffers nil failure/occurrence that leads to an MOR, e.g., a KPI of nil MORs.

This is easy — the supplier does not raise an MOR for failures that should be reportable, or "incorrectly" categorizes the failure to a non-MOR status.

Has the customer received the level of service that is actually expected and have we improved the safety system? No!

A better approach would have been to set up a KPI that requires the supplier to report all occurrences categorized using a mutually acceptable decision tree. The fact that an MOR is raised is not necessarily bad; it should drive the improvement behavior that ensures safety is maximized for the supplier and customer. If the supplier is invited to the customer's SMS meetings and is able to use the open and "just" forum to explain the root cause and fix for the MOR, the customer can satisfy itself that the right behavior is being driven by the KPI. Therefore if a KPI drives an incorrect behavior/action no one benefits, and safety could be compromised and is certainly not enhanced.

An integrated SMS is much less about processes and procedures (although these are the entry tickets) and much more about the customer's tolerance of "honest" failures remedied by quick and lasting root cause fixes. When this tolerance turns to frustration — typically due to unresponsive suppliers — the just and open reporting culture can quickly turn into a blame and closed culture.



Safety management systems are a subset of business risk management. Would you ever leave your business finances unchecked — just because you have set up KPIs and outsourced the activity?

The contrast between safety and business risk management is blurred even further with another component example:

If a supplier fits a sub-component with approved paperwork (certification) but does not provide traceability back to birth, from a safety perspective the component is airworthy; however, if the leasing company desires to have the component replaced (due to asset value maximization), the easiest argument to use is that the component is not "airworthy" and therefore "unsafe" utilizing loosely worded legislation to support their case.

Implementing an integrated SMS, based upon transparent quality management system, should be able to track this type of issue and thereby prevent an airworthy issue turning into a commercial issue turning into a safety issue.

In order to fully implement an integrated SMS the customer has to retain in-house technical, safety and risk knowledge. The volume of headcount and knowledge is partly proportional to the level of knowledge and demonstrable competence within the supplier. Therefore a lack of supplier knowledge/competence will result in higher customer cost and risk.

The MRO's of the future must minimize the need for customers to retain in-house expertise as much as possible — through advanced safety, quality and risk management competency. This will be a competitive differentiation between MRO's.

Will the suppliers and customers have a choice in this?

Not for long:

Regulation JAR/Ops/M and Part M are already mandating the need for operator driven safety and quality management systems. In practice MRO's have to set up interface documents that regulate their conduct.

It is my belief that the next round of regulation in this area will converge safety management systems right through the supply chain. This will be driven by aviation regulation and business risk regulation/developments.♦

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Fatigue Management in Canadian Aviation Maintenance Operations

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Transport Canada

Abstract

For the past few years, Transport Canada has worked to achieve a better understanding of fatigue issues in the Canadian aviation maintenance industry. The goal was to determine whether duty times of aircraft maintenance engineers (AMEs) should be regulated, and if so, to determine appropriate limitations. Through research efforts and consultations with the industry, it appeared that traditional approaches to AME fatigue, based on prescriptive limits to duty times, were unlikely to be an effective solution. An alternative, non-prescriptive approach was proposed, in which approved maintenance organizations (AMOs) would be required to implement a fatigue risk management system (FRMS) within their companies. The ultimate goal is to integrate an FRMS as a required component of a safety management system. In order to assist the industry in implementing an FRMS, Transport Canada has undertaken to produce a set of pre-approved methodologies, policy templates and training materials. In turn, AMOs can use these tools to meet their needs and ensure proper management of fatigue-related risks. This paper provides an overview of the various phases of the research, including project goals, current activities, desired outcomes and proposed future work.

Fatigue in Canadian Aviation Maintenance

The threat fatigue poses to aviation safety is now widely recognized. Fatigue degrades performance and significantly increases the risks of incidents and accidents. However, in many countries, no regulations exist to control hours of duty or to manage fatigue-related risks in aircraft maintenance operations. In these operations, hours of work are often governed solely by collective agreements, which vary from one operation to another. As these agreements are not necessarily oriented toward providing the individual with sufficient time to recuperate between two workshifts, they do not ensure full management of fatigue-related risks.

This was the situation in Canadian aircraft maintenance operations until recently, when Transport Canada decided to address the fatigue issue and started working on a solution. This was prompted by a report from the Safety of Air Taxi Operations Task Force (1), in which it was recommended that "Transport Canada initiate a Canadian Aviation Regulation Advisory Council (CARAC) review to determine if AME [aircraft maintenance engineers] duty times should be regulated, and if so, determine appropriate limitations." Transport Canada established a special CARAC working group with stakeholders from the aviation maintenance industry and, at the same time, commissioned a study on the hours of work of aircraft maintenance engineers throughout Canada (2). The results of this study provided evidence that fatigue and excessive periods of work may be present in the workforce. Other similar surveys performed in the U.S. and in the U.K. in the same period also supported these conclusions (3,4).

In a subsequent phase of this research, a fatigue risk assessment of maintenance tasks was performed (5). This study found that maintenance tasks involving planning, documenting, communicating, supervising, troubleshooting and inspecting can be severely affected by fatigue. The estimated risk of fatigue to aircraft maintenance operations was deemed high enough to warrant consideration of fatigue management strategies.

During the meetings of the special CARAC working group, representatives from Transport Canada and the industry agreed that traditional approaches to fatigue, based on prescriptive limits to duty times, were unlikely to be effective in improving safety, could be unwieldy, and were unnecessarily expensive with respect to compliance and enforcement. An alternative approach was sought, and the concept of fatigue risk management was proposed. This non-prescriptive approach to fatigue management was deemed preferable by all. In this approach, regulatory provisions would enable maintenance organizations to implement a fatigue management system tailored to their own particular circumstances as part of their broader safety management systems. From the regulator's perspective, the concept of fatigue risk management is a natural complement to the safety management system (SMS) being introduced throughout the Canadian Civil Aviation Regulations (CARs).

Safety Management Systems and Fatigue Risk Management Systems

Fatigue risk management systems (FRMSs) are based on the same premises as SMSs. The Transport Canada SMS model is based on the "Swiss cheese" model of defenses proposed by James Reason to explain accidents (6). According to this model, when failures in various levels of defense in a system align themselves, they allow a pathway for accidents to happen. To prevent accidents and incidents from happening, multiple defenses against hazards must be put in place at various levels in the organization. Moreover, SMSs are based on the establishment of a safety culture where everyone in the organization, employees and management alike, bears a responsibility for accident prevention. This ensures a pro-active safety culture where accident risk is a concern to everyone, as opposed to a reactive culture where individuals blindly follow procedures or regulations and where the final responsibility for safety is diffused.

Reason's model can be applied to the specific risk of fatigue. A fatigue-related incident or accident happens when fatigue-control mechanisms fail. In an FRMS, it is recognized that fatigue represents a safety hazard, and various levels of defenses are put in place to control fatigue-related risks. This is illustrated in Figure 1 by the fatigue hazard control model (7). This model illustrates five possible types of control mechanisms that can be layered to prevent fatigue-related accidents or incidents.

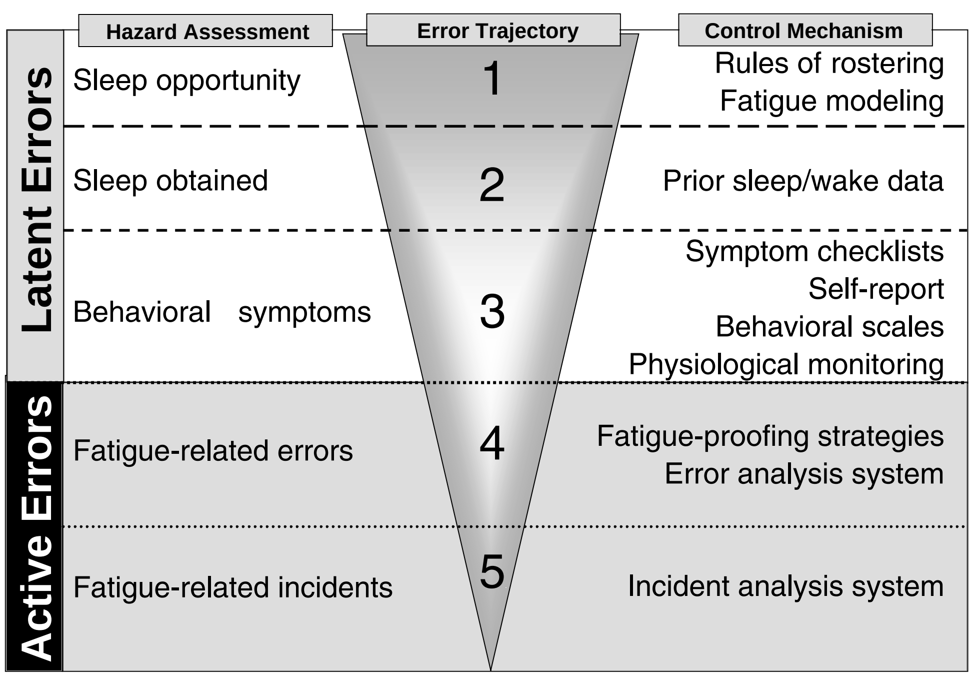

Figure 1

At the first level, the aim of the fatigue-risk control mechanism is to provide employees with sufficient time off to obtain adequate sleep. Various guidelines, scheduling tools and software exist to achieve this goal. This level of control within an FRMS is, in a way, similar to usual prescribed hours of work, as they both aim to provide sufficient rest to the individual. However, an FRMS ensures better management of fatigue risk, since it includes additional levels of defense for those situations where an individual does not get sufficient rest, even when enough time off is given.

At the second level, control mechanisms are put in place to verify that employees actually obtained the sleep they needed. The third level of fatigue risk management involves monitoring symptoms of fatigue-related impairment by the employees themselves, their co-workers and supervisors. An FRMS also has provisions for managers regarding the course of action to adopt in such instances, such as assigning the fatigued employee to less risky tasks, adopting short-term fatigue countermeasures (coffee, naps), sending the employee home and investigating persistent fatigue problems (sleep disorder screening, etc.).

Level four fatigue hazard controls involve using various means of foolproofing the workplace against fatigue errors through procedures such as double-checks, documentation, training, etc. Level five involves analyzing errors, incidents and accidents to verify fatigue involvement. These investigation procedures contribute to the evaluation of the adequacy of existing hazard controls, and highlight any need for additional defense measures.

Creating an FRMS Toolbox for the Industry

Since the concept of an FRMS is integral to the SMS, which has been introduced into the Canadian aviation maintenance industry, amendments to the Canadian Aviation Regulations (8) were drafted to incorporate the FRMS as a component of an SMS. Although many industry stakeholders were attracted by the non-prescriptive approach proposed, some expressed concern that this approach would not provide clear guidelines for the management of hours of work, thereby making it difficult to enforce in a consistent manner. There was also concern that the development of such an approach might be unnecessarily expensive for small operators.

To reduce the development costs to industry and prevent the need for each organization to “re-invent the wheel,” it was thought that the most effective solution would be to develop a public domain “FRMS toolbox.” Under the supervision of its R&D branch, the Transportation Development Centre, Transport Canada embarked on an initiative to produce such a toolbox that would define criteria for an acceptable FRMS, and provide a set of pre-approved policy templates, training materials and fatigue audit tools for approved maintenance organizations (AMOs). In this undertaking, Transport Canada sought the help of Dr. Drew Dawson and the Centre for Sleep Research (University of South Australia), who were involved in similar initiatives with the Civil Aviation Safety Authority (CASA) and Qantas in Australia. The resulting tools will allow AMOs to implement an FRMS that meets their own needs, and ensure the regulator that fatigue-related risks are being managed appropriately.

Toolbox Description

Transport Canada proposed the adoption of an FRMS comprising three types of activity:

- Development of policy statements for management and employees;
- Training and education programs for all employees; and
- Implementation of audit systems to assess and monitor fatigue risks within an organization.

The FRMS toolbox components, which address each of these activities, are described below.

Policy Documents

As is the case for the SMS, the establishment of company policies for the management of fatigue-related risks is the cornerstone of an FRMS. FRMS policy documents should include a mission statement in which the company's senior management recognizes fatigue as a significant safety hazard, and expresses its commitment to address related risks within the company. FRMS policies also state the responsibilities of workers, supervisors and management in dealing with fatigue, and establish operational procedures to define how the FRMS will work in practice.

In the development of the FRMS toolbox, policy exemplars were devised to provide guidance in designing FRMS policies that would be satisfactory to the regulator. These exemplars outline a policy structure that ensures a certain consistency across the industry. The exemplars also provide guidelines and content samples to support the policy design process, while allowing companies to customize the content to fit their own operational requirements.

The policy exemplars cover matters such as:

- Commitments from management;
- Purpose of FRMS implementation, FRMS objectives and FRMS stakeholders;
- Legislative and organizational requirements for FRMS;
- Responsibilities of management and employees regarding FRMS;
- Principles and procedures for the implementation of FRMS;
- FRMS training and education program: content, certification process, etc.;
- Guidelines and procedures to control fatigue risks; and
- Incident/accident reporting procedures.

The policy documents set the rules of fatigue risk management in a company. They contribute significantly to behavioral changes in the manner that all stakeholders deal with fatigue risks. To support these behavioral changes in the long term, it is also wise to re-align the perceptions and attitudes of the stakeholders toward fatigue. Training and education programs are thus essential to bring about these attitudinal changes.

FRMS Training Components

Training and education are essential to consolidate cultural change toward effective fatigue risk management. When implementing an FRMS, it is important that employees at all levels (management as well as operations) have a clear understanding of the reasons for change, and of their responsibilities therein. To achieve long-lasting behavioral change, it was decided that the training components of the FRMS toolbox would be competency-based to allow development of fatigue management skills in all trainees.

In these various training components, trainees learn about the five levels of fatigue hazard control (Figure 1). Various levels of defenses are emphasized, depending on the target audience: for employees, the focus is on managing fatigue and recognizing its symptoms in themselves and in others; for management, information is provided on higher organizational fatigue control mechanisms, such as scheduling, investigation of fatigue-related errors, accidents and incidents, as well as on periodical audits of the FRMS.

The proposed training tools provide companies with the flexibility to design the most suitable training program for their operations, depending on their size, level of operational fatigue risks, number of people to train and resources available for training. These training tools include:

- Introductory Fatigue Training Booklet;
- Employee Training and Assessment Unit (hard-copy and web version);
- Management Training or "How to Develop and Implement an FRMS"; and
- Train-the-Trainer Handbook.

Introductory Fatigue Training Booklet

This booklet is an introductory course designed to raise awareness of fatigue-related risks in a 24-hour work environment. The course provides trainees with practical information about fatigue hazards they are likely to face in the workplace, as well as fatigue management strategies. It can be used as a precursor to the employee training.

Employee Training and Assessment Unit (Hard-copy and Web Version)

This training package provides information on the causes and consequences of fatigue, as well as practical strategies for managing the impact of fatigue. Trainees learn how fatigue can deteriorate their performance, and how to recognize symptoms of fatigue in themselves and in others. In each chapter, learning objectives are stated at the beginning, followed by information on the topic. Relevant exercises and activities are presented, and revision questions are proposed at the end of each chapter to ensure that trainees can apply the knowledge acquired to everyday situations.

This training is available both in hard-copy format (which will be made available as a PDF file on Transport Canada's Web site) and in an interactive on-line version. This provides some flexibility for companies in the way they set up their training program: they can proceed with formal classroom training; provide the booklet as a self-taught course; or use the on-line version. A formal assessment module (in both hard-copy and on-line versions) completes the employee training to determine whether employees have achieved competency and can be awarded a certificate for successful completion of the training.

Management Training or "How to Develop and Implement an FRMS"

This training is intended for management representatives, safety officers, individuals or committees responsible for implementing an FRMS. It is an advanced training package on fatigue risk management, designed to be undertaken after completion of the employee training unit.

This tool teaches management personnel how to implement an FRMS in their company, and how to establish defenses against fatigue hazards at various organizational levels. For example, trainees receive guidance on how to write an FRMS policy and establish schedules that provide workers with sufficient opportunity for sleep. They also learn how to verify actual sleep obtained, how to monitor symptoms of fatigue and what to do in cases where employees are repeatedly reporting insufficient rest. Information is also included on the investigation of fatigue-related errors and accidents. Finally, the trainees learn how to periodically audit the implemented FRMS to ensure its adequacy and efficacy in controlling fatigue-related risks.

Train-the-Trainer Handbook

Depending on the size of the organization and resources available, some companies may decide to hire an external expert to train all the employees at one time. Alternatively, some companies may prefer to establish an internal capacity to present introductory fatigue management workshops. For the latter organizations, a trainer's handbook was added to the training components of the FRMS toolbox.

This handbook provides the background information to conduct the introductory fatigue workshop. It also contains information about how this workshop can be presented, the learning outcomes for the participants, descriptions of training techniques and questions to be anticipated from the participants. A bibliography of reference material is included to assist the trainer in preparing for the introductory workshop.

Fatigue Audit Tools

Fatigue audit tools, used to assess the level of fatigue at various levels of the work organization, complete the FRMS toolbox. A level one control mechanism includes scheduling tools that assess the sleep opportunity provided by the work schedules. Various software packages are currently available to perform such assessments. Transport Canada has included in the FRMS toolbox an adapted version of the fatigue model software developed by the University of South Australia's Centre for Sleep Research. This software, based on bio-mathematical modeling, will be available for purchase from the software manufacturer.

A low-cost option of this type of assessment/scheduling tool will also be included in the toolbox for small operations. This tool includes a simple scoring system in which schedules are assessed with regard to the following five parameters:

1. Number of hours worked in seven days;
2. Maximum shift duration;
3. Minimum "short break" between shifts (i.e., work-sleep-work);
4. Total number of hours of night work within a seven day period (9 pm–9 am); and
5. Frequency of long breaks (i.e., days away from work).

The sum of these ratings provides a score that determines the level of fatigue-related risk a work schedule is likely to generate. Knowing which tasks in the operation are more susceptible to fatigue, management can revise work schedules to reduce fatigue scores, or implement appropriate risk mitigating measures.

Fatigue audit tools are also used as level two and level three fatigue hazard controls to evaluate the actual sleep obtained and monitor fatigue symptoms experienced by the workers. The FRMS toolbox provides criteria and checklists to support operators in implementing these levels of fatigue control measures. At levels four and five, the contribution of fatigue to errors, incidents and accidents is investigated. With regard to the latter fatigue hazard controls, guidelines are provided in the various training tools to ensure that management and employees have the necessary knowledge to establish reporting systems and investigation protocols.

Proposed Next Steps

As a proposed next step to this initiative, Transport Canada would like to undertake an implementation trial with a small number of AMOs. The implementation trial would run for at least 12 months, possibly more. Participating operators would receive technical support to implement the FRMS, and monitoring activities would take place to allow the program to be continually refined. Data collection would also be carried out to assess the benefits of the FRMS. The goal is to refine implementation guidelines and the FRMS toolbox, and to identify any potential difficulties that may arise during FRMS implementation. Specific guidelines for various types of operations could also be extrapolated from this experience. Ultimately, an implementation trial would result in minimizing the cost and enhancing the efficiency of FRMS implementation for both the operator and the regulator.

Conclusion

To address the issue of fatigue in aviation operations, Transport Canada believes that the implementation of an FRMS within an SMS will provide AMOs with a flexible and company-specific approach to managing workplace fatigue. To support the implementation of these systems and reduce the development costs to the industry, an FRMS toolbox has been developed for the aviation maintenance sector. As a proposed next step on this route, implementation trials would be undertaken to fine-tune the tools and guidance material being provided to the industry. It is expected that, in the long term, a well-implemented FRMS will diminish the impact of fatigue problems, and therefore contribute to reducing the number of fatigue-related incidents and injuries, along with improving productivity and work-related satisfaction.♦

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References

1. Safety of Air Taxi Operations (SATOPS) Task Force. *SATOPS Final Report — SPRING 1998*. TP 13158. Ottawa: Transport Canada, Safety and Security, 1998. <www.tc.gc.ca/civilaviation/systemsafety/pubs/tp13158/TP13158.pdf>.

2. Rhodes, W. *Assessment of Aircraft Maintenance Engineers (AMEs) Hours of Work: Phase 1*. TP 13875. Montreal: Transport Canada, Transportation Development Centre, 2001. <www.tc.gc.ca/tdc/publication/pdf/13800/13875e.pdf>.

3. Sian, B. and Watson, J. Chapter 11: Study of fatigue factors affecting human performance in aviation maintenance. Phase IX Progress Report (1999). In *FAA/AAM Human Factors in Aviation Maintenance and Inspection Research Phase Reports (1991-1999)*. Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1999. <http://hfskyway.faa.gov/document.htm>.

4. Folkard, S. *Work Hours of Aircraft Maintenance Personnel*, CAA Paper 2002/06. London: Civil Aviation Authority, Safety Regulation Group, 2003. <www.caa.co.uk/docs/33/PAPER2002_6.PDF>.

5. Rhodes, W., Lounsbury, R., Steele, K. and Ladha, N. *Fatigue Risk Assessment of Aircraft Maintenance Tasks*, TP 14169E. Montreal: Transportation Development Centre, Transport Canada, 2003. <www.tc.gc.ca/tdc/publication/pdf/14100/14169e.pdf>.

6. Reason, J. *Managing the Risks of Organizational Accidents*. Brookfield, Vermont: Ashgate, 1997.

7. Dawson, D. and McCulloch, K. "Managing Fatigue: It's about sleep." *Sleep Medicine Reviews*, 2005.

8. Transport Canada, *Notice of Proposed Amendment (NPA) to Canadian Aviation Regulations (CARs), Part V – Airworthiness*. <www.tc.gc.ca/civilaviation/RegServ/Affairs/carac/NPAs/MM/menu.htm> (May 31, 2005).

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Managing Procedural Error in Maintenance

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Abstract

It is well established that procedural non-compliance is a common occurrence in maintenance operations. Hobbs & Williamson (2000) reported that 80 percent of maintainers surveyed deviated from procedures at least once in the past year; nearly 10 percent reported doing so often or very often. McDonald et al. (2000) reported that 34 percent of routine maintenance tasks were performed contrary to procedures. An analysis of NASA Aviation Safety Reporting System (ASRS) incident reports from 1998–2001 indicated that a significant proportion (44 percent) of maintenance reports pertained to procedural errors and implicated many types of maintenance documents, such as: maintenance manual, task cards, minimum equipment list and maintenance log.

The reasons for making these errors were diverse. Sometimes the procedure itself was deficient (e.g., incomplete, incorrect, unclear), or it was not the current version. Sometimes the source of the problem was the user of the procedure who misread or misinterpreted the document, or simply didn't follow it. Because the causes underlying procedural errors in maintenance cover a wide variety of problems, simplistic solutions have not provided long-lasting or systemic solutions. And in spite of useful document design tools, and information technologies that improve document production, procedural error in maintenance has persisted. However, as we increase our understanding of the causes and contexts in which procedural errors occur, the development of comprehensive solutions will accomplish far more than the correction of individual procedures and users. Rather, they will address the full complexity of the problem including issues such as information technology limitations, usability testing and training, document system standardization, and organizational safety culture.

Procedural Error

Procedural error in maintenance has been discussed, researched and addressed for many years, but like other complex, human factors issues, it seems to evolve rather than resolve. In reviewing some of the approaches developed by government, industry and research, I will try to integrate their findings and address some of the complications that may have impeded our progress toward procedural error reduction. At the heart of the problem is how we define "procedural error." If it is defined too narrowly, its solutions will be narrow and possibly lacking in important ways. Rather than invent one more narrow definition, I would rather build a more inclusive working definition that 1) expands the investigations of procedural error to include procedural non-compliance, 2) distinguishes between procedures as contributing factors and procedural outcomes, 3) broadens procedural errors to also include data and documents, and 4) includes manufacturer and operator-generated documents, as well as documents that include users outside the maintenance and inspection domain (e.g., minimum equipment list and maintenance log).

Maintenance Procedures and Documentation: How Big a Problem Is This?

The Role of Maintenance Error. Accidents and fatalities offer the worst case scenarios in aviation safety, but there are several ways to calculate where the greatest risks lie. When the U.S. Commercial Aviation Safety Team (CAST) was established in 1997 to develop and implement a data-driven, benefit-focused safety enhancement program, their goal was to develop recommendations to achieve 80 percent reduction in fatal accidents by 2007.

Their strategy for achieving this goal effectively was to target accident types that accounted for the largest proportion of risk, such as controlled flight into terrain, approach and landing, and loss of control. On this basis, a projected risk reduction of 73 percent could be achieved by 2007. To address the yet unmitigated risk, CAST, in 2003, chartered Remaining Risk teams to analyze accidents classified as icing, mid-air collisions, cargo, and maintenance and system failures. From this perspective, maintenance and system failures represented a small but significant contributor to the total accident rate.

The data depicted in Figure 1 is consistent with this view. In this 2003 Boeing chart, accidents are classified according to "primary causes," as designated by the accident investigation agency. Maintenance and inspection is relatively small, 3.7 percent from 1959 to 1990 and 4.5 percent from 1993 to 2002. But it is interesting to note the increase in percentage in the more recent years, due in part to the disproportionate drop in accidents attributing primary cause to cockpit crew. A chart similar to Figure 1 that pertains to the U.S. commercial jet fleet shows a similar trend; maintenance and inspection as primary cause doubles from 4.5 percent to 9.5 percent.

Primary factor	Number of accidents	
	1959–1992	1993–2002
Cockpit crew	540	166
Airplane	133	50
Maintenance & Inspection	**31**	**14**
Weather	36	36
Airport/ATC	43	11
Miscellaneous/other	59	27
Total with known causes	842	304
Unknown or awaiting reports	110	97
Total	952	401

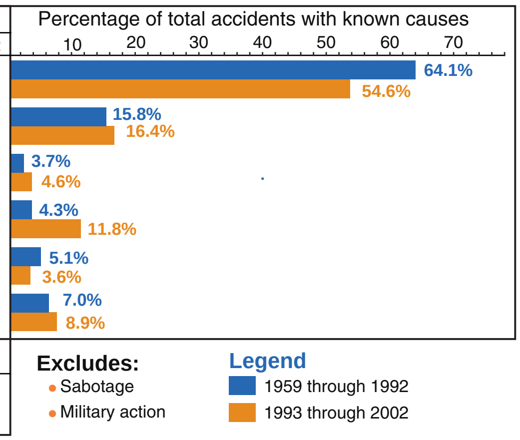

Figure 1: Primary Causes of All Accidents: Worldwide Commercial Jet Fleet (Boeing, 2003)

Levin, in his *USA Today* study (2004), observed a similar shift in his evaluation of 158 of the most severe U.S. airline crashes between 1980 and 2001. He found that accidents attributed to pilots dropped from six per 10 million flights in the 1980s to below four per 10 million in the 1990s, and below three per 10 million from 1995 through 2001. Maintenance emerged as the second-most-likely cause of accidents with an average of slightly more than one crash per 10 million flights in the 1990s. This category of accidents did not decline from 1995 through 2001.

There are several possible reasons for shifts in proportion. One reason, as Levin, proposes, is that a combination of innovative training and modern jets with better warning systems have helped pilots mitigate or recover from flight critical situations, thereby pushing forward the effects of remaining risks such as maintenance and weather. But another reason could be the increasing awareness and understanding of how accident sequences, root causes and contributing factors are analyzed. In the last 15 years we have learned a great deal about maintenance error and the role of human factors; in the last 10 years we have developed and applied more comprehensive and systematic investigation methods for data collection and analysis. The awareness and interest in understanding of pilot "error" started at least 15 years earlier.

A deeper understanding of "error," whether pilot, controller, maintainer or inspector, provides a conceptual basis for identifying multiple causes, distinguishing local versus organizational factors and, given enough data, assessing whether events are random, context-specific or systemic in nature. Tools such as Boeing's Maintenance Error Decision Aid (MEDA), the U.S. Navy's Human Factors Analysis and Classification System-Maintenance Extension (HFACS-ME), Root Cause Map, British Airways Maintenance Error Investigation (MEI) tool, TapRoot, etc. have given us an arsenal of tools for more fully describing accident and incident sequences. Unfortunately, investigations of the past may not have asked all of the questions we might have liked to ask, but these tools will provide useful guidance for systematic data collection and analysis in the future.

A final complication to assessing the size and sources of accident risk is the interdependence among factors; for instance, maintenance and flight crew. In the IATA Safety Report of 2003, the contribution of maintenance and technical failures was found to be 26 percent of 92 accidents worldwide. But they note that "accident scenarios . . . *are* . . . often a combination of the precipitant technical failure and the handling of the technical failure by the flight crew" (IATA, 2003). In addition, we have no easy way to know how many maintenance and technical failures were generated, but were detected and mitigated prior to developing into an emergency situation in flight. In spite of the hidden nature of maintenance errors and their likely underestimation, there is no doubt that human error in maintenance compromises aircraft reliability, thus increasing hazard potential for flight crews. Conversely, a reduction in maintenance error may create fewer opportunities for flight crew error.

The Role of Procedural Errors in Maintenance-caused Accidents. There is general consensus that procedures and documents are often involved in maintenance errors. Clearly they do not always end in an accident, but they do occur routinely. The following are two accidents, one from 1991 and one from 2003, in which procedures/documents are central to the accident sequence. Because the scenarios are different from each other in many ways, the causes and contributing factors identified by the National Transportation Safety Board (NTSB) represent some of the variety we find in procedural errors.

> **Flight 2574, Embraer 120, Eagle Lake, Texas, September 11, 1991**. Flight 2574, operating under FARs Part 135, experienced a sudden in-flight loss of a partially secured left horizontal stabilizer leading edge, leading to immediate severe nose-down pitchover, breakup of the airplane and subsequent crash near Eagle Lake, Texas. Probable cause of this accident was determined to be the failure of maintenance and inspection personnel to adhere to proper maintenance and quality assurance procedures for the airplane's horizontal stabilizer deice boots, which left the left horizontal stabilizer leading edge only partially secured. Contributing to the cause of the accident was the failure of management to ensure compliance with the approved maintenance procedures, and the failure of the regulator to detect and verify compliance with approved procedures. Thus, probable cause was attributed to maintenance and inspection personnel; contributing factors involved management and regulators. The relevant procedures, namely (company, FAA-approved) procedures for shift turnovers including the documentation of incomplete work on work cards, were *not* found to be inadequate. However the company was faulted for not considering the removal and replacement of the horizontal stabilizer leading edge deice boot as a required inspection item.

The accident of Flight 2574 is a prime example of procedural deviation; namely mechanics and inspectors failed to follow published technical documentation. Both personnel and their supervisors seemed to accept this form of procedural non-compliance as a routine practice. In this case, the procedures and documents for accomplishing the work existed and were not found to be inadequate. They were simply not followed.

In contrast, the inadequacy of procedures and documentation were significant contributors to the accident sequence of Flight 5481 described below.

> **Flight 5481, Raytheon (Beechcraft) 1900D, Charlotte, North Carolina, January 8, 2003.** This Beechcraft 1900D with 19 passengers and 2 crew, lost pitch control during takeoff and crashed, killing all on board. Probable cause was determined to be the incorrect rigging of the elevator control system compounded by the airplane's aft center of gravity, which was substantially aft of the certified aft limit. Contributing to the cause of the accident were (1) the operator's lack of oversight of the work being performed at the maintenance station; (2) the operator's maintenance procedures and documentation; (3) the operator's weight and balance program at the time of the accident; (4) the contractor's quality assurance inspector's failure to detect the incorrect rigging of the elevator control system; (5) the regulator's average weight assumptions in its weight and balance program guidance at the time of

the accident; and (6) the regulator's lack of oversight of the operator's maintenance program and its weight and balance program.

While probable cause, as determined by the NTSB, did not specifically target individuals as opposed to organizations, the contributing factors and subsequent recommendations were quite clear in assigning responsibility to numerous organizations: the operator, maintenance contractors, manufacturer and regulator. Specific procedure-related recommendations included:

- *Require manufacturers of Part 121 aircraft* to identify appropriate procedures for a complete functional check of each critical flight system; determine which maintenance procedures should be followed by such functional checks; and modify their existing maintenance manuals, if necessary, so that they contain procedures at the end of maintenance for a complete functional check of each critical flight system.

- *Require Part 121 air carriers* to modify their existing maintenance manuals, if necessary, so that they contain procedures at the end of maintenance for a complete functional check of each critical flight system.

- *Require Part 121 air carriers* to implement a program in which *air carriers and aircraft manufacturers review* all work card and maintenance manual instructions for critical flight systems and ensure the accuracy and usability of these instructions so that they are appropriate to the level of training of the mechanics performing the work.

Document Deficiencies and Non-Compliance. The accidents above illustrate how deviations from procedures can lead to devastating consequences. In both cases, procedural problems represent significant links in the event chain, which, if broken, could have effectively blocked the accident from occurring. The CAST Remaining Risk Maintenance and Systems team analyzed accident Flight 2574 and five others and developed two safety enhancements which are relevant to several types of procedural errors in maintenance:

- Enhancement 169: Ensure that work cards or other written instructions are used at the start of each task, and written and oral status reports are provided at every shift change. Procedures should be written to include clear responsibility and authority for work assignments, and necessary manuals (operational and maintenance) are complete, accurate, available and appropriately used.

- Enhancement 175: Airlines/maintenance should provide logbook entries and visible tagging, where appropriate, any time flight critical configuration changes are made during maintenance that are not immediately visible … .

These enhancements address procedural errors that are unintended mistakes as well as procedural non-compliance. They address aspects of procedures and documents (e.g., complete, accurate and role-specific), as well as aspects of the workplace (e.g., properly available) and users (e.g., properly used). They address the role of procedures and documents as contributing factors to user errors as well as procedural actions that are errors in themselves (e.g., failure to provide required maintenance documentation such as reports and log entries).

Clearly, the NTSB recommendations and safety enhancements above go far beyond a simple "primary cause" focus by addressing procedural errors as contributing factors, errors that fall into the broader context of normative practices, oral as well as written communication, and the roles of organizational oversight and management, supervisor, team and individual responsibilities. Such a breakdown of factors is suggestive of the types of classification techniques now widely used in investigation and research. The next section will provide examples of what we have learned about these factors.

Maintenance Procedures and Documentation: What Kind of Problem Is This?

Although the number of cases is too small for statistical analysis, the following study presents the results of applying one error investigation schema to a set of 15 maintenance-caused accidents. It supports the notion that procedures and documentation occupy a central position in maintenance and inspection and suggests that procedural issues may be tightly linked with other factors in the operational setting.

Analysis of Maintenance-caused Accidents. Schmidt, Lawson and Figlock (2002) conducted a post hoc HFACS-ME analysis of 15 NTSB maintenance-caused accidents (1976–1995). The schema builds on the Reason model (1995) which distinguishes organizational and work environment factors that provide the context within which individual actions are made. Any number of factors (averaging 13 per accident) could be included in each accident description, and each first level factor (organizational, work environment, maintainer conditions and maintainer actions) comprised second and third level subcategories.

Schmidt's data show that all but one of the 15 accidents (93 percent) had some kind of organizational or supervisory factor associated with them, while maintainer conditions such as readiness and crew coordination factors were slightly less represented (80 percent). Work environment factors such as equipment and workspace exerted the least influence, but were still found in 60 percent of the cases. With respect to maintainer actions, it was not surprising to see a variety of errors (e.g., judgment, memory and knowledge) reported in 80 percent of the accidents; reports of non-compliance were noted in 40 percent. With regard to procedural errors, inadequate documentation contributed in 80 percent, or 12 of the 15 accidents. In these 12 reports, inadequate documentation was always accompanied by inadequate processes and inadequate supervision; and it was accompanied 75 percent of the time by a cluster of other factors, including inadequate operations, uncorrected problem and inadequate training/preparation. While 15 are too few cases from which to generalize, there is a suggestion that factor combinations would be useful to explore with a larger database.

Survey and Incident Data Research. It has been well established that procedural errors and procedural non-compliance are common occurrences in maintenance operations. Hobbs and Williamson (2000) have reported that 80 percent of maintainers surveyed deviated from procedures at least once in the past year; nearly 10 percent reported doing so often or very often. McDonald et al. (2000) reported that 34 percent of routine maintenance tasks were performed contrary to procedures. A large and varied list of reasons why people don't follow procedures comes from a study by Human Reliability Associates and appears in the U.K. Civil Aviation Publication (CAP) 716 (2002, Chapter 3). Reasons include document deficiencies (inaccurate, impractical, inaccessible), as well as user practices (they find "better" ways to work, are unsure of policies, don't feel they need them).

In addition to surveys, procedural problems in maintenance have been the subject of a series of analyses of NASA Aviation Safety Reporting System (ASRS) incident reports. Maintenance reports represent a small 3 percent of total reports received, but over the last four years, we have built a research database that adds about 450 reports a year. Our current cumulative total is now over 2500.

In 2003, Patankar et al. conducted a study of over 1,000 reports from 1998 to 2001, and found a significant proportion (44 percent) of maintenance reports pertained to procedural errors. Because ASRS reports are voluntary reports they do not represent a random sample of the overall system. Nevertheless, they offer a relatively large sample of events that provide personal accounts directly from reporters. An analysis of these 44 percent (458 reports) looked at contributing factors, maintenance error type and operational events (see Figure 2, page 238). They were coded using adapted MEDA (1994) categories. A large proportion of these incidents (76 percent) reported types of information factor (e.g., not used, not understood, inadequate or incorrect) that contributed to maintenance error; 43 percent reported incorrect documentation errors, and 55 percent resulted in non-compliance with procedures or paperwork.

A follow-on study by Patankar et al. (2004) found that a great variety of maintenance documents were involved in the 458 reports, including maintenance manual, task cards, minimum equipment list, maintenance log, etc. Then, in order to develop an efficient way to perform a content analysis of these reports, they applied the Perilog text analysis software to the narrative section of each report (McGreevy, 1997). In doing so, the entire dataset could be modeled, and the most representative 10 percent of reports (46/458) could be identified. An exploratory analysis of these 46 revealed eight basic scenarios; four described document deficiencies, and four described types of user errors (see Figure 3, page 238). Revisiting the document types of these 46, some documents are

Adapted from Boeing's (1994) Maintenance Error Decision Aid (MEDA) Category System for Investigation

Contributing Factors

- ✓ **INFORMATION**
  - ➤ Incorrect
  - ➤ Too much/conflicting
  - ➤ Update process too long
  - ➤ Incorrectly modifying mfg MM/SB
  - ➤ Not used
  - ➤ Unavailable/accessible
  - ➤ Not understandable
- ✓ Equipment
- ✓ Airplane Design
- ✓ Job/Task
- ✓ Qualifications/Skills
- ✓ Individual Performance
- ✓ Environment/Facilities
- ✓ Organizational Issues
- ✓ Supervision
- ✓ Communication

Maintenance Error Type

- ✓ Improper Installation
- ✓ Improper Servicing
- ✓ Improper Fault Isolation/Inspection
- ✓ **OTHER: Incorrect Documentation**
- ✓ Foreign Object Damage
- ✓ Surrounding Equipment Damage
- ✓ Improper Repair
- ✓ Personal Injury

Operational Event

- ✓ Flight Delay
- ✓ Flight Cancellation
- ✓ Gate Return
- ✓ In-Flight Shut down
- ✓ Air Turn-back
- ✓ **OTHER: Non-compliant Release of A/C (paperwork)**
- ✓ Aircraft Damage
- ✓ Injury
- ✓ Diversion
- ✓ Rework

Of 1046 ASRS maintenance reports submitted between August 1998 to April 2002, 458 (44%) involved procedural errors. A report was selected if it could be reliably coded as exemplifying one or more of any of the MEDA categories **highlighted** above.

Figure 2: Identification of ASRS Reports Related to Procedural Errors Using Modified Maintenance Error Decision Aid (MEDA) Categories

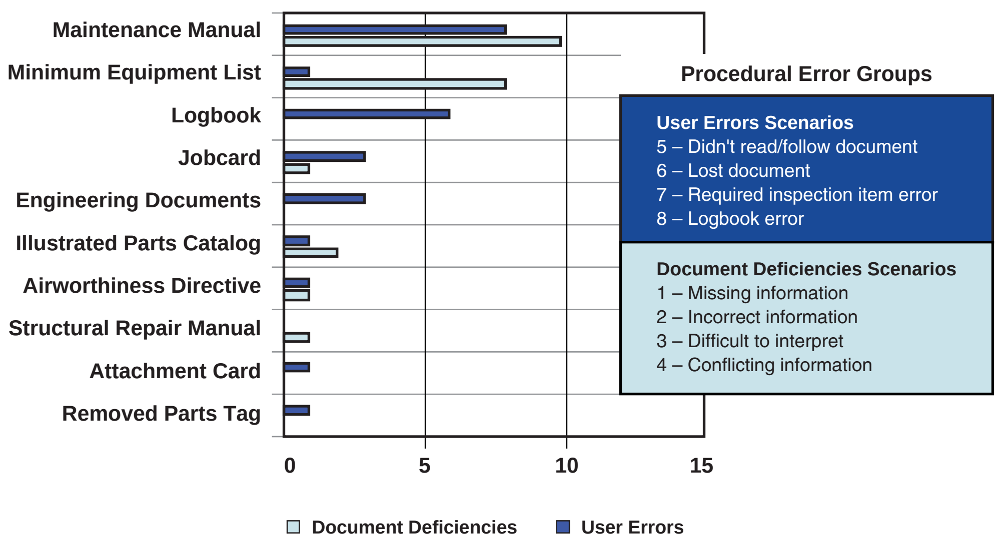

Figure 3: Procedural Error Groups and Associated Documents of 46 Representative ASRS Incident Reports

associated with both of the procedural error groups; but the ones that are more clearly associated with one error group over the other suggest more error-specific interventions.

Another study that bears discussing is a recent study of organizational and supervisory factors by Lattanzio et al. (2005). Starting with 1,187 MEDA-coded ASRS reports (1996–2001), 101 reports had organizational and supervisory factors coded as contributing factors. In these cases, a generic scenario emerged with the following pattern: the reporter of the event had a *problem* and went to a *resource* (organizational or supervisory) for help. *Responses* to their request for information from resources were fairly simple. They received no support, wrong information or instruction to commit an infraction (non-compliant action). Note that, since these are incident reports, we would expect only those events with unsuccessful outcomes. Successful resolutions would not be reported.

Thus, the 101 reports were further coded for originating problem (paper, parts, workload/time/staffing or training), resource sought (supervisor, management, engineering, maintenance control, logistics or one's own work group), and response received (no support, wrong information, infraction). The overall breakdown is shown in Figure 4.

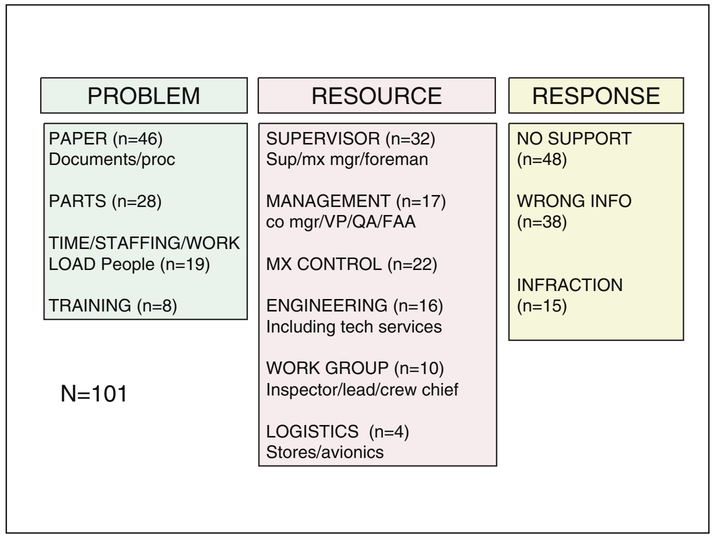

Figure 4: Breakdown of Organization/Supervisory Reports by Problem, Resource and Response

Looking at the 46 reports that originated with a paper (procedure or document) problem, we find that the reporters try varied strategies. When they seek out a "technical" resource (e.g., work group, engineering, maintenance control), their primary problem is that information received is incorrect. They sometimes get no support (no answer or action), but instruction to commit an infraction is rare. In contrast, when the reporter goes to management (supervisors or other management personnel), the most frequent response is no support. Instruction to commit an infraction is also relatively frequent although wrong information is not much of an issue.

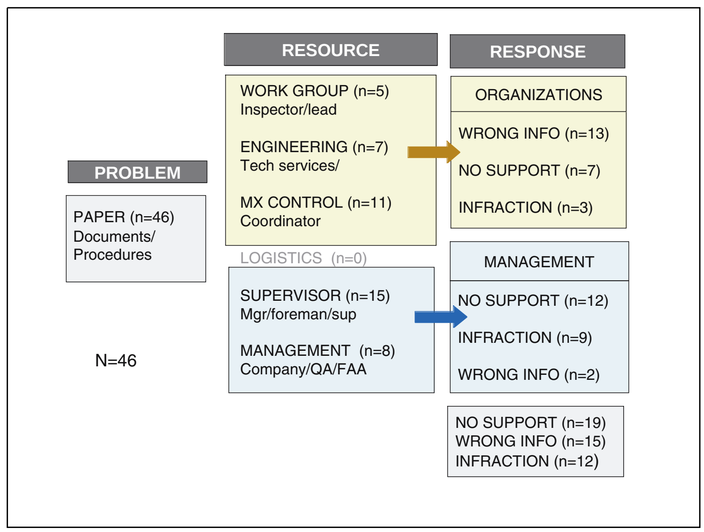

Figure 5: Breakdown of Organization/Supervisory Reports by Problem, Resource and Response

What is interesting about these reports is that we should be able to resolve the problems with "technical" resources by improving documents and data, and by making information more accessible, complete and unambiguous. An example of this scenario is the following:

 # 445851 (1999):

WHILE IN THE PROCESS OF DOING HIS WEEKLY CHK A MECH RPTED TO ME THAT THERE WAS FUEL LEAKING OUT OF THE MID-ENG DRAIN LINES. … **I ASKED MAINT CTL WHICH LIMITS DO YOU USE, AS THE MANUAL WAS NOT TOO CLR ON THE PWR SETTINGS. I ASKED THEM (MAINT CTL) TO CALL PWR PLANT ENGINEERING TECHNICAL DESK.** THEY DID AND IT WAS RELAYED TO ME BY MAINT CTL THAT PWR PLANT ENGINEERING SAID: THE PROPER PROC WAS TO RUN THE ENG AT IDLE, COUNT THE DROPS … WE PERFORMED THIS PROC AND WHEN WE DID … THIS WAS FOUND TO BE WITHIN THE SERVICEABLE LIMITS OF MAINT MANUAL XX-XX-XX PAGE XXX. **I RELEASED THE ACFT … NEXT MAINT LAYOVER. I FOUND THE MAINT MANUAL OF**

> **THIS REF VERY IMPRECISE AND LEAVING A LOT UP TO JUDGEMENT. BECAUSE I WAS DEALING WITH A TOTAL OF 6 ACFT AND 8 OR 9 MECHS I WAS NOT EXAMINING THE MAINT MANUAL AS CLOSELY AS I SHOULD HAVE BEEN AND RELYING TOO MUCH ON THE VERBAL INFO FROM MAINT CTL.**

Resolving the problem when management is sought is less a matter of information flow and more a matter of being available with appropriate guidance on policy and practices.

> **#511741 (2001):**
>
> **WAS FORCED TO SIGN OFF WORK PERFORMED TO THE FORWARD AUX TANK THAT WAS INCORRECT AND WORK THAT I DID NOT DO**. WAS WORKING FUEL LEAK OF THE FORWARD AUX TANK. TANK BAG WAS REMOVED ALONG WITH THE BAG COMPONENTS. BAG WAS INSTALLED BACK IN ACFT. COMPONENTS WERE INSTALLED AND TANK CLOSED. TANK WOULD NOT HOLD PRESSURE WHEN TESTED. FOUND APPROX 5 GALLONS OF FUEL IN CAVITY. **SUPVR MADE ME SIGN OFF FORWARD AUX TANK COMPONENTS THAT I DID NOT INSTALL, AND SUPVR FORCED ME TO SIGN OFF INSTALLING FORWARD AUX TANK COMPONENTS PER XX-XX-XX WHICH DOES NOT COVER FUEL TANK COMPONENTS. … THE SUPVR IGNORED THE LEAKING TANK AND REQUIRED A SIGNOFF OF THE PAPERWORK.**

The study above illustrates how procedural error events often go beyond individual actions to implicate other departments and management personnel within a company.

Multi-User Documents. In addition to the cases where individuals try to resolve policies and procedures by turning to their management or technical support, there are also cases in which procedures and documents explicitly involve multiple users. For instance the minimum equipment list (MEL) can involve maintenance, flight crews, dispatch, ramp, fuelers and others. Munro's study of 143 MEL-related ASRS reports (2003) revealed several contributing factors that could apply to any procedural error (e.g., time pressure, lack of familiarity, communication). However, unclear MEL and interpretation of the MEL (which together comprised 36 percent of the MEL reports) require particular attention to consistency across user groups as well as each group's unique information requirements. The reports in this study reflect the maintainer's perspective, but it is equally likely that pilots, dispatchers and others may be submitting reports reflecting their MEL problems. Interpretation of MEL is similarly problematic across multiple users. In these reports, maintenance control, flight crew, dispatch, engineering and FAA were all named as MEL users. Resolution of interpretation issues would clearly require a multi-user strategy.

Other work focused on MEL is that of Seamster and Kanki (2005), who have been working with the master minimum equipment list (MMEL) industry group. In anticipation of updating the electronic format of maintenance documents, this group has been tasked with providing operator requirements to the manufacturers and FAA so that the new electronic format will facilitate publication and revisions. This, in turn, will enhance standardization and usability for MEL users. Seamster and Kanki collected usability requirements from the MMEL industry group to determine the most important requirements for the new format, and to provide industry an opportunity to consider human factors issues that have been problematic in the transition from MMEL to the operational MEL. When the electronic data transfer standards become established (from manufacturer to operator), the operator gains a single, shared and re-usable information repository that can help ensure consistency for all user groups while retaining the flexibility to display information in the most user-centric media and format.

Multi-user procedures highlight the issue of variation in user requirements as well as process inconsistencies. Hall (2002) discusses these problems as faced by repair stations when they are given airline documents that are not compatible with their media, terminology or processes. Killion and Bongard (2002) observe that repair station issues are further compounded by a diversified customer base. Not only do individual airlines' programs, regulations and procedures differ from those of the repair station, but the airlines comprising their customer base may differ from each other.

Manufacturer Documents. This leads us to the general issue of manufacturer procedures and documents that operators use or modify to fit their operations. While many issues apply to both operator documents and manufacturer documents, there are several issues that are unique to the aircraft technical manual that comes from the original equipment manufacturer (OEM). Chapparo and Groff (2002) conducted a survey and field interviews with technicians, engineers, union safety representatives and management and found that their perceptions were similar across most manufacturers and aircraft types (with the exception of out-of-production aircraft). They felt that aircraft manuals contained relatively few factual errors, but cited many usability issues. Poor usability (such as trying to find information, or lack of clarity) could lead to aircraft and parts damage, as well as improper maintenance, and more than 60 percent of the respondents felt there was a better way to perform tasks. At a systemic level, the survey reported that problems are under-reported, and when they are reported, they often remain uncorrected.

These reasons are similar to those given earlier on "why people don't follow procedures" (CAP 716), but some issues are unique to manufacturer documents. Hall (2002) provides a litany of problems with aircraft and component maintenance manuals, beginning with reluctance to amend manuals for older-model aircraft, accessibility, readability, portability and training. Component maintenance manuals frequently have outdated data, and tasks that cannot be performed. Their inability to obtain maintenance data from the OEM eventually creates more unresolved problems for the operators. As mentioned earlier, the increasing use of electronic technologies may greatly facilitate the transfer and updating of data, but this will require that industry information standards be established.

Why Do These Problems Persist?

It would be one-sided to say that accident investigation and procedural error research stopped at the point of description and explanation. Rather, investigations are followed by recommendations, incidents are followed by corrective actions, and procedural error research is followed by the research and development of interventions and preventive strategies. For example, in the area of document design, authoring standards are provided for Simplified English (AECMA PSC-85-16598), in DOE technical writing guidance (DOE-STD-1029-92) and in Drury's (1997) Document Design Aid and numerous experimental studies that validate this guidance. To reduce documentation errors, Taylor (1993) has described an approach that involves the workforce and incorporates a maintenance resource management training framework. The approach emphasizes error awareness and the improvement of documentation practices. From regulators, we have seen requirements in some countries and advisories in others that address the need for both manufacturers and operators to validate their procedures for correctness and usability. The sharing of safety information and feedback loops among operators, regulators and manufacturers is also advocated to encourage correct and updated information.

User errors may be simple slips due to local factors or they may be intentional deviations for complex reasons. While simple errors may be resolved by paying attention to local work environment or individual factors, procedural non-compliance requires investigation of organizational level factors from high level company policies to workforce practices on the floor. We have seen user errors that are due to lack of technical support or inaccessible documents, and user errors that are condoned by management in a company culture that fails to instill corporate safety values and policies.

When we begin to understand the investigation models with their networks of contributing factors, it is clear that there may be as many solutions as there are combinations of factors. Since most events are described by multiple interdependent factors that are both local and organizational, the degree to which interventions will be successful may be linked to how completely the intervention matches the network of factors. Interesting work on the relationships among contributing factors, and errors through correspondence analysis, are found in Hobbs and Williamson (2000) and Hobbs and Kanki (2003). Luxhoj (2002) has been exploring the relationships among factors through Bayesian Belief Network methodology and builds influence diagrams that illustrate a full accident sequence.

A better understanding of the relationship among factors and errors can ultimately simplify the analysis of actions in complex operations. It is also important to investigate errors according to the more inclusive definition of procedural error introduced at the beginning of the paper.

- *Errors and Non-compliance*. By addressing only procedural errors that are simple slips or lapses, procedural non-compliance (excluding cases where individuals would be judged reckless or malicious) will be unresolved. There is sometimes a fine line in making judgments of intention, but it is important to understand and address why procedural non-compliance is so common and what are the reasons behind these actions.

- *Contributing Factors and Outcomes*. Procedures that are contributing factors to errors can be addressed through procedural review, analysis and validation but they may remain as latent hazards if they are not reported. Procedural errors are often visible but require an understanding of why they occur. Establishing the contributing factors to these events will provide a better idea of why they are occurring.

- *Procedures and Documents*. Because documents are often job aids that embody procedures, it is important to understand that procedural problems may or may not include documentation problems; similarly, documentation problems do not necessarily imply a faulty procedure. However, usability improvements can be made at both procedure and document levels.

- *OEM and Multi-user Documents*. Documents from the OEM as well as those that are operator-generated may benefit from many of the same document design guidelines. However, there are special considerations to bear in mind when documents and data transfer across organizational boundaries. Multi-user documents that include users outside the maintenance and inspection domain (e.g., MEL and maintenance log) or outside the operator workforce (e.g., contract maintenance) must additionally consider issues of consistency and compatibility of programs, regulations, and processes, as well as terminology and formatting.

In summary, the maintenance industry, including operators, manufacturers, regulators and researchers, has tackled procedural problems in maintenance for quite some time. So, it is disheartening to see these problems persist and contribute to accidents in spite of significant advances in developing recommendations, guidelines and intervention strategies. A greater understanding of error sequences and contributing factors, including our expanded definition of procedural error, can help us to systematically investigate and characterize error. But the more complex problem characterizations seem to demand interventions so comprehensive and complex that we could never address more than a few. How then, can we develop a balanced and feasible approach?

The following are three building blocks:

- First, it is essential that organizations promote a reporting culture, one in which people are not afraid to disclose safety information. Even the best planned safety management system can be undermined by a lack of data or data that is unreliable.

- Second, fully characterizing errors is labor intensive but these efforts should not be carried out with the intention of addressing every factor separately. It may be appropriate to address specific local factors, but responding to every factor is neither practical, nor well founded. The greater usefulness of the error data is its incorporation into an error management system in order to analyze and trend data once large enough samples are obtained.

- Third, comprehensive changes should be risk-based; that is, resources and process improvements should be implemented on the basis of priorities determined by one's own safety data. Responding to every problem is not feasible, nor is it effective management of resources.

A strategy of building a safety database with data that is well defined and understood can provide both near-term and long-term benefits. In addition to pointing to immediate corrective actions, the data can eventually become the basis for making risk-based management decisions, and developing more relevant safety metrics and monitoring tools. Perhaps most important in maintenance — where errors may be invisible — is the fact that a reporting culture will encourage revealing errors that could otherwise remain hidden, unexpected hazards.♦

References

AECMA (Association European des Constructeurs de Materiel Aerospatial). Simplified English: A Guide for the Preparation of Aircraft Maintenance Documentation in the International Aerospace Maintenance Language. AECMA Document: PSC-85-16598.

Boeing. *Statistical summary of commercial jet aircraft accidents*. Seattle, WA, 2003.

Chapparo, Alex, and Groff, Loren S. "User Perceptions of Aviation Maintenance Technical Manuals." In *Proceedings of 16th Symposium on Human Factors in Aviation and Maintenance,* San Francisco, CA, 2002.

Civil Aviation Authority. CAP 716, *Aviation Maintenance Human Factors* (EASA/JAR145 Approved Organisations) Guidance Material on the UK CAA Interpretation of Part-145, Human Factors and Error Management Requirements, 2003. <www.caa.co.uk>.

DOE Standard**,** *Writer's Guide for Technical Procedures*, DOE-STD-1029-92.

Drury, Colin G., Saran, A. and Driscoll, David M. "Documentation design aid development." Chapter 4 in *Human Factors in Aviation Maintenance, Phase 8: Progress Report*, DOT/FAA/AM-97XX. Springfield, VA: National Technical Information Service, 1997. <http://hfskyway.faa.gov/jobaids.htm>.

Hall, David A. "Aviation Maintenance Documents and Data in the United Kingdom." In *Proceedings of 16th Symposium on Human Factors in Aviation and Maintenance*. San Francisco, CA, 2002.

Hobbs, Alan and Williamson, Anne. *Aircraft Maintenance Safety Survey: Results*. Canberra: Australian Transport Safety Bureau, 2000.

Hobbs, Alan and Kanki, Barbara G. "Correspondences between Error Types and Incident Circumstances in ASRS Maintenance Reports." In *Proceedings of the 12th International Symposium on Aviation Psychology*. Dayton, OH: Wright State University, 2003.

Hobbs, Alan and Williamson, Anne (2003). "Associations between errors and contributing factors in aircraft maintenance." *Human Factors*, 45, 2003, 186–201.

IATA Annual Safety Report, 2003.

Killion, Tim and Bongard, Jeff. "Document Challenges in Repair Station Environments." In *Proceedings of 16th Symposium on Human Factors in Aviation and Maintenance*. San Francisco, CA, 2002.

Levin, Alan. "Fewer Crashes Caused by Pilots." *USA Today*, March 1, 2004. <www.usatoday.com/travel/news/2004-03-01-crash_x.htm>.

Levin, Alan. "Accidents Caused by Maintenance." *USA Today*, May 20, 2005. <www.usatoday.com/news/nation/2003-12-22-maintenance-table.htm>.

Luxhoj, James T. "Risk Analysis of Human Performance in Aviation Maintenance." In *Proceedings of 16th Symposium on Human Factors in Aviation and Maintenance*, San Francisco, CA, 2002.

Munro, Pamela A. and Kanki, Barbara G. "An Analysis of ASRS Maintenance Reports on the Use of Minimum Equipment Lists." In *Proceedings of the 12th International Symposium on Aviation Psychology*. Dayton, OH: Wright State University, 2003.

McDonald, Nick, Corrigan, S., Daly, C., and Cromie, Sam. "Safety management systems and safety culture in aircraft maintenance organisations." *Safety Science*, 34, 151–176. 2000.

McGreevy, Michael W. "A Practical Guide to Interpretation of Large Collections of Incident Narratives Using the QUORUM Method." *NASA Technical Memorandum 112190*. Moffett Field, CA: NASA, 1997.

Munro, Pamela A., Kanki, Barbara G. and Jordan, Kevin. "Reporting discrepancies: An assessment of the informational needs of airline pilots and mechanics." In *Proceedings of the Safety Across High-Consequence Industries Conference*. St. Louis, MO: St. Louis University, 2004.

National Transportation Safety Board. Aircraft Accident Report: *Britt Airways, Inc., d/b/a Continental Express Flight 2574, In-flight Structural Breakup, EMB-120RT, N33701, Eagle Lake, Texas, September 11, 1991*. NTSB/AAR-92/04, PB92-910405. Washington, D.C., 1992.

National Transportation Safety Board. *Aircraft Accident Report: Loss of Pitch Control During Takeoff, Air Midwest, Flight 5481, Raytheon (Beechcraft) 1900D, N233YV, Charlotte, North Carolina, January 8, 2003*. NTSB/AAR—04/01, PB2004-910401. Washington, D.C., 2004.

Patankar, Kirsten, Lattanzio, Diane, Munro, Pamela and Kanki, Barbara G. "Identifying Procedural Errors in ASRS Maintenance Reports using MEDA and Perilog." In *Proceedings of the 12th International Symposium on Aviation Psychology*, Dayton, OH: Wright State University, 2003.

Patankar, Kirsten., Lattanzio, Diane and Kanki, Barbara G. "A content analysis of representative procedural errors in ASRS maintenance reports." In *Proceedings of the Safety Across High-Consequence Industries Conference*. St. Louis, MO: St. Louis University, 2004.

Rankin, William L. and Sogg, Steven L. "Update on the Maintenance Error Decision Aid (MEDA) Process." Paper presented at the MEDA/MEMS Workshop and Seminar, May 21–23, 2003. Aviation House, Gatwick, England, 2003.

Reason, J. *Managing the risks of organizational accidents*. Aldershot, England: Ashgate, 1997.

Schmidt, John K., Schmorrow, D. and Hardee, Michael. *A preliminary human factors analysis of naval aviation maintenance related mishaps*. SAE Technical Paper 983111. Warrendale, PA: Society of Automotive Engineers, 1998.

Schmidt, John, Lawson, Donald and Figlock, Robert. "Human Factors Accident Classification System Analysis of Select National Transportation Safety Board Maintenance Related Mishaps." In *Proceedings of 16th Symposium on Human Factors in Aviation and Maintenance*. San Francisco, CA, 2002.

Seamster, Thomas and Kanki, Barbara G. "Human Factors Design of Electronic Documents." In *Proceedings of the 13th International Symposium on Aviation Psychology*. Oklahoma City, OK: Wright State University, 2005.

Taylor, James C. and Thomas, Robert L. "Written Communication Practices as Impacted by a Maintenance Resource Management Training Intervention." *Journal of Air Transportation*, Vol. 8, No.1, 2003. pp. 69–90.

About the Author

Barbara Kanki, who received a Ph.D. in behavioral sciences at the University of Chicago, has been a research psychologist in human factors at the NASA Ames Research Center for nearly 20 years. She conducts crew factors research in both aviation and space systems, specializing in the analysis of work group dynamics, and the role of organizational risk factors.

From her original work in flight crew resource management, she has extended a human-centered approach to the maintenance and inspection domain, and since 2000, has managed the maintenance human factors tasks within the NASA Aviation Safety and Security Program.

Dr. Kanki has overseen projects that focused on maintenance error management, maintenance resource management, risk and task analysis, advanced displays and procedural improvements. On many of these topics, she has also participated in industry and FAA working groups, consulted on accident investigations and space shuttle assessments, and maintained collaborative relationships with other high-risk, complex operations such as nuclear power, medical teams and fire fighting.

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The Role of Human Factors Training and Error Management in the Aviation Maintenance Safety System

David Hall
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Safety and the Maintenance System

The aviation maintenance system is required to reliably produce airworthy aircraft for service, and at a cost that provides for sufficient profit for the business to continue. The system is heavily dependent upon people performing as the system designers intended. The challenge — in the face of increasing maintenance errors, financial insecurity within the industry and the airline's increasing demands for cost reduction — has been how to make a reliable system from such unreliable components.

The maintenance system is designed and controlled by Managers to achieve two objectives. The first is to have a system that will efficiently meet production objectives. The second is to comply with the requirements. Without meeting these two objectives, a company ceases to exist by virtue of going bankrupt or having its approval revoked by the Regulatory Authority. In spite of public statements, safety is rarely a primary objective of a company. It exists to make money; it does not exist to be safe. Safety is one of many competing objectives with the potential to do harm if mismanaged. The probability of an airline having a maintenance related accident is, and always has been, extremely remote. It is true to say that an airline or maintenance organization is more likely to cease trading due to financial or regulatory compliance reasons than an accident. Faced with the foregoing, it is not surprising that the maintenance system is weighted in favor of minimizing cost, maximizing profit and complying with the requirements. Very few Chief Executive Officers have lost their jobs due to an aircraft accident. However, many have lost their jobs due to the financial underperformance of their companies.

The Board of Directors, in almost real time, knows the financial and regulatory compliance state of their company. Both of these activities are closely managed and tightly controlled. On the other hand, maintenance safety data is often poorly collected and therefore unable to be analyzed in any meaningful way. The result is that the safety health is rarely known by an organization and every maintenance incident comes as a complete surprise.

A few years ago, the reality of the relationship between an organization's finances and safety was brought home to me. An Operator had spent significant resources on developing and implementing a Safety Management System (SMS), although not required by the regulatory agency. It was at the time undergoing "due diligence" as part of being sold to another airline. They were prepared to sell the company if a certain share value could be agreed. In order to reduce its overheads and increase the value of the company, it dismantled its SMS and made redundant the staff involved. The stark reality was that the company was worth more without a Safety Management System than it was with one.

The Maintenance System as a Compliant and Efficient Process

The maintenance system is designed and controlled by managers within the organization. They design it to be an efficient way of performing maintenance and to meet the requirements of the National Aviation Authority. Any additional processes will come under scrutiny to ensure that they add to efficiency or do not conflict with the requirements. "Good ideas" rarely get implemented without financial and regulatory justification. If they do, they do not survive. We saw in the 1990s progressive business processes such as Total Quality Management

Systems (TQM) and Business Process Re-engineering (BPR), etc., imported into the aviation domain from non-safety-critical industries. As a result of these, and others, many safety-adding processes and Maintenance Program tasks were stripped out. These processes and tasks were often the results of lessons learned after “near miss” incidents or common sense safety precautions. Unfortunately, when specific targets of, say, a 20 percent cost reduction in maintenance are set for the program objectives, they are difficult, or impossible, to justify. The business processes demand that the technical expert demonstrate why the process or task should be included, not the manager to justify why it should not. We appear to have learned nothing from the Challenger Space Shuttle accident, where the technical experts were required to justify why the launch should be postponed instead of the program managers justifying why the Shuttle should be launched.

Today, as a result of new business processes, we have a very efficient system of maintenance, approved by the NAA as meeting the requirements, and supposedly operated by the organization in accordance with the approved procedures.

The Maintenance System as a System of Safety

In the early days of aviation, safety was assured through the competence of the individual. He was examined and licensed such that he could make the determination that an aircraft was airworthy. This principle was sound until such times as the aircraft became too large and sophisticated for a person to do this. In the early 1950s, it became impossible for an individual to assure safety; it now required a system of maintenance and airworthiness control to do this. It can now be said that the Technical Records clerk inputting flying hours into a computer is just as critical to safety as the Technician with a flashlight and a wrench. The maintenance system is complex and largely opaque to the individual. The importance of performing tasks in a certain manner and in a prescribed sequence are not obvious, as he or she does not have full knowledge of the system and the way it interacts with other parts of the system.

People have always made mistakes. It is, after all, part of being human and intrinsically fallible. Those who design the maintenance system normally cater for these within the safety system by such things as performing second inspections, tagging equipment, requiring a written handover log, providing training, or making some tasks physically impossible to be done incorrectly. However, the one thing that is always assumed is that the people will follow the procedures. If people do not do things in the way that the system designer intended and described in the procedures or Maintenance Data, then safety is no longer assured. In these circumstances, we have effectively handed safety assurance back to the individual who we know does not know the risks associated with violating the procedures.

It is interesting to ask Technicians and Managers what their role is and the purpose of procedures with respect to the maintenance system. Managers will tell you that they design a system, describe it in procedures and expect them to be followed. The Technician will tell you that he is responsible for ensuring that the aircraft is safe when it is released to service and will follow procedures except when he thinks it is safe to deviate from them. “I wouldn’t work around a procedure unless I thought it was safe,” he will tell you. He believes he is an expert and does not need to slavishly follow procedures; that is why he has a license — to attest to his competence. He still believes that he is responsible for safety assurance, not the system.

The maintenance system, as approved by the NAA, is also our safety system but is fundamentally flawed.

The safety system assumes three things:

- The requirements cover all activities such that safety is assured;
- The procedures describing the organization’s safety system meet the requirements; and,
- The procedures will always be followed by the maintenance personnel.

Safety assurance is solely based on an assumption that the requirements are comprehensive, that procedures exist to cover all safety related activities and that people would follow the procedures. The first two points are safety assurance system weaknesses inherent in having prescriptive requirements rather than objective based requirements. This paper does not attempt to debate the relative strengths of the two philosophies; rather, it accepts that the vast majority of aviation requirements consist of prescriptive codes and that this is unlikely to change. However, the assumption that procedures and rules are always followed is flawed and needs much greater debate.

The fact is that people routinely do not follow all procedures. It is for this reason that Quality audits and maintenance incident investigation invariably determine that the procedures are inadequate and violations of those that do exist have occurred. The typical reaction to such an audit finding or maintenance incident is to amend or write another procedure and administer some sort of warning to the erring staff to follow the procedures. At some point, we will have to realize that the procedures do not reflect the way that maintenance is normally performed and procedural violations are routine, as the work force works around the rules to meet the production goals.

It is against this backdrop that human factors programs have developed. We now have over 17 years of maintenance human factors research and implementation, but all the indications are that maintenance errors and their effects are not diminishing as we all expected. To understand why this may be, we first have to understand the maintenance system itself and then how the training and error management techniques have been applied in practice.

History of Human Factors in Maintenance

In April 1998, we were all shocked by the Aloha B-737 accident that exposed the weaknesses and fragility of the maintenance system. From this time, human factors became a key area of focus for maintenance related accident prevention. The principle strategies employed were error management and human factors training.

The ICAO Flight Safety and Human Factors Study Group report in 1995 resulted in changes to Annex 6 of the Chicago Convention. ICAO published this change in November 1998. Training in maintenance human factors was made a Standard for the signatories of the Chicago Convention to adopt and embed in their national requirements. This amendment to the Standards and Recommended Practices (SARPs) was a significant change, but ICAO gave no practical guidance on the subject. As a result, many National Aviation Authorities have struggled with how to achieve compliance with this new subject that was little understood by them and their industry. Even now, many countries still do not require their industry to perform human factors training within the maintenance organizations, a full seven years after the published changes.

The history of error management in maintenance is different from the requirement for training. It was born out of the FAA research conducted after the Aloha accident and Boeing's desire to prevent their aircraft being involved in a maintenance related accident. The result in 1992 was MEDA (Boeing Maintenance Error Decision Aid), a tool to investigate maintenance errors from a human perspective rather than a technical one that had historically been performed. By 1996, the U.K. CAA was promoting its adoption by its industry as it struggled to find solutions to a series of maintenance related near accidents (ref AAIB reports AAR 1/92, 2/95, 3/96); and by 2000, it had declared a formal policy that it expected maintenance organizations to adopt the principles pending a formal requirement. In Europe, the JAA amended JAR 145 in January 2003 to include requirements for Human Factors training and an Occurrence Management System.

Maintenance Error Management Programs

We understand that errors will naturally occur in any system and the rate by which they occur can be influenced by the design of the system. A badly designed system will provoke more errors than a well-designed system.

The goals of error management are therefore twofold:

- To understand the underlying causes of error and then to change, or "harden," the system to prevent recurrence; and,

- To provide the system with data such that the safety health of the organization can be made.

The Maintenance Error Management Systems, such as MEDA and others, work well in investigating and fixing the honest, or "system induced," errors. These are the mistakes made by well-intentioned, competent people where the system provoked them into making an error. This part of the process works well, but the full intent of the programs is not being achieved due to the following:

- Organizations are more concerned with fixing their immediate problems than stopping future, system induced problems from occurring. An analysis of multiple events is frequently not carried out; therefore, it is assumed that the contributing factors are random rather than a much wider system induced problem.

- Investigators are trying to fix problems by addressing the immediate causal factors and not confronting the deeper-rooted organizational and latent failures — for example, providing additional lighting or amending a procedure, rather than tackling the deeper issue of why there was insufficient staff or an unrealistic deadline given by management.

- Procedural violations and at-risk behavior are significant contributing factors but are not adequately captured to enable analysis.

- The causes of violations and at-risk behavior are not investigated.

Discipline is determined by the severity of the outcome, not the behavior of the person — for example, omitting to check an oil filler cap is fitted, resulting in an in-flight shutdown, will result in greater punishment than omitting to check the cap that does not result in an expensive air turn-back.

Most error management tools in use by maintenance organizations are designed to effectively manage errors, not violations. They fail to adequately address at-risk behavior and procedural violations. These two areas have since been found to play a far more prominent role in maintenance mishaps than first thought in the early 1990s, when the tools were being developed. Anecdotal evidence drawn from the results of error management programs within organizations in the U.K. suggests that procedural violations and at-risk behavior are a contributing factor in approximately 80 percent of maintenance errors. When tools such as MEDA were being developed, it was assumed that Mechanics and Technicians were all good people who know the rules and therefore that maintenance mishaps simply had to be due to things outside of their control. That is to say, that the system itself provoked them into making the mistake.

Human Factors Training

A common understanding, or agreement, on the goal of human factors training has never been achieved and has resulted in confusion, both within industry and the regulatory communities. Initial thoughts on Human Factors training for maintenance personnel were based on a belief that communication and teamwork were the issues that required addressing. This was something akin to Crew Resource Management that was being provided to Flight Crew. Early Human Factors training therefore focused on providing the communication and teamwork skills in an attempt to reduce errors. This then evolved into training that provided knowledge on why we make mistakes and gave tips on personal strategies to prevent us from making them again. We now know much more about what contributes to maintenance errors, and the reasons are much wider than originally thought, and that people cannot easily avoid making mistakes that were never intended.

However, many organizations still believe that if it is people who make errors, all they need to do is to give them human factors training, and they will not make mistakes in the future. Training mechanics and technicians on teamwork or why they make mistakes will have very little effect on them making mistakes in the future. As discovered during the early years of the “Demming” quality initiatives, approximately 95 percent of the problems are rooted in the inadequacies of the system, over which the individual workers have no control. Most organizations are therefore putting the emphasis on training the mechanics and technicians, rather than the managers that design and control the maintenance system and who can make the necessary changes. Managers need to understand that they play a very significant part in why errors are made and procedures are violated. Knowledge with respect to human and organizational factors is far more appropriate to them than to the work force, given that they are responsible for designing a reliable system of maintenance. If given a choice of training the managers or the work force, I would contest that educating the managers would make a greater safety and efficiency gain. A system that employs good human factors principles would have a far greater effect than educating the work force on avoiding error traps that management have set them. The goal of Human Factors training should therefore be to educate all personnel within the maintenance system such that the best human factors principles are applied.

Summary

The maintenance safety system is not as inherently robust as we would like to believe. It is also under considerable financial and commercial pressure, such that safety and production are competing for the resources, with non-mandatory, safety adding efforts normally losing out. The weakness was assumed to be that people perform unreliably due to system induced errors. It relies on people following procedures, but it would now appear that procedural violations are a threat that is not being managed.

The Error Management Programs and Human Factors training that would provide a positive improvement are not being applied in the way that they need to, and the benefits we hoped for are therefore not being achieved.

Error management tools are being used, although not in an optimum fashion. Data that should flow back into the system to be used to measure the safety health of an organization is frequently not being collected.

Maintenance Human Factors training has evolved since the early 1990s, and we no longer have agreement on what its objectives are.♦

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New Capabilities for Weather Accident Prevention

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Introduction

In February 1997, a U.S. goal was established to reduce the fatal accident rate for aviation by 80 percent within ten years. An Aviation Safety Investment Strategy Team was created by the National Aeronautics and Space Administration (NASA) to define research needs and the relative priority of each based on technology readiness and potential impact on safety. Weather is a causal factor in 30 percent of all aviation accidents, and weather accident prevention was identified by the Strategy Team as a key area to be addressed. The following areas were assigned high priority for research and development: weather data dissemination; crew/dispatch/air traffic control monitoring, presentation and decision aids; weather product generation; advanced aviation meteorology; and turbulence hazard solutions.

In April 1997, the U.S. National Aviation Weather Program Council issued a strategic plan[1] that was followed in 1999 by the definition of National Aviation Weather Initiatives.[2] Research and development areas designated for NASA included multi-functional color cockpit displays of weather hazards; cockpit-oriented weather products; flight information services and communications systems; quantification of hazards; and satellite-based, ground-based, and aircraft-based forward-looking technologies for hazard sensing.

The Federal Aviation Administration (FAA) launched its Safer Skies Focused Safety Agenda in 1998 to address the U.S. aviation safety goal. Weather was identified as a top-priority cause of fatal general aviation (GA) accidents. A government and industry GA Weather Joint Safety Analysis Team (JSAT) was created, followed by a GA Weather Joint Safety Implementation Team (JSIT), to address accident causes and potential interventions.[3] A principal recommendation was "Provide more accurate and precise graphical depictions of the location of weather hazard areas, through improved weather forecasts, pilot weather reports and weather observations. Effectively deliver this information to pilots on the ground and in the air, to controllers, flight service station (FSS) specialists and dispatchers."

NASA established an Aviation Safety Program (AvSP), re-designated Aviation Safety and Security Program (AvSSP) in 2004, to develop technologies needed to help the FAA and the aviation industry meet the national safety goal. Within the AvSSP, a Weather Accident Prevention Project has developed new capabilities to reduce weather-related accidents. Many of these accidents have been attributed to a lack of weather situation awareness by pilots in flight. Improving the strategic and tactical weather information available and its presentation to pilots in flight can enhance weather situation awareness and enable avoidance of adverse conditions. Over the past seven years, capabilities have been developed for cockpit presentation of graphic weather information, for turbulence prediction and warning, for automated airborne in-situ weather reporting and for data linking of weather information between airplanes in flight and providers and users on the ground. This paper describes these capabilities for airborne detection, dissemination and display of weather information developed by NASA in partnership with FAA, National Oceanic and Atmospheric Administration (NOAA), industry and the research community. Additional information on the technologies developed to enable these capabilities can be found in Refs. 4-6.

Cockpit Weather Information Systems

The history of transport aircraft safety improvements has been studied by Huettner,[7] who sees the information technology revolution as offering the next opportunity for major reductions in accident rates. He notes that aviation weather is the one major variable that is not within the control of technology or aviation system planners. In his view, the optimal weather information system would tell pilots only what they need to know, allow them to go as close to hazardous weather as possible for maximum efficiency of flight, and yet not subject the aircraft or its passengers to hazardous or undesirable conditions. The end objective would be real-time strategic and tactical weather information that could be used to separate aircraft from hazardous weather in the same way that they are separated from other aircraft today. Ritchie[8] has noted that, “Deteriorating weather conditions are frequently the cause of changes in flight objectives. The pilot needs to know quickly where the weather is better and what to do to get there.”

At its simplest, an aviation weather information (AWIN) system (Figure 1) consists of weather products, a means for distributing the products to the users and a means to present the information to the users. However, pilots need more than just weather information for in-flight decision making. This includes aircraft capabilities, such as the ability to fly over weather or through icing conditions; pilot capabilities, such as the ability to fly in instrument meteorological conditions; and information on flight-path-relevant terrain, obstacles, airspace restrictions and traffic. Data links are needed to exchange information between airplanes and ground stations. Aircraft-to-aircraft links may be needed for timely exchange of in situ weather reports. Information from on-board sensors may be passed to ground-based weather systems for incorporation in updated forecasts and reports that can be subsequently transmitted to aircraft in flight. Data-link weather information systems are intended to provide information for long-term strategic planning and to augment on-board sensors such as weather radar and lightning detectors. The timeliness, accuracy and presentation of cockpit weather information need to support decisions that result in safe and efficient actions.

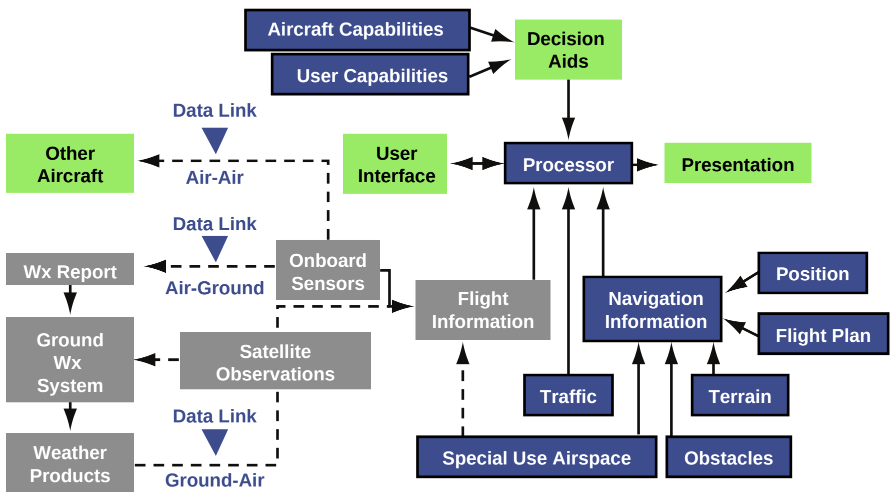

Figure 1. Block diagram of aviation weather information system.

Requirements for weather information systems reflect the needs of the various aviation communities. Transport and business aircraft usually have very capable avionics suites, have the ability to fly over or through many types of adverse weather and are flown by two professional pilots. Low-end GA airplanes and rotorcraft are typically flown by a single non-professional pilot and operate at lower altitudes in the weather. Commuter and regional aircraft share some characteristics of transports and some of GA airplanes — they have two professional pilots, but often operate at lower altitudes in the weather. Both installed and portable weather display technologies have been evaluated to meet the needs of the different user groups. NASA efforts have addressed national data-link weather information capabilities for GA, and both national and worldwide capabilities for transport aircraft.

Results of a market study[9] indicated cockpit weather systems are a viable product concept with strong business cases in the transport, commuter, and business markets. In the GA and rotorcraft market segments, the business cases were sensitive to variations in cost and savings estimates; however, improved safety alone was found to be sufficient motivation for the GA and rotorcraft segments to adopt the technology. Building on the prior work of Crabill and Dash,[10] Georgia Tech Research Institute (GTRI) performed a study for NASA to establish weather information needs by category of user and phase of flight in support of both strategic and tactical decisions.[11] The study also defined aviation weather sensor capabilities and needs for hazard avoidance.

In 1998, building on knowledge gained from studies in the early 1990s of prototype data-link cockpit weather information systems for transports (Cockpit Weather Information System[12,13]) and GA aircraft (Pilot Weather Advisor[14,15]), NASA initiated cooperative research efforts with industry-led teams to "jump start" the development and implementation of AWIN systems for both transport and general aviation operators. The operational capabilities of these end-to-end systems were demonstrated through prototypes and in-service evaluations with teams led by Boeing and Honeywell for worldwide transport operations and ARNAV Systems and Honeywell-Bendix/King for U.S. national general aviation operations. These "first generation" systems utilized existing weather products reformatted for data link and display in the cockpit.

General Aviation Cockpit Weather Information Systems

Building on the NASA GA cooperative research efforts, Honeywell-Bendix/King has partnered with the FAA to create a Flight Information Services Data Link (FISDL)[16] system that provides data-link weather nationwide in the U.S. This FISDL system achieved operational status in early 2002.[17]

Various factors related to the implementation and use of data-link cockpit weather information systems have been studied through surveys, simulation and flight tests. Pilots have been surveyed to characterize what sources of pre-flight and in-flight weather information are used most and the desirability of various weather products for pre-flight and in-flight use.[18] Business jet pilots,[19] who have an excellent safety record, have been studied to determine how they access weather information and use it to make decisions.

Experiments have investigated textual and graphic weather information presentation formats and the effects on pilot navigation decisions.[20–22] Results of these studies supported the need to display the airplane's position as part of graphic weather depictions; to provide an indication of distance or range; and to present the age of the weather information rather than the time of creation. The resolution of the graphic depictions of data-linked next generation radar (NEXRAD) weather information was shown to affect pilot navigation decisions in adverse weather situations.[23] When resolution of NEXRAD images was increased, i.e. each pixel represented a smaller area, pilots were more likely to continue their flights with the expectation that they could fly around or between significant weather.

Sequential presentation of a series of NEXRAD images, commonly referred to as looping, has received considerable attention for indicating weather trends. Studies have explored design options and tradeoffs for in-flight weather looping products, compared looping with other weather trending presentations, and developed a new "aircraft looping" concept to compensate for the pilot's moving reference frame.[24,25] Trend information presented via looping of NEXRAD images and display of the National Convective Weather Forecast (NCWF) product have been found to provide a significant increase in situation awareness to the pilot with respect to location, proximity, and direction of movement of convective weather. However, over-reliance on the information presented by the data-link system at the expense of accessing more conventional sources of information such as FSS and automated surface observing systems (ASOS), was found to offset the improved situation awareness to the extent that decision making was no different with or without the cockpit weather display.[26]

A study of how well general aviation pilots detect convective weather in flight with different weather information sources[27–29] indicated that the best in-flight convective weather situation awareness might be achieved when pilots use all three weather sources (radio voice communication, out-the-window view, and data-link display) together. A flight experiment examining the effect of the location in the cockpit of a graphic weather information display (Figure 2) on the ability of general aviation pilots to access weather information[30] has indicated that a display mounted in the center of the instrument panel was most preferred, although all positions studied were acceptable. Overall, pilots were able to access weather information much faster via the data-link system than via voice transmissions from ground stations such as ASOS.

Figure 2. Prototype of AWIN display mounted to yoke of NASA C-206 research airplane.

Commercial Transport Cockpit Weather Information Systems

Honeywell International, in a joint effort with NASA, developed a Weather Information Network (WINN) capable of providing graphical weather information to the cockpit of commercial and business aircraft flying anywhere in the world. The network included airborne displays, airborne and ground-based servers, and multiple providers of weather products and data-link services. An open architecture was adopted to accommodate any kind of data-link technology. Both a satellite-based link and a terrestrial very-high frequency/ultra-high frequency (VHF/UHF) telephone link were evaluated. Several different types of weather information could be overlaid or viewed individually. Evaluations were performed with systems installed in a Citation business jet, a United Airlines B-777 flight simulator, NASA's B-757 transport research airplane (Figure 3) and a United Air Lines Airbus A320 (Figure 4). During the winter of 2001, United Air Lines conducted over 40 in-service evaluation flights with the WINN system incorporated in a prototype electronic flight bag (EFB). Aircraft position information was provided by a portable global positioning system (GPS). Weather products were delivered to the airplane via a GTE Airphone and included airport observations (METARs), terminal area forecasts (TAFs), ground weather radar reflectivity (NEXRAD), turbulence, significant weather cautions (graphic SIGMETs) and satellite cloud images. Information was displayed on a Fujitsu Pen Tablet. An average of 1 to 2 percent time savings (and thus cost) per leg was attributed to increased weather situation awareness. Based on these trials, a potential reduction in aircraft communications addressing and reporting system (ACARS) messaging traffic (and thus cost) of 40 to 50 percent was estimated.

Figure 3. Data-link weather display in cockpit of NASA B-757.

Figure 4. Data-link weather display on tablet computer in cockpit of United Airlines A320.

NASA has examined how data-linked weather information can best be used with other existing weather information available to pilots in flight. On-board radar, lightning detection systems, in situ reports from other aircraft and information from collaboration with ground weather briefers need to be combined effectively with the products delivered to the pilot via data-link. With a data-link weather information infrastructure in place, means need to be developed to help pilots search the information sources available, identify trends and changes affecting their flight, and make timely decisions to avoid hazardous weather.

Working with GTRI and Rockwell Collins, NASA has developed a prototype cockpit weather information system with the capability to combine information from both on-board sensors and data-links and to display graphical and textual weather information to the pilots. This Airborne Hazard Awareness System (AHAS) can automatically parse text and weather data, convert it to graphics, evaluate both tactical and strategic hazards in the weather data stream and provide alerts to pilots. Weather products include visibility, ceiling, winds, gusts, precipitation, thunderstorm proximity and severity, hail, icing, and turbulence. Satellite echo top data are correlated with NEXRAD attribute data to associate storm tops with storms in the NEXRAD data. Hazards assessed include proximity of SIGMETs en route, winds aloft en route, projected thunderstorm intercept, remarks from METAR stations along the flight plan, pilot reports (PIREPs) within a corridor of the flight plan, and crosswinds, ceiling and visibility at the destination airport. A sample tactical display is shown in Figure 5, and a sample strategic display is shown in Figure 6. The components of AHAS resulted from technologies developed through Enhanced Weather Radar[31] and Advanced Weather Awareness and Reporting Enhancements[32] cooperative research between NASA and Rockwell Science Center (now Rockwell Scientific).

Figure 5. Airborne Hazard Awareness System tactical display with combined presentation of on-board weather radar and data-linked NEXRAD.

Figure 6. Airborne Hazard Awareness System strategic display interface.

An Aviation Weather Information Display Study (AWIDS) conducted by GTRI, Rockwell Collins, and the University of Iowa used the AHAS to investigate the advantages of integrating the display of on-board weather radar with data-linked NEXRAD.[33] Weather radar information close ahead of the airplane combined with track-up data-linked NEXRAD imagery was compared to separate displays of on-board weather radar and north-up or track-up NEXRAD. Fourteen airline and business pilots participated in a part-task simulation using the B-737-800 simulator at the University of Iowa's Operator Performance Laboratory. The subjects were found to be more likely to make correct deviation decisions with the integrated display. Greater situation awareness, lower workload and ability to make weather decisions sooner were also attributed to the integrated display. Usefulness of the integrated display for avoidance of adverse weather was linked to the inclusion of such things as cloud tops in the NEXRAD information.

NASA-sponsored studies have investigated flight crew trust of the displayed weather information and the way that flight crews react as a team to displays of impending adverse weather. A simulation experiment conducted for NASA by Old Dominion University[34] investigated the influence of agreement or disagreement between on-board weather radar and data-linked NEXRAD displays, distance to adverse weather, and pilot flying on flight crew situation awareness, workload, and deviation decisions. Fifteen pilot-copilot crews flew a simulated route while reacting to weather events presented in two graphical formats on a separate display. Results indicated that crews trusted the on-board weather radar more than the data-linked weather information. When both systems agreed, the crews trust of the data-linked weather display increased. When the on-board and NEXRAD displays did not agree, the crews trusted the on-board radar more, but still used the NEXRAD to augment their overall situation awareness. Crews were more likely to make correct deviation decisions when the NEXRAD system depicted the impending adverse weather.

Implementation of Cockpit Weather Information Systems

Knowledge gained from NASA and industry research and development on cockpit weather information systems has been incorporated in related guidelines and standards. The RTCA has published Minimum Aviation System Performance Standards (MASPS) for Flight Information Services-Broadcast (FIS-B) Data Link[35] for systems used in the U.S. national airspace. The standards can be used by the FAA Flight Standards and Aircraft Certification Services to develop criteria for approval of FIS-B airborne equipment. Results have also been incorporated in FIS-B guidance included in FAA Advisory Circulars[36] and the Aeronautical Information Manual.[37] The FAA has also issued guidance on EFBs, including portable, attached, and installed devices.[38]

In the U.S., data-link cockpit weather information systems have now become a commercial off-the-shelf item, especially for general aviation. Numerous companies have formed alliances to combine weather information, communications and display technologies into systems to deliver weather information to the cockpits of general aviation airplanes. A variety of display devices and information delivery architectures are being employed to address the varied needs of GA operators. The June 2005 issue of *AOPA Pilot* magazine[39] noted, "Data link came to the handheld market a little more quickly than to panel mounts — simply because it's easier to bring the uncertified product into the cockpit. And the lure of graphics in the cockpit coupled with a reasonable cost to equip with a basic system has driven pilots to make the purchase of a data-link system their first major hardware buy since they invested in a handheld com or GPS." The *AOPA Pilot* article goes on to note that one manufacturer of both portable and panel-mount data-link, weather information systems has sold 2,000 units in less than three years. Not long after this article appeared, a handheld GPS receiver with color moving-map display and integral satellite-broadcast data-link weather display became commercially available. The FAA recently began implementation of a U.S. national universal access transceiver (UAT) network for provision of traffic and flight operational information, including weather, data-linked to the cockpit of equipped aircraft.[40] Initial weather products include text METARs, TAFs, and special aviation reports (SPECIs) and graphic NEXRAD precipitation maps. Despite the challenging financial conditions confronting U.S. airlines, one major carrier has indicated plans to begin equipping its fleet with EFBs showing data-link weather information by the end of 2005. Operational benefits of strategic avoidance of convective weather are a key justification for the equipage.

Turbulence Prediction and Warning Systems

Aircraft encounters with atmospheric turbulence are the leading cause of injuries to transport aircraft passengers and crews. The overall operational cost to the airline industry is estimated to be about $750 million/year.[41] NASA created a team to conduct turbulence modeling and simulation studies to understand the hazard imposed for commercial transport aircraft; to develop airborne systems, such as radar and lidar, for predicting turbulence ahead of the aircraft and displaying the level of hazard to the airplane, and to develop automated reporting of the hazard level when turbulence is encountered. These technology developments have resulted in airborne capabilities to provide turbulence information to flight crews with sufficient accuracy and timeliness to enable appropriate actions to be taken to prevent injuries and aircraft damage.

Cabin occupants who are seated with their seat belts securely fastened are rarely injured in turbulence encounters. A Cabin Turbulence Warning Experiment[42] utilizing the FAA Civil Aeromedical Institute's full-scale B-747 wide-body aircraft simulator (Figure 7, page 257), human passenger subjects, and active line-qualified flight attendants from three separate airlines established the time needed to secure the cabin. If the pilot receives a reliable turbulence alert, and announces a warning within 10 seconds, over 95 percent of the passengers and flight attendants can be securely seated within 110 seconds; thereby removing them from the risk of injury caused by a turbulence encounter.

Figure 7. FAA Civil Aeromedical Institute B-747 wide-body aircraft simulator.

Enhanced Turbulence Radar

NASA teamed with AeroTech Research, the National Center for Atmospheric Research (NCAR), the Research Triangle Institute (RTI), and Rockwell Collins for the development and validation of airborne turbulence hazard detection capabilities. Development was dependent on two factors. First, about 75 percent of turbulence encounters were found to occur near significant convective activity, even though the aircraft may have been out of the clouds.[43] Second, existing airborne wind shear radars possess reflectivity-detection and signal-processing capabilities that could be utilized at altitudes above 2,000 ft above ground level (AGL) to enable look-ahead turbulence detection and hazard prediction. A research airborne radar unit with initial turbulence detection algorithms was developed and subsequently flight tested on NASA's B-757 research airplane in late 2001.[44,45] Atmospheric conditions of past turbulence encounters that resulted in passenger or crew injuries were modeled and served as validation cases for this prediction technology.[46,47]

Atmospheric conditions were modeled and used in flight simulators to study the response of the NASA B-757 to various turbulence encounters. A turbulence encounter hazard severity level based upon root-mean-square (RMS) normal acceleration was correlated to items going weightless in the cabin, which is an indicator of potential passenger injury. The same atmospheric turbulence, however, will produce widely varying aircraft response depending upon aircraft type, weight, configuration and flight conditions. The range of flight capabilities (weight, altitude, airspeed) of large jet transports necessitated that a "hazard table" would be needed for each major aircraft type to accurately determine the hazard severity level associated with the radar-derived parameter of atmospheric turbulence, spectral width. During the spring of 2002, the NASA B-757 was used to test an airborne radar with a signal processor incorporating a turbulence prediction algorithm and internal radar parameter data logging capability. The research radar was evaluated in the vicinity of convective activity that produced atmospheric turbulence. The research radar unit contained special software for statistically predicting the atmospheric spectral width (deviation in Doppler velocities) using multiple radar antenna scans, computing the 757's anticipated response to the encounter using the hazard tables, and generating a near-real-time hazard level display at an on-board researcher console (Figure 8). For validation of this look-ahead turbulence hazard prediction capability, aircraft response measurement software was developed that used the acceleration at the airplane's center of gravity and other aircraft flight parameters to compute "truth" RMS normal acceleration.

Figure 8. Research radar console on NASA B-757 shown during a turbulence encounter.

The spring 2002 flight tests, which compiled 55 turbulence encounters, validated the research concepts and indicated that moderate-to-severe turbulence hazards to the aircraft could be predicted with 80 percent confidence and at least a

90 second warning time could be provided for radar reflectivity levels above 15dBz.[48] Hazard severity thresholds were determined that reflect when passengers should be seated, seat belts should be buckled and cabin equipment should be secured. To extend this capability beyond the B-757, a set of aircraft-specific hazard tables was developed using aircraft flight simulators for eight different commercial jet transports. This enables radar manufacturers and turbulence algorithm developers to relate the spectral width radar parameter to actual aircraft response. It has been estimated that implementation of these capabilities could provide a 50 percent reduction in turbulence induced injuries to passengers and flight attendants.[42,49]

During the latter half of 2003, the radar development team partnered with Delta Air Lines (DAL) for an in-service evaluation of a pre-production prototype airborne radar incorporating the enhanced turbulence mode. A Rockwell Collins WXR-2100 commercial airborne weather radar, that already had automated antenna multi-scan capability, was used. The radar was modified with updated algorithms for spectral width radar signal processing, a B-737-800 turbulence hazard table algorithm, a data bus flight parameter interface, a flash memory data logger, and a turbulence color display capability. The prototype radar unit received FAA certification and was installed on a DAL B-737-800 in 2004. This prototype Enhanced-Turbulence (E-Turb) Radar provides turbulence hazard prediction capability extending at least 25 nm ahead of the aircraft. Two levels of magenta are used on the radar display to indicate turbulence hazards — one based upon "ride quality" (light turbulence), and one based upon need to "secure the cabin" (moderate to severe turbulence). Reports from the DAL crews indicate that the accuracy and consistency of the encounter predictions, and aircraft response when turbulence could not be avoided, have resulted in confidence in the E-Turb mode. This in-service evaluation extends through September 2005. Figure 9 shows the E-Turb Radar components used for the DAL 737-800 in-service evaluation.

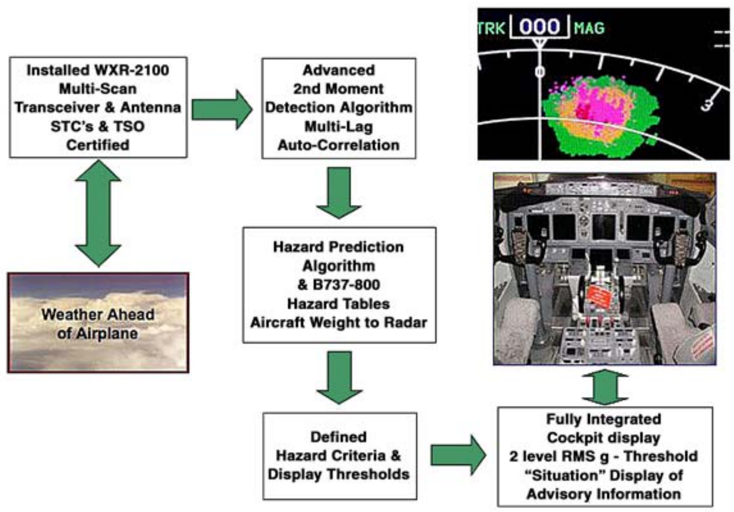

Figure 9. Block diagram of Enhanced-Turbulence Radar implementation for in-service evaluation.

Through June 2005, 416 events have been analyzed from data downloaded from the E-Turb Radar aboard the DAL 737-800. Of these, 46 events occurred with no radar display of predicted turbulence, but the aircraft experienced turbulence; 139 events occurred where the radar displayed regions of turbulence, but the aircraft did not penetrate the region; and 231 events occurred where the aircraft displayed turbulence and penetrated the region. Initial comparison of radar-predicted accelerations and measured accelerations for these 231 events indicates that the E-Turb Radar produces reliable predictions within a 95 percent confidence interval.

Infrared radar (lidar) uses reflected energy from natural aerosols to detect turbulence in much the same way that conventional weather radar uses reflection from atmospheric moisture to detect the presence of turbulence and dangerous weather conditions. Although lidar is attenuated by moisture, this technology has the potential to augment conventional weather radar to detect dangerous turbulence that occurs in clear air that is devoid of moisture. Beginning in 1998, a series of flight tests were conducted to assess lidar for turbulence detection.[50,51] Although the results were favorable, practical application to commercial aircraft will require system improvements to increase efficiency, increase detection range and reduce size.

A NASA-FAA-Industry Turbulence Certification Team was formed in 2000 to address FAA certification of turbulence prediction radar and to work issues in concert with the technology development. To reduce the cost and time for certification flight-testing, development of a certification-via-simulation process was undertaken. Four atmospheric data sets have been developed that depict actual turbulence encounters, two for the NASA B-757 aircraft, and two from documented accident cases of commercial transport aircraft.[47,49,52,53] A radar simulator, developed for the NASA Predictive Wind Shear System Project, was modified to interface with the four turbulence data sets and hazard table algorithm. An automated scoring package was also developed. The resulting capability enables a turbulence prediction algorithm to be tested via simulation of an airplane flight path through known atmospheric turbulence, and the output of the algorithm to be displayed and scored. A three-year project is now underway by the FAA to further develop E-Turb Radar certification standards and guidance.

Automation of Turbulence Encounter Reporting

Currently, turbulence encounter reporting depends primarily on PIREPs passed from the cockpit to controllers, briefers and dispatchers via voice communications. These "ride reports," however, do not produce consistent, accurate and timely reports of the location and severity of aircraft-encountered turbulence.

The airplane turbulence response algorithms developed for evaluating the E-Turb Radar performance provide a means to convert airplane response into an RMS normal acceleration level that can be communicated to other aircraft and, using a response algorithm for that airplane, converted into a relevant hazard level specific to the receiving airplane. These algorithms or "hazard tables" provide the basis for an automated turbulence encounter reporting system. Thresholds were established for triggering automated turbulence reports, and the resulting information was packaged into a message for automatic transmission to other airplanes aloft and to airline operations centers with sufficient timeliness to benefit turbulence avoidance decisions. This capability, designated Turbulence Automated PIREP System (TAPS), provides timely and accurate reporting of turbulence encounters and directly relates to the hazard metrics used to display turbulence detected by an enhanced-turbulence-mode radar. In the spring of 2002, TAPS capability was demonstrated by transmitting turbulence-encounter-generated information via a satellite communication research data link from the NASA B-757 to a ground station at the NASA Glenn Research Center. Figure 10 shows a time history of a turbulence encounter using the TAPS algorithm and the threshold levels for transmission from the aircraft.

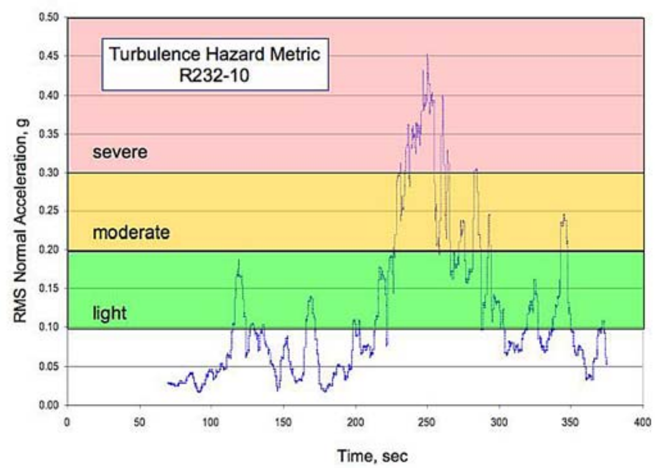

Figure 10. Time history of a turbulence encounter showing the threshold levels for reporting.

Beginning in 2004, in-service evaluation of TAPS was undertaken in partnership with DAL. By September 2004, the entire DAL fleet of 71 B-737-800 aircraft was TAPS-enabled and sending reports to the airline operations center. One of these airplanes is also equipped with the E-Turb Radar; therefore, for this airplane, TAPS is a significant aspect of radar performance validation for turbulence encounter and response prediction. During 2005, the TAPS-equipped fleet has been expanded to include some DAL B-767-300 and -400 aircraft that typically fly oceanic routes. Through June 2005, over 13,000 TAPS reports have been logged and analyzed.

WebASD, the display system utilized by the DAL dispatchers, was modified to display TAPS reports within its existing flight-following capabilities. All dispatchers within the DAL flight operations center (about 130) are participating in the evaluation of the system, which began in June 2005 and extended through September 2005. Dispatchers have been highly supportive of the accuracy and consistency of TAPS reporting. Inspection and maintenance personnel use TAPS to determine inspection needs right after significant encounters and schedule necessary resources at the airplane's destination site. Figure 11 (page 260) shows a system configuration of the TAPS for the in-service evaluation. Figure 12 (page 260) shows an actual WebASD display for a dispatch terminal.

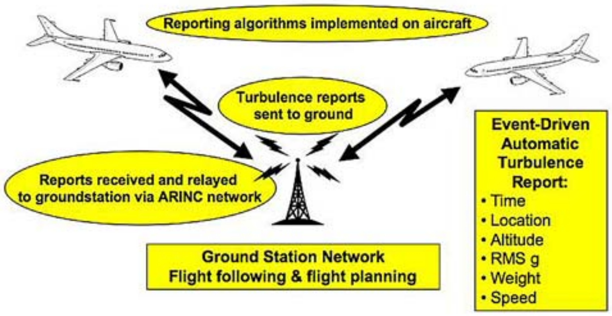

Figure 11. Turbulence Automated Pilot Report System configuration implemented for in-service evaluation.

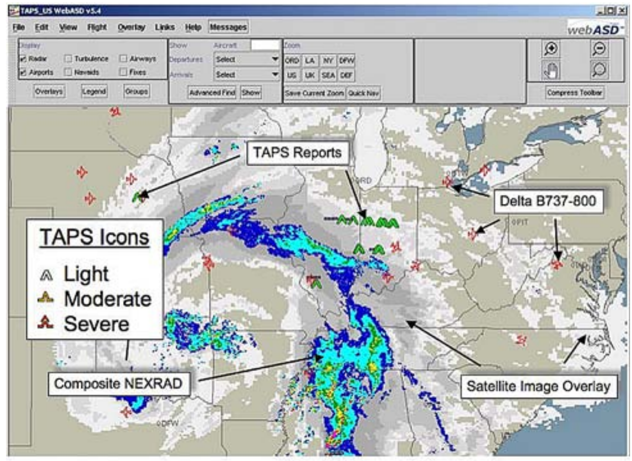

Figure 12. WebASD display showing turbulence reports.

Automated Airborne Weather Reporting

A key to safer and more efficient operations is knowing where the hazardous weather is (observations) and where it's going to be in the future (forecasting). Improved forecasting and dissemination of hazardous weather locations enable aircraft operators to strategically avoid atmospheric hazards such as icing, turbulence and thunderstorms, thus improving aviation safety, efficiency and mobility. Current ground-based and in-situ observations have significant voids in atmospheric observations. Most of the moisture, a key factor in hazardous weather development, is at altitudes below 25,000 ft., and existing observation systems provide few, sparse data in this region. Currently, the Meteorological Data Collection and Reporting System (MDCRS)[54] collects position, temperature and wind data transmitted to the ground from participating jet transport aircraft via ACARS and sends the information to the U.S. National Weather Service (NWS) for input to forecast models. Because these airplanes operate into and out of only about 60 major airports in the U.S., the atmospheric soundings are limited to these locations. At cruise altitudes, observations are high above most of the adverse weather. A few of these aircraft have also been equipped to report moisture and turbulence data.

Aircraft operating at the lower altitudes and serving smaller airports have the potential to make a significant contribution to improving weather products through the collection and dissemination of in-flight weather observations. Aircraft, such as those operated by regional airlines and package carriers, flying defined routes on a regular basis, appear to be the best candidates for airborne weather reporting. There are approximately 1,500 regional airline and 500 package carrier aircraft currently operating in the U.S. Business and other GA aircraft could be used to fill remaining voids in weather reporting. Implementation of an automated, in situ, airborne weather reporting system using these airplanes will require viable sensors and an extensive data-link communication network.

Tropospheric Airborne Meteorological Data Reporting

NASA has worked with the FAA, NWS, industry and research community to develop automated-weather-reporting capabilities for small aircraft.[55,56] A robust, compact, lightweight, low-cost, integrated sensor system, referred to as a Tropospheric Airborne Meteorological Data Reporting (TAMDAR) sensor, has been developed to automatically measure and report humidity, pressure, temperature, wind, turbulence, icing, and location from aircraft in flight. TAMDAR enables the use of smaller, lower-flying aircraft as airborne sensor platforms to generate in-situ measurements, provides the capability to make observations at all flight altitudes and significantly increases the quality and coverage, both temporal and spatial, of atmospheric observations, thus enabling improvement in the accuracy of hazardous aviation weather identification and its avoidance for safety of flight. The prototype sensor has been evaluated in flight against established atmospheric measurement systems on airplanes operated by the University of North Dakota, NOAA, U.S. Navy and NASA. Communications architectures and technologies have also been developed for distribution of data to the NWS, FSS and other aircraft in flight. Most recently, Mesaba Airlines' fleet of Saab 340s has been equipped with the TAMDAR system for a 12-month operational evaluation and scrutiny by the "weather community."

The sensor (Figure 13) consists of a probe (external to the aircraft) and an attached signal processing unit. The probe body has the shape of a symmetric airfoil with span of 4.05 inches and chord of 2.6 inches. Dynamic pressure, sensed via a port protruding from the leading edge, and static pressure, sensed via a port located on the trailing edge of the sensor body, are used to compute indicated and true airspeed. An additional algorithm computes eddy dissipation rate (an aircraft independent measure of turbulence).[57] A flow tube directs air into a sensing cavity containing an air temperature sensor and two relative humidity (RH) sensors. Airflow from the sensor cavity is discharged through holes (four on each side) near the base of the sensor. A leading edge notch incorporates two pairs of infrared (IR) transmitters and detectors for ice detection. A built-in GPS provides time, latitude and longitude for each observation and provides the ground track, which is used with externally provided heading information to calculate winds aloft. The signal-processing unit computes derived parameters from basic measurements. These data are then formatted and output to a data-link transceiver. The signal-processing unit can be updated with new algorithms, sampling rates or calibration constants via the data link. The electrical connections to the aircraft include power for the sensors and signal processor, power for the deicing heating elements, signals to and from a dual GPS/data-link antenna and an output from the aircraft heading sensor.

Figure 13. TAMDAR sensor showing probe body (top) and attached signal processor unit (box at bottom).

All observation intervals are based on static pressure (altitude) with a timed default. This observation protocol is a modification of ARINC 620 Version 4, which is being standardized by the World Meteorological Organization (WMO) Aircraft Meteorological Data Relay (AMDAR) Panel.[58] A time default for observation intervals ensures periodic reports during cruise when there is no significant change in measured ambient pressure. If a report has not been transmitted for a default period of 15 minutes, then a report is transmitted. Special observations are triggered by an icing onset.

Great Lakes Fleet Experiment

An operational evaluation of TAMDAR capabilities, referred to as the Great Lakes Fleet Experiment (GLFE),[59,60] started in January 2005 and runs through January 2006. TAMDAR sensors have been installed on 63 Mesaba Airlines Saab 340 turboprop aircraft (Figure 14, page 262) flying in the Great Lakes region of the U.S. Each day, these aircraft make over 400 flights to 75 airports and provide more than 800 soundings for a total of over 25,000 daily observations in the region shown in Figure 15 (page 262). These observations are significant when compared with the approximately 100,000 daily MDCRS observations of wind and temperature over the entire contiguous U.S.

Figure 14. Mesaba Airlines Saab 340.

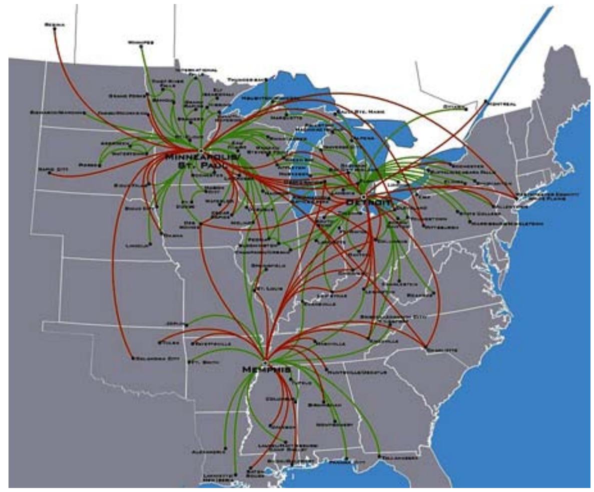

Figure 15. Mesaba Airlines routes in region of U.S. covered by Great Lakes Fleet Experiment.

Forecasters at NWS forecast offices and researchers at the Forecast Systems Laboratory (FSL) are using TAMDAR data and evaluating its impact on weather forecasts. NWS forecasters generate Area Forecast Discussions and special reports to document cases in which the GLFE data make a notable difference in their forecast decisions. Direct comparisons are being made between wind, temperature and humidity data from TAMDAR and from radiosondes. The University of Wisconsin transportable sounding team[61] has conducted atmospheric soundings at Memphis International Airport for comparison with data from TAMDAR-equipped airplanes operating into and out of Memphis. TAMDAR data are also being used for assessment of impact on performance of the Rapid Update Cycle (RUC) aviation weather forecast code.[62,63] Two identical versions of the RUC are being run, one using TAMDAR data and one not. The resulting forecasts are then compared with observations from radiosondes and wind profilers to assess the benefits of incorporating TAMDAR data. During the GLFE, Mesaba pilots are completing PIREP forms to note time, flight phase, altitude, location, temperature, icing state, cloud tops, turbulence, in/out of cloud, and precipitation type for comparison with TAMDAR observations. Researchers at NCAR are analyzing these reports as part of a Real Time Verification System.[64] Researchers at NCAR are also evaluating the impact of TAMDAR data on the Current Icing Potential (CIP) algorithm,[65] the prediction of convective precipitation, short-term forecasts of convection,[66] and on precipitation forecast skill. Using the University of North Dakota Cessna Citation atmospheric research airplane, NCAR is performing an evaluation of the TAMDAR turbulence reporting algorithm and comparing it with other methods of reporting eddy dissipation rate (EDR) as a measure of turbulence.[67]

Weather Information Communication

Weather information communications allow the sharing of data and information between the ground and air domains and information transfer between aircraft. Figure 16 (page 263) depicts the data-link development approach used in accomplishing the communications technology improvements to date and the representative communications links. Communications requirements and associated data-link architectures optimal for the delivery of graphical weather products to GA and commercial-air-transport cockpits have been investigated.[68,69,70] These studies established current, mid-term (2007) and long-term (2015) weather communications needs and resulting requirements. Through a NASA cooperative research agreement with Honeywell International, a VHF Data Link Mode 2 (VDLM2) data link operating in the aeronautical VHF frequency band was demonstrated with broadcast data rates up to 31.5 Kbps. Under contract to NASA, ViGYAN developed a satellite-based aviation weather information system known as the Pilot Weather Advisor to broadcast text and graphical weather information to aviation users at any altitude, anywhere in the U.S. NASA also investigated the use of state-of-the-art satellite digital audio radio systems (SDARS) for delivery of weather information. Recently XM Radio and Sirius have begun offering U.S.

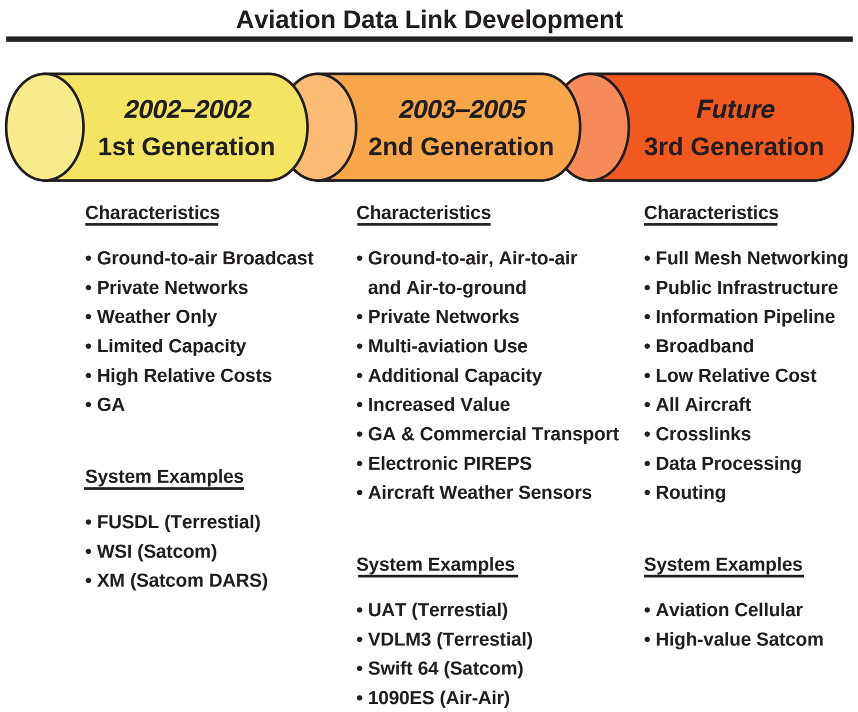

Figure 16. Approach to data link development.

nationwide compact-disc-quality digital audio radio services to home and automotive subscribers via SDARS commercial satellites. Internationally, WorldSpace has been offering similar services.

NASA, in partnership with WorldSpace and Rockwell Collins, investigated the feasibility of SDARS for FIS transmission to GA aircraft in South Africa during September 1999 using the AfriStar SDARS satellite. With excellent performance demonstrated in South Africa, NASA, Rockwell and WorldSpace continued the investigation by partnering with Jeppesen and American Airlines to evaluate the dissemination of graphical weather products to airliners flying oceanic routes between the U.S. and the Pacific Rim.[71] Early success and stimulation of the market by NASA-industry cooperative research and development efforts from 2000 through 2002 contributed to the development and deployment of first generation commercial systems, including the Honeywell FISDL, WSI InFlight, and XM WX Satellite services. These first generation systems broadcast a set of weather products to the cockpit from the ground via satellite or terrestrial stations. Due to their one-way nature, on-demand individual pilot requests of weather information beyond the prearranged suite are not supported. Transmission of hazardous weather observations from aircraft-to-aircraft or to the ground was not possible.

Since then, weather dissemination data links for the next, or second, generation of AWIN systems have been developed, validated by laboratory and flight testing, and recommendations made to the aviation community. These data links encompass the communication domains of ground-to-air, air-to-ground and air-to-air, including both commercial and government systems. These systems, though, remain aviation focused, not being shared by a broad diverse user base. Data-link capacity was increased with application to a broader user base, both commercial and GA, that could reduce equipage cost. Automated in situ weather reporting, event-driven automated turbulence reporting, and on-demand pilot requests are enabled in these second generation systems.

The process of selecting aviation data links to demonstrate dissemination of weather information included concept of operations, communications requirements, candidate architectures, modeling and simulation, current and planned equipage, current use restrictions, policies affecting future data links, and cost of the data links. Aviation data-link architectures were selected based on their ability to disseminate weather information during the en-route phase of flight. This included ground-to-air transmission to the flight deck of graphical and textual weather information, air-to-ground transmission of in situ weather observations, and air-to-air transmission of turbulence hazard information between aircraft. Ground networking was addressed only as it applies to the routing of airborne-sensed weather information from ground stations to data collection centers and of weather products from providers to ground stations for transmission to aircraft.

Three distinct operational architectures were addressed based on aircraft class and operational airspace: (1) U.S. national capability for regional and GA operations; (2) U.S. national capability for commercial transport operations; and (3) global capability for transport operations. To be recommended as a viable solution, a data link had to demonstrate (1) transmission and reception of weather information without impacting "normal" traffic and (2) feasibility of an operational implementation. The validation of data links was accomplished through partnerships between NASA, FAA, industry and academia.

U.S. National Capability for GA and Regional Aircraft

The Universal Access Transceiver (UAT) system, previously selected by the FAA for GA automated dependent surveillance broadcast (ADS-B) services, was selected for development of a GA and regional weather dissemination capability. The goals of the FAA in encouraging equipage meshed with NASA's needs to provide weather information in all the communication domains for GA over a multi-use link not funded or supported solely by the aviation weather information service providers and users. UAT equipment was modified and utilized to satisfy requirements for ground-to-air broadcast of weather information, air-to-ground delivery of atmospheric data from airborne sensors and air-to-air reporting of weather hazard information to aircraft within range.

The necessary data link modifications were limited to the recognition and routing of additional messages not currently in the UAT standard traffic, and did not require a redesign of the UAT message formats and structures. Airborne weather sensor data were inserted into an unused portion of the UAT ADS-B message for transmission. Reception of these data by other aircraft required avionics modifications to enable recognition, extraction and routing of the data to the flight-deck display, and display modifications for the presentation of the data. Sensor data reception at the ground required ground based terminal (GBT) modifications enabling recognition, extraction and routing to the appropriate ground users. Additional weather products were defined enabling recognition and processing of these as valid products at the GBT for transmission, at the aircraft avionics for reception and at the aircraft display for presentation.

Laboratory testing was conducted at the FAA Technical Center in 2004. Flight testing during the spring of 2005 provided final validation of the weather dissemination capabilities. These tests used two NASA Learjets equipped with modified avionics and an operational UAT GBT installed at the Cleveland Hopkins International Airport, USA.

U.S. National Capability for Commercial Transport Aircraft

A weather dissemination capability was developed for commercial transport aircraft within a U.S. national network that included (1) ground-to-air reception and display of FIS-B weather products, (2) air-to-ground pilot weather information requests, (3) dissemination of data from own-ship turbulence encounters to other aircraft and ground users and (4) reception, processing, and delivery to the cockpit of turbulence reports from other aircraft.

The FAA VHF Data Link Mode 3 (VDLM3) and 1090 Extended Squitter (ES) ADS-B data links were selected for development of a commercial transport weather dissemination capability. VDLM3 was utilized for ground-to-air broadcast of weather information and air-to-ground reporting of turbulence encounters. Weather information from the appropriate weather service information center was routed to the VDLM3 ground stations from which it was then broadcast to the aircraft. VDLM3 also accommodated pilot requests for specific weather information not included in the basic ground-to-air broadcast and the subsequent augmented broadcast containing the requested information for a pre-determined period of time. The VDLM3 ground network provided routing of turbulence reports to the appropriate data collection center. 1090ES satisfied the requirements for air-to-air delivery of turbulence reports through broadcast to all aircraft within reception range. These air-to-air turbulence encounter reports are a limited version of the in situ turbulence reports sent to the ground via the VDLM3 air-to-ground data link.

Weather information from the ground to aircraft used a broadcast message. Although a VDLM3 ground-to-air broadcast capability exists by design, this mode of communication had not been implemented to date. The required data-link modifications included the enabling of Transport Control Protocol/Internet Protocol (TCP/IP) directly over VDLM3 in lieu of the Aeronautical Telecommunications Network (ATN) protocol stack in the

Communication Management Unit (CMU) and recognition and routing of messages not currently in the VDLM3 standard planned traffic.

A turbulence encounter message was incorporated within the standard 1090ES message structure. Location, aircraft type, turbulence severity and other required parameters needed for relevance processing on the receiving aircraft were broadcast directly (air-to-air) between aircraft. Location of the transmitting airplane was obtained from the already transmitted/received ADS-B message to minimize the size of the turbulence message. The 1090ES ground stations were not used for this or any other weather related messaging because modeling and simulation had indicated an inadequate capacity.

Laboratory testing with VDLM3 avionics and ground stations and 1090ES avionics was completed in November 2004. Flight-testing providing final validation of VDLM3 weather dissemination capabilities occurred at the FAA Technical Center in the spring of 2005. Flight testing of 1090ES weather dissemination capabilities occurred in spring 2005 utilizing two NASA Learjets equipped with modified 1090ES avionics.

Global Capability for Transport Aircraft

A weather dissemination capability was developed for commercial transport aircraft operating in international and oceanic environs that included (1) ground-to-air reception and display of FIS-B weather products, (2) dissemination of data from own-ship turbulence encounters to other aircraft and ground users and (3) reception, processing and delivery of turbulence reports from other aircraft. The architecture selected for development of an international/oceanic global weather dissemination capability used the SWIFT 64 Multiple Packet Data Service (MPDS) mode via the Inmarsat satellite constellation. Requirements for ground-to-air broadcast of weather information and reporting of turbulence hazards to the ground and other aircraft were satisfied utilizing the SWIFT 64 network service provided by SITA.

Current cockpit communications have focused on circuit switched satellite capabilities, failing to capitalize on the newer services and associated capabilities that packet services could provide in a more cost efficient manner. For the international and oceanic environments, packet based, Inmarsat I3 services and capabilities were selected for the dissemination of weather information. Packet services to date in the cabin have been available only on a best effort basis providing no guarantee to quality, availability or latency of the data required for use by the cockpit.

A test bed emulator of the aircraft environment, including both the cockpit and cabin users, was developed and interfaced to the Inmarsat I3 constellation for the testing. IP was chosen as the network protocol, and algorithms for seamless on-board separation of packet data services between cockpit and cabin have been evaluated.

Future Weather-Dissemination Data Links

Weather dissemination technology progress has been significant but has relied on the innovative use of existing or planned data links. Weather data and information are expected to increase along with other communication demands for a new generation of air traffic control, safety and security functions requiring a broadband link serving all aircraft. Cross-linking capabilities, increased ground and air data processing and complex/flexible routing schemes must also be addressed in future communications systems. These future capabilities will only be realized if the equipment and services to support the networks and enabling data link are affordable. Broad user-based shared commercial systems, such as true aviation cellular and high value satellite communications, may hold the key to reduction in costs.

Summary

Capabilities have been developed by the National Aeronautics and Space Administration (NASA) in partnership with the Federal Aviation Administration (FAA), National Oceanic and Atmospheric Administration (NOAA), industry and the research community for airborne detection, dissemination and display of weather information. First-generation data-link cockpit weather information systems have been implemented, especially by GA operators. A prototype next-generation cockpit weather information system has been developed with the capability to combine information from both on-board sensors and data-links and to display graphical and textual weather information to the pilots, evaluate both tactical and strategic hazards in the weather data stream and provide alerts. The capability has been developed for on-board weather radars to accurately detect turbulence and display its severity up to 25 nautical miles ahead of commercial jet transports. Automated, event-driven, turbulence encounter reporting using an acceleration-based hazard metric has been developed for commercial jet transports. Both of these turbulence capabilities have progressed from prototype systems and research aircraft to in-service evaluations with a major U.S. air carrier. Automated airborne in situ weather reporting has been developed to provide atmospheric soundings and observations from aircraft in flight to improve forecasting and identification of regions of hazardous weather. These capabilities have been implemented on a fleet of regional airplanes for a yearlong evaluation by the weather community. Data-link technologies have been developed for first-generation systems that enable affordable and reliable broadcast of a set of weather products to the cockpit from the ground via satellite or terrestrial stations. Weather dissemination data links for the next-generation systems have been developed and validated through laboratory and flight tests. These capabilities for airborne detection, dissemination and display of weather information, currently in the initial stages of implementation, will provide more precise and timely knowledge of the weather and enable pilots in flight to make decisions that result in safer and more efficient operations.♦

References

1. National Aviation Weather Program Council Joint Action Group for Aviation Weather: National Aviation Weather Program Strategic Plan. Office of the Federal Coordinator for Meteorology, FCMP321997, April 1997.

2. National Aviation Weather Program Council Joint Action Group for Aviation Weather: National Aviation Weather Initiatives. Office of the Federal Coordinator for Meteorology, FCMP341999, February 1999.

3. Federal Aviation Administration: Safer Skies: Focused Safety Agenda — Weather Joint Safety Implementation Team. Final Report, March 2000.

4. Stough, H. Paul, III; Shafer, Daniel B.; Schaffner, Philip R.; and Martzaklis, Konstantinos S.: Reducing Aviation Weather-Related Accidents Through High-Fidelity Weather Information Distribution and Presentation. ICAS Paper ICA065iP, August 2000.

5. Stough, H. Paul, III; and Martzaklis, Konstantinos S.: Progress in the Development of Weather Information Systems for the Cockpit. SAE Paper 2002011520, April 2002.

6. Stough, H. Paul, III; Watson, James F., Jr.; Daniels, Taumi S.; Martzaklis, Konstantinos S.; Jarrell, Michael A.; and Bogue, Rodney K.: New Technologies for Weather Accident Prevention. AIAA20057451, September 2005.

7. Huettner, C.: Toward a Safer 21st Century — Aviation Safety Research Baseline and Future Challenges. NP 1997-12-231-HQ, 1996.

8. Wiener, Earl L.; and Nagel, David C. (editors): Human Factors in Aviation. Academic Press, 1998, page 578.

9. Kauffmann, P.; and Pothanun, K.: Estimating the Rate of Technology Adoption for Cockpit Weather Information Systems. SAE Paper 2000-01-1662, 2000.

10. Crabill, N. L.; and Dash, E. R.: Pilot Automated Weather Support System (PAWS) Concepts Demonstration Project. DOT-FAA-RD-91-9.

11. Keel, Byron M.; Stancil, Charles E.; Eckert, Clifford A.; Brown, Susan M.; Gimmestad, Gary G.; and Richards, Mark A.: Aviation Weather Information Requirements Study. NASA CR-2000-210288, June 2000.

12. Scanlon, Charles H.: A Graphical Weather System Design for NASA Transport Systems Research Vehicle B-737. NASA TM 104205, February 1992.

13. Scanlon, Charles H.: Cockpit Graphical Weather Information Shown to Enhance Efficiency, Safety, and Situation Awareness. Proceedings of the Flight Safety Foundation 39th Annual Corporate Aviation Safety Seminar, April 13-15, 1994, pp. 83–94.

14. Kilgore, W.A. et al: Pilot Weather Advisor. NASA SBIR Final Report. NASA Contract NAS1-19250, September 1991.

15. Shashi, S.; and Crabill, Norman L.: Pilot Weather Advisor. NASA SBIR Final Report. NASA Contract NAS1-19595, December 1994.

16. FAA News: FAA and Industry Bring Data Link Services to the Cockpit. Federal Aviation Administration, Washington, D.C., APA 85-99, July 30, 1999.

17F. AA: FAA Announces Operational Flight Information Services Data Link. FAA Press Release APA 08-02, February 25, 2002.

18. Latorella, Kara; Lane, Suzanne; and Garland, Daniel: General Aviation Pilots' Perceived Usage and Valuation of Aviation Weather Information Sources. NASA TM-2002-211443, February 2002.

19. Latorella, Kara; Pliske, Rebecca; Hutton, Robert; and Chrenka, Jason: Cognitive Task Analysis of Business Jet Pilots' Weather Flying Behaviors: Preliminary Results. NASA TM-2001-211034, July 2001.

20. Yuchnovicz, Daniel E.; Burgess, Malcolm A.; Heck, Michael L.; Novacek, Paul F.; and Stokes, Alan F.: Assessment of the Effects of Delayed Weather Information Datalinked to the Cockpit on Pilot Navigation Decision Making. 19th Digital Avionics Systems Conference, October 2000.

21. Yuchnovicz, Daniel E.; Novacek, Paul F.; Burgess, Malcolm A.; Heck, Michael L.; and Stokes, Alan F.: Use of a Data-Linked Weather Information Display and Effects on Pilot Navigation Decision Making in a Piloted Simulation Study. NASA CR-2001-211047, August 2001.

22. Novacek, Paul F.; Burgess, Malcolm A.; Heck, Michael L.; and Stokes, Alan F.: The Effect of Ownship Information and NexRad Resolution on Pilot Decision Making in the Use of a Cockpit Weather Information Display. NASA CR-2001-210845, December 2001.

23. Beringer, Dennis; and Ball, Jerry: Effects of NEXRAD Graphic Data Resolution and Direct Weather Viewing on Pilot Judgments of Weather Severity and Willingness to Continue Flight. Proceedings of the 47th Annual Meeting of the Human Factors & Ergonomics Society, Denver, CO, 2003.

24. Chamberlain, Jim; and Lemos, Katherine: Design Considerations for Presenting Data-Linked Animated Radar Imagery on In-Flight Displays. Proceedings of the 23rd Digital Avionics Systems Conference, Indianapolis, IN, 2004.

25. Lemos, Katherine; and Chamberlain, Jim: In-Flight Weather Trending Information: Optimal Looping Characteristics for Animated NEXRAD Images. Proceedings of the 23rd Digital Avionics Systems Conference, Indianapolis, IN, 2004.

26. Burgess, Malcolm A.; and Thomas, Rickey P.: The Effect of NEXRAD Image Looping and National Convective Weather Forecast Product on Pilot Decision Making in the Use of a Cockpit Weather Information Display. NASA/CR-2004-212655, March 2004.

27. Latorella, Kara A.; and Chamberlain, James P.: Decision-making in Flight with Different Convective Weather Sources: Preliminary Results. Proceedings of the 11th International Symposium on Aviation Psychology, Ohio State University, Dayton, OH, 2001.

28. Chamberlain, James P.; and Latorella, Kara A.: Convective Weather Detection by General Aviation Pilots with Conventional and Data-Linked Graphical Weather Information Sources. The 20th Digital Avionics Systems Conference, October 2001.

29. Latorella, Kara; and Chamberlain, James P.: Graphical Weather Information System: Usability, Perceived Utility, and Preferences from General Aviation Pilots. SAE Paper 2002-01-1521, April 2002.

30. Burt, Jennifer; Chamberlain, James P.; Jones, Kenneth M.; and Coyne, Joseph T.: The Impact of a Weather Information System Display on General Aviation Pilot Workload and Performance. SAE Paper 2002-01-1522, April 2002.

31. Kronfeld, Kevin: Enhanced Weather Radar (EWxR) System. NASA/CR-2003-212406, June 2003.

32. Ruokangas, Corinne C.; and Kelly, Wallace E., III: Advanced Weather Awareness and Reporting Enhancements. NASA/CR-2004-212993, 2004.

33. Lapis, Mary Beth; Schnell, Tom; and Keller, Mike: Aviation Weather Information Display Study (AWIDS). Georgia Tech Applied Research Corporation, Final Report NASA Contract NAS1-02056 Order No. 6012, October 2004.

34. Bliss, James P.; Fallon, Corey; Bustamante, Ernesto; Bailey, William R., III; and Anderson, Brittany: Reactions of Air Transport Flight Crews to Displays of Weather During Simulated Flight. Old Dominion University Research Foundation, Final Report NASA Grant No. NAG-1-03061, January 2005.

35. RTCA, Inc.: Minimum Aviation System Performance Standards (MASPS) for Flight Information Services - Broadcast (FIS-B) Data Link. RTCA/DO-267A, 2004.

36. FAA: Use of Cockpit Displays of Digital Weather and Operational Information. Advisory Circular AC No: 00-63, September 9, 2004.

37. FAA: Aeronautical Information Manual 2005. Chapter 7 Safety of Flight, Section 1-11 Meteorology - Flight Information Services Data Link (FISDL), 2004.

38. Federal Aviation Administration: Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Bag Computing Devices. Advisory Circular AC No: 120-76A, March 17, 2003.

39. Boatman, Julie K.: Avionics Market: The Age of Avionics. AOPA Pilot, June 2005, pp. 94-101.

40. FAA: Automatic Dependent Surveillance-Broadcast (ADS-B) and Other Broadcast Services – Initial Capabilities in the National Airspace System (NAS). Notice to Airmen, April 14, 2005. URL: http//www.faa.gov/ntap/NTAP05APR14/gen05002.htm

41. Triplett, William: The Calculators of Calm. Air & Space Smithsonian, March 2005, pp. 54-61

42. Bogue, R.; and Larcher, K.: Aircraft Cabin Turbulence Warning Experiment. 20th International Aircraft Cabin Safety Symposium, 10-13 Feb 2003, Los Angeles, CA.

43. Kaplan, M.L.; Huffman, A.W.; Lux, K.M.; Charney, J.J.; Riordan, A.J.; and Lin, Y.: Characterizing the Severe Turbulence Environments Associated With Commercial Aviation Accidents---Part I: 44 Case Study Synoptic Observational Analyses. NASA/CR-2002-211918, August 2002.

44. Hamilton, D.W.; and Proctor, F.H.: Meteorology Associated with Turbulence Encounters during NASA's Fall-2000 Flight Experiments. 40th Aerospace Sciences Meeting & Exhibit, January 14-17, 2002, Reno, NV, AIAA Paper No. 2002-0943.

45. Hamilton, D.W.; and Proctor, F.H.: Convectively-Induced Turbulence Encountered During NASA's Fall-2000 Flight Experiments. 10th Conference on Aviation, Range, and Aerospace Meteorology, May 13-16, 2002, Portland, Oregon, Amer. Meteor. Soc., pp. 371-374.

46. Proctor, F.H.; Hamilton, D.W.; and Bowles, R.L.: Numerical Study of a Convective Turbulence Encounter. 40th Aerospace Sciences Meeting & Exhibit, January 14–17, 2002, Reno, NV, AIAA Paper No. 2002-0944.

47. Proctor, F.H.; Hamilton, D.W.; and Bowles, R.L.: Numerical Simulation of a Convective Turbulence Encounter. Preprints 10th Conference on Aviation, Range, and Aerospace Meteorology, 13–16 May 2002, Portland, Oregon, Amer. Meteor. Soc., pp. 41–44.

50. Soreide, D.C.; Bogue, R.K.; Bowdle, D.A.; and Hannon, S.M.: Airborne Coherent Lidar for Advanced In-flight Measurements (ACLAIM) – Flight Testing of the Lidar Sensor. 9th Conference on Aviation, Range, and Aerospace Meteorology, 12-16 September 2000, Orlando, FL.

51. Teets, E, H.; Ashburn, C.; Bogue, R. K.; and Ehernberger, L. J.: Turbulence and Mountain Wave Conditions Observed with an Airborne 2-micron Doppler Lidar. 11th Conference on Aviation, Range, and Aerospace Meteorology, 4–8 October 2004, Hyannis, MA.

49. Hamilton, D.W.; and Proctor, F.H.: An aircraft encounter with turbulence in the vicinity of thunderstorm. 21st AIAA, Applied Aerodynamics Conference, 23-26 June 2003, Orlando, Florida, AIAA Paper No. 2003–4075, 11 pp.

48. Hamilton, D.; Bowles, R.; and Cornman, L.: FY02 TPAWS Radar NASA B757 Flight Campaign Summary. NASA Weather Accident Prevention Project (WxAP) Review [CD-ROM], 20–21 November 2002, Boston, MA.

52. Lane, T. P., R. Sharman, and T. L. Clark: A Modeling Investigation of Near-Cloud Turbulence. Preprints, 10th Conference on Aviation, Range, and Aerospace Meteorology, American Meteorological Society, Portland, OR, 13–16 May 2002, pp. 364–366.

53. Proctor, F.; and Hamilton, D.: Certification Methods and Tools. NASA Weather Accident Project (WxAP) Review, 2–4 June 2004, Las Vegas, NV.

54. Moninger, W.R.; Mamrosh, R.D.; and Pauley, P.M.: Automated Meteorological Reports from Commercial Aircraft. Bulletin of the American Meteorological Society, February 2003, 84, pp. 203–216.

55. Daniels, Taumi S.: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Development. SAE Paper 2002-01-1523, April 2002.

56. Daniels, T. S.; Tsoucalas, G.; Anderson, M.; Mulally, D.; Moninger, W.; and Mamrosh, R.: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Development. 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, American Meteorological Society, October 2004.

57. MacCready, Paul B., Jr.: Standardization of Gustiness Values from Aircraft. Journal of Applied Meteorology, August 1964, Vol. 3, pp. 439–449.

58. World Meteorological Organization Aircraft Meteorological Data Relay Panel ARINC-620 Version 4.

59. Moninger, W. R.; Daniels. T. S.; Mamrosh, R. D.; Barth, M. F.; Benjamin, S. G.; Collander, R. S.; Ewy, L.; Jamison, B. D.; Lipschutz, R. C.; Miller, P. A.; Schwartz, B. E.; Smith, T. L.; and Szoke , E. J.: TAMDAR, The Rapid Update Cycle, and the Great Lakes Fleet Experiment. 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, American Meteorological Society, October 2004.

60. Mamrosh, R.D.; Brusky, E. S.; Last, J. K.; Moninger, W. R.; and Daniels, T. S.: The TAMDAR Great Lakes Fleet Experiment. Ninth Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, San Diego, CA, American Meteorological Society, January 2005, paper IOAS-AOLS 5.1.

61. Feltz, W. F.; Smith, W.L.; Knuteson, R.O.; Revercomb, H.E.; Woolf, H.M.; and Howell, H.B.: Meteorological Applications of Temperature and Water Vapor Retrievals from the Ground-Based Atmospheric Emitted Radiance Interferometer (AERI). Journal of Applied Meteorology, Vol. 37, No. 9, 1998, pp. 857–875.

62. Benjamin, S.; Bleck, R.; Brown, J.; Brundage, K.; Devenyi, D.; Grell, G.; Kim, D; Manikin, G.; Schwartz, B.; Smirnova, T.; Smith, T; and Weygandt, S.: Mesoscale Weather Prediction with the RUC Hybrid Isentropic-sigma Coordinate Model and Data Assimilation System. Symposium on 50th Anniversary of Operational Numerical Weather Prediction, College Park, MD, American Meteorological Society, 2004.

63. Benjamin, S., Brewster, K.A.; Brummer, R.L.; Jewett, B.F.; Schlatter, T.W.; Smith, T.L.; and Stamus, P.A.: An Isentropic Three-hourly Data Assimilation System Using ACARS Aircraft Observations. Monthly Weather Review, 1991, 119, pp. 888–906.

64. Mahoney, J. L.; Henderson, J.K.; Brown, B.G.; Hart, J.E.; Loughe, A.; Fischer, C.; and Sigren, B.: The Real-Time Verification System (RTVS) and its Application to Aviation Weather Forecast. 10th Conference on Aviation, Range, and Aerospace Meteorology, 13–16 May, 2002, Portland, OR.

65. Bernstein, B.C.; McDonough, F.; Politovich, M.K.; Brown, B.G.; Ratvasky, T.P.; Miller, D.R.; Wolff, C.A.; and Cunning, G.: Current Icing Potential (CIP): Algorithm Description and Comparison with Aircraft Observations. Journal of Applied Meteorology, in press 2005

66. Theriault, K.E.; Wolfson, M.M.; Forman, B.E.; Hallowell, R.G.; Moore, M.P.; and Johnson, R.J., Jr.: FAA Terminal Convective Weather Forecast Algorithm Assessment. 9th Conference on Aviation, Range, and Aerospace Meteorology, 11–15 September, 2000, Orlando, Florida.

67. Cornman, L.B.; Morse, C.S.; and Cunning, J.: Real-time Estimation of Atmospheric Turbulence Severity from In-situ Aircraft Measurements. Journal of Aircraft, Vol. 32 (1), pp. 171–177, 1995.

68. Lockheed Martin Aeronautical Systems, AvCS, Inc.: Data Communications Requirements, Technology and Solutions for Aviation Weather Information Systems, Phase I Report — Aviation Weather Communications Requirements. NASA Contract N66001-97-C-8605, March 1999.

69. TRW, ARINC, and SAIC: Communications System Architecture Development for Air Traffic Management & Aviation Weather Information Dissemination — AWIN 2007 Architecture. Contract NAS2-98002, 2000.

70. Tanger, Thomas; FAA FIS Data Link Assessment and Recommendations. Draft Version 1.0, NASA Internal Report, December 2001.

71. Kerczewski, Robert J.; and Haendel, Richard: Using Global Satellite Digital Audio Radio Systems for Aviation Weather Dissemination. SAE Paper 2002-01-1530, April 2002.

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Sharing Safety Data — An Example of Cooperative Industry-Regulatory Data Analysis

Including a Review of the Prevalence and Severity of Propulsion-Related Events

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Abstract

In the early 1990's, the Aerospace Industries Association, in conjunction with the European Association of Aerospace Industries (AECMA), provided the Federal Aviation Administration (FAA) with a study aimed at the development of more effective methods to identify, prioritize and resolve safety-related problems occurring on commercial aircraft engines. This initial Continued Airworthiness Assessment Methodologies (CAAM) study covered a variety of propulsion system and auxiliary power unit (APU) events perceived to impact safety, presenting historical data on event frequency and severity at the airplane level. The information was used by the FAA to help identify and prioritize responses to individual engine, propeller and APU safety concerns. It also proved vital to the development of effective safety initiatives in the propulsion community. Recently, the CAAM team was re-established to update the data study with the latest information on propulsion system accidents and incidents.

The CAAM teams that developed both data studies are models of cooperative safety data sharing between industry and airline organizations, and between those organizations and the FAA. This paper will address the methodology that the teams followed, the problems encountered and the development of the de-identified safety databases. Additionally, the paper will provide a review of the data, covering the prevalence and relative severity of propulsion-related events. The reader will thus gain an understanding of the range of propulsion system malfunctions, how often they occur, and the level of threat they have posed historically.

Introduction

Propulsion system malfunctions are rare in the life of any one engine or airplane; any particular airline or manufacturer — and even the Federal Aviation Administration (FAA), which is typically limited to data from the United States — thus may not have the capability to understand the true system-wide risks. Under the auspices of the Aerospace Industries Association Propulsion Committee (AIA PC), a team of FAA, airline and industry propulsion experts met over the 2001–2004 time period to cooperatively collect operational data on propulsion system malfunctions and use that information to develop a picture of the extent and relative severity of these malfunctions. By coming together to share information in a protected forum, each organization was able to gain a fuller picture than that available internally.

An earlier database had been developed by the AIA and the European Association of Aerospace Industries (AECMA) to develop more effective methods to identify, prioritize and resolve safety-related problems occurring on commercial aircraft engines. This activity succeeded to such a great extent that its information has been used to identify and prioritize responses to propulsion system safety threats. Additionally, the information highlighted the need for special activities to address the leading causes of propulsion system–related accidents. These activities included the development of focused inspections for the highest-risk rotating engine components and interventions to address Engine Failure Recognition and Response (EFRR — sometimes termed Propulsion System Malfunction Plus Inappropriate Crew Response [PSM+ICR]).

Methodology

Each member organization brought its data; in addition, commercially available databases were reviewed to corroborate and expand the database. The information was reviewed by the team internally to the team meetings, and agreements were reached with regard to the level of severity of each event. Team members could not take others' data out of the team, nor was it provided to them. An unbiased participant was selected to serve as the keeper and analyst of the data for the period of the team's existence; after the data was summarized and the report published, individually identified data was no longer available.

The fleet covered was Western-built transport category airplanes in commercial use for the time period 1992 through 2000. Data reporting was most complete from the fleets of more recent turbofan-powered airplanes; some of the smaller airplanes within the transport category designation, especially turboprop-powered airplanes, had very limited reporting. However, the very severe events on these aircraft were able to be captured from the commercial accident databases; undoubtedly, reporting was less than complete for the lower-severity events on smaller out-of-production airplanes. The scope of the reporting was limited to propulsion systems, including auxiliary power units (APUs). Data collection for some of the extremely numerous events, such as flammable fluid leaks or false indications, was limited in some cases to a one-year sample and the event incidence over nine years was then extrapolated.

Military airplanes, even those certified with commercial type certificates, were excluded on the grounds that the operational environment of military aircraft was not typical of the commercial fleet. Events on commercial airplanes during nonrevenue flights were collected for the information they provided on hazard ratios, but they were not counted in the occurrence rates.

The events were reviewed by the team and grouped by event cause. Data analysis provided information on event quantities and rates, as well as the conditional probabilities, termed hazard ratios, of more serious events. The event causes were also ranked by their contribution to the overall propulsion-related accident rate.

The events were also divided by engine type — turboprop, low-bypass-ratio (LBPR) turbofan, and high-bypass-ratio (HBPR) turbofan. Additionally, for the event categories of uncontainment and multi-engine events, the HBPR data was further divided by engine generation. (See the Appendix for engine model by generation.)

The earlier database and analysis included the development of standardized definitions of system and APU-related aircraft hazard levels based on the consequences to the aircraft, passengers and crew. These hazard levels are based on the actual observed consequences to the airplane and its occupants, rather than what might have happened. This assessment of what actually occurred allows the calculation of objective conditional probabilities — hazard ratios — of serious events occurring given the underlying occurrence of the basic event. The hazard ratios can vary significantly; in other words, not all base events have an equal conditional probability of resulting in a serious event. Use of objectively developed hazard ratios allows differentiation between the risks posed by different safety threats.

In the course of the activity described in this paper, several revisions, additions and refinements were made to the standardized definitions developed during the first database effort to account for new event categories (for example, propulsion system fumes) as well as to focus more clearly on the true risks of other event categories (for example, a change to associate "uncontrolled fire" with fire zone containment).

Standardized Aircraft Event Hazard Levels and Definitions

The following standardized hazard levels are intended to objectively assess aircraft-level severity.

Level 0 — Consequences with no safety effect

a. In-flight shutdown of a single engine with no airplane-level effect other than loss of thrust and associated services, above an altitude of 3,000 feet.

b. Casing uncontained engine failure, contained within the nacelle.

c. Malfunctions or failures that result in smoke and/or fumes that have no effect on crew or passengers beyond their notice of the event. The production of smoke or fumes as a consequence of some failures or malfunctions is an expected condition for which the airplane is designed and crew procedures are established.

Level 1 — Minor consequences

a. Uncontained nacelle damage confined to affected nacelle/APU area.

b. Uncommanded power increase, or decrease, at an airspeed above V_1 and occurring at an altitude below 3,000 feet (includes in-flight shutdowns [IFSD] below 3,000 feet).

c. Multiple propulsion system malfunctions or related events, temporary in nature, where normal functioning is restored on all propulsion systems and the propulsion systems function normally for the rest of the flight. Includes common cause environmental hazard-induced events.

d. Separation of propeller/components which cause no other damage.

e. Uncommanded propeller feather.

f. Propulsion system (engine or propeller) malfunctions resulting in severe vibration.

Level 2 — Significant consequences

a. Nicks, dents and small penetrations in any aircraft principal structural element.

b. Slow depressurization.

c. Controlled fires (i.e., inside fire zones). Tailpipe fires that do not impinge upon aircraft structure, or that do not present an ignition source to co-located flammable material, are also considered level 2.

d. (1) Flammable fluid leaks that present a fire concern. Specifically, fuel leaks in the presence of an ignition source and of sufficient magnitude to produce a large fire.

(2) Fuel leaks that present a range concern for the airplane.

e. Minor injuries.

f. Multiple propulsion system or APU malfunctions, or related events, where one engine remains shut down but continued safe flight at an altitude 1,000 feet above terrain along the intended route is possible.

g. Any high-speed takeoff abort (usually 100 knots or greater).

h. Separation of propulsion system, inlet, reverser blocker door, translating sleeve or similar substantial pieces of aerodynamic surface without level 3 effects.

i. Partial in-flight reverser deployment or propeller pitch change malfunction without level 3 consequences.

j. Malfunctions or failures that result in smoke or toxic fumes that cause minor impairment or minor injuries to crew and/or passengers. A level 2 event may result in an emergency being declared to initiate Air Traffic Control priority sequencing. This does not inherently imply that the event was a level 3.

Level 3 — Serious consequences

a. Substantial damage to the aircraft or second unrelated system.

b. Uncontrolled fires that escape the fire zone and impinge flames onto the wing or fuselage, or act as ignition sources for flammable material anticipated to be present outside the fire zone.

c. Rapid depressurization of the cabin.

d. Permanent loss of thrust or power greater than one propulsion system.

e. Temporary or permanent inability to climb and fly 1,000 feet above terrain (increased threat from terrain, inclement weather, etc.) along the intended route.

f. Any temporary or permanent impairment of aircraft controllability caused by propulsion system malfunction, thrust reverser in-flight deployment, propeller control malfunction or propulsion system malfunction coupled with aircraft control system malfunction, abnormal aircraft vibration or crew error.

g. Malfunctions or failures that result in smoke or other fumes on the flight deck that result in serious impairment. Serious impairment includes the loss of crew's ability to see flight deck instrumentation or perform expected flight duties. Concerns about long-term effects are not addressed.

Level 4 – Severe consequences

a. Forced landing. Forced landing is defined as the inability to continue flight where imminent landing is obvious but aircraft controllability is not necessarily lost (e.g., total power loss due to fuel exhaustion will result in a "forced landing"). An air turnback or diversion due to a malfunction is not a forced landing, since there is a lack of urgency and the crew has the ability to select where they will perform the landing.

b. Actual loss of aircraft (as opposed to economic) while occupants were on board.

c. Serious injuries or fatalities.

Level 5 — Catastrophic consequences

Catastrophic outcome. An occurrence resulting in multiple fatalities, usually with the loss of the airplane.

General notes applicable to all event hazard levels

a. The severity of aircraft damage is based on the consequences and damage that actually occurred.

b. Injuries resulting from an emergency evacuation rather than from the event that caused the evacuation are not considered in evaluating the severity of the event. It is recognized that emergency evacuations by means of the slides can result in injuries, without regard to the kind of event precipitating the evacuation.

Event Categories

Propulsion system events were organized into the following event categories:

Single propulsion system event

a. *Uncontained*. A significant safety event that initiates from an uncontained release of debris from a rotating component malfunction (blade, disk, spacer, impeller, drum/spool). In order to be categorized as uncontained, the debris must pass completely through the nacelle envelope. Parts that puncture the nacelle skin but do not escape or pass completely through are considered contained. Fragments that pass out of the inlet or exhaust opening without passing through any structure are not judged to be "uncontained." Starter and gearbox uncontainments are specifically excluded.

b. *Engine overspeed.* Engine acceleration to a rotor speed above that sanctioned in the type certificate datasheet.

c. *Case rupture*. A significant safety event that initiates from a sudden rupture of a high-pressure vessel or case with the resultant release of high-pressure gases into the under-cowl cavity. Case ruptures resulting from uncontained release of debris from a rotating component malfunction are excluded. Case ruptures include those events that propagate from fatigue-type cracks as well as ruptures related to secondary malfunctions (e.g., flame impingement).

d. *Case burnthrough*. Case burnthrough is defined as a local case penetration that initiates from local overtemperature of the case external wall due to an internal engine malfunction (e.g., fuel nozzle leakage, internal bearing compartment fires, titanium fires). Burnthroughs are distinguished from ruptures by their lack of an explosive release of high-pressure gas. A common cause of case burnthrough is localized penetration due to fuel nozzle malfunction. Events involving accessory component cases also contribute to this category; for example, sump fires that propagate internally and result in burnthrough of piping or that initiate gearbox fires. The key aspect, whether in the primary gas path or accessories, is that fire initiates from an internal malfunction and proceeds to burn through a case, tube or gearbox to reach external regions.

e. *Under-cowl fire.* A safety-significant propulsion system fire-related event involving combustion external to the engine casings. Under-cowl fires are those that occur within the nacelle and on the engine side of the strut or installation fire barrier/wall. Internal pylon fires, including events where fuel leaks from the pylon and initiates a fire under the cowl, are to be excluded. Under-cowl may be within fire zones or flammable fluid zones. Tailpipe fires and hot air leaks resulting in fire warnings, without combustion, are excluded from the definition and documented separately. Fires that remain internal to the engine casing are excluded.

f. *Flammable fluid leak.* Leak of fuel, oil or hydraulic fluid into the pylon or dry bay, or under the engine cowls, which could credibly lead to a fire. Leaks collected from shrouds and components and drained directly overboard by a dedicated drain were excluded from those leaks under consideration due to their lack of being fire safety concerns. Drips and seeps were also excluded. In-tank leakage was excluded.

g. *Compartment overheat/air leak*. High-pressure or -temperature air leaks due to casing or high-pressure/temperature air duct system malfunctions within the nacelle or in the pylon.

h. *Engine separation*. Separation of the engine, with or without the strut/pylon. Events resulting from ground contact are excluded.

i. *Cowl separation*. Separation of nacelle components such as inlets, cowls, thrust reversers, exhaust nozzles, tail plugs, etc. Separation of relatively small sections of skin, blow-out panels or other small pieces that are unlikely to threaten continued safe flight and landing are excluded. Events resulting from ground contact are excluded.

j. *Engine failure recognition and response (EFRR)*. Sometimes referred to as propulsion system malfunction and inappropriate crew response (PSM+ICR). A significant safety event initiating from a single propulsion system malfunction (excluding propeller system), which, by itself, does not threaten the aircraft, but is compounded by inappropriate crew response (i.e., crew did not execute checklist/ normal flying duties). A typical example of EFRR is an IFSD followed by inappropriate crew response that caused the aircraft to crash. Not counted are cases of gross error negligence (such as deciding to take off with an engine known to be inoperative).

k. *Crew error.* A significant safety event caused by a propulsion system malfunction or improper operation that was caused by an inappropriate crew action, excluding sabotage, gross negligence and suicide. Not counted are events where inappropriate crew action causes a propulsion system malfunction through very indirect means such as flying the airplane into the ground or running the airplane into equipment on the taxiway/runway.

l. *Reverser/beta malfunction — in-flight deploy*. A significant safety event wherein a thrust reverser deploys in flight, or a propeller enters beta mode in flight (exclusive of design intent).

m. *Reverser/beta malfunction — failure to deploy*. A significant safety event resulting from the failure of a thrust reverser to deploy or a propeller to enter beta mode when commanded.

n. *Fuel tank rupture/explosion*. A burst failure of a fuel tank or explosion within a fuel tank.

o. *Tailpipe fire.* Fire within the tailpipe, where visible sustained flames exit the tailpipe. Engine surge/stall and hot starts resulting in a “glow” are excluded, as are events resulting from deicing fluid ingestion.

p. *False/misleading indication.* Indication that was appreciably different from reality, to the point where an indication difference was noticed by the pilot or subsequent investigation. This included parameters that were higher than actuality, lower than actuality or completely absent, and also discrete warnings or alerts that were falsely present or absent. Individual EICAS messages were excluded since these were very type-specific and numerous.

Multiple-engine power loss event

a. *Environmental*. A significant safety event initiating from essentially simultaneous power loss from multiple propulsion systems for an environmental cause (e.g., bird, ice, rain, hail or volcanic ash ingestion).

b. *Maintenance.* A significant safety event initiating from multiple propulsion system power loss from clearly improper maintenance (e.g., failure to restore oil system integrity after inspection).

c. *Other/unknown*. A significant safety event initiating from multiple propulsion system power loss for reasons other than those characterized elsewhere, or where the initiating event(s) are unknown. This includes unrelated events of engine power loss within the same flight.

d. *Fuel contamination.* A significant safety event initiating from power loss from multiple propulsion systems from fuel contamination. Sequential power loss and recovery is excluded.

e. *Fuel mismanagement*. A significant safety event initiating from power loss from multiple propulsion systems from improper management of the airplane fuel system (e.g., tank crossfeed). Sequential power loss and recovery is excluded.

f. *Fuel exhaustion*. A significant safety event initiating from power loss from multiple propulsion systems from complete exhaustion of the airplane fuel reserves. Sequential power loss and recovery is excluded.

APU system event

a. *Uncontained*. An uncontained rotating component malfunction that allows debris to exit through the APU containment casings.

b. *Axial uncontained*. Major rotating components that exit the APU containment casings in an axial direction (i.e., without penetrating the case).

c. *Overspeed*. Acceleration of a rotor beyond the speed sanctioned in the type certificate datasheet.

d. *Fire*. Combustion external to the APU casings. Tailpipe fire data and hot air leaks resulting in fire warnings, without combustion, are excluded from the definition and documented separately.

e. *Tailpipe fire*. Fires within the tailpipe and exiting the tailpipe, where flames are visible. Hot starts resulting in a "glow" are excluded.

f. *Compartment overheat*. High-temperature air leaks due to casing high-pressure/temperature air duct system malfunctions within the APU.

Propeller system event

a. *Propeller separation/debris release*. Separation of single or multiple blades, or large piece thereof, due to blade or hub malfunction. Note that events occurring after groundstrike are included for their information on the threat to the aircraft or its occupants.

b. *Autofeather/pitch lock*. Propeller system malfunction leading to inability to control the propeller. Control hunting is excluded as a normal product behavior.

c. *Propeller system failure recognition and response (PFRR)*. Sometimes referred to as propeller system malfunction plus inappropriate crew response (propeller PSM+ICR). A significant safety event initiating from a propeller system malfunction which, by itself, does not threaten the aircraft, passengers or crew, but is compounded by inappropriate crew response.

d. *Crew error*. A significant safety event caused by a propeller system malfunction or improper operation that was caused by an inappropriate crew action, excluding sabotage, gross negligence and suicide (e.g., operation in beta mode in violation of operating instructions). Not included are events where inappropriate crew action causes a propeller system malfunction through very indirect means such as flying the airplane into the ground or running the airplane into equipment on the taxiway/runway.

Propulsion system fume event

Significant smoke and/or fumes on the flight deck or cabin that are generated by the propulsion system.

Challenges to the Effort

The initial scope was very ambitious, being greatly expanded from that of the first CAAM report — both in types of events to be assessed and also in the kind of information to be gathered about each event. The difficulty and labor of collecting and collating the data were underestimated. In particular, the less serious events might have only sketchy details, and analysis of those event categories (e.g., leaks) was therefore very difficult.

An economic downturn in the airline industry sharply reduced the resources available part-way through the project. Some manufacturers found themselves unable to carry out their initial intent of submitting data for their events. This was partly addressed by there being redundancy in reporting; at least two manufacturers were involved in each event (airframer and engine/propeller/APU manufacturer).

The approach developed by the first CAAM group had proven its practical utility, and commonality with that approach was considered highly desirable. However, there were various inconsistencies in the approach (defining lower-level event severity by means of a list of event types) which caused some controversy. In some cases, the intent of the first team was not well documented and definitions had to be re-interpreted for clarity.

Reported Findings From the Analysis

The database encompassed 146 million flights on turbofan-powered airplanes — 45 million on LBPR; 101 million on HBPR. Turboprop participants reported 25 million flights.

Figures 1–4 (pages 278–280) provide an ordering of the leading causes of serious (hazard level 3, 4 and 5) and severe (hazard levels 4 and 5 only) events for turbofans and turboprops. (Note that this type of ordered bar chart is termed a Pareto chart.) Event categories not on the charts did not have any higher-level events.

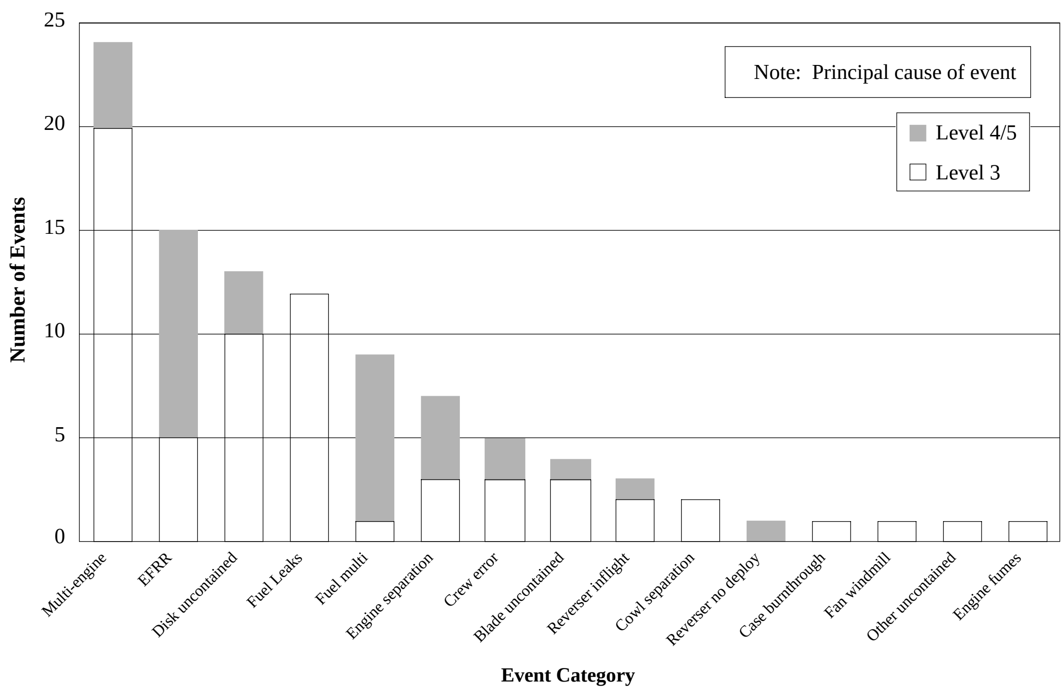


Figure 1. Turbofan Level 3+ Events — 1992–2000

For APUs, there were six level 3 fires, one level 3 tailpipe fire, and one level 3 APU fume event. No APU events reached level 4 or 5 severity.

Figure 5 (page 281) provides a matrix of the rates (per 100 million flights) for each of the event categories.

Propulsion system fumes (i.e., engine- or APU-produced fumes) on turbofan-powered engines occurred at a reported rate of 3E-5 per flight (or 3,000 per 100 million departures). Level 3 propulsion fume events occurred at a reported rate of 2E-8 per flight (or two per 100 million departures).

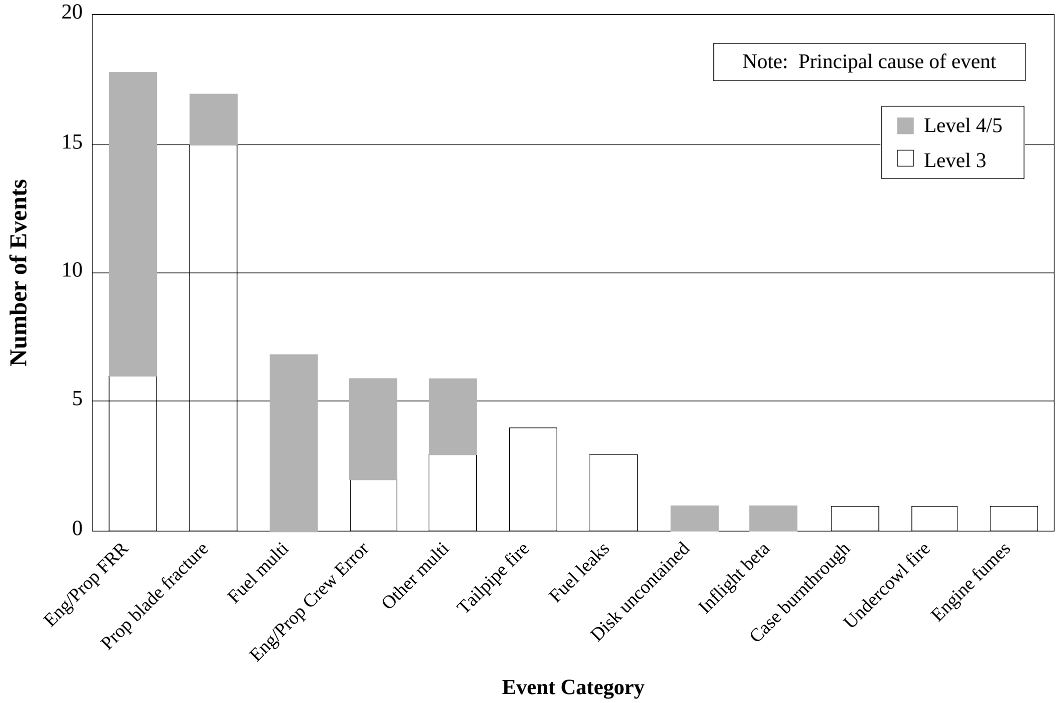


Figure 2. Turboprop Level 3+ Events — 1992–2000

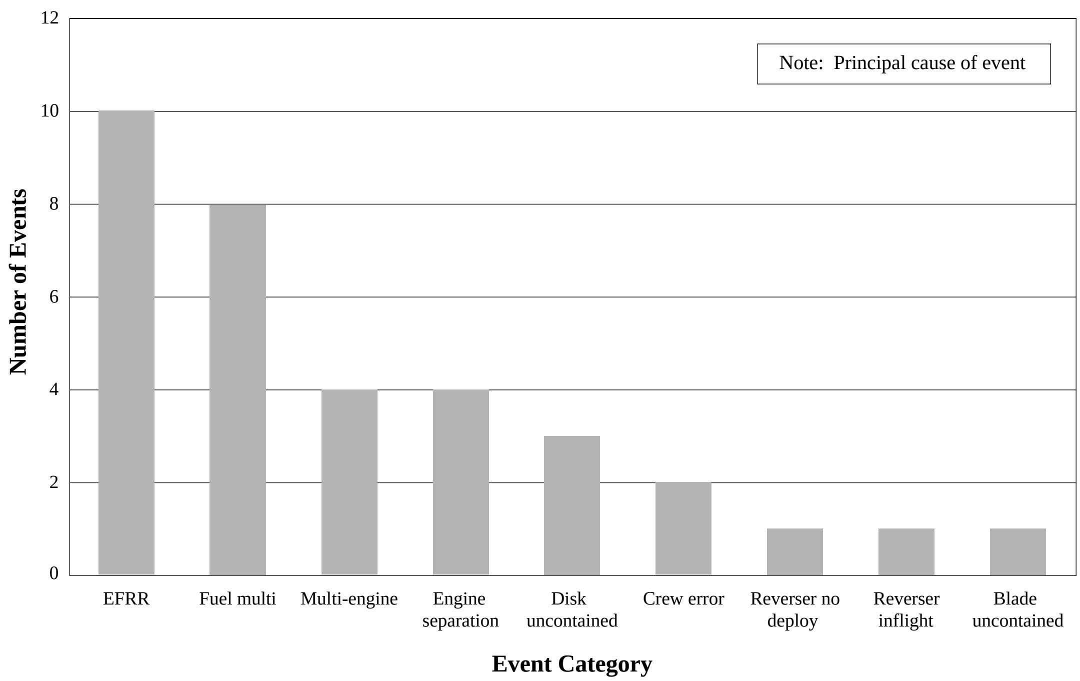


Figure 3. Turbofan Level 4+ Events — 1992–2000

Figure 6 (page 282) displays a comparison of first and second generation HBPR engine event rates (per 100 million flights) for selected event categories.

Note that the rates in Figures 5 and 6 include the events of at least the listed severity level; for example, the “level 3+” rate includes all events of level 3, 4 or 5 severity.

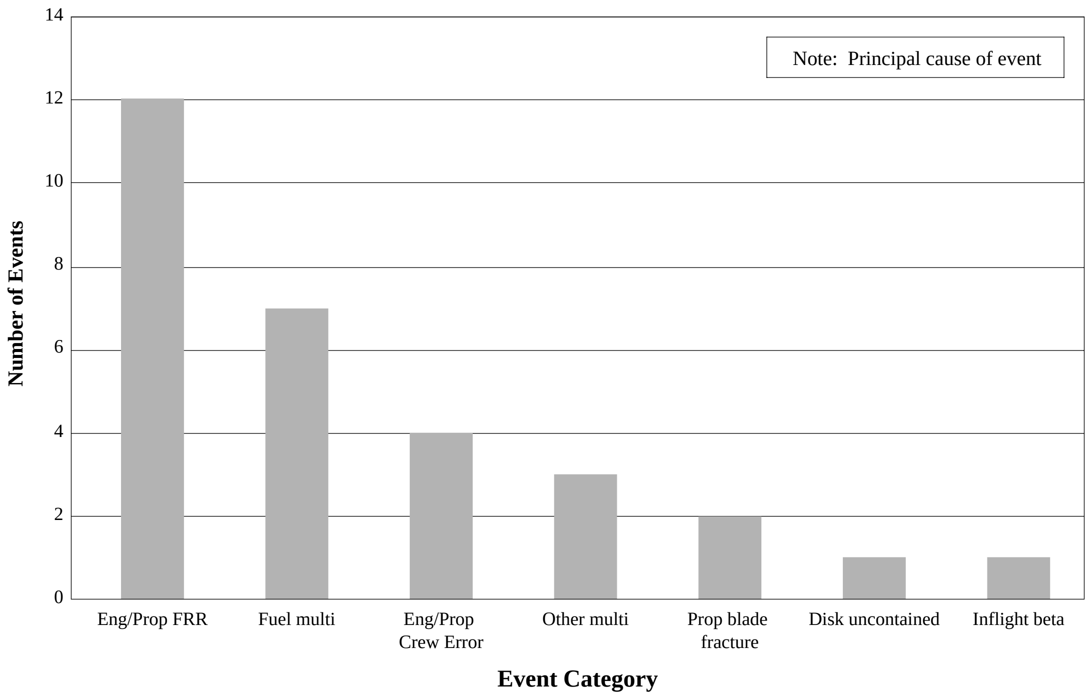


Figure 4. Turboprop Level 4+ Events — 1992–2000

Figures 7–12 (pages 282–285) are the hazard ratio Paretos for the different engine types. If an event category is not listed, there was inadequate data to calculate a hazard ratio.

Hazard ratios for Engine Failure Recognition and Response (EFRR)

Hazard ratios for EFRR after turbofan in-flight shutdown (IFSD) or significant power loss are provided in Figure 13 (page 285) below. These hazard ratios are conservative, as only IFSDs were used in the denominator, not all power loss events. Throttle split or overboost events are not included, due to lack of data on occurrence rate. Level 3+ hazard ratios are not calculated because of suspected significant under-reporting of level 3 PSM+ICR events. IFSD numbers for the period 1992–2000 were estimated from a one-year data sample. IFSD data was not available for the turboprop fleet.

The number of EFRR events remained relatively constant compared to the first study.

Conclusions

The team documented a number of conclusions. Primarily, as in the previous analysis, the data clearly demonstrates the importance of human factors in propulsion-related flight safety, especially in the turboprop fleet. Several interventions have been developed, including “Engine Failure Recognition and Response” pilot training material and recommendations for improved realism for the simulation of engine failures. Continued emphasis on this leading cause of propulsion-related accidents is required.

Secondly, multiple-engine power loss events, again especially in the turboprop fleet, require industry attention to develop potential interventions. An important element of multi-engine events is fuel exhaustion, which of course also encompasses human factor issues.

Second generation HBPR turbofans display significantly improved uncontainment and multi-engine power loss event rates over first generation rates. (Note that these two categories are the only ones for which a generational

ENGINE TYPE	TURBOPROP				LBPR				HBPR			
HAZARD LEVEL	All	3+	4+	5	All	3+	4+	5	All	3+	4+	5
MALFUNCTION TYPE	EVENT RATES											
UNCONTAINED	36	4	4	0	59	15	6	2	129	10	1	–
Blade	4	–	–	–	46	4	2	2	97	2	–	–
Disk, Spool, etc.	24	4	4	–	13	11	4	–	26	7	1	–
Other	8	–	–	–	0	–	–	–	6	1	–	–
ENGINE OVERSPEED	*	–	–	–	†	–	–	–	†	–	–	–
CASE RUPTURE	0	–	–	–	13	–	–	–	7	–	–	–
CASE BURNTHRU	12	4	–	–	7	–	–	–	27	1	–	–
UNDER–COWL FIRE	79	16	–	–	24	–	–	–	85	3	–	–
FLAM FLUID LEAK	2115	12	–	–	*	4	–	–	*	8	–	–
Oil/Hydraulic Leak	1830	–	–	–	*	–	–	–	*	–	–	–
Fuel Leak	284	12	–	–	*	4	–	–	*	8	–	–
OVERHEAT/AIRLEAK	*	–	–	–	*	–	–	–	*	–	–	–
ENGINE SEPARATION	8	–	–	–	13	9	6	2	3	3	1	1
COWL SEPARATION	12	–	–	–	59	2	–	–	115	1	–	–
EFRR	*	47	43	32	*	18	11	4	*	7	5	4
CREW ERROR	*	4	4	4	*	7	4	–	*	*	–	–
REVERSER/BETA – IN-FLIGHT DEPLOY	*	20	16	8	7	–	–	–	13	3	1	1
REVERSER/BETA –FAILURE TO DEPLOY	*	24	4	–	*	*	–	–	776	2	2	–
FUEL TANK RUPTURE	–	–	–	–	2	2	2	2	1	1	1	1
TAILPIPE FIRE	*	16	–	–	*	–	–	–	*	1	–	–
FALSE/MISLEADING INDICATION	1059	4	4	4	*	–	–	–	8911	–	–	–
MULTI–ENG – NON-FUEL SUBTOTAL	51	28	16	8	42	33	6	4	69	17	3	0
Environmental	47	24	12	8	18	11	2	2	36	5	–	–
Maintenance	–	–	–	–	–	–	–	–	7	5	3	–
Other/Unknown	4	4	4	–	24	22	4	2	27	7	–	–
MULTI-ENG – FUEL SUBTOTAL	20	20	20	12	13	9	9	4	19	3	3	
Fuel Contamination	*	8	8	8	2	–	–	–	4	1	1	–
Fuel Mismanagement	*	–	–	–	4	2	2	–	13	–	–	–
Fuel Exhaustion	16	16	16	4	7	7	7	4	2	2	2	–
PROP SYS SUBTOTAL	620	122	24	8								
Blade Sep/Debris	324	67	8	4								
Autofeather/Pitch Lock	296	4	–	–								
PFRR	*	24	4	–								
Propeller Crew Error	*	20	12	4								
GRAND TOTAL	*****	**241**	**111**	**59**	*****	**93**	**42**	**18**	*****	**53**	**16**	**7**

*Hazard ratio not calculated due to non–reporting of base events.

Note: Totals have removed the effect of multiple event categories for the same event.

Figure 5. Aircraft Event Rates (per 100 million departures) — 1992–2000

ENGINE TYPE	FIRST GENERATION HBPR				SECOND GENERATION HBPR			
HAZARD LEVEL	ALL	3+4+5	4+5	5	ALL	3+4+5	4+5	5
MALFUNCTION TYPE	EVENT RATES							
UNCONTAINED								
Blade	656	22	–	–	34	–	–	–
Disk, spool, etc.	200	67	11	–	6	1	–	–
Other	33	11	–	–	1	–	–	–
MULTI-ENGINE								
Environmental	189	44	–	–	21	1	–	–
Maintenance	44	33	11	–	3	2	2	–
Other/Unknown	211	67	–	–	9	1	–	–
Fuel Contamination	11	–	–	–	3	1	1	–
Fuel Mismanagement	133	–	–	–	1	–	–	–
Fuel Exhaustion	11	11	11	–	1	1	1	–

Figure 6. Aircraft Event Rates (per 100 million departures) — 1992–2000 Comparison of First and Second Generation HBPR

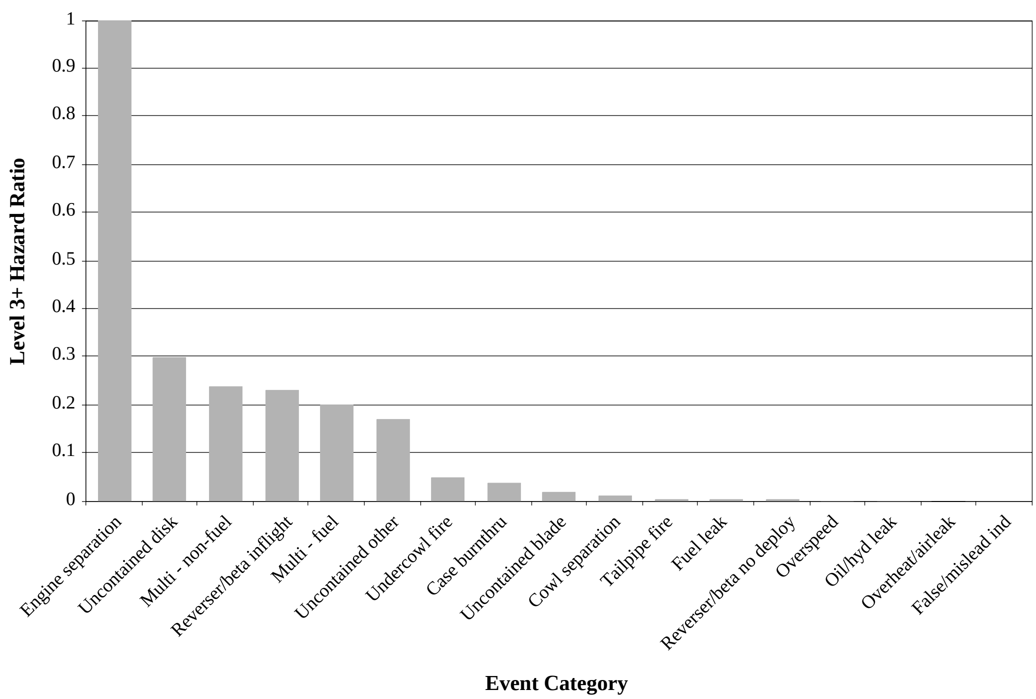


Figure 7. HBPR Turbofans — Level 3+ Hazard Ratios

analysis was performed.) Uncontainment rates are also improved over the earlier database (1982–1991 inclusive) for all engine categories.

The number of case rupture and case burnthrough events is significantly lower for each engine type compared to the earlier study.

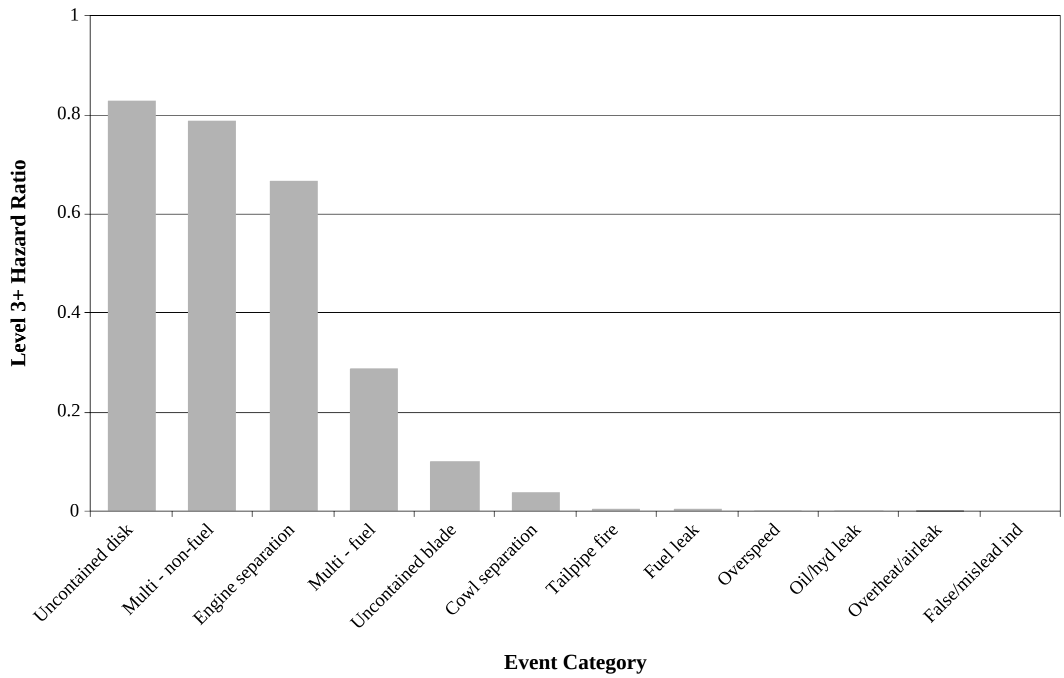


Figure 8. LBPR Turbofans — Level 3+ Hazard Ratios

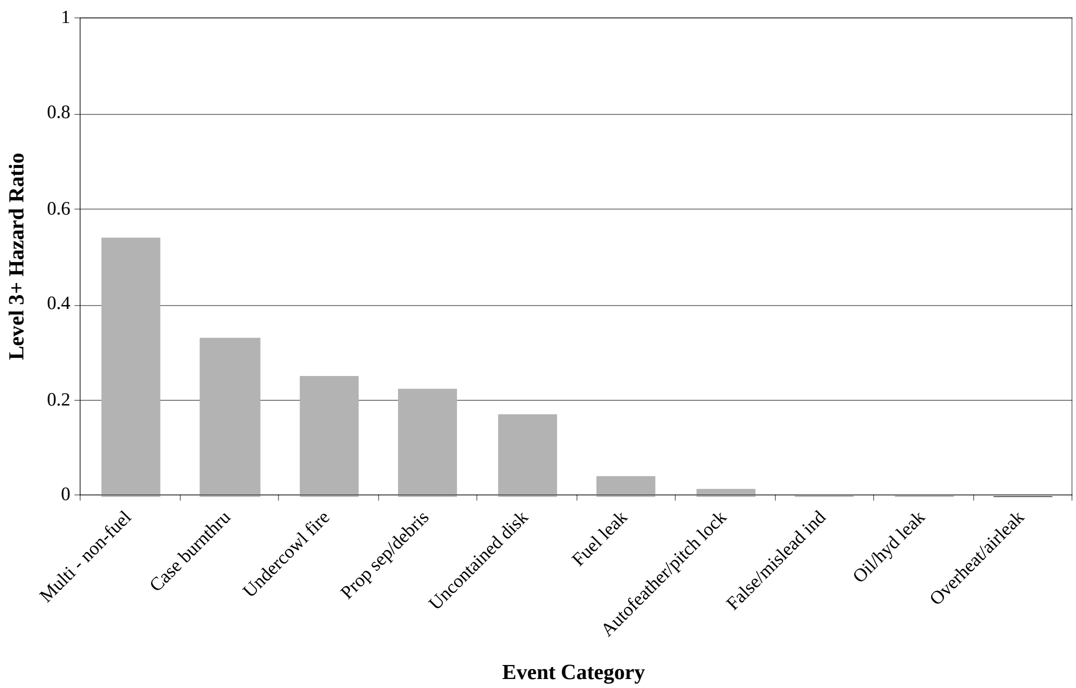


Figure 9. Turboprops — Level 3+ Hazard Ratios

For under-cowl fire, the numbers of events and the hazard ratios are very similar to those observed in the first study, even though the definition of "uncontrolled fire" was made more restrictive for the second study. The rates show some improvement for the high-bypass-ratio turbofan fleet, and some deterioration for the turboprop fleet.

As in the first study, the data continues to demonstrate that the conditional probability of a serious event resulting from a propulsion system high-pressure air leak or compartment overheat is very low.

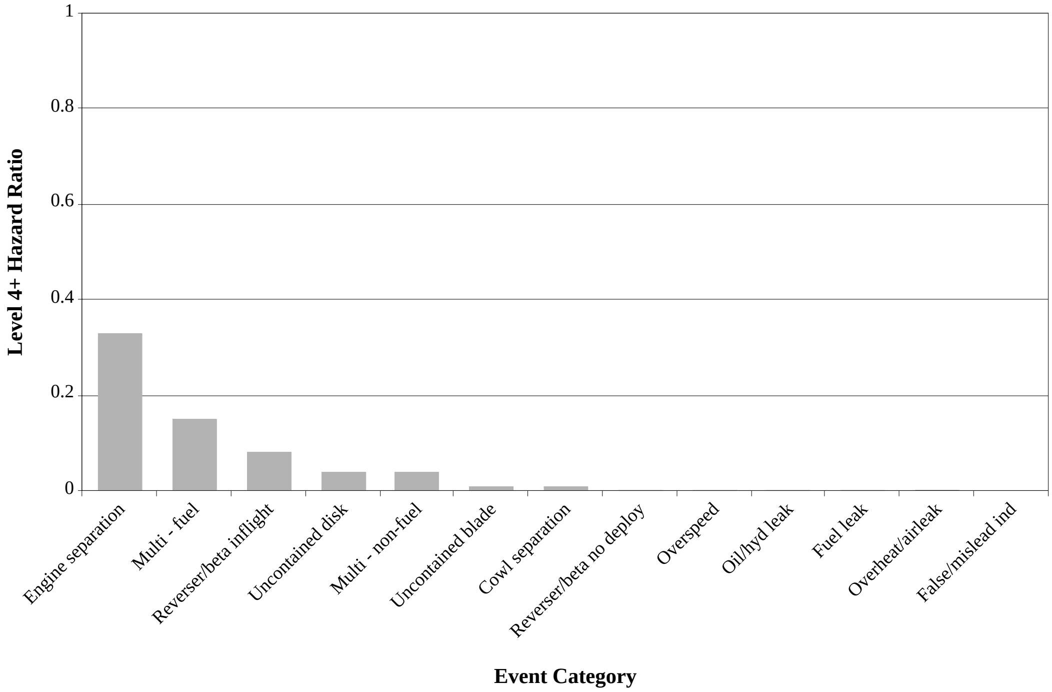


Figure 10. HBPR Turbofans — Level 4+ Hazard Ratios

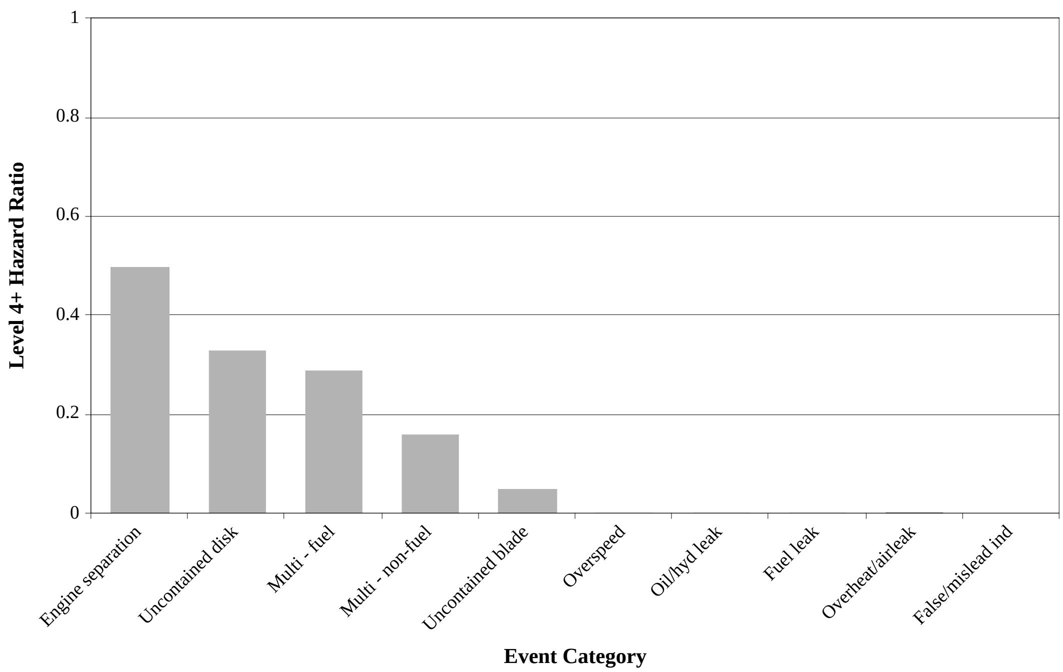


Figure 11. LBPR Turbofans — Level 4+ Hazard Ratios

The number of cowl separation events has increased since the first study, primarily in the high-bypass-ratio turbofan fleet. It should be recognized that the event definition has been expanded to include ground events as well as flight events, contributing to the increase. The hazard ratio remains low.

For engine separation, the number of events, number of serious events and low-bypass-ratio fleet event rate have all increased since the first study. Again, the scope of this event category has been broadened to

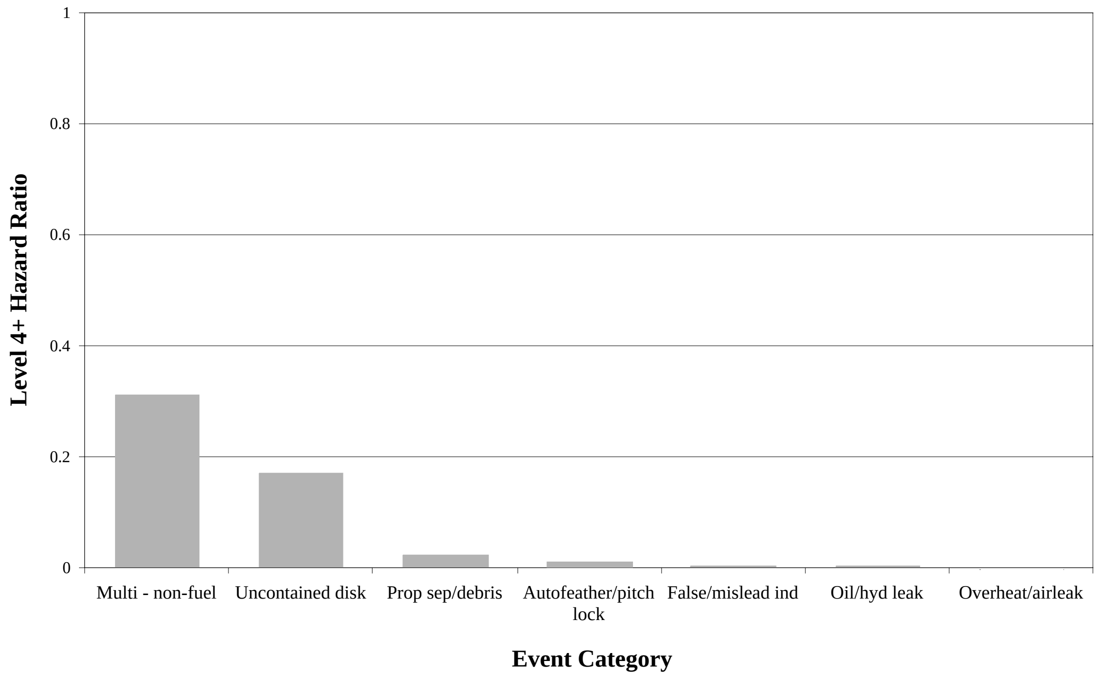


Figure 12. Turboprops — Level 4+ Hazard Ratios

ENGINE TYPE	ALL TURBOFANS				
HAZARD LEVEL	IFSDs[1]	Level 4 EFRR Events	Level 4+ Hazard Ratio	Level 5 EFRR Events	Level 5 Hazard Ratio
Takeoff	992	0	.002	2	.002
Climb	3957	0	<.0003	0	<.0003
Cruise	6226	1	.0002	0	<.0002
Descent	1525	0	<.0007	0	<.0007
Landing/Go-around	128	0	.008	1	.008
Unrelated to flight phase		1		1	
TOTAL	12,829	2	.0005	4	.0003

[1]IFSDs estimated based on sampling.

Note that there is a significantly higher hazard ratio for flight phases close to the ground.

Figure 13. Effect of Flight Phase on EFRR Hazard Ratio 1992–2000

include on-ground events. It should be noted that the engine separation events appear strongly linked to cargo operations.

There was an increase in the number of reverser/beta severe events over the first study; however, most of the severe events were instances of in-flight beta malfunction, which was not included in this event category in the first study. The number of severe events associated specifically with thrust reversers was significantly lower.

The definition of a level 3 multi-engine power loss event was expanded for the activity summarized in this paper to include events wherein engine power was completely lost for a sufficient time that the airplane lost at least 5,000 feet of altitude. In the previous study, many of these events would have been classified as less serious than level 3. There was also more data collected from the turboprop fleet than for the first report, and the power losses were grouped differently. Nonetheless, the high-bypass-ratio turbofan fleet had fewer multiple-engine power loss events for environmental causes than in the first study.

The hazard ratio for APU uncontainment remains undefined, since no high-severity events have occurred in either the earlier study or this update. Fire remains the most significant issue for APUs.

Recommendations

The data and analysis summarized in this report should be used to prioritize safety-related industry studies, research and regulatory activities. Additionally, the hazard ratios should be used to help establish the risks posed by specific propulsion safety threats, and thus inform the timing of mitigations to address them.

Follow-on studies should be initiated for high-risk areas to address them in more depth. Mitigations focused on the requirements for new products should begin with a study of the generational effect, to verify that these are also high-risk areas for more recently designed products. Development of a Pareto for the second and third generation products alone would bring additional insight into prioritization.

Similar studies should be developed for in-service events across the entire spectrum of aircraft events.

The FAA and foreign authorities should harmonize continued airworthiness efforts. Currently, differences between continued airworthiness policies sometimes result in separate mitigation strategies for the same safety threat.

Studies should be conducted to identify the role of maintenance error in the data collected.♦

Appendix

First generation high-bypass-ratio turbofans are those developed in the late 1960s to enter service in the early 1970s (as originally documented in SAE AIR4770):

RB211-22B, CF6-6, CF6-50, JT9D.

Second generation high-bypass-ratio turbofans, in the context of this report, include all engines developed after the first generation. However, future work may discriminate further between those engines entering service in the 1980s and those designed and developed after that time frame. The report included the following engines as second generation:

ALF502, LF507, AE3007, CFE738, TFE731-20/40/60, CF6-80A, CF6-80C and later CF6 models, CFM56-2, CFM56-3 and later CFM56 models, CF34, GE90, V2500, PW2000, PW4000, RB211-535C, RB211-524B4 and later RB211 models, RR Tay and Trent.

The third generation engines, in future analyses, might include the following (some of which are currently grouped in with the second generation):

GE90, CFM56-7, GP7000, GEnX, PW6000, Trent 800 and later models, HTF7000, TFE731-50 and other engines certified after 1990.

References

1. "Technical Report on Propulsion System and Auxiliary Power (APU) Related Aircraft Safety Hazards," October 25, 1999, FAA Engine & Propeller Directorate.

2. "2nd Technical Report on Propulsion System and Auxiliary Power (APU) Related Aircraft Safety Hazards," January 31, 2005, FAA Engine & Propeller Directorate.

Both available on line at http://www.faa.gov/aircraft/air_cert/design_approvals/engine_prop/engine_sp_topics/

About the Authors

Ann Azevedo is the FAA's chief scientist and technical advisor for aircraft safety analysis. She has developed training material for and taught statistical, risk and experimental design courses both in industry and the FAA. She has been the lead for engine safety analysis harmonization, for the development and distribution of engine failure pilot training material, and for risk analyses on a wide variety of issues.

She is a charter member of various Commercial Aviation Safety Team (CAST) analytical and implementation teams to support the goal of fatal accident rate reduction. Ms. Azevedo has served as an expert panel member and presenter at the Society of Automotive Engineers Weibull Analysis conference.

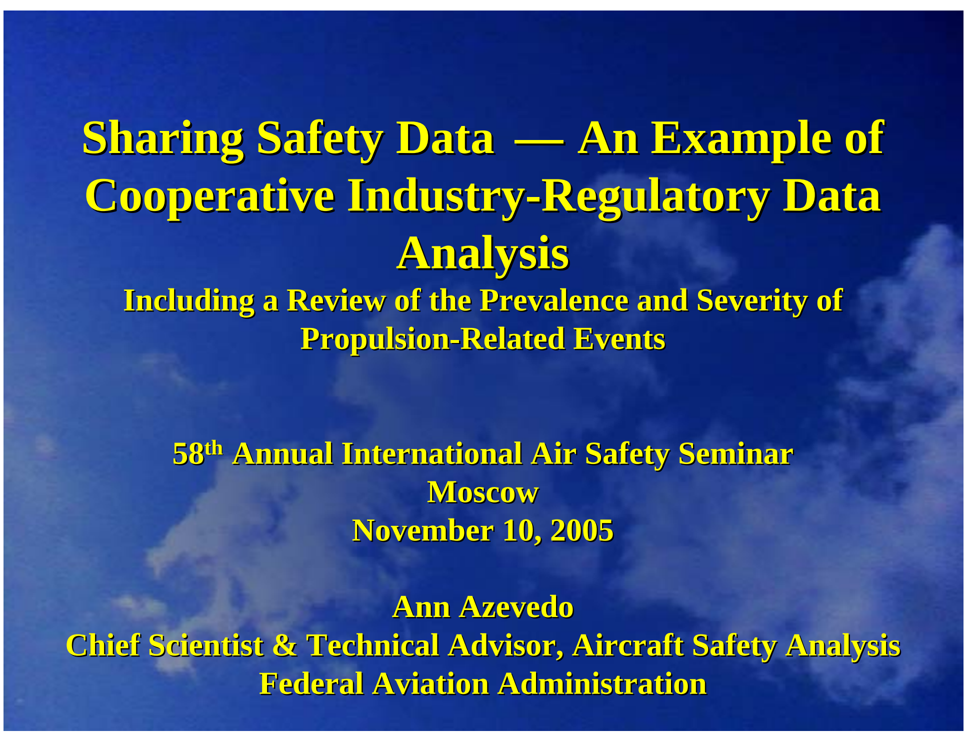
Prior to joining the FAA, Ms. Azevedo had 18 years of industry experience at Pratt & Whitney in risk analysis, materials, and manufacturing engineering.

Sarah Knife is the principal engineer for airplane and regulatory safety in the Chief Engineer's Office of General Electric Aircraft Engines (GEAE). She has provided technical and statistical leadership in engine installation design and in propulsion system safety analysis over the past 25 years, working for Rolls-Royce, General Electric and Boeing.

Dr. Knife has served on numerous FAA-industry committees dedicated to safety initiatives and safety-related rulemaking, and has led teams in developing video and text training packages for use by pilots in response to propulsion system malfunctions.

Dr. Knife holds a Ph.D. in aeronautics from Cranfield University, and a B.Sc. in physics (Honors) from the Victoria University of Manchester. She has previously published papers on the safety analysis of aircraft propulsion systems and on human factors methodologies requirements for propulsion system design.

Additional material follows on pages 287–302.



History

- Public perception of aircraft safety is coincident with the number of accidents per calendar time period
- Increase in the number of accidents per calendar time period due to increases in the number of departures

History (continued)

- Available resources must be focused in areas that offer the greatest potential for accident prevention (Pareto principle)
- Recognition by the propulsion community that there was a need to understand the types of events that were occurring, and their conditional probabilities of resulting in an accident or serious incident

CAAM (Continued Airworthiness Assessment Methodologies) Committee

Formed to develop methods and use historical data to identify and prioritize unsafe conditions based on occurrence probability and consequence

- <u>Occurrence Probability</u> — Tabulate
- <u>Consequence</u> —
  - Standardized aircraft hazard levels
  - Hazard ratio (given that a malfunction has occurred, what is the likelihood it is a serious event?)

CAAM Committee (continued)

- Manufacturers (engine, airframe), airlines, regulatory agencies
- Each brought data to the table to discuss openly within the team
- “Honest broker” kept data (for length of team activity) and performed analysis
- Sanitized version of data presented in reports and final analysis

Data Reporting

- Propulsion system (including APU) events on Western-built, transport category airplanes
- 1992–2000 (update to earlier 1982–1991 database)
- Reporting most comprehensive on large turbofans; limited reporting of out-of-production airplanes, especially turboprops
  - Severe events captured, minor events may be underreported

Data Analysis

- Events grouped by type of event
- Events divided into engine type — turboprop, low-bypass-ratio turbofan, high-bypass-ratio turbofan
- Event quantities and rates calculated
- Conditional probabilities (“hazard ratios”) of more serious events
- Event causes ranked by their contribution to the overall propulsion-related accident rate

Challenges

- Ambitious scope — greatly expanded from the first database both in types of events to be assessed and also in the kind of information to be gathered about each event
- The difficulty and labor of collecting and collating the data was underestimated

Challenges (cont.)

- Airline industry economic downtown sharply reduced the resources available part-way through the project
- Some manufacturers unable to submit data — partly addressed by redundancy in reporting (at least two manufacturers involved in each event — airframer and engine/propeller/APU manufacturer)

Challenges (cont.)

- Various inconsistencies existed in the approach developed as part of the first database; caused controversy in this effort
- In some cases, the intent of the first team was not well documented and definitions had to be re-interpreted for clarity

Definitions

- Hazard level — Event outcome, as defined by its effect on the aircraft, passengers and crew
- Hazard ratio — The conditional probability that a particular propulsion failure mode will result in an event of a specific hazard level

A Note on Hazard Levels

- The hazard level determination for a particular incident or accident is an objective assessment of what actually happened
- It does *not* mean that the base event will always result in that outcome

Hazard Levels

- Level 5 — Catastrophic consequences
  - Multiple fatalities, usually with the loss of the airplane

Hazard Levels (cont.)

- Level 4 — Severe consequences
  - Hull loss
  - Serious injuries or fatalities
  - Forced landing

Hazard Levels (cont.)

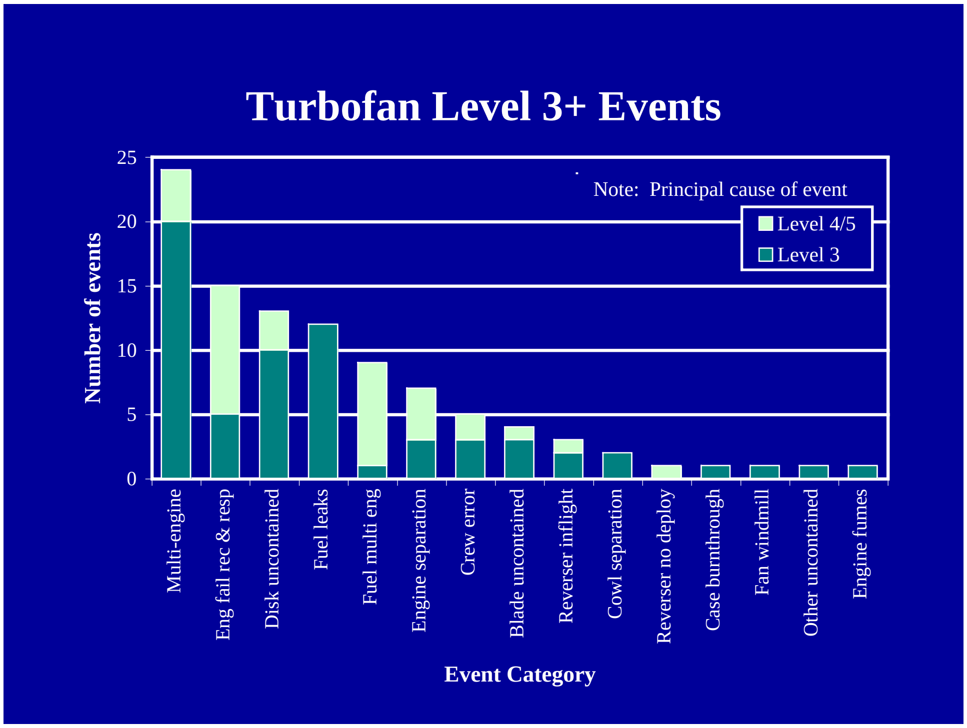
- Level 3 — Serious consequences
  - Substantial damage to aircraft or second unrelated system
  - Uncontrolled fire or rapid depressurization
  - Permanent loss of thrust/power greater than one propulsion system
  - Temporary or permanent inability to climb or control
  - Smoke/fumes sufficient to cause serious impairment

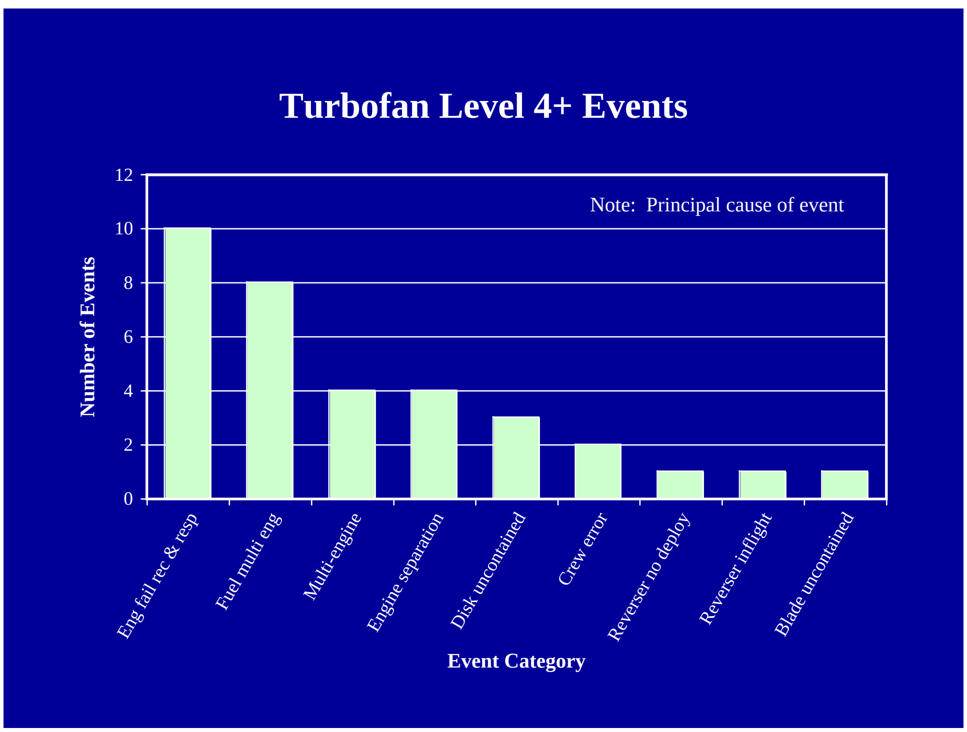
Hazard Levels — Lower Levels

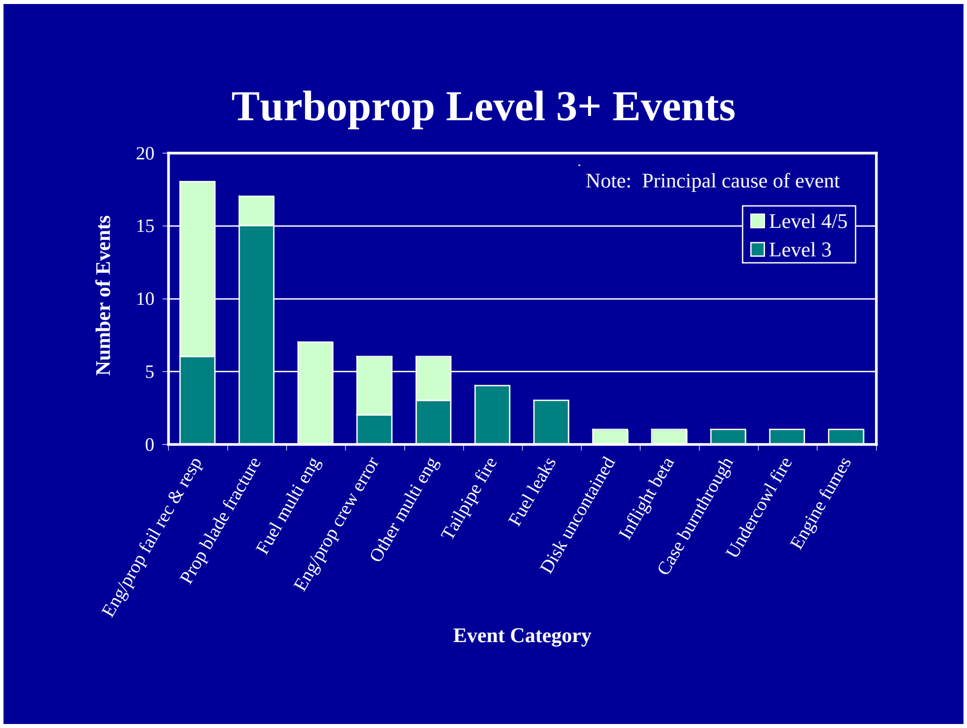
- Level 2 — Significant consequences
  - Minor injuries/damage, high-speed abort, etc.
- Level 1 — Minor consequences
  - Nacelle uncontain, shutdown below 3,000 feet, etc.
- Level 0 — No safety consequences
  - Shutdown above 3,000 feet, case uncontain, etc.

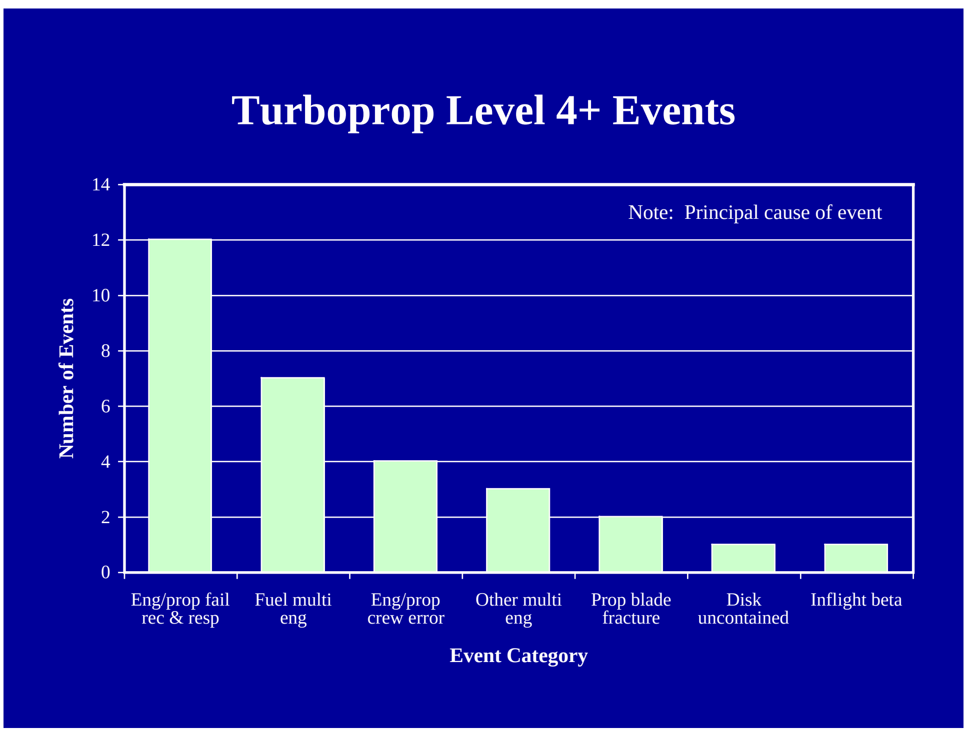
Results

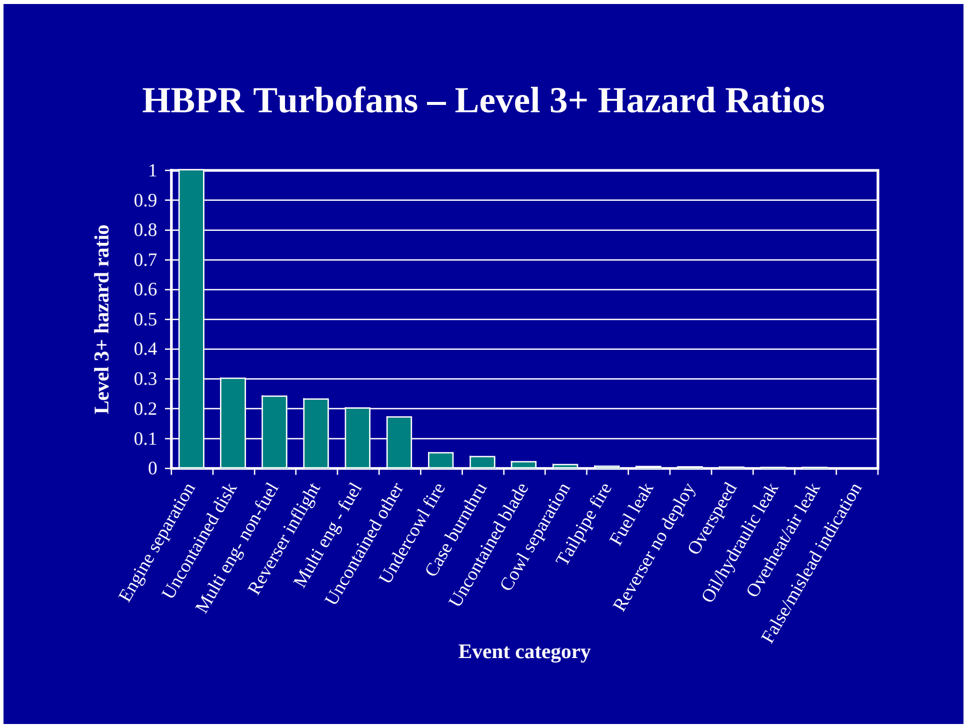
- Turbofans — 146 million flights
  - 45 million LBPR
  - 101 million HBPR
- Turboprops — 25 million flights

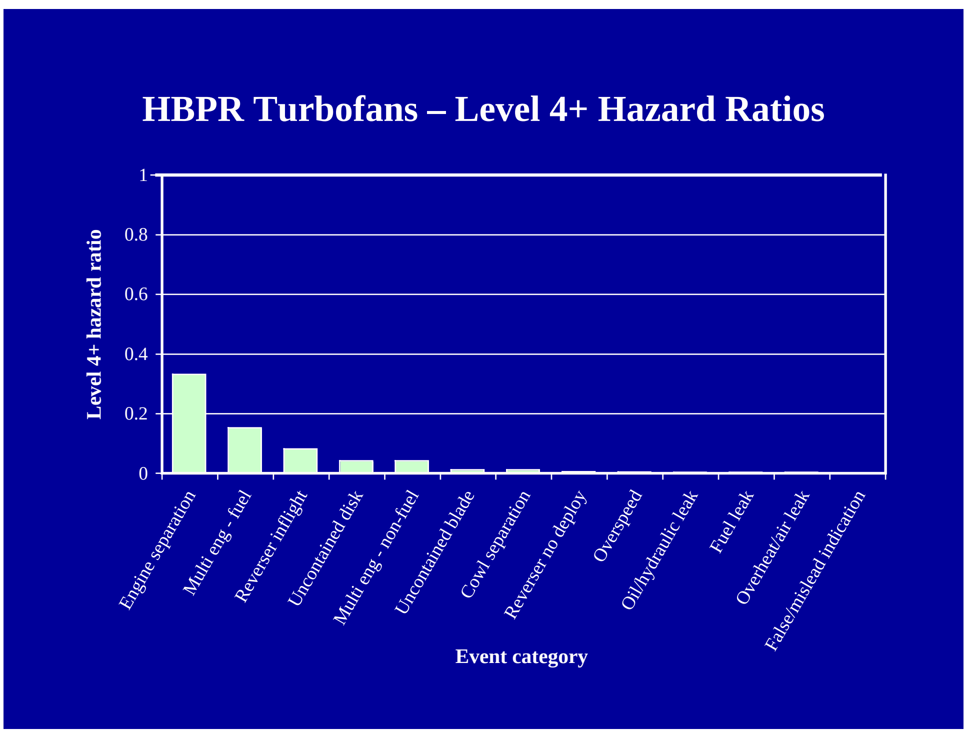

Turbofan Level 3+ Events
Note: Principal cause of event
Level 4/5
Level 3
Number of events
25
20
15
10
5
0
Multi-engine
Eng fail rec & resp
Disk uncontained
Fuel leaks
Fuel multi eng
Engine separation
Crew error
Blade uncontained
Reverser inflight
Cowl separation
Reverser no deploy
Case burnthrough
Fan windmill
Other uncontained
Engine fumes
Event Category

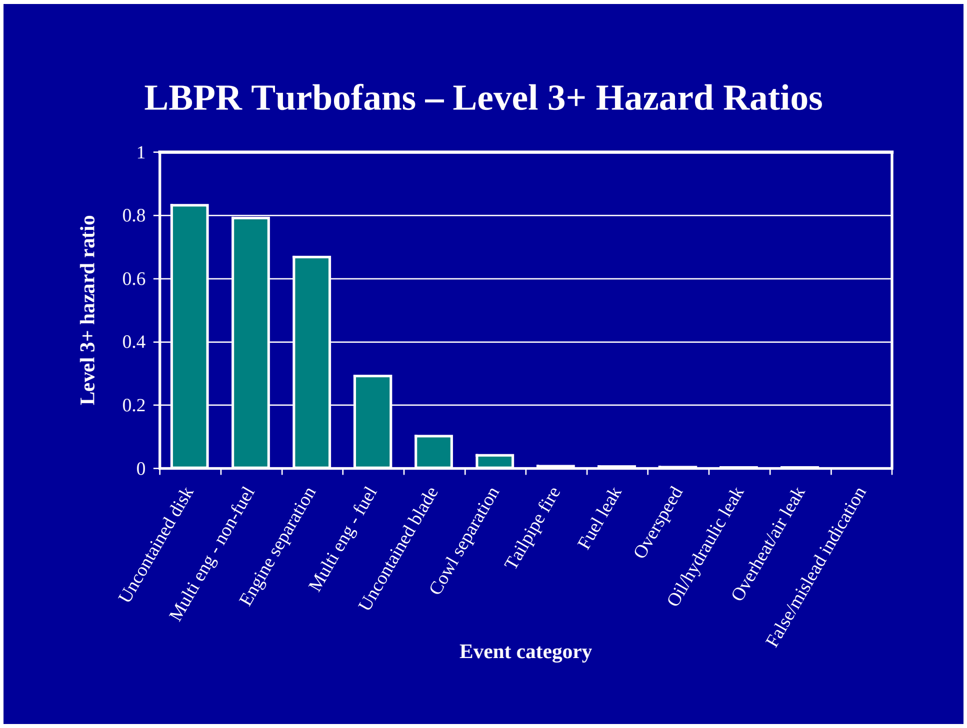

Turbofan Level 4+ Events
Note: Principal cause of event
Number of Events
12
10
8
6
4
2
0
Eng fail rec & resp
Fuel multi eng
Multi-engine
Engine separation
Disk uncontained
Crew error
Reverser no deploy
Reverser inflight
Blade uncontained
Event Category

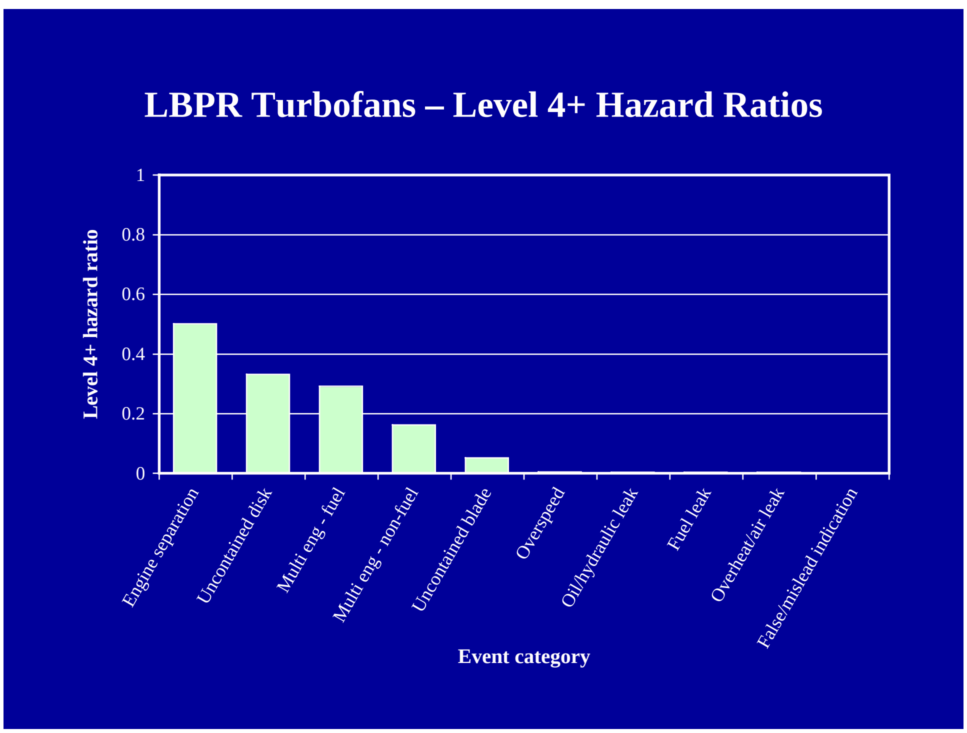

Turboprop Level 3+ Events
Note: Principal cause of event
Level 4/5
Level 3
Number of Events
20
15
10
5
0
Eng/prop fail rec & resp
Prop blade fracture
Fuel multi eng
Eng/prop crew error
Other multi eng
Tailpipe fire
Fuel leaks
Disk uncontained
Inflight beta
Case burnthrough
Undercowl fire
Engine fumes
Event Category

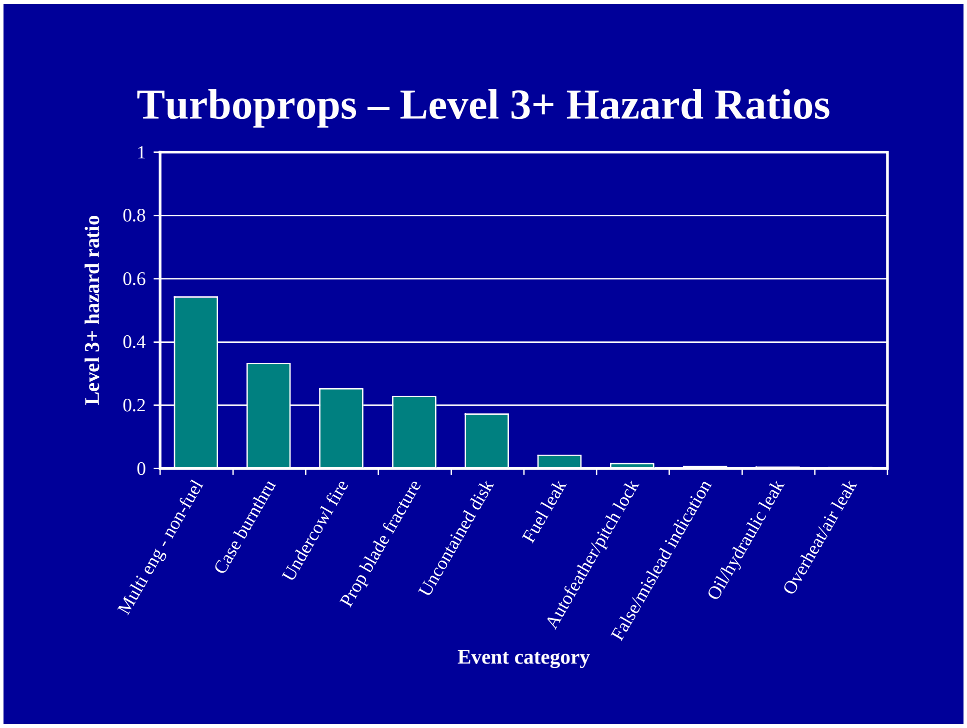

Turboprop Level 4+ Events
Note: Principal cause of event
Number of Events
14
12
10
8
6
4
2
0
Eng/prop fail rec & resp
Fuel multi eng
Eng/prop crew error
Other multi eng
Prop blade fracture
Disk uncontained
Inflight beta
Event Category


HBPR Turbofans – Level 3+ Hazard Ratios
Level 3+ hazard ratio
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Engine separation
Uncontained disk
Multi eng- non-fuel
Reverser inflight
Multi eng - fuel
Uncontained other
Undercowl fire
Case burnthru
Uncontained blade
Cowl separation
Tailpipe fire
Fuel leak
Reverser no deploy
Overspeed
Oil/hydraulic leak
Overheat/air leak
False/mislead indication
Event category

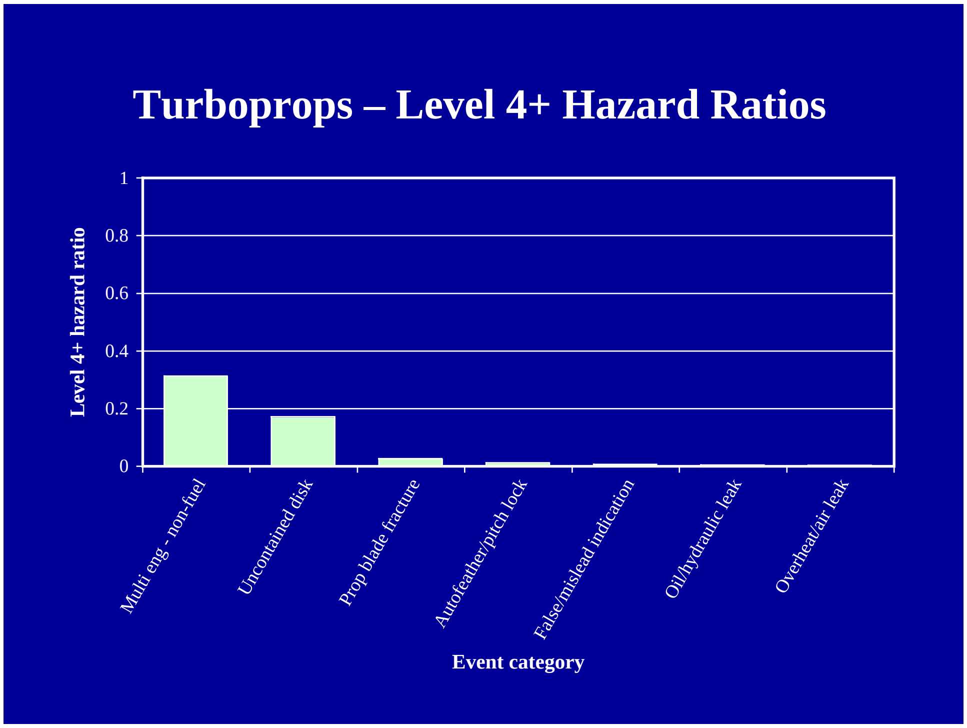

HBPR Turbofans – Level 4+ Hazard Ratios
Level 4+ hazard ratio
1
0.8
0.6
0.4
0.2
0
Engine separation
Multi eng - fuel
Reverser inflight
Uncontained disk
Multi eng - non-fuel
Uncontained blade
Cowl separation
Reverser no deploy
Overspeed
Oil/hydraulic leak
Fuel leak
Overheat/air leak
False/mislead indication
Event category


LBPR Turbofans – Level 3+ Hazard Ratios
Level 3+ hazard ratio
1
0.8
0.6
0.4
0.2
0
Uncontained disk
Multi eng - non-fuel
Engine separation
Multi eng - fuel
Uncontained blade
Cowl separation
Tailpipe fire
Fuel leak
Overspeed
Oil/hydraulic leak
Overheat/air leak
False/mislead indication
Event category


LBPR Turbofans – Level 4+ Hazard Ratios
Level 4+ hazard ratio
1
0.8
0.6
0.4
0.2
0
Engine separation
Uncontained disk
Multi eng - fuel
Multi eng - non-fuel
Uncontained blade
Overspeed
Oil/hydraulic leak
Fuel leak
Overheat/air leak
False/mislead indication
Event category



Turboprops – Level 3+ Hazard Ratios
Level 3+ hazard ratio
1
0.8
0.6
0.4
0.2
0
Multi eng - non-fuel
Case burnthru
Undercowl fire
Prop blade fracture
Uncontained disk
Fuel leak
Autofeather/pitch lock
False/mislead indication
Oil/hydraulic leak
Overheat/air leak
Event category



Turboprops – Level 4+ Hazard Ratios
Level 4+ hazard ratio
1
0.8
0.6
0.4
0.2
0
Multi eng - non-fuel
Uncontained disk
Prop blade fracture
Autofeather/pitch lock
False/mislead indication
Oil/hydraulic leak
Overheat/air leak
Event category

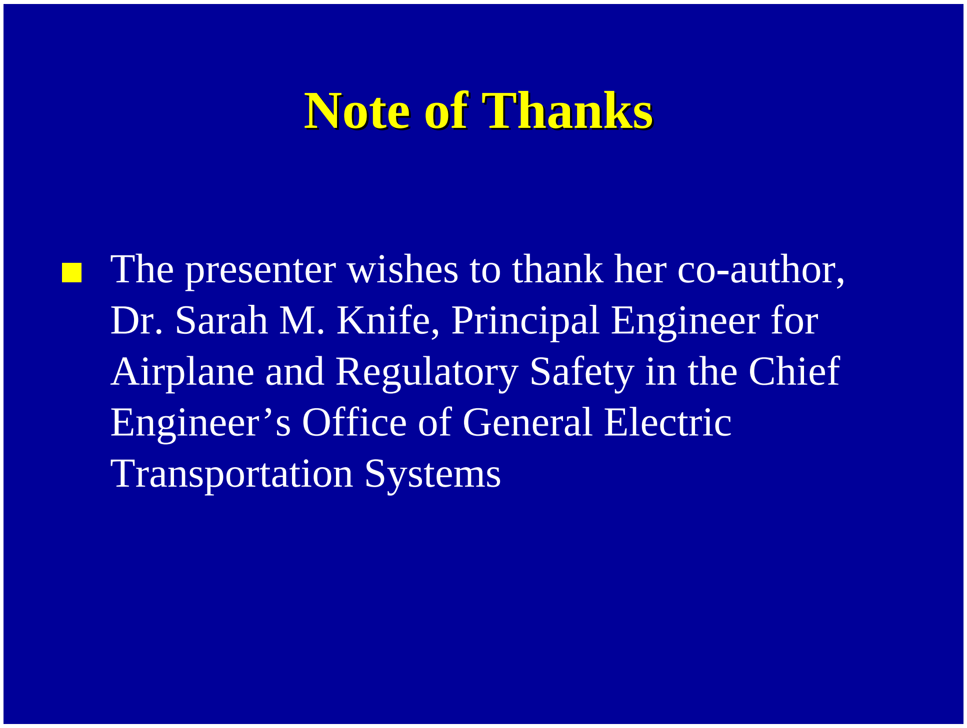
Engine Failure Recognition and Response (EFRR)

ENGINE TYPE	ALL TURBOFANS				
HAZARD LEVEL	IFSDs	Level 4 EFRR Events	Level 4+ Hazard Ratio	Level 5 EFRR Events	Level 5 Hazard Ratio
Takeoff	992	0	.002	2	.002
Climb	3957	0	<.0003	0	<.0003
Cruise	6226	1	.0002	0	<.0002
Descent	1525	0	<.0007	0	<.0007
Landing/Go-around	128	0	.008	1	.008
Unrelated to flight phase		1		1	
TOTAL	12,829	2	.0005	4	.0003

Significantly higher HR for flight phases close to the ground

Conclusions

- Data clearly demonstrate the importance of human factors in propulsion-related flight safety, especially in the turboprop fleet
- Multiple-engine power-loss events, again especially in the turboprop fleet, require industry attention to develop potential interventions
  - An important element of multi-engine events is fuel exhaustion
- Other specific conclusions documented in the accompanying paper


Note of Thanks
■ The presenter wishes to thank her co-author, Dr. Sarah M. Knife, Principal Engineer for Airplane and Regulatory Safety in the Chief Engineer's Office of General Electric Transportation Systems

♦♦♦♦

Changing National Safety Culture Through Data Sharing

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Abstract

In late 2004, the U.S. Joint Program Development Office of the Federal Aviation Administration (FAA) convened the Aviation Safety Information Sharing Task (ASIST) team to define an ideal future state for safety information sharing in the commercial aviation community. The team offered a vision for a future in which the air transportation system is accident free, because hazards are identified and risks are managed before they cause accidents. Safety information from stakeholders would be accessed through an information sharing process available to decision makers for managing risk. But the road to this future state requires a great deal of change — today, data is closely held to prevent inappropriate use; in the envisioned future, data would be shared among participants through secure networks and under mutually agreeable rules of engagement. Getting there requires both *building technology* and processes from the vision of the final state, and *building trust* though developing ongoing safety data sharing efforts. In that sense, it is a call for national safety culture change. This paper will discuss in detail a key set of efforts supporting this broader vision, embodied in the Voluntary Aviation Safety Information-sharing Process (VASIP). VASIP provides a means for the commercial aviation industry and the FAA to collect and share safety-related information and to use that information to proactively identify, analyze and correct safety issues that affect commercial aviation. VASIP is a vehicle for national safety culture change through data sharing. It is, therefore, a key first step toward building the attributes that will lead the industry toward a worldwide aviation system that systematically mitigates risk and continually reduces the likelihood of accidents.

1. Introduction

As of this writing, the U.S. aviation industry is progressing through the safest period in the history of commercial aviation, as measured by accidents. According to the Federal Aviation Administration (FAA), as of July 31, 2005, the U.S. air carrier fatal accident rate for all FARs Part 121 and Part 135 carriers was only 0.025 fatal accidents per 100,000 takeoffs. On a three-year average, the corresponding accident rate in the U.S. is 0.017 in 100,000 departures [Ref 1]. This is the equivalent of one fatal accident per 5.9 million flights.

For several decades, the airline industry has taken great pride in its ability to continually strive to lower the accident rate. As shown in Figure 1 (page 304), however, while some regions have enjoyed a low accident rate, other regions of the world are not experiencing the same success [Ref 2]. As these regions continue to expand their aviation presence, all countries will need to work harder towards reducing their accident rates. Doing so will require preventing recurrence of accident scenarios that are already understood and identifying and resolving developing risk.

Much of the advance in aviation safety has been the direct result of a "forensic approach" to accident prevention, or more accurately, accident recurrence. When an aircraft accident occurred, the country's accident investigation authority would take a close look at what went wrong and issue recommendations to the regulator, aircraft

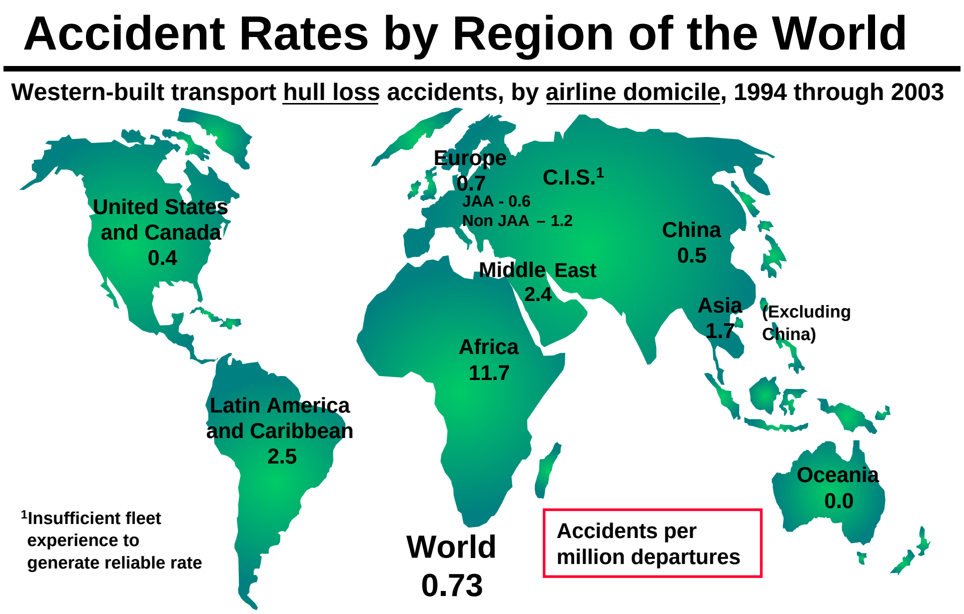


Figure 1. Accident Rates by Region of the World

manufacturer, airline, etc. to fix the probable cause of the accident. While the forensic approach to accident reduction has worked very well in the past and undoubtedly will be necessary in the future, it is also clear that a more "prognostic" approach will be required to achieve further substantial reductions, particularly in countries with historically low accident rates. Some of those countries are setting goals for even lower rates. For example, in the United States, the goal set by a White House commission is to reduce the commercial fatal accident rate to 0.010 per 100,000 departures by 2007. That reflects another 40 percent reduction in the accident rate from the 2005 level.

To meet these goals, regulators, employees and airline managers must recognize that the absence of accidents is not proof of safety. Accidents and serious incidents are outcomes of ongoing risks. Their numbers or lack thereof are inadequate and misleading, because their causes are both systemic and probabilistic in nature. Post-accident investigations often find the same chain of events has occurred before, with only some random factor preventing serious consequences in previous events. Well-managed airlines can still have accidents and even significant risks may not be realized for some time. In order to further reduce the accident rate, initiatives must begin that will measure the underlying risks.

Where are those risks found? As the famous Bird Triangle illustrates (see Figure 2, page 305), while fatal accidents are extremely rare and incidents of injury and minor damage occur occasionally, near-misses and work errors can take place on a daily basis. Most of these are unobserved and unreported, but the environmental threats or operating errors they represent can lead to a fatal accident under the right circumstances. There is relatively little information about those errors, in contrast to what is learned from accidents. To reduce our accident rates throughout the world, it is necessary to learn about the many near-misses and work errors. If those errors can be significantly reduced, then the worldwide accident rate can also be reduced.

This thirst for information about work errors and hazards was the genesis of the safety initiatives many airlines have now adopted. Flight Operations Quality Assurance (FOQA) programs, originating in Europe, and voluntary reporting programs similar to the Aviation Safety Action Programs (ASAP) in the United States have grown significantly throughout the world. Voluntary reporting programs have been developed for pilots, flight attendants,

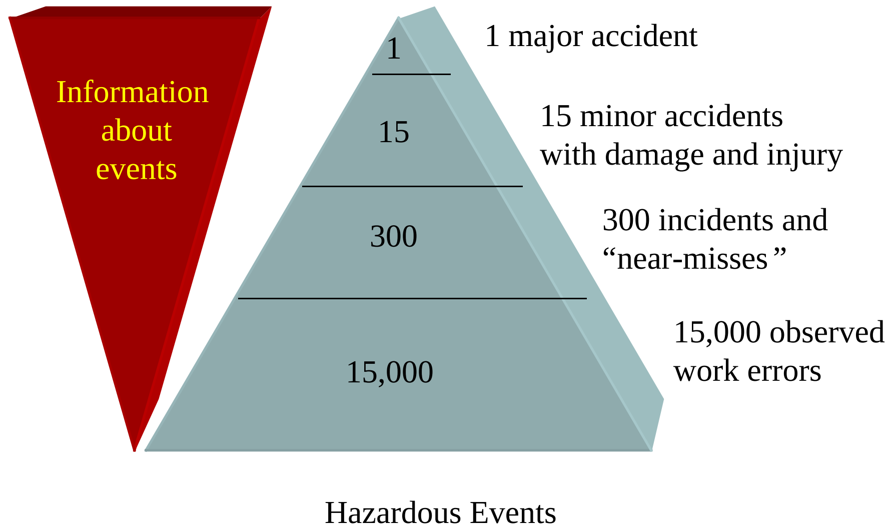


Figure 2. The Bird Triangle

dispatchers, maintenance and ramp personnel. There are also ongoing discussions to expand these programs to air traffic controllers.

Voluntary safety initiatives such as FOQA and ASAP can help the airline industry detect hazards and vulnerabilities in our air transportation system. By recording data from our airplanes and receiving reports from the front-line employees, it is possible to see not only *what* is happening, but also *why* it is happening. However, in order for these proven programs to work effectively, there has to be a willingness of employees to participate in these programs and a willingness of airline management to act on the risks identified through this data. A climate needs to exist at the organizational level of the airlines that encourages or even rewards people to report their errors and incidents; a climate often referred to as safety culture. A broader interpretation of this climate extends to government — the government must be prepared to act on information identifying risk in services the government controls or provides. This broader view looks across organizations and approaches a national safety culture.

In late 2004, the U.S. Joint Program Development Office of the FAA convened the Aviation Safety Information Sharing Task (ASIST) team to define an ideal future state for safety information sharing in the commercial aviation community. Its work was to be responsive to FAA, industry and the Commercial Aviation Safety Team (CAST) calls for improved safety data sharing. The team, which included the authors, offered a vision for a future in which the air transportation system is accident free, because hazards are identified and risks are managed before they cause accidents. Safety information from stakeholders is accessed through a safety information sharing process and is available to decision makers for managing risks.

But the road to this future state requires a great deal of change. The ASIST team described necessary attributes of the future state and a roadmap of how to get there. Key attributes included building a just culture in which information sharing promotes safety through a secure, trusted environment; support for action across organizational boundaries; management of sharing systems by stakeholders; a foundation of incentives for participation; sharing that is comprehensive of relevant stakeholder perspectives; interoperability across disparate information systems; and dependability of information systems. The roadmap requires both *building technology* and processes from the vision of the final state, and *building trust* though developing ongoing safety data sharing efforts. In that sense, it is a call for national safety culture change.

2. Safety Culture

a. Definitions

The term “safety culture” was first officially used in the initial report from the International Atomic Energy Agency (IAEA) about the nuclear accident at Chernobyl in 1986, when two explosions blew off the 1,000-ton concrete cap sealing the Chernobyl-4 reactor. A “poor safety culture” was identified as a factor contributing to the Chernobyl disaster by the IAEA (cited in Cox and Flin [Ref 3]). In the United States, safety culture came to the forefront as a result of an aviation accident — the in-flight breakup and crash of Continental Express Flight 2574 near Eagle Lake, Texas, on Sept. 11, 1991. In the 1992 National Transportation Safety Board (NTSB) report on that accident, John Lauber, then a member of the NTSB, wrote a dissenting statement regarding the finding of probable cause that he felt should have included: “the failure of Continental Express management to establish a corporate culture which encouraged and enforced adherence to approved maintenance and quality assurance procedures” [Ref 4].

Much of the subsequent literature focuses on defining safety culture. Definitions vary depending on the industries involved. In their report to the FAA in June 2002, researchers from the Aviation Research Lab at the University of Illinois found several commonalities among those various definitions which include [Ref 5]:

1. Safety culture is a concept defined at the group level or higher, which refers to the shared values among all the group or organization members.
2. Safety culture is concerned with formal safety issues in an organization, and closely related to, but not restricted to, the management and supervisory systems.
3. Safety culture emphasizes the contribution from everyone at every level of an organization.
4. The safety culture of an organization has an impact on its members’ behavior at work.
5. Safety culture is usually reflected in the contingency between reward systems and safety performance.
6. Safety culture is reflected in an organization’s willingness to develop and learn from errors, incidents and accidents.
7. Safety culture is relatively enduring, stable and resistant to change.

Effective safety culture is presumed to require leadership from the top, to permeate the organization across work groups and distributed organizational units, and to be measurable at the bottom — by the actions of front-line employees and the quality of the service provided to its customers. Senior management motivates through its organizational culture, and employees understand and do their part.

b. Building Safety Culture

In the United States, the laws and regulations place responsibility directly on the air carriers for the management of safety, quality control and quality assurance. It is not the responsibility of the FAA to perform these functions, but to require and ensure they are performed. Airline management must focus its attention on those things over which it does have control. James Reason argues that airlines control internal organizational processes that address safety risks. These processes continuously move an airline in a direction of increasing resistance to an accident or increasing vulnerability [Ref 6]. Maintaining resistance requires managing these processes and ensuring performance consistent with process throughout the organization. This requires establishing both proactive process measures (identifying hazards, errors, violations, and workplace and organizational factors) and reactive outcome measures (accidents, incidents and other losses). From this perspective, outcome measures are symptoms of underlying precursor conditions. Management effects change through the process and emphasizes its measure.

Reason [Ref 6] identified four critical components to building a safety culture [Ref 6]:

1. *Reporting Culture* — an organizational climate in which people are prepared to report their errors and near-misses.

2. *Just Culture* — an atmosphere of trust where personnel are encouraged, even rewarded, for providing essential safety information, but also understand the difference between acceptable and unacceptable behavior within the organization.

3. *Flexible Culture* — can easily revert back and forth from hierarchical to horizontally structured organizational operations where first-line supervisors have decision-making authority to get the job done — an investment in employees and in their training.

4. *Learning Culture* — the willingness and competence to be objective in order to make the right decisions from its reporting culture and to implement needed corrections.

While much can be written about each of these critical components, reporting and perceived justness in dealing with reported problems and events are the first steps. Front-line personnel have to be convinced of the value in filing safety reports. In order to do that, an organization must get rid of the disincentives to report. There are at least five widely accepted conditions to help achieve a reporting culture:

1. Indemnity against disciplinary action
2. De-identification or confidentiality
3. Separation of those with enforcement authority from the safety risk assessment process
4. Effective reporter feedback as well as feedback to employees in general
5. Ease of reporting

Airlines pursuing strong safety cultures balance profit goals with safety goals, determining how to deploy corporate resources to achieving both. This can be a very delicate and complex balancing act (Figure 3), complicated by

Figure 3. Balancing Profit Goals with Safety Goals

the fact that profit goals are easily measurable in dollars, market share, on-time performance, etc., while safety goals are more difficult to measure. Safety risk management uses multiple approaches to identify and treat safety hazards. ASAP or similar programs pursue employee reports. FOQA allows the monitoring of key aspects of flight operations. On-site surveys of operations and audits assess the effectiveness of safety processes. Quality control and quality assurance functions become an integral part of the safety processes. Personnel involved in the process understand both safety risk management and human factors. Each of these initiatives becomes a key safety measure. However, those programs must be rooted in a supportive culture, providing climate for non-punitive performance monitoring, measurable reporting from front-line employees about hazards encountered, and feedback concerning the corrective actions taken by the organization. These programs are based on a partnership among the airline, its employees and the regulator, and a shared approach to safety values. Safety concerns important to front-line employees must become observably important to the Chief Executive Officer; what is critical to the front-line government inspector must become so to the management of the regulatory authority. Sound safety culture both drives and is reinforced by safety data program participation.

c. Generalization to Industry and National Culture

Interestingly, almost all of the focus on safety culture has discussed culture within organizations. An industry-level or national safety culture has not been similarly explored. But within the United States, as competing airlines have adopted safety data programs and met under FAA sponsorship to discuss what they've learned, airlines and their employees have recognized that many of the risks are cross-organizational and corrective action will require national-level action. From that perspective, the spread of these programs may change the national culture. Sharing of information generated by these programs can make that change more deliberate. Successful experience with sharing can move the industry or nation towards the end state envisioned by the ASIST team.

3. Setting the Stage Through a Participatory Process

Proactive safety initiatives such as FOQA and ASAP have been proven at many airlines throughout the world. In addition to providing regulators and airline managers critical information to operate efficiently and effectively manage risk, they have laid the foundation of strengthening the safety culture within their individual organizations.

In October of 2001, the FAA published U.S. Federal Regulations regarding FOQA programs. Under 14 CFR 13.401 (the FOQA rule), the FAA established the requirement that an operator with an FAA-approved FOQA program " … will provide the FAA with aggregate FOQA data in a form and manner acceptable to the Administrator." This rule also provided key protections for shared data — reports and analyses provided by the airlines are confidential, proprietary and protected to the extent allowed by law, including, but not limited to, all applicable exemptions of the U. S. Freedom of Information Act (FOIA).

In conjunction with establishing the FOQA rule, the FAA established the FOQA Aviation Rulemaking Committee (ARC) and in 2002 they established the ASAP ARC. One of the purposes of the FOQA ARC was to develop the process for complying with the FOQA rule for providing the aggregate data to the FAA Administrator. As the FOQA ARC worked to develop this process, the ASAP ARC joined with them to develop a process for the sharing of both de-identified FOQA and ASAP data on a volunteer basis that would both satisfy the FAA's FOQA rule and provide a process for the commercial aviation industry and the FAA to share safety-related information. In turn, this information would be used to proactively identify, analyze and correct safety issues that affect commercial aviation.

The Voluntary Aviation Safety Information-sharing Process (VASIP) was developed by the ARCs as an information-sharing initiative at a national level. VASIP provides a means for the commercial aviation industry and the FAA to collect and share safety-related information and to use that information to proactively identify, analyze and correct safety issues that affect commercial aviation. The key to VASIP is the development of a technical process to extract de-identified safety data from any participating airline FOQA or ASAP, aggregate it through a distributed database and make it accessible to appropriate government and industry stakeholders for analysis. The FAA Associate Administrator for Aviation Safety requested that NASA develop a distributed archive technology on its behalf to enable the sharing of FOQA and ASAP data among participating air carriers, the FAA and employee organizations. NASA's Aviation Safety and Security Program accepted this request and is developing the distributed archive technology for FOQA and ASAP data. The FOQA and ASAP ARCs articulated a statement of technical requirements for both archives. Initially, the process is envisioned to focus on issues that have been identified through individual airline programs. Ultimately, it will be capable of analyzing those issues that are identified from the aggregate safety database, as well.

VASIP is a vehicle for national safety culture change through data sharing. Airlines, employees and government are moving from an environment where data is closely held to prevent inappropriate use, to one in which data is shared among participants through secure networks and under mutually agreeable rules of engagement. It seeks to demonstrate that sharing data can identify, understand and help resolve key safety issues, while doing no harm to those who bring the data to the table. It is, therefore a key first step toward building the attributes described by the ASIST team and one that will lead the industry toward a worldwide aviation system that systematically mitigates risk and continually reduces the likelihood of accidents.

VASIP is intended to accomplish two separate but complementary objectives. One is the development of the technical process to extract de-identified safety data from any participating FOQA or ASAP program, merge it, and then make it accessible to appropriate industry and FAA stakeholders for analysis. The other is the development of the comprehensive, structured process among all stakeholders that will permit them to analyze aggregate industry safety data, identify problem areas, develop and implement appropriate corrective action plans, and then measure the effectiveness of those actions and share the conclusions with stakeholders. Follow-on development can include connecting other safety data, such as the Aviation Safety Reporting System (ASRS) or the National Aviation Safety Data Analysis Center (NASDAC), with VASIP to broaden understanding of issues identified through safety data.

4. Building a Technical Solution

A participatory process at a more detailed level was required to develop an acceptable technical solution. The VASIP Executive Steering Committee (ESC) appointed three groups to develop key requirements for FOQA and ASAP archiving. Two Data Aggregation Working Groups (FOQA and ASAP DAWGs) were tasked with developing definitions of the data to be shared and requirements for the systems and networks on which sharing would take place. The FOQA and ASAP DAWGs prepared a set of documents for approval by the ARCs that defined technical requirements for the archives, from which NASA was able to design the required hardware, software and networking. A Procedures and Operations (P&O) subcommittee was established to define the rules under which data sharing would be accomplished.

The FOQA DAWG confronted two key challenges of sharing very large databases composed of high-frequency measurements of multiple parameters on many flights by many types of aircraft. First, aircraft in use in the United States vary in number of parameters recorded from a low of 32 on older models to a high exceeding 3,000 on currently manufactured aircraft, with many different makes and models falling somewhere in between. Frequency of measurement varies from .25 to 8 hertz by parameter and aircraft type. The DAWG identified a core set of 384 parameters to be shared where available, and stipulated that the archiving process should accept any parameter on this list recorded by any participating aircraft in its native sampling rate. Aircraft on the low end would populate only a small sample of these parameters, aircraft on the high end would populate all of them, and analyses would proceed using available parameters. All flights would be de-identified as to airline and specific time and date of flight. This results in a flexible analysis process incorporating more aircraft with basic analyses and fewer aircraft as analyses become more complex. Second, where to store data and accomplish analysis presented practical and political problems. One model would transfer de-identified data to a central location for processing and analysis. This would require very high bandwidth for FOQA data and raised concerns over whether participatory control over analyses could be assured over the long term. The FOQA DAWG recommended instead a distributed archive concept, wherein de-identified data resides on local archive servers on each airline's premises networked to a central analysis server at the archive host's facilities (NASA Ames, during VASIP development). De-identified data would be transferred to each local archive server on a routine basis. Analyses would be accomplished from the central server under direction of the VASIP ESC by sending messages to each local server. The local servers then accomplish analyses and relay results back to the central server. This keeps data on the premises and under control of its owners, but allows information to be integrated across airlines.

The ASAP DAWG accepted this model, but was confronted with somewhat different challenges. While FOQA data is large, U.S. carriers currently use only two commercial vendors of FOQA software, which allowed NASA to contract for transfer of data in a standard format from vendor workstations to local archive servers. While ASAP data has fewer parameters or fields, it is collected in six different formats through vendor- or company-owned hardware and software. The ASAP DAWG was confronted with a challenge of interoperability — making data in airline-specific formats compatible for analysis. Selection of a parameter or field list from large, but relatively standard, lists across airlines and aircraft types as in FOQA was not possible for ASAP. Instead, the ASAP DAWG needed to inventory the different formats, examine commonalities among fields, and develop an archive field structure. Surprisingly, this was a more difficult task than that presented to the FOQA DAWG. Over a series of meetings, the ASAP DAWG specified demographic fields describing who (such as crew position, but not name or airline), when and where; event-type fields describing what occurred (such as an altitude deviation or runway incursion); and internal (to the reporting work group, such as the cockpit) and external contributing factors. This results in 80 primary and 466 secondary fields being shared where available from each participating airline.

The Procedures and Operations subcommittee defined the rules and procedures under which VASIP analyses would be accomplished. It defined a comprehensive, structured process among stakeholders that will permit them to analyze aggregate industry safety data, identify problem areas, develop and implement appropriate corrective action plans, measure the effectiveness of those actions, and share the conclusions among stakeholders. These rules range from who can be involved in conducting analysis to specific types of comparisons or information that cannot be presented in analysis results because they could be reverse-engineered to identify an individual airline. The rules are designed to be very specific as sharing begins; in some cases to cause rules to be written into software. But the P&O subcommittee recognized that VASIP is a place to build trust that industry-level good can be accomplished without individual and corporate harm. The procedures allow development of a flexible architecture for future analyses, when trust allows freeing of certain restrictions, and call for procedural revision as knowledge and trust evolve. In fact, the resulting technical solutions envision a day when the central server can be replaced by a set of functions on each local server, allowing each airline to compare itself to the aggregate of all other airlines, but not allowing direct airline-versus-airline comparisons by the airlines themselves or government agencies.

Using the technical requirements presented by the DAWGs and those P&O rules that required software rules, NASA was able to design the required hardware, software and networking for distributed archives of flight data and safety reports. Figure 4 (page 311) represents the infrastructure and process being developed for the Distributed National FOQA Archive (DNFA). Each gray rectangle at the top represents a participating airline. At the top of each of theses boxes is shown their local FOQA processing system, supplied by their vendor. NASA has entered into contracts with Austin Digital, Inc. (ADI) and SAGEM Avionics, Inc. (who, between the two, provide FOQA processing services to all currently participating airlines) to transfer FOQA data in a standard format across a NASA-supplied one-way firewall onto a NASA-supplied Local Archive Server (LAS) indicated at the bottom of each of the "airline" boxes. Each LAS is networked securely to a central server housed at Ames Research Center.

On each LAS, data are processed into standard, compressed files and are stored on the LAS until the VASIP Executive Steering Committee (ESC) identifies an issue requiring access to, and research on, the archive. The ESC appoints a working group to study the issue and that group defines specific queries to be processed by the archive. Entry of these queries on the Central Server issues commands (indicated by the green arrows) to each

LAS, where searches for only those events that are relevant to the query and where calculations of summary statistics are accomplished.

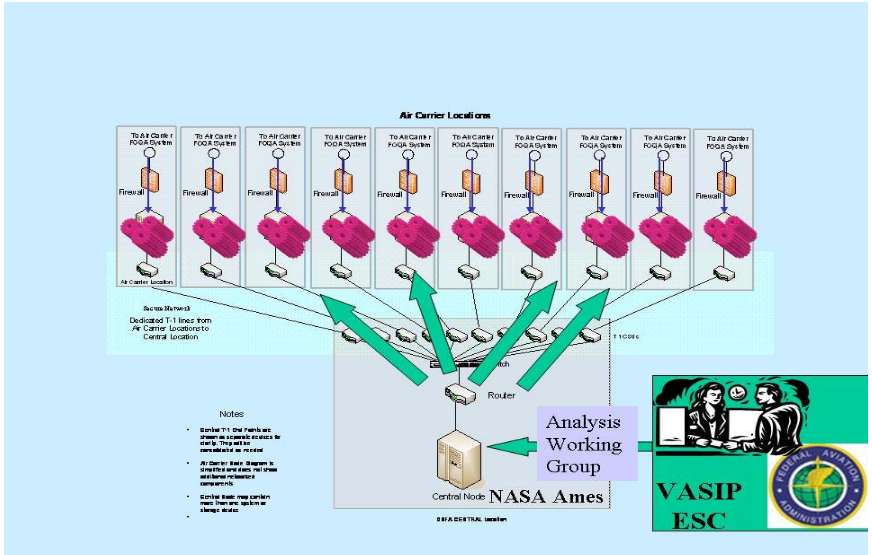


Figure 4. The Concept of the Archive of Distributed FOQA Data

After these analyses are completed on each LAS, de-identified lists of flights meeting the search criteria and the summary statistics are forwarded to the central server where they are aggregated. This is indicated by the red arrows in Figure 5. The Analysis Working Group reviews these aggregated analyses, summarizes findings into a report, and provides the report to the ESC.

The infrastructure diagrammed in Figures 4 and 5 is highly flexible. The set of command and aggregation functions generated by the Central Server for information relative to each query that is then used in the aggregated analyses could also be distributed to each LAS. In that configuration, analyses could be conducted within any node and each participating airline could compare itself to the aggregated results of all the participating airlines (though not to any individual airline).

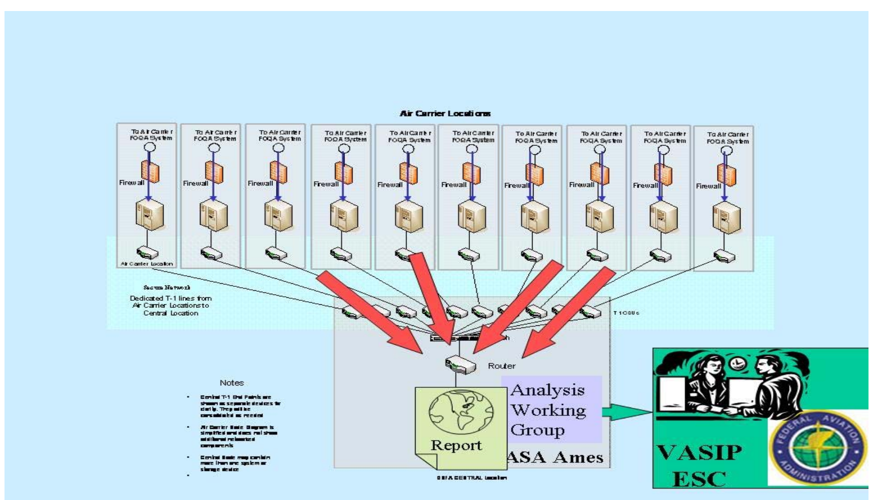


Figure 5. The Concept of Accessing the Archive of Distributed FOQA Data

Figure 6 (page 312) represents the comparable infrastructure and process for the distributed-archive concept being developed for the Distributed National ASAP Archive (DNAA). The primary differences in the process for

DNAA from that of the DNFA are the participation in analyses by the University of Texas at Austin (UT) under a Cooperative Agreement with NASA, and the LAS connection to each airline's ASAP servers rather than to the FOQA vendor machines. While NASA was able to contract with two FOQA vendors to accomplish the push of data to the DNFA, the airlines themselves are responsible for pushing the ASAP data to the DNAA. Some of these airlines have vendors (one system is supplied by UT to several airlines) who will accomplish this work; others must accomplish it through their own IT departments.

The ESC and Analysis Working Group roles in the DNAA are the same as they are in the DNFA, and we expect that each working group will, in practice, work with both archives to respond to ESC questions.

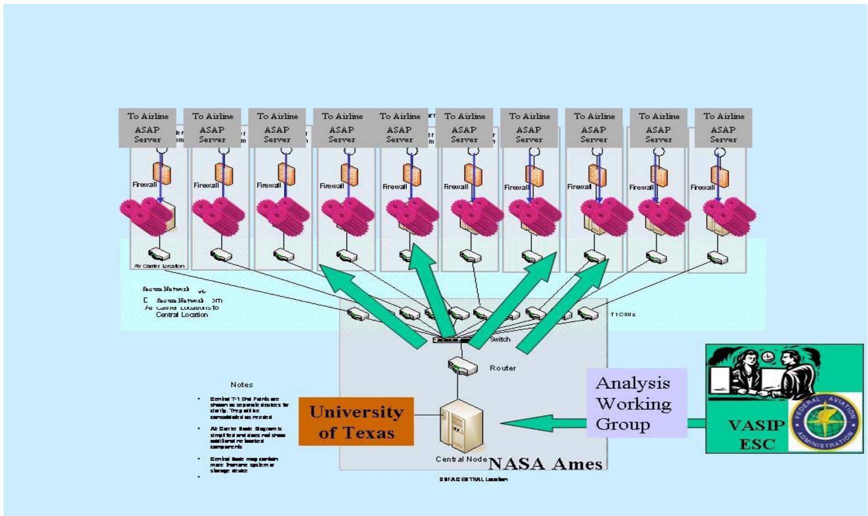


Figure 6. The Concept of the Archive of Distributed ASAP Reports

Figure 7 shows that the creation of reports by the Analysis Working Groups and their distribution to the VASIP ESC are the same for the DNAA as for the DNFA.

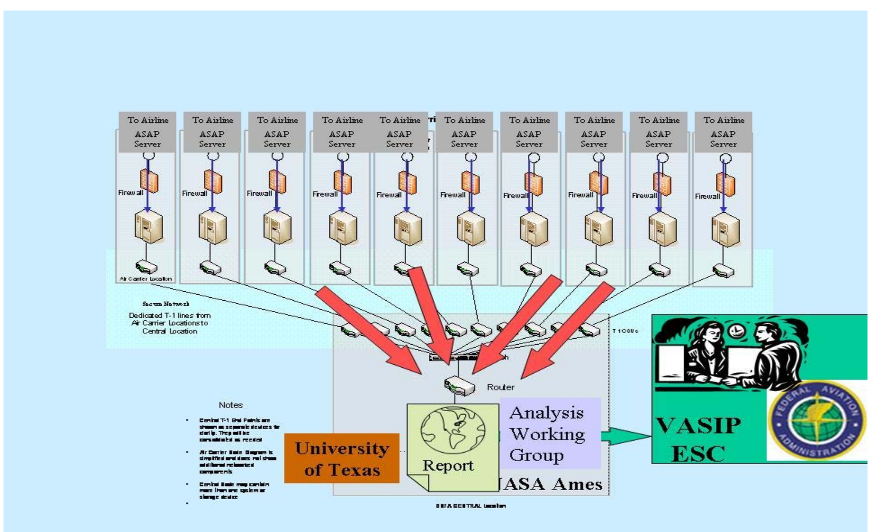


Figure 7. The Concept of Accessing the Archive of Distributed ASAP Reports

The two-year plan for NASA support for VASIP provides for implementation and demonstration of the DNFA and the DNAA. The Wide Area Network will be connected and Local Archive Servers deployed by January 2006 to airlines that have agreed to participate this year. Queries and analyses can then be accomplished on data from those airlines. By October 2006, hardware, software and networking will be deployed to all airlines that have agreed to participate in the second year of the project. Queries and analyses can then be accomplished on data from all participating airlines.

VASIP is as much a process for developing trust in data sharing as it is a technology for accomplishing sharing functions. The airlines, their employees and their representatives need experience with sharing that demonstrates that industry-level good can be accomplished without individual or corporate harm. That requires procedural controls on when and how analyses are conducted, which are reflected in the policy documents governing the archive operation and, in some cases, written into software. Analyses and reports will only be run as directed by the VASIP ESC.

6. Conclusions — The Path to Cultural Change

The envisioned future state of safety information sharing in the commercial aviation community laid out by the ASIST team in late 2004 provides a roadmap for the U.S. aviation industry. That roadmap requires both building technology and processes and building trust through developing ongoing safety data sharing efforts. Ultimately it will lead to a safety culture in which information sharing promotes safety through a secure and trusting environment.

While management, employees and government surveillance will continue to be responsible for establishing the motivation and process for strong safety cultures within airlines, the VASIP initiative attempts to take this to a higher level, across numerous organizations. The success of VASIP depends upon the safety culture of these individual organizations to ensure that the right information has been captured for sharing, and upon the organizations collectively working with government to understand safety issues and take action to prevent the next accident.

Much has been accomplished towards safety information sharing goals in the United States. Government and industry have assessed the value of a sound safety culture. They have articulated the value of information sharing and their vision of a desired future state. The airlines, regulators and employee groups have worked collaboratively to enhance the provisions of regulatory and legal safeguards so that information gained from these programs are not used inappropriately for enforcement or disciplinary purposes. These same stakeholders have also taken a collaborative approach to develop the requirements for the VASIP initiative, one that resulted in a technical solution.

While much has been accomplished in a short time, there are still many challenges ahead. There are still airlines without the necessary safety culture in place to enable them to establish FOQA or ASAP programs. While the technical solution for information sharing has been developed, it has yet to be implemented. Implementation in early 2006 will come with a new set of challenges.

Still forthcoming will be experiences of success in identifying hazards that have not been seen previously and taking corrective action. Such successes will continue to build trust and further promote a strong safety culture throughout the industry. There will also be an expansion of the types of analyses that can be done on the shared information as well as further expansion to other types of data. This will ultimately lead to an integration of data across all stakeholders in the aviation community.

Most, if not all, of the aviation safety challenges that existed prior to the events of Sept. 11, 2001 still exist today. Some are being addressed; others need work. There are many system-wide capacity and traffic management initiatives that are ongoing. Aircraft manufacturers are developing new aircraft types that will be introduced into the world airlines’ fleets and airspace. Airport infrastructures will be challenged to meet the growing traffic demands.

Government and industry together do not have the resources to accomplish all of these initiatives without cooperatively establishing priorities, and carefully evaluating the research needed to support that prioritization.

FOQA and ASAP are proven programs for improving safety at many airlines, and they can help the airlines, regulators and employee associations with that prioritization. They have undoubtedly contributed to the lowering of accident rates throughout the world. However, in the past, much of the focus on these programs was concentrated on what they could do *to* the industry. Today, it is essential that the focus be widened to also look at what these programs can do *for* the industry.

In addition, these safety programs have to do more than just collect data. The data has to be analyzed and studied. There needs to be an adequate feedback loop to the flight crews and those within government and industry who can make the changes to improve the safety of the air transportation system. This is all possible with the commitment from the senior management levels at the airlines and from regulators and employee associations. With this commitment the industry will continue down the path of cultural change that will further improve the safety of the aviation industry throughout the world.♦

References

[1] *Aviation Week & Space Technology*, Volume 163, Number 8, August 22/29, 2005, p. 70.

[2] FAA Organizational Updates, presented at 2005 Europe/U.S. International Safety Conference, June 1, 2005.

[3] Cox, S., and Flin, R. (1998). "Safety Culture: Philosopher's Stone or Man of Straw?" *Work and Stress*, 12(3), pp. 189–201.

[4] National Transportation Safety Board, Aircraft Accident Report, *Inflight Structural Breakup, Britt Airways, Inc., d/b/a Continental Express Flight 2574, EMB-120RT, N33701, Eagle Lake, Texas, September 11, 1991*, PB92-910405, NTSB/AAR-92/04, July 1992.

[5] Wiegmann, D., Zhang, H., von Thaden, T., Sharma, G. and Mitchell, A. Aviation Research Lab, Institute of Aviation, University of Illinois at Urbana-Champaign, *A Synthesis of Safety Culture and Safety Climate Research*, Contract No. DTFA 01-G-015. A special report prepared at the request of the U.S. Federal Aviation Administration, June 2002.

[6] Reason, J. (1997). *Managing the Risks of Organizational Accidents*. Aldershot, England: Ashgate.

About the Authors

Capt. Terry McVenes serves as executive air safety chairman for the Air Line Pilots Association, International (ALPA). He represents ALPA pilots in airline safety and engineering matters arising within the industry. His responsibilities include oversight of more than 600 safety representatives from 43 airlines in the United States and Canada, as well as budgetary and management supervision of over 200 projects within the ALPA safety structure.

Capt. McVenes is a current member of the Steering and Oversight Committee for the ALPA International safety structure and a former member of the Operations Committee and MMEL Working Group. He also represents ALPA pilots on the FAA's Flight Operations Quality Assurance (FOQA) Aviation Rulemaking Committee.

Prior to his current appointment, Capt. McVenes was executive air safety vice chairman, chairman of the Central Air Safety Committee for US Airways, and chairman of the Aircraft Evaluation Committee. He coordinated the establishment of the Aviation Safety Action Program (ASAP) and served as a member of the FOQA Monitoring Team.

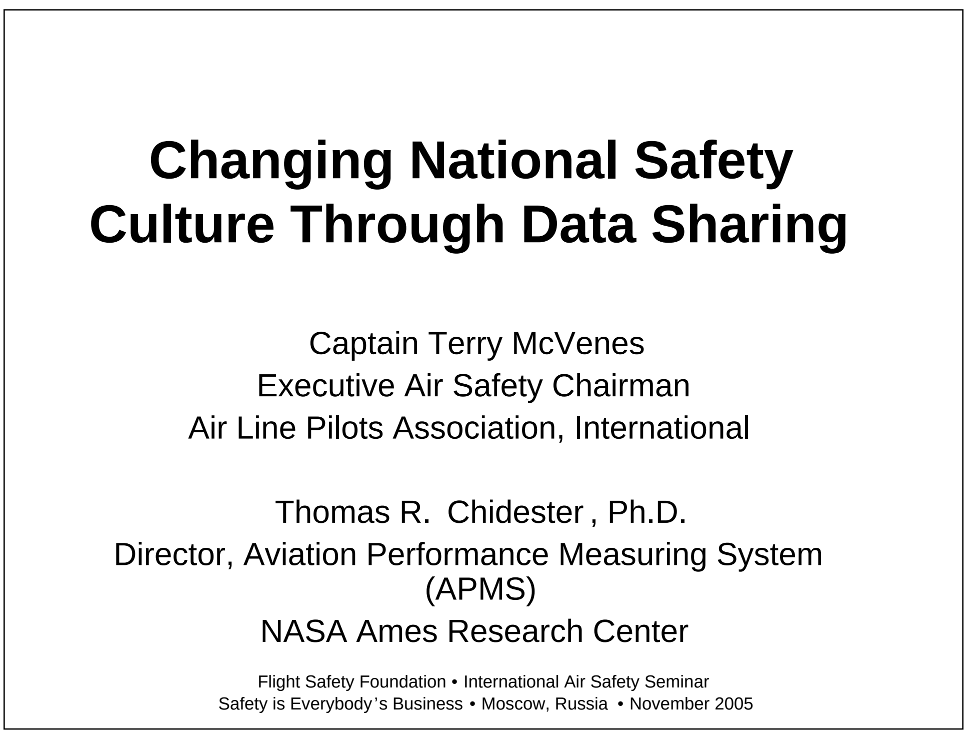
Capt. McVenes began his airline career in 1978 with Rocky Mountain Airways in Denver, Colorado, flying the DHC-6 (Twin Otter) and DHC-7 (Dash 7) aircraft. He was hired by Pacific Southwest Airlines (PSA) in March 1985, which later merged into US Airways. He is type-rated on the DHC-7, BAe-146, FK28, DC-9, MD-80, A320 and B-737. He currently is a captain on the Airbus A320 for US Airways and has more than 17,000 flight hours.

Thomas R. Chidester, Ph.D., is the director of the Aviation Performance Measuring System program at NASA Ames Research Center. In this capacity, he manages the development team working to design advanced concepts and software for analysis of aircraft flight data.

He served as manager of human factors and safety training for American Airlines from 1990 to 2001. There, he led the re-development of classroom human factors programs for pilots and flight attendants and assisted in the development of line-oriented flight training on all American Airlines' aircraft fleets. Dr. Chidester also accomplished analysis, publication and reporting for ASAP, then a cooperative, experimental safety action program developed by American, the Allied Pilots Association and the FAA. From 1996 to 2000, he served as the chair of the Air Transport Association Subcommittee on Automation Human Factors.

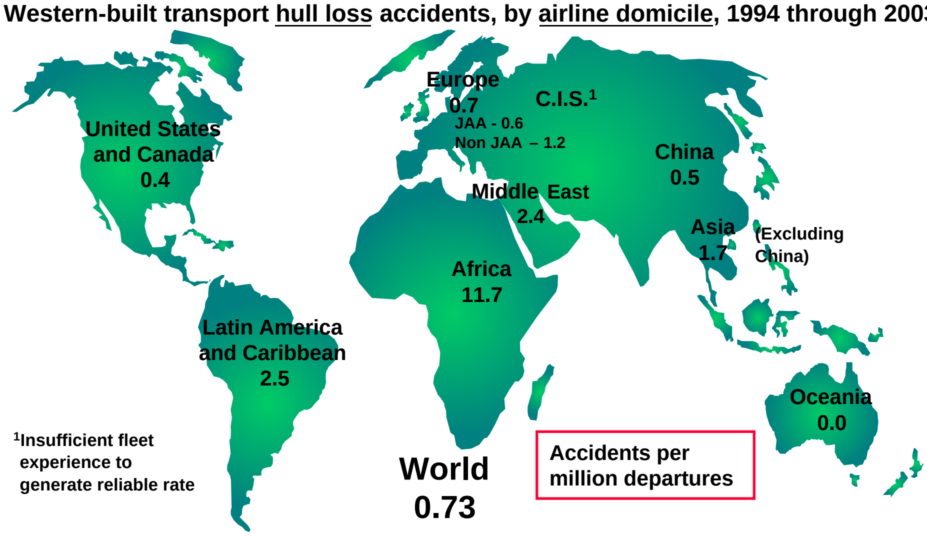
Dr. Chidester earned master's and doctoral degrees at the University of Texas at Austin. In 1986, he began a National Research Council Resident Research Associateship at NASA Ames Research Center, and subsequently was employed as a research psychologist with the Aerospace Human Factors Research Division. There, he led efforts to complete two full-mission simulation studies — the first examining the effects of leader personality on crew effectiveness, the second performance and workload consequences of aircraft automation. He also supervised several other research programs.

Additional material follows on pages 315–321.



Accident Rates by Region of the World

Western-built transport hull loss accidents, by airline domicile, 1994 through 2003



[1]Insufficient fleet experience to generate reliable rate

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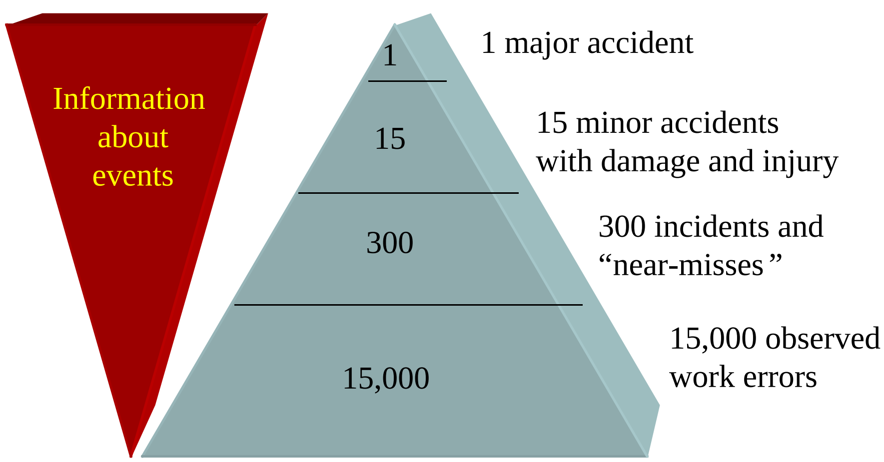
Why Voluntary Safety Programs?



Hazardous Events

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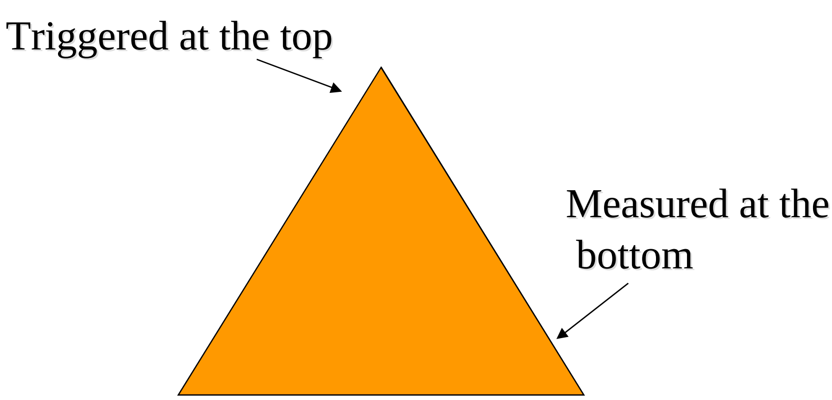
Corporate Safety Culture Is



Safety culture starts at the top of the organization and permeates the entire organization.

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What Good Is That?

A "safety culture" gives aviation managers the tools to *operate* efficiently and *manage* safety risk effectively!

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Programs Are Based on

- Partnership with the company, employees and the regulator
- Shared approach to "safety values"
- Promoting a sound safety culture

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Trust

- Between Individuals
- Between Institutions
- Leaving a Legacy

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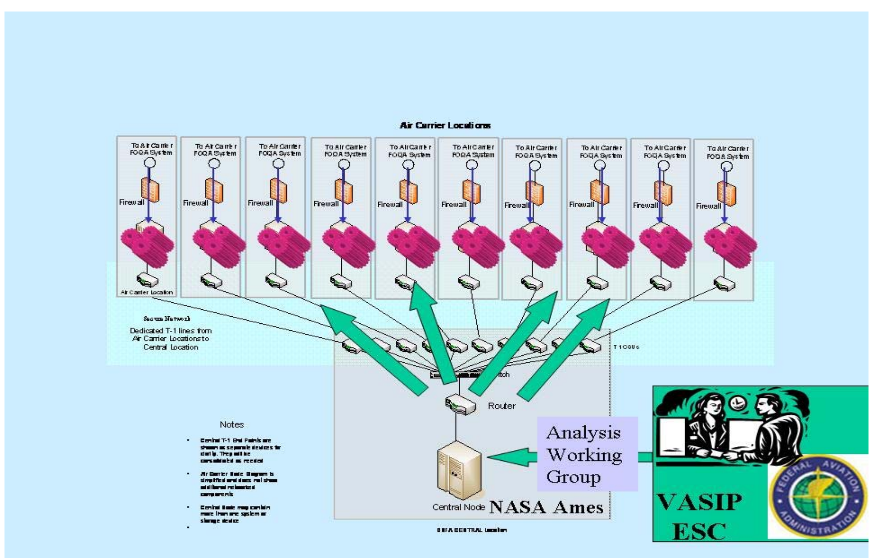
Concept of the Archive of Distributed FOQA Data



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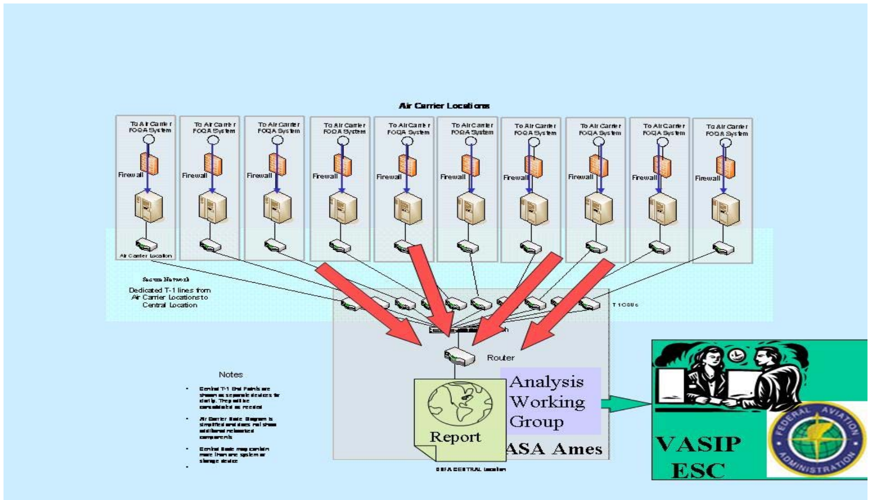
The Concept of Accessing the Archive of Distributed FOQA Data



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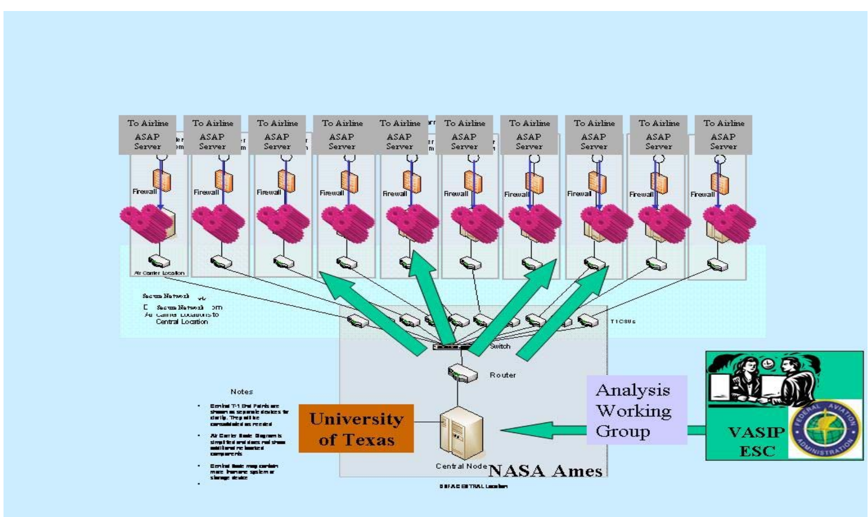
The Concept of the Archive of Distributed ASAP Reports



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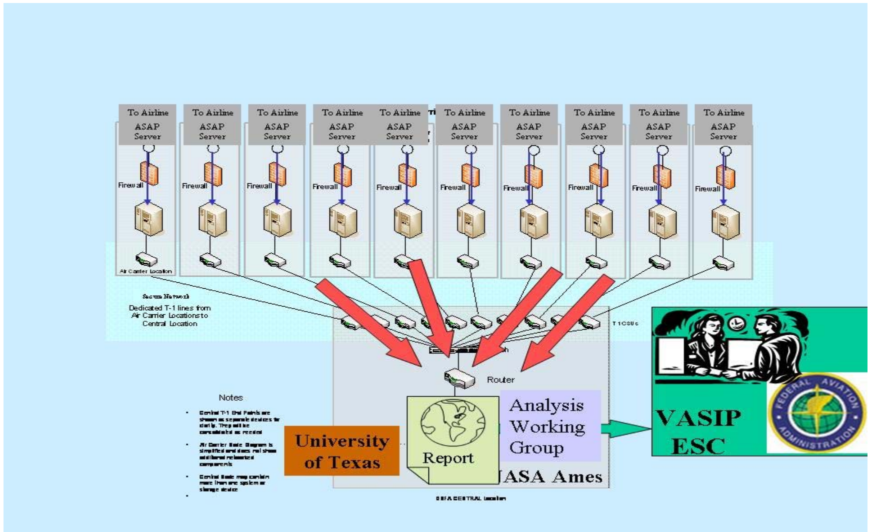
The Concept of Accessing the Archive of Distributed ASAP Reports



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Structural Integrity Challenges

Kay Yong, Ph.D., and Thomas Wang
Aviation Safety Council of Taiwan

Abstract

A significant element of an aircraft's continuing airworthiness and subsequent operational safety is dependent upon prescribed inspections of the significant structures being carried out as scheduled. The idea is that the aircraft structure can sustain anticipated loads in the presence of fatigue, corrosion or accidental damage until such damage is detected through scheduled inspections, and the damaged part is replaced or repaired in accordance with approved methods.

On May 25, 2002, China Airlines Flight CI611 crashed over the Taiwan Strait approximately 23 nautical miles northeast of Makung, Penghu Islands of Taiwan. Radar data indicated that the aircraft experienced an in-flight breakup at an altitude of 34,900 feet. All 225 occupants aboard the flight were killed.

The wreckage recovery operation for the CI611 accident investigation lasted nearly five months, and recovered approximately 1,500 pieces of wreckage. One of the pieces of wreckage that was recovered included a repair doubler. Underneath the doubler, a fatigue crack was observed. The wreckage examinations revealed a pre-existing crack on the aircraft skin underneath the doubler. However, the crack was not detected during any scheduled structural inspection or any other inspections until the residual strength of the structure fell below the fail-safe capability.

The aviation industry is continually evolving, with significant changes in aircraft design philosophy, maintenance programs and inspection processes. These developments impose further pressure on both operators and civil aviation authorities to keep pace with the changing aviation environment. The CI611 accident, and inspections of repairs on older aircraft that have been carried out since the accident, clearly demonstrate that a combination of inappropriate systems and inadequate maintenance activities could lead to undetected hidden structural damage to the aircraft pressure vessel, with the possible ultimate result of an aircraft accident.

Introduction

On May 25, 2002, 1529 Taipei local time, China Airlines (CAL) Flight CI611, a Boeing 747-200, crashed into the Taiwan Strait approximately 23 nautical miles northeast of Makung, Penghu Islands of Taiwan. Radar data indicated that the aircraft experienced an in-flight breakup at an altitude of 34,900 feet, before reaching its cruising altitude of 35,000 feet. The aircraft was on a scheduled passenger flight from Chiang Kai-Shek (CKS) International Airport, Taipei, Taiwan, to Chek Lap Kok International Airport, Hong Kong, China. One hundred and seventy-five of the 225 occupants on board the CI611 flight, which included 206 passengers and 19 crewmembers, sustained fatal injuries; the rest are missing and presumed dead.

The Aviation Safety Council (ASC), an independent agency of the Taiwan, government responsible for investigation of civil aviation accidents and serious incidents, immediately launched a team to conduct the investigation of this accident. The investigation team included members from the Civil Aeronautical Administration (CAA) of Taiwan, and CAL. In accordance with ICAO[1] Annex 13, the National Transportation Safety Board (NTSB) of USA, the state of manufacture, was invited as the Accredited Representative (AR) for this investigation. Advisors to the

[1] Taiwan, is not an ICAO Contracting State but follows the technical standard of that organization.

investigation. Advisors to the U.S. Accredited Representative were the U.S. Federal Aviation Administration (FAA), the Boeing Commercial Airplane Company, and Pratt & Whitney.

After two years and nine months of data collection, aircraft wreckage recovery and examination, laboratory tests, and analysis, the final report[2] was published on Feb. 25, 2005.

Wreckage Examination

The wreckage recovery operation for the CI611 accident investigation lasted nearly five months, recovering approximately 1,500 pieces of aircraft and 175 bodies. A 200-inch wide, 260-inch long piece of wreckage was found and named item 640[3] (Figure 1). It was a piece of section 46[4] skin panel which ranged from Body Station 1920 (STA 1920) to Body Station 2181 (STA 2181), Stringer 23 right (S-23R) to Stringer 49 left (S-49L) and was found along with a repair doubler installed from STA 2060 to STA 2180 and from one side between S-48L and S-49L to the other side between S-50R and S-51R (Figure 2).

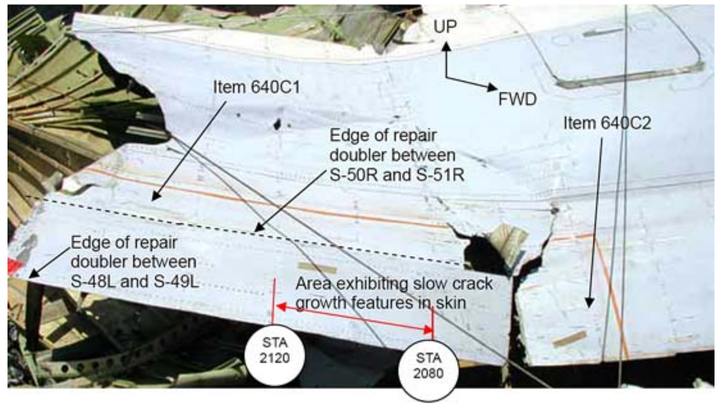

Figure 1. Wreckage Item 640

The 23-inch wide, 125-inch long external repair doubler was attached to the skin by two rows of countersunk rivets around its periphery as well as by fasteners common to the stringer and shear tie locations. After disassembly of the doubler from the skin and removal of the protective finishes, scratching damage was noticed on the faying surface[5] of the skin. This damage consists of primarily longitudinal scratching distributed in an area of 120 inches by 20 inches. Evidence of an attempt to blend out these skin scratches, in the form of rework sanding marks, was noted over much of the repair surface.

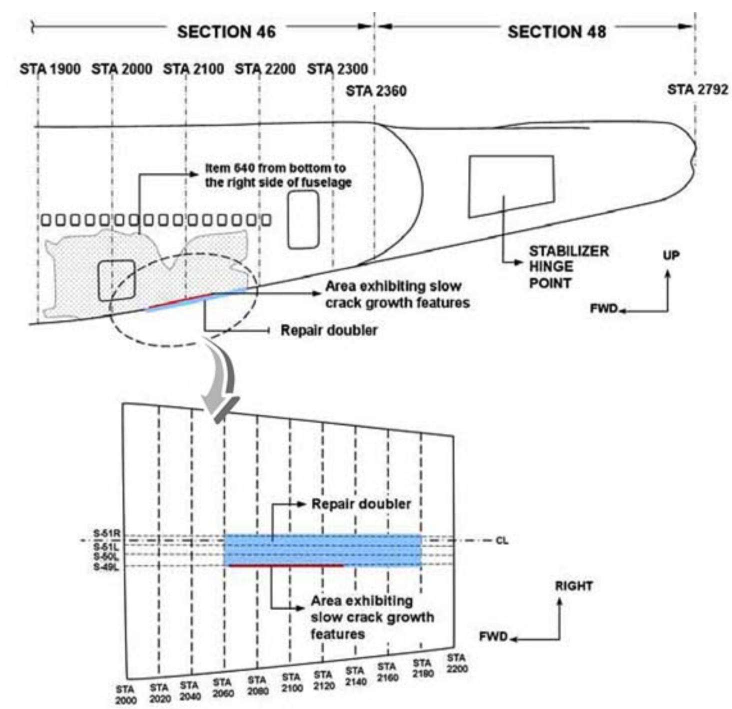

Figure 2. Item 640 and the repair doubler

A flat-fracture surface (indicative of slow crack growth mechanisms) on the skin underneath the edge of the repair doubler near S-49L was found during the field examination and the suspected portions were segmented from parent item 640 and then sent to Chung-Shan Institute of Science and Technology (CSIST) and Boeing Materials Technology (BMT) for further examination and tests.

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[2] Available at http://www.asc.gov.tw

[3] The item was number 640 in the recovery sequence.

[4] Pressurized fuselage aft of wing and wheel well area.

[5] The surface of a material in contact with another to which it is or will be joined.

Examination of the Fracture Surfaces

The fracture surface common to the second row of rivets above S-49L was examined with a combination of visual, low power optical (up to 30X magnification), high power optical (up to 1000X) and Scanning Electron Microscopic (SEM) methods after the fracture surfaces were cleaned with a soft bristle brush and acetone. The rivets and holes along the fracture surface were numbered from +17 to 93 as shown in Figure 3.

Evidence of fatigue cracking was found and confirmed by both CSIST and BMT. Most of the fatigue cracking area presented a flat profile in the direction of through skin thickness. There was a cumulative length of 25.4 inches, including a 15.1-inch main fatigue crack and other smaller fatigue cracks[6] aft and forward extending from hole +14 to hole 51.

Beside fatigue damage, another type of fracture feature exhibiting a pattern of overstress was observed. This overstress fracture propagated along the fracture surface parallel with S-49L forward from hole 10 and aft from hole 25.

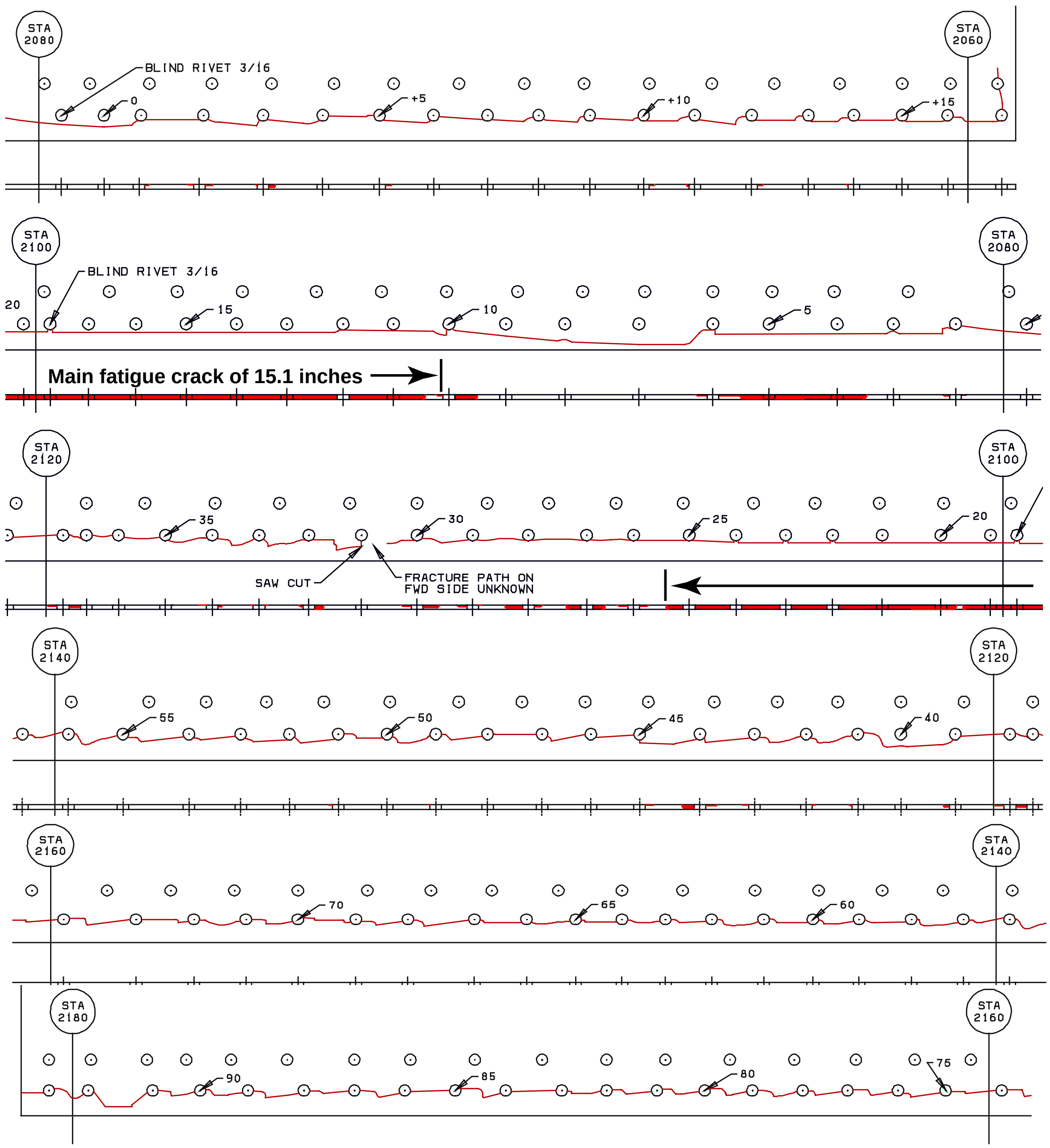

Figure 3. Distribution of the fatigue cracks (areas in red)

[6] Can be referred to as "Multiple Site Damage (MSD)".

The laboratory observations showed that the main fatigue crack and most of the multiple site damage (MSD) were initiated from the scratches on the faying surface of the skin that existed at or just beyond the peripheral row of fasteners common to the repair doubler. The pattern of the fatigue crack differs from traditional crack patterns. The standard cracking configuration assumes those cracks grow forward and/or aft from hole to hole. But the crack configuration of wreckage item 640 identified in the laboratories does not show any evidence of forward-aft striations within the flat-fracture fatigue areas. Instead, the crack growth pattern on Item 640 shows an increasing growth rate through thickness. This can be attributed to the cracks growing from many origins on the skin surface at the scratch locations and propagating inward (Figure 4).

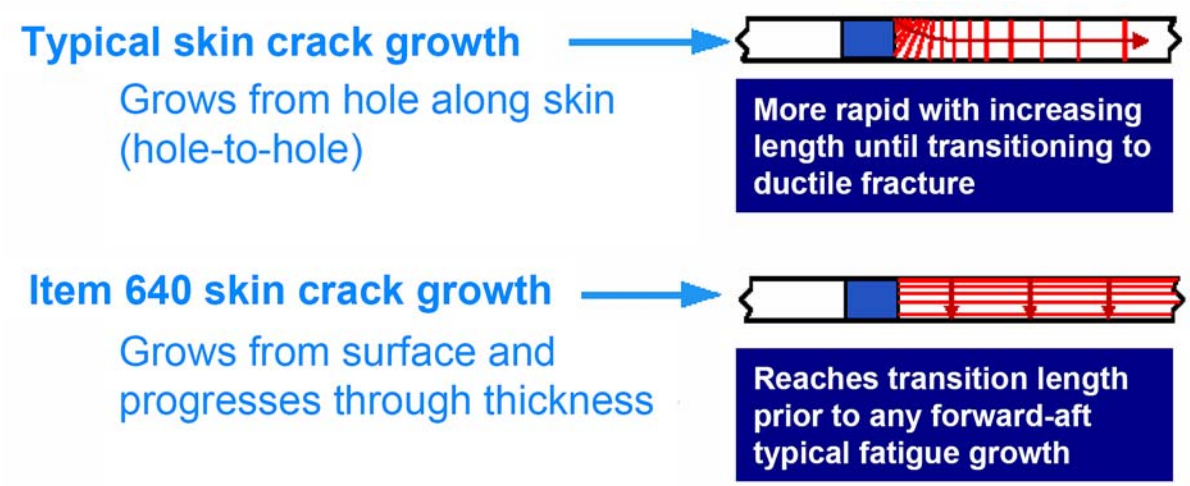

Figure 4. Cracking on Item 640 differs from typical fatigue crack

The Existing Crack Prior to the Breakup

According to the BMT report, numerous areas of the overhanging portion of the faying surface of the doubler exhibited signs of localized fretting damage (Figure 5). Low power optical examination suggested the damage resulted from hoop-wise movement of the skin against the doubler. Therefore, the Safety Council concluded that there was a pre-existing crack on the aft fuselage portion bottom skin of the accident aircraft near STA 2100 and the fretting damage was most likely the result of repetitive crack opening/closure during the pressure cycle.

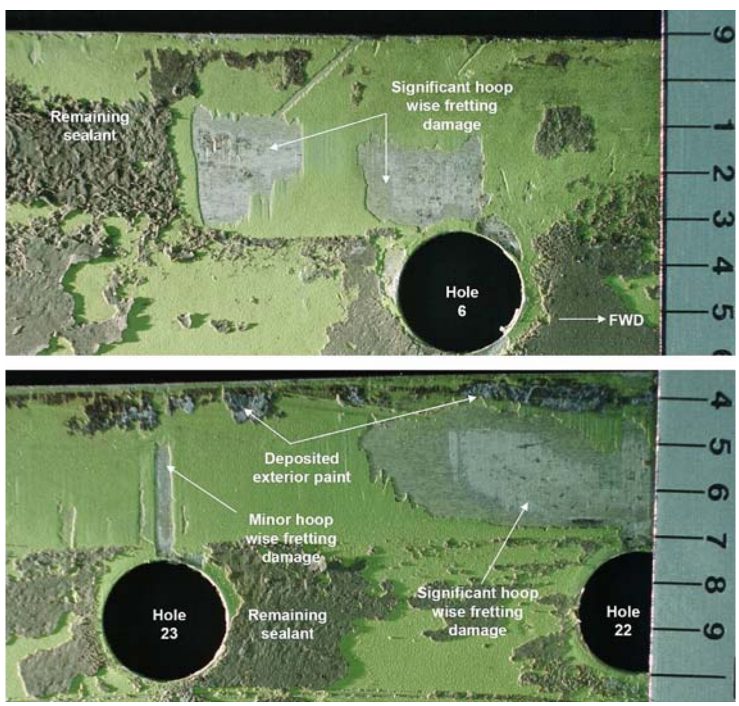

Figure 5. Fretting damage observed on faying surface of the repair doubler

Another piece of evidence of the pre-existing crack was the presence of regularly spaced marks on the fracture surface (Figure 6, page 327) and the compressive deformation of the aluminum cladding along the edge of the fracture common to the faying surface (Figure 7, page 327). This suggested that there were stable extensions of fatigue progression in areas outside of the main fatigue crack. The

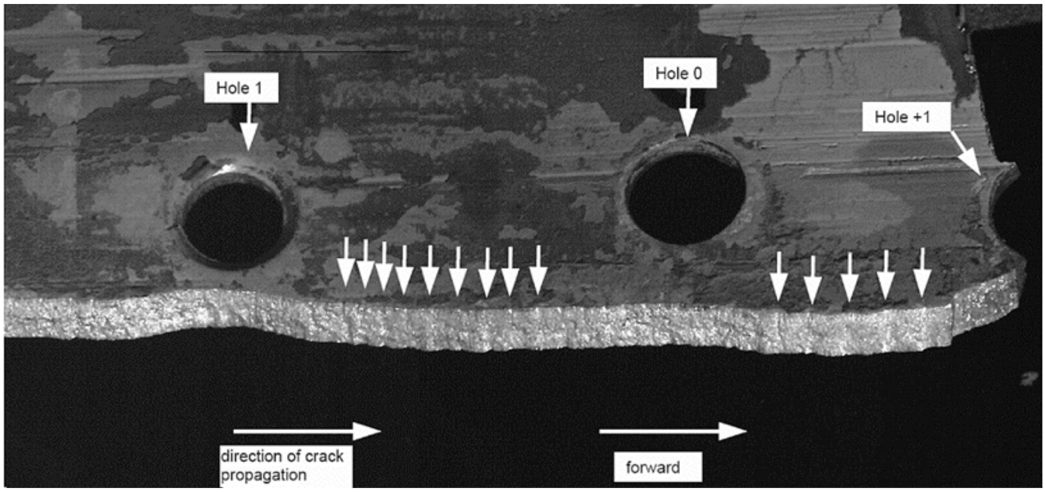

Figure 6. The regular spacing of cracking increments found on Item 640

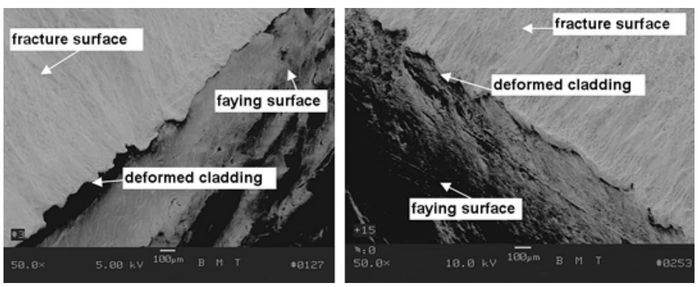

Figure 7. SEM photographs of the cladding near hole 3 (left) and +15 (right)

BMT report referred to this phenomenon as "quasi-stable crack growth."

The likelihood of the fretting marks, regularly spaced marks, and deformed cladding being a result of some other factors, such as post-accident damage to the fracture surface, was considered relatively low. The Safety Council believes that all the indications mentioned above were most likely caused by the repetitive opening and closure of the pre-existing crack. The distribution of the fretting marks from STA 2061 to STA 2132 suggested that there would have been a continuous crack of at least 71 inches in length before the breakup of the aircraft.

In order to assess the effect of the pre-existing crack on the integrity of the structure, an analysis of the structural stress and residual strength[7] was conducted. According to the results of the analysis, when the crack was over 58 inches, the residual strength of the aft fuselage portion bottom skin assembly would decrease below that required to withstand the operating stress levels (Figure 8, page 328), and would exceed the skin assembly capability limit under the application of normal operational loads.

The Tail Strike in 1980 and the Subsequent Repairs

The accident aircraft had a tail strike occurrence at Kai Tak International Airport, Hong Kong, on Feb. 7, 1980. According to the aircraft logbook, the aircraft was grounded for "fuselage bottom repair" from May 23 to May 26, 1980. The major repair and overhaul record in the logbook indicated that aft-belly skin repair was accomplished in accordance with CAL engineering recommendation and Boeing Structural Repair Manual (SRM) 53-30-03 fig. 1.

However, after examining wreckage item 640, the Safety Council concluded that the May 1980 repair to the tail strike damage area of the accident aircraft was not accomplished in accordance with the Boeing SRM. Specifically, the Boeing SRM allows scratches in the damaged skin within allowable limits to be blended out. If, however, the damage was too severe and beyond allowable limits, the damaged skin had to be cut off and a doubler was to be installed to restore the structural strength, or the damaged skin was to be replaced with a piece of new skin. The damaged skin of the accident aircraft was beyond the allowable limit specified by the SRM. Instead of either of these acceptable options, a doubler was installed over the scratched skin. In addition, the external

[7] Residual strength is the strength capability of a structural component for a given set of damage, or cracks.

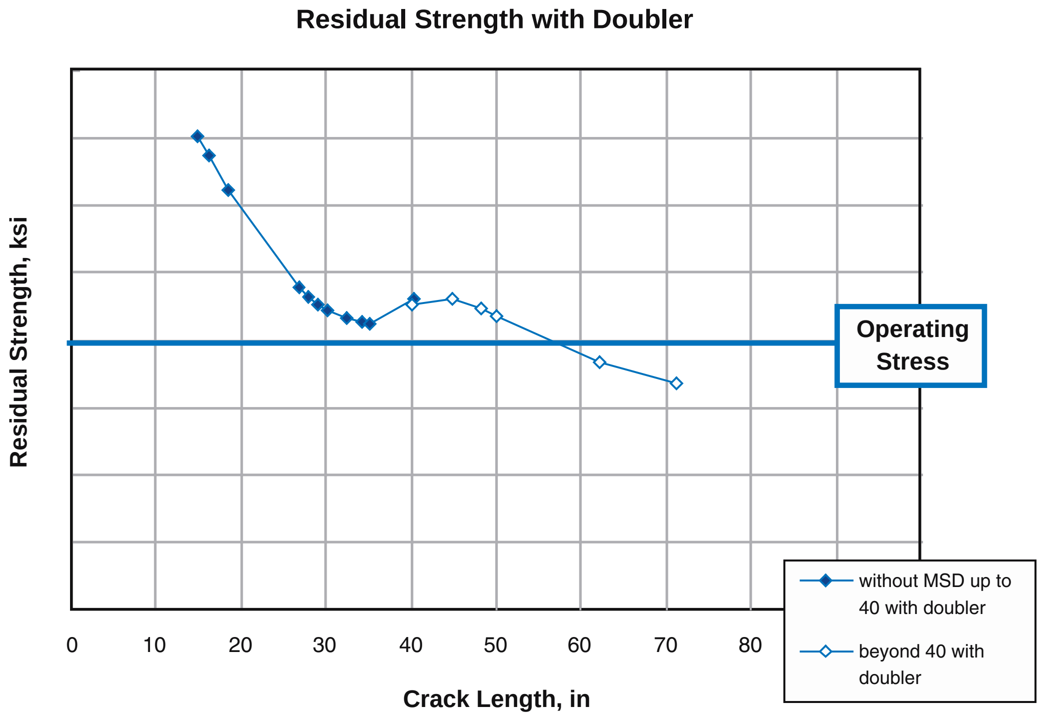

Figure 8. Residual strength of cracking

doubler did not effectively cover the entire damaged area as scratches were found at and outside the outer row of fasteners securing the doubler. When the doubler was installed with some scratches outside the rivets, there was no protection against the propagation of a concealed crack in the area between the rivets and the perimeter of the doubler. As a result, since the 1980 repair, the accident aircraft had been operated with an inadequate repair and subsequent deterioration was not detected during routine maintenance and other inspections.

Structural Inspections

The accident aircraft was maintained in accordance with the schedule of the China Airlines Boeing 747-200 Aircraft Maintenance Program (AMP). The AMP was developed from the Boeing 747 Maintenance Planning Data (MPD). This MPD listed Boeing recommended scheduled maintenance tasks including those listed in the FAA Maintenance Review Board (MRB) reports, plus additional tasks recommended by Boeing. The AMP work scope consisted of General Operation Specifications, Systems, Structure Inspection Program (SIP) and Corrosion Prevention and Control Program (CPCP). The program was designed to control environmental deterioration, including fatigue damage, corrosion and accident damage.

Damage tolerance[8] principles were incorporated into the AMP to ensure that structural damage would be detected in a timely manner. In addition to the AMP requirement, several inspection programs were designed to find the fatigue-related damage for B747-200 aircraft. The Supplemental Structural Inspection (SSI) addresses the areas that were determined to require specific supplemental inspections for fatigue cracking. The Repair Assessment Program (RAP) provides inspection requirements for fuselage repairs. In addition, ADs and SBs are issued for areas with in-service findings and some of these directives/bulletins address fatigue related damage.

As mentioned, wreckage item 640 included a repair doubler. Underneath the doubler was the region of fatigue crack. Almost all of the fatigue crack was located underneath the doubler and would not have been detectable

[8] An evaluation of the strength, detail design and fabrication must show that catastrophic failure due to fatigue, corrosion, manufacturing defects or accidental damage will be avoided throughout the operational life of the airplane.

from the exterior of the aircraft. Further, because the cracking initiated from the external surface of the fuselage skin and propagated inward, the damage also would not have been visually detectable from inside the aircraft until the crack had propagated all the way through the fuselage skin.

Maintenance records of the accident aircraft indicated that the last interior structural inspection of the aft lower lobe area (region of fatigue crack) was completed in January 1999. The inspection was intended to perform corrosion prevention of the interior of fuselage bilge area and to detect early stages of corrosion or indications of other discrepancies, such as cracks or any structural damage. During that inspection, 17 discrepancies adjacent to the doubler of item 640 were found; however, the fatigue crack was not discovered.

Striation estimates performed in connection with this accident investigation revealed that the number of cycles that it took for the multiple origin points of the fatigue fracture to propagate through the thickness to the interior of the fuselage skin ranged from approximately 2,400 to approximately 11,000 cycles. However, it is unknown exactly when the crack growth began. Therefore, it would be difficult to estimate how soon after the repair the first signs of cracking would have been detectable[9]. Furthermore, it was unable to determine whether the fatigue cracks had propagated all the way through the fuselage skin or the length of the crack if it had propagated through the skin at the time when the accident aircraft structural inspection was conducted.

The most widely used nondestructive inspection methods for structural inspection at the CAL were the visual and high frequency eddy current inspection. According to the maintenance records, high frequency eddy current had not been used for structural inspection to the section between STA 2060 and 2180 on the accident aircraft. Moreover, high frequency eddy current inspection is not able to detect cracks through a doubler. Therefore, the crack would still not be detected if external high frequency eddy current had been used for structural inspection.

Repair Assessment Program

The RAP is based on the fact that the aircraft structure will accumulate repairs during service. When aircraft age, both the number and age of the existing repairs increase and become a concern because of the possibility that repairs may develop, cause or obscure metal fatigue, corrosion or other damage occurring in the repaired area.

The continued structural integrity of the aircraft depends primarily on the maintenance program, with inspections conducted at the right time, in the right place and using the most appropriate technique. However, some repairs described in the aircraft manufacturers' SRMs were not designed to current standards. Repairs accomplished in accordance with the information contained in the early versions of the SRMs may require additional inspections if evaluated using the current methodology.

Repair assessment is a process evaluating the impact of repairs on the damage tolerance of the aircraft structure and, therefore, assuring the continued structural integrity of the repaired and adjacent structure. The scope of the RAP is limited to the structural areas of the fuselage pressure boundary where damage tolerance of the original structure may be reduced by a repair.

The accident aircraft had accumulated 19,447 flight cycles by May 25, 2000. According to the FAA-approved Repair Assessment Guidelines, it should begin the assessment process (at least complete repair examination) at or before the next major check (D-check equivalent) after the incorporation of the guidelines and prior to 22,000 cycles.

The repair assessment of the accident aircraft was scheduled at the 7C-Check (November 2002) before the aircraft accumulated 22,000 flight cycles. Unfortunately, at the time of the accident, the accident aircraft had accumulated a total of 21,398 flight cycles, just before it reached the assessment threshold.

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[9] The NTSB noted that other instances in which fatigue cracking originating at damage hidden by a repair may not have begun until long after the repair was accomplished, but the crack propagated to failure within as few as approximately 4,000 cycles after it began (see detail in NTSB Safety Recommendation A-03-07 to A-03-10).

Structural Integrity Challenges

A significant element of an aircraft's continuing airworthiness and subsequent operational safety is prescribed inspections of the significant structures being carried out as scheduled. The idea is that the aircraft structure can sustain anticipated loads in the presence of fatigue, corrosion or accidental damage until such damage is detected through scheduled inspections, and the damaged part is replaced or repaired in accordance with approved methods.

The result of the item 640 wreckage examinations indicated that a pre-existing crack was on the aircraft skin underneath the doubler before the accident flight. The hidden scratches and associated MSD and fatigue crack were not detected in any scheduled structural inspection nor any other inspections of the accident aircraft until the residual strength fell below the fail-safe capability.

Although damage at multiple sites has been addressed in residual strength analyses since 1978[10], the presence of widespread fatigue damage (WFD)[11] can significantly reduce the strength of the structure. The safe damage detection period between the threshold of detection and limit load capability may also be reduced in the presence of WFD. In particular, because of the multiple forms of WFD and low probability of detection, WFD is particularly dangerous to aircraft structure.

Considerable activities were undertaken by the Structures Airworthiness Assurance Working Group (AAWG) to address WFD concerns and resulted in development of recommendations for audits of structures with regard to WFD and recommended inspection programs. However, the design of those programs has not considered issues of poor workmanship, or inadequacies in implementation of designated procedures from each sector involved in the process, such as the operators, government authorities or even international auditing efforts.

The aviation industry is continually evolving, with significant changes in aircraft design philosophy, maintenance programs and inspection processes. These developments impose further pressure on both operators and civil aviation authorities to keep pace with the changing aviation environment. The CI611 accident, and inspections of repairs on older aircraft that have been carried out since the accident, clearly demonstrate that a combination of inappropriate systems and inadequate maintenance activities could lead to undetected hidden structural damage to the aircraft pressure vessel, with the possible ultimate result of an aircraft accident.

Lessons Learned and Actions Taken

The investigation of the CI611 accident revealed that the hidden damage and fatigue fractures found on the accident aircraft were not detected in any scheduled structural inspection or any other inspections prior to the in-flight structural breakup. The findings raise serious safety concerns because of the possibility that similar hidden damage could exist on other transport-category aircraft and the fatigue cracking in the pressurized compartments of an aircraft could lead to a catastrophic structural failure.

On Nov. 26, 2002, Boeing issued an Alert Service Bulletin (ASB) 747-53A2489, which describes procedures for a one-time external visual inspection of the fuselage skin at the aft belly portion of the section 46 fuselage for repair doublers. If a repair doubler is installed, and the repair doubler meets all four criteria described in the Bulletin, the follow-on inspections and corrective actions will be necessary, including removal of the doubler, a one-time assessment (inspection) of the skin under the doubler for damage (scratches, cracking) and repair of any damage found.

Effective on Feb. 20, 2003, the FAA issued an airworthiness directive (AD 2003-03-19) requiring a one-time inspection of the fuselage skin of the aft lower body for certain repair doublers, and follow-on inspections and

[10] The regulatory changes of FARs Part 25.571 in 1978 to require that damage tolerance evaluation must consider WFD.

[11] According to the FAA Structural Integrity of Transport Airplanes, MSD is one of the two sources of WFD. It is characterized by the simultaneous presence of cracks at multiple structural details that are of sufficient size and density that the structure will no longer meet its damage tolerance requirement and could catastrophically fail.

corrective actions if such doublers are installed. For certain airplanes, this action includes optional repetitive inspections of the fuselage skin for scratches or cracking. Several other countries also issued ADs requiring inspections and corrective actions substantially similar to those described in SB 747-53A2489 and AD 2003-03-19.

The findings of the CI611 investigation and the findings from other 747 inspections performed as a result of SB 747-53A2489 indicated that improper repairs were not an isolated occurrence. Therefore, on April 8, 2003, the NTSB recommended that the FAA establish appropriate criteria to identify those pressure vessel repairs to transport-category airplanes that could be hiding damage that, if not addressed, may lead to multiple-site fatigue damage and fatigue cracking and could result in structural failure of the airplane; issue an airworthiness directive requiring all operators of transport-category airplanes with pressure vessel repairs identified as a result of structural damage other than those covered by Service Bulletin 747-53A2489 to immediately remove the repair doubler to determine whether hidden damage that could lead to multiple-site fatigue damage (MSD) or fatigue cracking is present; and inform maintenance personnel about the circumstances of this accident and emphasize that improper repairs to the pressure vessel may be hiding damage that allows the development of multiple-site fatigue damage and fatigue fracturing that could lead to structural failure.

On Feb. 25, 2005, based on the results of the investigation, the ASC recommended that the CAL should perform structural repairs according to the SRM or other regulatory agency approved methods, without deviation, and perform damage assessment in accordance with the approved regulations, procedures and best practices. Also, the ASC recommended that both the CAA and FAA ensure that the process for determining implementation threshold for mandatory continuing airworthiness information, such as RAP, includes safety aspects, operational factors, and the uncertainty factors in workmanship and inspection. The information of the analysis used to determine the threshold should be fully documented. In addition, the ASC recommended that Boeing develop or enhance research effort for more effective non-destructive inspection devices and procedures.♦

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We Need to Know What We Don't Know

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Abstract

This paper explains why air carriers must foster a healthy, active safety reporting program. Today, the LOSA Archive contains data from a base of 3,309 flight segments (cycles), during which trained observers identified threats each flight crew faced and the errors they made. Using the LOSA data to extrapolate a theoretical maximum number of errors, the paper forecasts the total number of errors made for a given number of flight segments. About 35 percent of these are consequential, and every air carrier would be well advised to seek the root causes for possible systemic correction. Many countries have programs similar to ASAP, and either understand it or can use other program models to develop their own. Using ASAP-type data, each air carrier could objectively analyze trends, improve standard operating procedures, or modify training or business processes accordingly, and reduce errors they can control. While the complete elimination of human error is not possible, any reduction in the number of errors has the potential to reduce the number of incidents and accidents. The use of this data presents what the author believes is a compelling case, and shows the vital role a non-punitive type of safety reporting program can play in reducing safety risks. The paper shows that a robust reporting program is the main ingredient in a healthy safety culture. It describes both what a safety culture is, and what it is not. Regulatory action should not be needed to follow through on the premise suggested by this paper. The only real requirement is a spirit of cooperation and partnership towards a common goal between company management, employees and the regulator.

What is Safety?

For decades, U.S. airline industry labor relations have been argumentative, and conflict between management and organized labor the norm (Hoffer Gittell, 2003:2). Such conflict exists in many businesses, and is not solely a U.S. phenomenon. However, in an organization that engages in business products or services that pose higher than normal risks to the end user, such as air transportation, internal conflict may not be a productive attribute. "The evidence from other industries suggests that low trust and high conflict combine to have substantial negative effects on performance outcomes" (Hoffer Gittell, 2003:6). For example, "Ignoring years of research on human error, exhortations to professional, error-free behaviors — as pathetic as futile — have been daily currency in safety practices. The fundamental issue, simple as it is, has been consistently dodged: while safety is yet another means to achieve aviation production goals, mythical beliefs perpetuated since World War II have fostered the perception of safety as an end in itself" (Maurino quoted in Johnston, 1997:xvi). When dealing with a very educated and professional work force, such as flight crew, a manager must realize that they are not going to commit an error on purpose. They are human and they will make mistakes, but any such " … errors are largely unintentional. It is very difficult for management to control what people did not intend to do in the first place" (Reason, 1997:154). This lack of an ability to control the unintentional errors of their employees creates a conflict of expectations between management and the employee. On the occasion when expectations are met, sometimes coincidentally, it becomes too easy to conclude that things are finally "right." Safety is risk management, and it is an active process, a journey, not a destination. "Pursuing safety and effectiveness in aviation is an endless quest, which allows for no time to rest over accomplishment. It requires particular solutions to specific deficiencies which present themselves under substantially different symptoms and circumstances over time" (Maurino, 1995:xii).

All Accident Data

Anyone who has spent even a brief amount of time examining the aviation safety record has learned that for day-to-day or even year-to-year management of an aviation enterprise, " … negative outcome data (accidents, incidents, etc.) are too sparse, too late and too statistically unreliable to support effective safety management" (Reason, cited in Maurino, 1995:134). However, taken in the context of a long period of time and used for a more global analysis, such data can show valuable clues to aid in planning. Accident data from the Boeing Company of all airplanes heavier than 27,000 Kgs maximum gross weight, except for those manufactured in the Commonwealth of Independent States and those commercial models in military service, were used in this analysis. It comprised a total of 393 accidents which occurred between 1992 and 2001 (Flight Safety Foundation, 2002:14). It is important to note that this is "all accident" data, not the more often cited "fatal accident" data. Most will accept the notion that a particular accident type has a precursor incident(s) or near-miss(es) of a similar nature, that quite possibly could be measured on a similar frequency distribution. One of the key findings is that 47 percent of these accidents involved landing; hard, off the side of the runway, off the end of the runway, or gear fails to extend or collapses. These almost always resulted from an undesired aircraft state, and are directly attributable to the handling of the aircraft and the flight crew's proficiency. That is not to say that there were not other factors behind the final mishandling, but it was the outcome. From the archives of the Line Operations Safety Audits (LOSA), we learn that "the phase of flight most prone to external threats was also most likely to contain flightcrew errors — the descent/approach/landing phase of flight" (Klinect, 1999:686). This finding is in concert with the accident data cited above.

LOSA Data

Line Operations Safety Audits (LOSA) use trained expert observers, and present no jeopardy to the crews. Thus the data gathered is of high quality in representing how that crew might be expected to perform without observation (Helmreich, 1999:678). Early LOSA results compared threat and error rates between different participating air carriers, and found considerable variations (Helmreich, 1999:680). As of November 2004, the LOSA Archive contained 3,309 observation reports. Based on these, the average flight experienced 2.7 threats and 2.2 errors. The errors are further broken down as shown in Table 1 (Klinect, 2005).

Table 1. LOSA Error per Flight Breakdown

Errors/flight	Description
0.5	Undetected by crew, inconsequential
0.7	Intentional non-compliance
1.0	Consequential (0.5 – undesired aircraft state)
2.2	Total

We are only interested in two of the three segments of the error, because the crew is not even aware of the third. First, we must be concerned because "intentional non-compliance errors should signal the need for action since no organization can function safely with widespread disregard for its rules and procedures. One implication of violations is a culture of complacency and disregard for rules … . Another possibility is that procedures themselves are poorly designed and inappropriate, which signals the need for review and revision. More likely, both conditions prevail and require multiple solutions" (Helmreich, 1999:680). Irrespective of the possible "violation" nature of intentional non-compliance, it is too important to obtain data about them to focus on retribution. Among professional air carrier crews they are most often a product of poorly constructed procedures, in a culture that is deaf to the few who express their concern. Second, among the consequential errors, one-half of an error per flight results in an undesired aircraft state. This most dangerous error is vital to be captured for correction. In any case, 1.7 errors per flight are known to the crew and could be reported if an appropriate reporting system existed.

Undesired Aircraft States

Already mentioned, but not yet described, an undesired aircraft state is when it is in a position of increased risk. Vertical and lateral deviations, or an unstable approach, or hard or long landings are some but not all of the possible conditions (Helmreich, 1999:679). It should come as no surprise that "undesired aircraft states are theorized to be at the cusp of an incident or accident" (Klinect, 1999:687). In fact, these are exactly the contributor to the 47 percent landing accident statistics. While gear problems may exist for technical reasons, automation rarely lands long, or loses directional control. The point here, again, is not to castigate professional flight crews. The point is to promote the need to obtain data about all such events, or rationally, as many as possible, so they can be analyzed and common causes (i.e., latent systemic factors) identified.

Voluntary Reporting

Despite good intentions, years of work and countless attempts at programs, we have vacillated between believing on one hand that human error could be eliminated, and on the other that we must manage errors. "Given that most human factors safety programs are not data-driven, it only stands to reason that they have produced intervention strategies that are only marginally effective at reducing the occurrence and consequences of human error" (Wiegmann and Shappell, 2003:18). As is usually the case, the business community demanded data to prove the case. We knew we had no data, but to get it we found mountains to overcome, because people are not going to report on themselves. "Studies in the U.S.A. of so-called high-reliability organizations have suggested that some complex systems can function efficiently only if all incentives to hide information about errors are removed, so that near-misses and minor malfunctions can be fully analyzed and discussed in order to head off major accidents and failures" (Hood, 1996:48). The simple fact is that "an informant may be willing to report an event, but not be able to give a sufficiently detailed account of the contributing factors. Sometimes reporters are not aware of the upstream precursors. On other occasions, they may not appreciate the significance of the local workplace factors. Together, the willingness and the ability issues are likely to have two effects: not all near-misses will be reported, and the quality of information for any one event may be insufficient to identify the critical precursors. But the very considerable successes of the best schemes indicate that the advantages greatly outweigh these difficulties" (Reason, 1997:119). "Data collection to support the safety culture must be ongoing and findings must be widely disseminated" (Helmreich, 1999:681). Almost a decade ago, the FAA, in cooperation with one major U.S. air carrier, began a test program which has today evolved into the Aviation Safety Action Program (ASAP). Almost all U.S. carriers now participate, jointly with the FAA and their labor groups. Among flight crew members, U.S. air carrier industry experience shows an average of 1.5 ASAP reports per pilot per year. It should be noted that this figure is from companies with "mature" programs; those with at least 18 months experience with the program, the majority of them (McClure, 2005).

The Gravity of the Problem — an Example

Up to this point, the reader is likely wondering where I am going, or what is new in what I am saying. To satisfy that need I offer an example. The data is already presented, except for an air carrier. This hypothetical air carrier flies long-haul, exclusively cargo operations. The information in Table 2 provides a very cursory description necessary to our example.

Table 2. Hypothetical Air Cargo Carrier

Value	Attribute
24,000	Departures per year
1,000	Flight crew members
42	Aircraft operated
120	ASAP reports submitted in one year

Using the error breakdown data from the LOSA data, in conjunction with the air carrier data in Table 2, we can extrapolate the number of voluntary reports which are theoretically possible for the given carrier. Table 3 shows the analysis.

Table 3. Errors Versus Reporting per Year

Value	Attribute
1.7 x 24,000 = 40,800	Total errors known to the crew per flight times annual departures = Possible reportable errors
0.29%	Received reports per error
0.5 x 24,000 = 12,000	Undesired aircraft state errors per flight times annual departures = Possible reportable errors
1.0%	UAS reports per error
1.5 x 1,000 = 1,500	U.S. industry report per year experience times number of flight crew = Possible reportable errors
8.0%	Industry reports per error

When we contrast the number of errors with the number of actual reports received, we find out we need to know what we don't know. Even the most progressive air carriers are experiencing this problem, a deficit of data, to some degree. In this example, the number of reports received is only 1 percent of the expected number of UAS, and that's making the assumption that all reports are of that nature. Even using the more liberal and empirical U.S. industry experience, we are only receiving reports about 8 percent of the expected number of UAS, again making the same assumption. However, the goal is and should be, more reporting. So what do we need to do? Very simply: "… valid feedback on local and organizational factors promoting errors and incidents is far more important than assigning blame to individuals. To this end, it is essential to protect informants and their colleagues as far as possible from disciplinary actions taken on the basis of their reports" (Reason, 1997:198).

Safety Culture

The role of organizational culture began to be discussed in the business literature in the early 1990's. A portion of such a culture relates to the safety of high-risk operations. However, " … most documented efforts to define and assess safety culture have arisen outside the aviation industry. Furthermore, there exists considerable disagreement among safety professionals, both within and across industries, as to how safety culture should be defined and whether or not safety culture is inherently different from the concept of safety climate" (Wiegmann et al., 2002: 16). This fairly recent conclusion indicates a need for the aviation industry to develop and adopt a consistent definition, perhaps a standard, to use in the future. To contribute to such a dialogue we will explore some of the other writings on the subject. Few would dispute that "the key to proactive safety management lies in identifying latent failures and remedying them before their consequences are visited upon the organization. The fundamental requirements are therefore structural and cultural, given that effective risk management structures can only function effectively in the presence of an organizational sub-culture which endorses and promotes feedback and remediation" (Maurino, 1995:51). This is because " … human error does not take place in a vacuum, but within the context of organizations which either resist or foster it" (Maurino, 1995:xi). Therefore, if we are serious about making progress in countering the effects of human error, we must pursue both structural and cultural efforts. In over a decade of writings " ... there is evidence within the management science literature to indicate that recent attempts to manipulate corporate behavior by changing organizational cultures have met with only limited success; organizational cultures are notoriously resistant to change, and there is no reason to suppose that a safety culture will be any different in this respect. ... Attempts to change safety culture solely by management edict (decree) or by imposition of external regulation (prescription) will meet with limited success" (Johnston, 1997:37). This is because management cannot dictate culture. All that they can do is provide a medium in which to foster a culture. The resulting " … organizational cultures can be ranged along a spectrum of information flow from pathological to bureaucratic to generative" (Westrum in Phimister et al., 2004:183). "Organizations which are able and willing to respond promptly to feedback and modify their relationship to both the internal and external operations environments have been described as 'generative'" (Westrum, cited in Maurino, 1995: 51). It is this complete loop of Plan-Do-Check-Act, coupled with an open, welcoming interest in employee input that brings about a positive change along Westrum's continuum. Change is possible, but will succeed only when actions back up management pronouncements. Each culture type has characteristics, and accidents typically have a dominating feature from among violations, neglect, overload or design flaws. The distribution of the contribution of each of these features correlates to the spectrum of culture; pathological is more likely to breed violations, where generative is more likely to suffer design flaws (Westrum in Phimister et al., 2004: 182–3). Four principal elements comprising a good safety culture are: management from a strategic level, which encourages a distribution of attitudes of care and concern throughout the organization, including norms and rules for handling hazards, and the impetus for people to continually reflect on their safety practices (Johnston, 1997: 33). One of the better definitions of safety culture is: "The culture of an organization may be defined as a set of rarely articulated, largely unconscious beliefs, values, norms and fundamental assumptions that the organization makes about itself, the nature of people in general and its environment. In effect, culture is a set of 'unwritten rules' that govern 'acceptable behavior' within and outside the organization" (Mitroff, cited in Maurino, 1995: 7). Along the same lines is this one: "The safety culture of an organization is the product of individual and group values, attitudes, competencies and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety programs. Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measure" (cited by Reason, 1997:194).

Notwithstanding any existing definition in academic literature, and outside of some common business standard, it is easy to see that "safety is strongly influenced by the culture and climate of an organization (the goals, values, attitudes, beliefs and shared practices that pervade an organization). However, the means by which organizational culture can be influenced to achieve safety goals are still not well understood" (Maurino, cited in Johnston, 1997: 8). Structurally, "organizational climate may be viewed, in part, as a product of senior management" (Maurino, 1995:129). This is the medium in which a culture grows. Traditional disciplines have noted two fundamental characteristics found in culture, the first being observable behaviors and the second being a system of symbols or meanings which comprise a shared cognitive system. Such a safety culture creates, re-creates and regenerates itself based on the behaviors and cognitive responses of the members of the culture. In this way, the climate established by management results in the culture that the employee group gives back to management through their response (Johnston, 1997:32). In this way, a safety culture "is," but before it can be, it has to have essential ingredients. The "has" is the climate created by the rules and the environment provided by the company in its work spaces. Within that, the employees will respond to it and provide a culture, not necessarily to the company's or their own liking. But it will be the "is." If either group feels the culture needs to change, the company will have to cause a climate change that will foster an opportunity for culture change. In this, "trust" is a vital component (Reason, 1997:220).

Trust

"Trust is a critical element of a safety culture, since it is the lubricant that enables free communication. It is gained by demonstrating a non-punitive attitude toward error and showing in practice that safety concerns are addressed" (Helmreich, 1999:681). It is not the place of safety professionals to tell management how to manage, but the data are compelling, and a part of it comes down to leadership. It takes more than just a direct report from the safety officer to the CEO, and more than the spoken commitment to safety by senior managers. "In leadership, trust is a decision that followers make to rely on a leader under a condition of risk. The principal components of trust are reliance and risk. In leadership, the risk refers to the possibility that the followers will be misled and experience distress if a leader proves untrustworthy. Reliance is the notion that the follower's fate is determined by leader's actions" (Csorba, 2004:8). Employees are interested in the viable financial future of their air carrier; none of them desires to have to find a new position, or start a career over again. They will willingly follow. If we are to succeed, today's air carrier leadership must understand and embrace that " ... what creates trust in such corporate leaders is the leader's manifest respect for the followers" (Csorba, 2004:24). The business case is equally simple: "Gains from a high-trust workplace culture … appear to accrue both to firms and to their employees" (Hoffer Gittell, 2003:22).

Blame

Almost 30 years ago, a pioneer safety professional recognized that "human failures are not usually blameworthy as they stem from insufficiency of knowledge or skill or foresight … which allowed human error to occur too readily … . I would not write off crew error accidents as unavoidable but view them as accidents which, with better design of aircraft, instruments, ground aids, training or procedures are amenable to reduction" (Dr. Walter Tye, U.K. CAA controller of safety circa 1973, cited in Hurst, 1976: 63–64).

Then 20 years later, with very little movement from stagnant thinking about blame, another voice writes, " ... blame and punishment do not have, in themselves, any prevention value. Thus blame and punishment should be avoided because the knowledge that a culprit has to be found whenever an error has occurred will invariably prevent the full and candid reporting of incidents and unsafe events to the detriment of opportunities for learning about the system" (Johnston, 1997:39).

At this same time, when most of the technical solutions to accident causes had been applied, and human error loomed as the greatest area needing attention, we realized that "the recognition that near-misses and other failures are opportunities for learning about the behavioral characteristics of socio-technical systems, leading to the possible avoidance of disasters, has led to proposals to establish no-blame cultures in organizations. Such approaches would seek to generate a climate of openness in which workers are not frightened to report minor incidents or unsafe acts, and senior management are receptive to critical ideas from lower tiers within the organization, customers and outsiders" (Hood, 1996:65). There was, in fact, already a pioneer in the aviation world, though not an air carrier. Since 1980 Shell Oil had adopted a series of management programs to generate a no-blame culture through their aviation arm as well as their tanker fleet and they've had remarkable success in reduced injuries, reduced accidents and reduced incidents. Of course they've been involved in aviation since 1930, a long and rich history (Hood, 1996:65). Many in the managements of air carriers have held such ideas in disdain, in part due to loss of direct control. Nevertheless, " … no-blame approaches to risk management, contrary to being recipes for irresponsibility, seem to offer creative ways forward for managing complex socio-technical systems within organizational contexts. However, the constraints placed on the establishment of 'no-blame culture' by the micro-political factors examined above, and by the structural features of the technology question, pose a series of difficult management problems" (Hood, 1996:66).

Still, management feels compelled to appear to do something when an accident occurs. "The key to understanding the role of blame is to consider it in social and psychological terms. Committing a serious error — especially if it has significant public repercussions — compels a reaction on the part of either government or corporate management. It is notable that such reactions often vary according to the degree to which the error was publicized or gave rise to public disquiet. In such circumstances, punitive action is taken to be a signal of management's intention to act and is often seen as a sign that management is willing to move to prevent a recurrence of similar events. Managers, especially if inexperienced, tend to feel they have to be seen to do something and a sanction of some form is the action that most readily comes to many minds. The manager's … assessment of how senior management, or the public, expects them to act will probably be of greater significance in such circumstances than anything to do with justice, risk management or accident prevention" (Hood, 1996:76).

The facts are that many societies (national cultures) have an expectation of redress, whether it is litigious or fiduciary. We still have a problem with criminalization after aircraft accidents in many parts of the world. If you accept the notion that professional flight crew do not commit errors on purpose, and do not desire to risk their own lives in the process, then a new paradigm is necessary. "Effective risk management systems can only operate effectively in a subculture that endorses and promotes feedback and remediation. A no-fault/no-blame ethos is clearly an essential element. Any such system must also be structured appropriately and be perceived to operate with integrity and effectiveness" (Hood, 1996:78). This is not a panacea or golden bullet, but it is a key change, without which we will make no further progress with the problem of human errors in aviation.

Conclusion

We must pursue the safety culture necessary to improve the reporting. However, there is more we must do to ensure continued increase in the number of reports over time. "Apart from a lack (or loss) of trust, few things will stifle incident reporting more than the perceived absence of any useful outcome" (Reason, 1997:200). It is for this reason that the feedback of de-identified information must be timely and complete. Without that, flight crew's enthusiasm for any program will wane and the vital data will remain out of reach. Lest anyone should think that this premise will eliminate all accidents, let me be clear that "generative organizations may seem to be accident-proof, but they are not" (Westrum in Phimister et al., 2004:184). Further, "good organizations can have bad accidents and even large numbers of near-misses — this is not as paradoxical as it first sounds, since only good organizations are likely to receive such reports in the first place" (Maurino, 1995:157). It is still worth pursuing more and better reporting for the reduction alone, given that taken to a mathematical infinity, we will never eliminate accidents. Keep in mind that safety, as risk management, is a process, and " … it is worth pointing out that if you are convinced your organization has a good safety culture, you are almost certainly mistaken. Like a state of grace, a safety culture is something that is striven for but rarely attained. As in religion, the process is more important than the product. The virtue — and the reward — lies in the struggle rather than the outcome" (Reason, 1997:220).

Among the many hundreds of safety professionals in aviation worldwide, " … a cynical observer might comment that senior managers are often happy to accept the rewards of corporate success, while distancing themselves from failure. But if senior management is responsible for success, who is responsible for failure?" (Hood, 1996: 64). The answer is all of us. Everyone involved in air transportation owns the problem. Not all of us can do something, especially without management's commitment, but it is still our problem on several levels. For them, the business case has too often been, " ... as Senator Joseph Lieberman aptly put it in a speech on business ethics: 'the bottom-line has become the only line we're willing to draw'" (Csorba, 2004:106).

However, there is a counterpoint that cannot be discounted. "It takes only one organizational accident to put an end to all worries about the bottom line" (Reason, 1997:240). Accidents always bring losses both direct and indirect in a market-based global economic system. "Thus, efforts to build an effective labor relations system by focusing on the quality of the relationships among employees, supervisors and managers … appear to offer considerable potential for improving firm financial performance and the industry's overall service quality" (Hoffer Gittell, 2003:25). With the culture that will enrich safe operations, comes one that also enriches the quality of operations, a double return for a modest effort. The work will not be easy; management personnel will have to commit to not only permitting, but encouraging employee involvement in process development and operations. "What matters most is that we go beyond the obvious and grapple with the complexity, for explanation lies in the details" (Vaughan, 1996: 463).♦

References

Csorba, L.T. (2004) *Trust*. Nashville, Tennessee, U.S.: Thomas Nelson.

Flight Safety Foundation. "Data Show 393 Accidents Among Western-built Large Commercial Jets From 1992 Through 2001." *Flight Safety Digest* Volume 21 No. 11 (November 2002):13–16.

Helmreich, R.L., Klinect, J.R. and Wilhelm, J.A. (1999). Models of threat, error, and CRM in flight operations. In *Proceedings of the Tenth International Symposium on Aviation Psychology* (pp. 677–682). Columbus, Ohio, U.S.: The Ohio State University. <http://homepage.psy.utexas.edu/homepage/group/HelmreichLAB/Publications/pubfiles/pub240.pdf>.

Hoffer Gittell, Jody, von Nordenflycht, Andrew and Kochan, Thomas A. “Mutual Gains or Zero Sum? Labor Relations and Firm Performance in the Airline Industry” (March 2003). MIT Sloan Working Paper No. 4298-03; Institute for Work and Employment Research Working Paper No. 01-2003. <http://ssrn.com/abstract=395447>.

Hood, C. et al. (1996) *Accident and Design, Contemporary Debates in Risk Management*. London, England: University College London Press.

Hurst, R. (ed.) (1976) *Pilot Error — A Professional Study of Contributory Factors*. London, England: Crosby Lockwood Staples.

Johnston, N. et al. (1997) *Aviation Psychology in Practice*. Aldershot, England: Ashgate Publishing Ltd.

Klinect, J.R., Wilhelm, J.A. and Helmreich, R.L. (1999). Threat and error management: Data from line operations safety audits. In *Proceedings of the Tenth International Symposium on Aviation Psychology* (pp. 683-688). Columbus, OH: The Ohio State University. (UTHFRP Pub241)

Klinect, James R. Telephone interview by author. March 2005.

Maurino, D. et al. (1995) *Beyond Aviation Human Factors*. Aldershot, England: Ashgate Publishing Ltd.

McClure, Donald. Telephone interview by author. March 2005.

Phimister, James R., Bier, Vicki M., Kunreuther, Howard C. (eds.) (2004) *Accident Precursor Analysis and Management. Reducing Technological Risk Through Diligence*. Washington, D.C., U.S.: The National Academies Press.

Reason, J. (1997) *Managing the Risks of Organizational Accidents*. Aldershot, England: Ashgate Publishing Ltd.

Vaughan, D. (1996) *The Challenger Launch Decision*. Chicago: University of Chicago Press.

Wiegmann, D. A., Zhang, H., von Thaden, T., Sharma, G. and Mitchell, A. (2002). *A Synthesis of Safety Culture and Safety Climate Research*. University of Illinois Institute of Aviation Technical Report (ARL-02-3/FAA-02-2). Savoy, IL: Aviation Research Lab.

Wiegmann, D. and Shappell, S. (2003) *A Human Error Approach to Aviation Accident Analysis*. Aldershot, England: Ashgate Publishing Ltd.

Additional material follows on pages 341–349.

We Need to Know What We Don’t Know

by
Captain Scott C. Schleiffer
Group Chairman for Human Factors & Training
Air Safety Committee
Air Line Pilots Association, International

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What Is Safety?

- Absence of accidents or incidents?
- Presence of programs/management?
- Positive outcomes of internal and external audits?
- Safety is risk management.
- Active effort to identify hazards, analyze risk and establish controls to mitigate.

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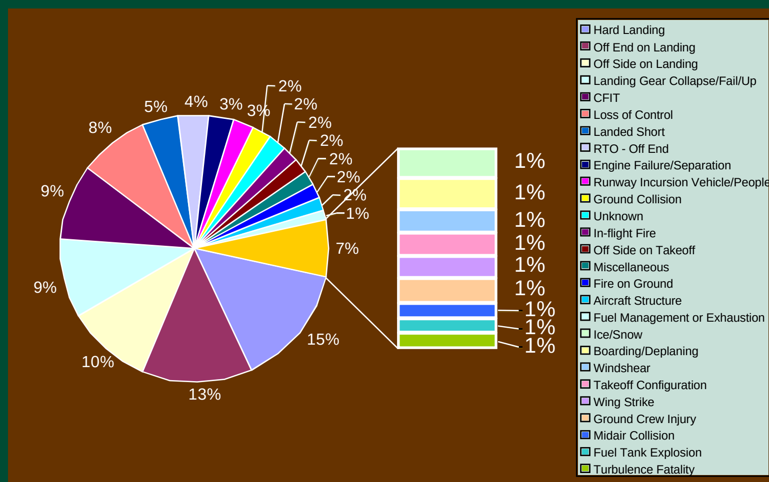
Aircraft Accidents by Category 1992–2001



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Precursors vs. "Fatals"

- 47% of accidents involve landing
- CFIT under control through GPWS, EGPWS, TAWS
- LOC well on the way with URT Aid, Rev 1
- Human factors still a key to remainder of slices going forward.

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What Do We Know?

- LOSA Archive data – 3,309 flights
- 2.7 threats/flight
  - 15% not managed, become errors
  - 1.7 environmental
  - 1.0 airline
- 2.2 errors/flight
  - 50% of all errors are during Descent, Approach and Landing Phases

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Error Breakdown

- 2.2 Errors/flight
  - 0.5 - Undetected by crew, inconsequential
  - 0.7 - Intentional non-compliance
  - 1.0 – Consequential (0.5 – Undesired aircraft state)
- 1.7 Errors/flight => Potential report under ASAP

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Undesired Aircraft State

Undesired aircraft state is a compromised situation placing the flight at increased risk.

- Lateral or vertical deviations
- Speed too high or low
- Incorrect configuration
- Unstable approach
- Abrupt aircraft control
- Long landing – No G/A
- Firm landing
- Forced landing
- Wrong taxiway, ramp, runway, country
- Runway incursion

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Hypothetical Example I

- **Long-haul cargo 2004**
- **24,000 departures**
- **1,000 crewmembers**
- **42 aircraft**

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Hypothetical Example II

- **Long-haul Cargo CY 2004**
- **Received 120 ASAP reports**
- **Could have had 24,000 x 1.7 = 40,800**
- **Should have had 24,000 x .5 = 12,000**
- **Received/Should = 1%**

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Hypothetical Example III

- **Long-haul Cargo CY 2004**
- **Received 120 ASAP reports**
- **Industry experience 1,000 x 1.5 = 1,500**
- **Received/Industry = 8%**

Either way, 1% or 8%,

We don't know what we don't know

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Safety's Foundation

- Safety's foundation is a corporate culture which actively fosters risk management.
  - Safety is a set of programs, proactive and reactive.
  - It accepts and acknowledges human fallibility.
  - But most important, it's an attitude of every employee.

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Reporting

- Culture of reporting requires trust to foster interest in acknowledging problems and allowing employees to help in finding solutions.

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Non-Punitive Data Collection

- Aircrew and other operational personnel will not be forthcoming with the needed information if the data can be used against them.
- Any likelihood that safety-critical information will be used against the person or organization reporting the incident needs to be reduced … practically eliminated.

Are there not compelling reasons to encourage accurate and timely reporting of safety data?

Safety Culture Parallels CRM

Think of it like this:

- We all understand CRM in the context of the cockpit.
- Culture is the result of a CRM between and among all the employees and the company management.

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Management Is the Captain

- Management is the captain but, like the flight deck captain, must solicit, listen to, evaluate and act on the best available information and the recommendation of the group.

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Two Captains

- The best captain is respected for how much and how well he uses the input of all.
  - He is very safe and very efficient.
  - He is trusted.
- A dictatorial captain is unsafe and not very efficient.
  - He just has control.
  - He is despised.

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Why LOSA, ASAP, FOQA, etc.?

"The essence of a good flight data analysis and reporting system is that it should be confidential and non-punitive. The concept is that it is better to know about a potential problem – so it can be analyzed and the underlying reasons corrected in order to prevent its recurrence before it leads to something more serious – than to punish those that might have made an error, etc. …"

Flight Safety Foundation
November 2002

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Conclusion

- We need a system where errors are observed, reported, analyzed and corrected on a systematic basis.
- Reporting is the key.
- Reporting requires a culture of openness, encouragement, non-punitive treatment and an understood willingness by all to face the facts, and act to correct problems.

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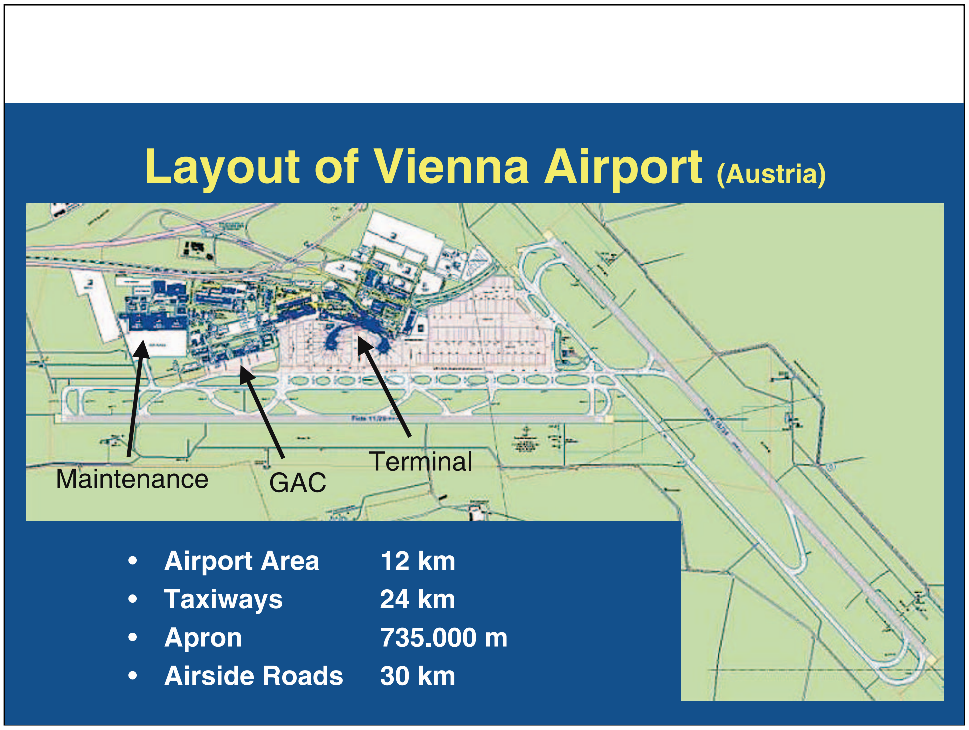
♦♦♦♦

Safe Operation During Airport Construction

Gerhard Gruber
Vienna International Airport

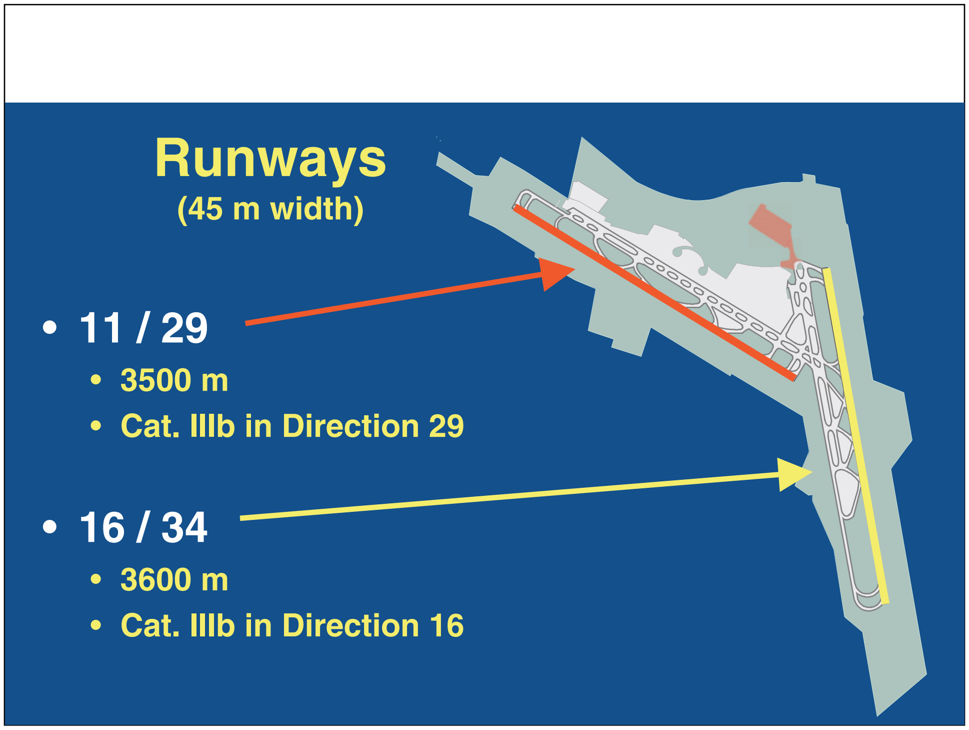


Layout of Vienna Airport:

The main facilities of the airport are located in the northern part and consist of the passenger facilities, the terminal including the two piers (total 20 passenger-loading bridges) and the apron.

The maintenance facility of the home carrier Austrian Airlines is located in the western part.

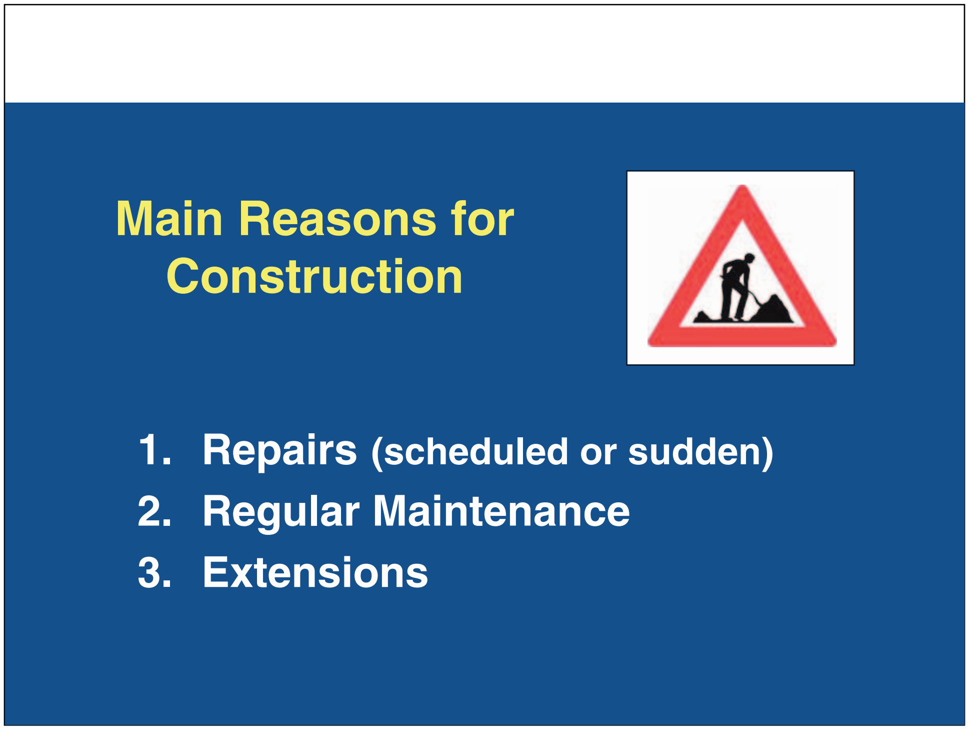
Next to the Austrian Airlines maintenance facility is the General Aviation Center.



Runway layout of Vienna Airport:

Vienna Airport has two runways.

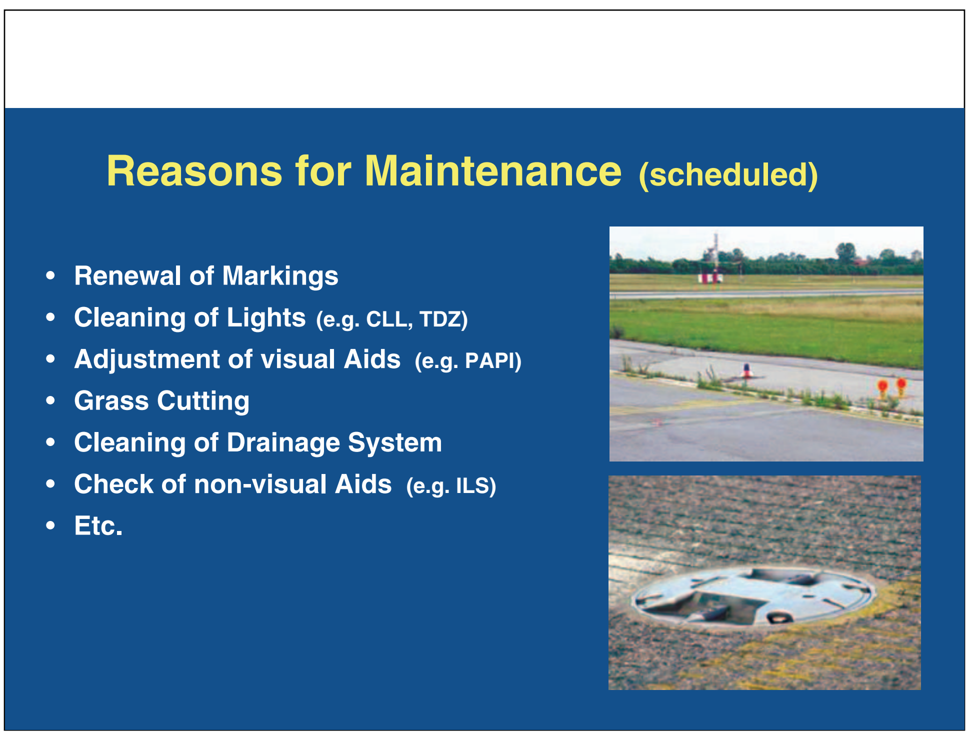
Since the runways are not parallel, no independent operation is possible.



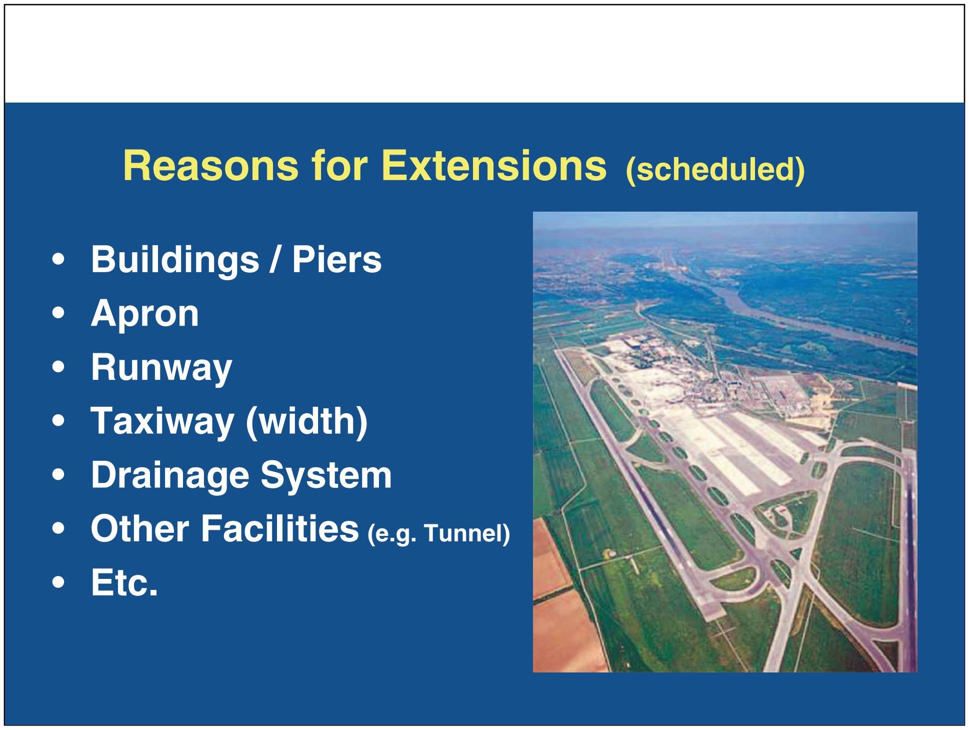
Main reasons for construction are

1. Repairs (this may be planned ahead or on immediate need)
2. Regular maintenance
3. Extension of facilities

Some reasons for repair work at Vienna Airport in the past.



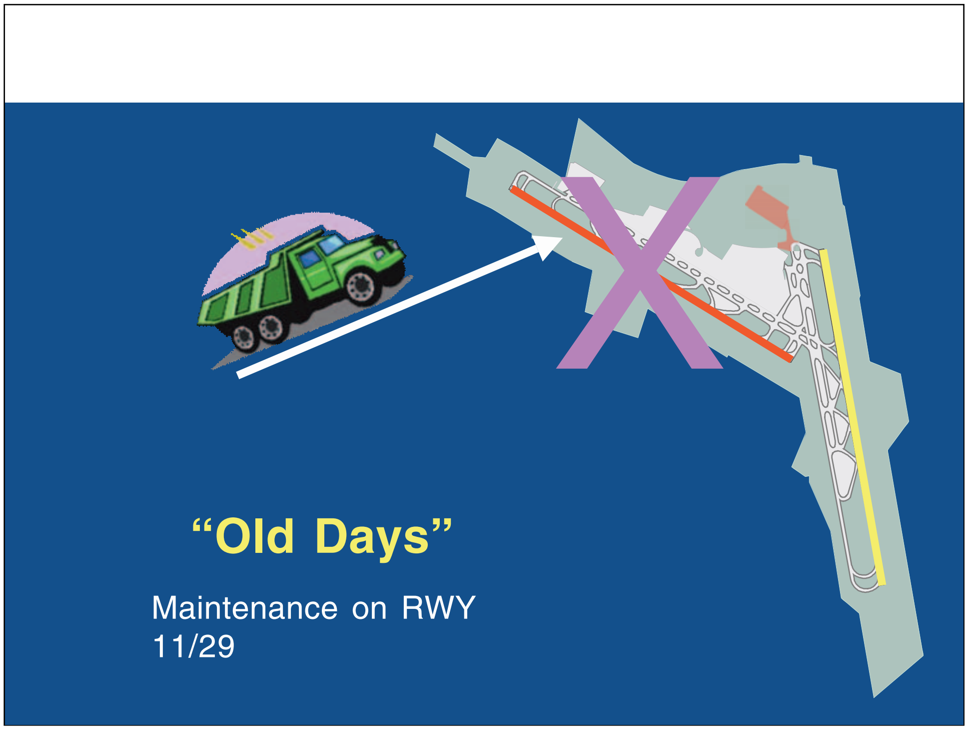
Some reasons for maintenance work in Vienna in the past.



Some examples for extensions at Vienna Airport in the past.

There are many reasons for the time of construction.

But there is never a “right time” to have restrictions due to construction.

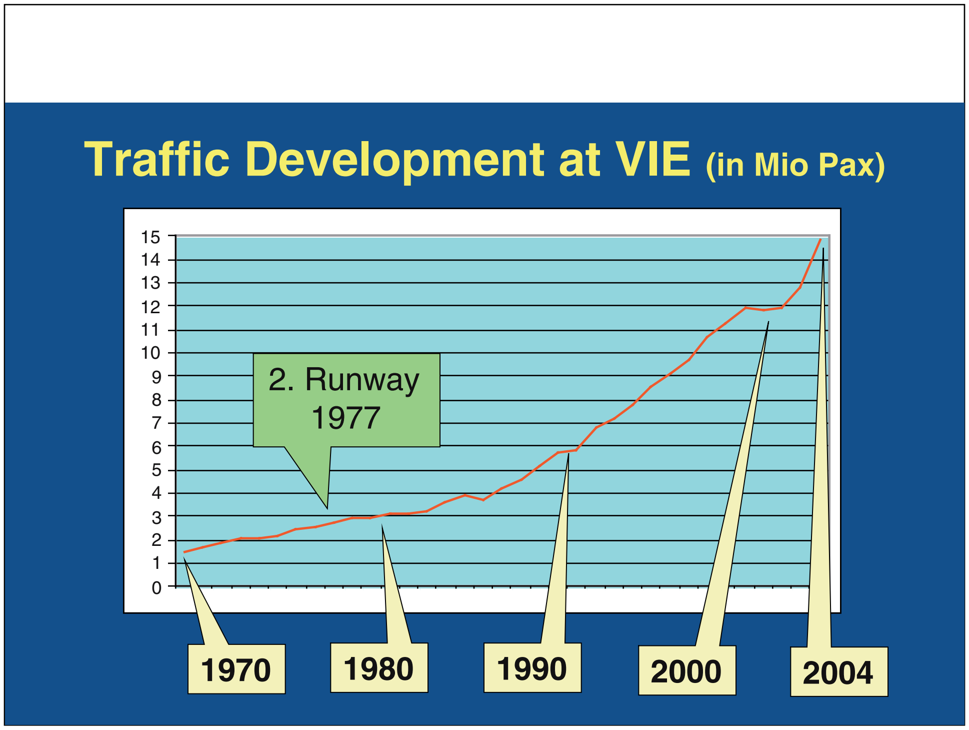


Construction in the past was quite simple compared to today's situation.

Since capacity demand was low, a single runway operation did not create any restrictions.

Construction site and aircraft operation were well separated.

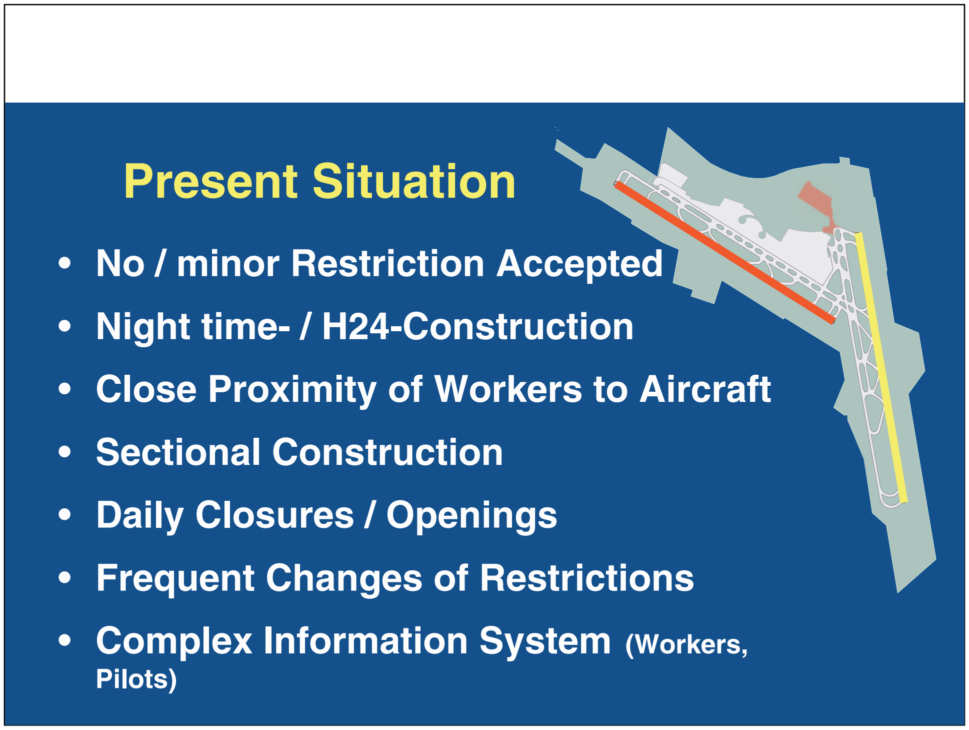
No crossing of an active movement area was necessary.



Aviation is a fast growing business.

In the ’70s there was rather low traffic increase compared to today.

Airports are facing big capacity demands requiring excessive construction.



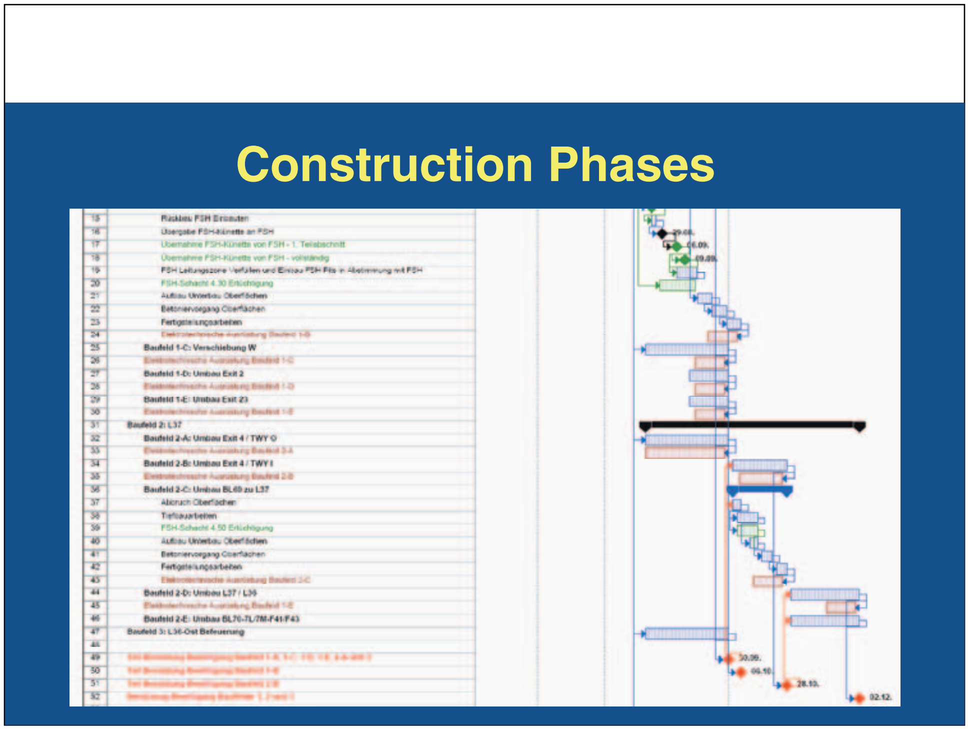
Today's situation requires no capacity restrictions.

This means that constructions must be performed

- During nighttime
- In sections
- In close proximity of aircraft operations.

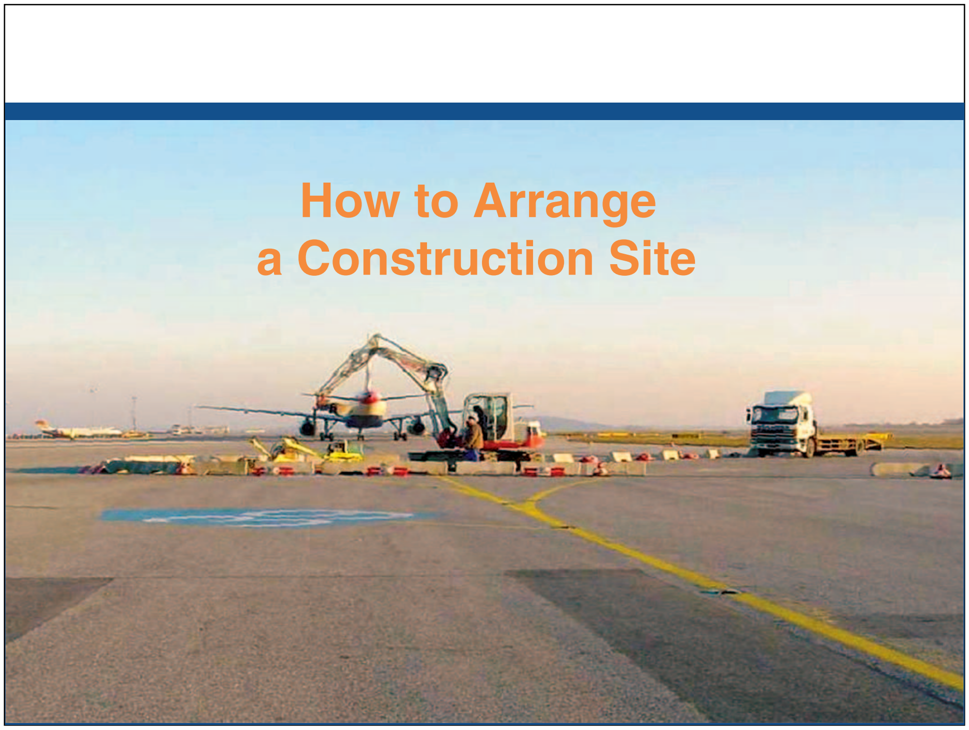
Crossings of movement areas by ground vehicles require special precautions and also special staff training.

A big challenge for the airport operations staff is the re-opening of movement areas during nighttime.



This is a MS Project excerpt of construction phases on the movement areas.

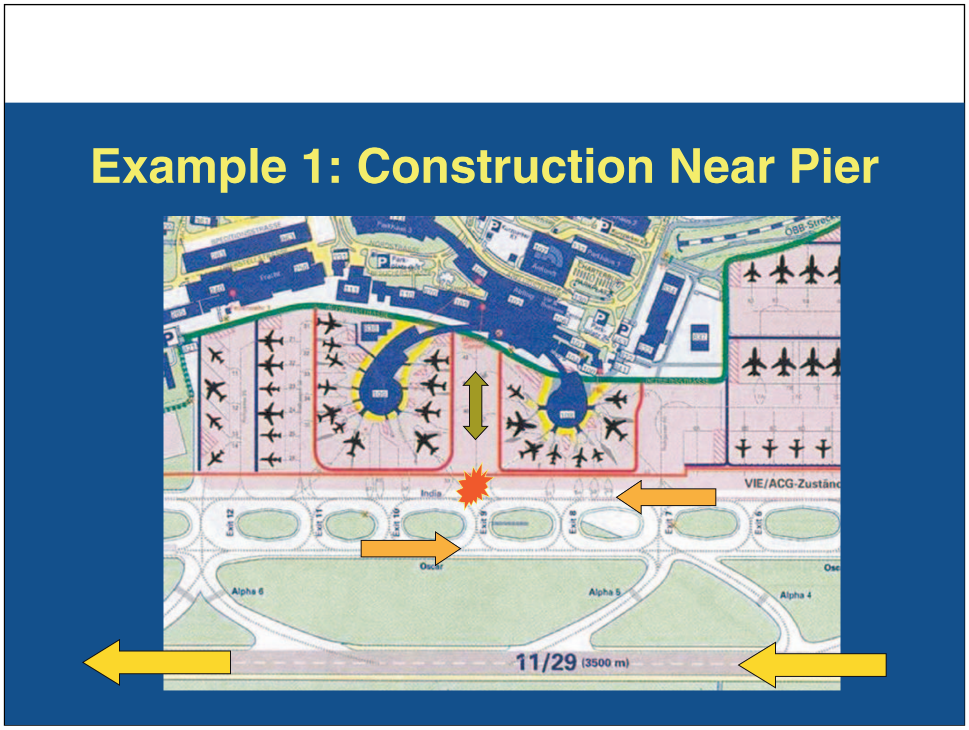
To avoid unscheduled closure or restrictions of movement areas, the planning as well as the actual construction must be very accurate.



Some examples of how to protect a construction site and to ensure safe airport and aircraft operations.

Abnormal situations (like construction near aircraft operations) are dangerous.

It is very important to consider all possibilities and arrangements of the construction site in order to avoid any hazard.

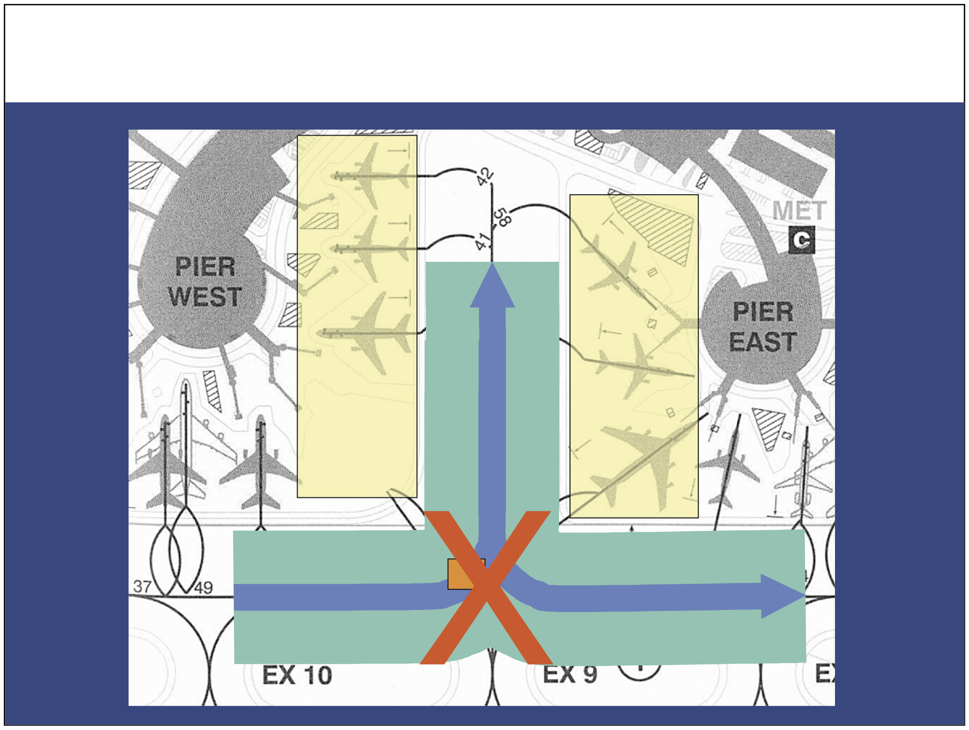


Runway 11/29 is for takeoff and landings.

The parallel taxiways are used as the main taxiways.

The taxi lane between the two piers is the busiest area at the airport.

It is obvious that this pavement is stressed excessively and therefore prone to fatigue.

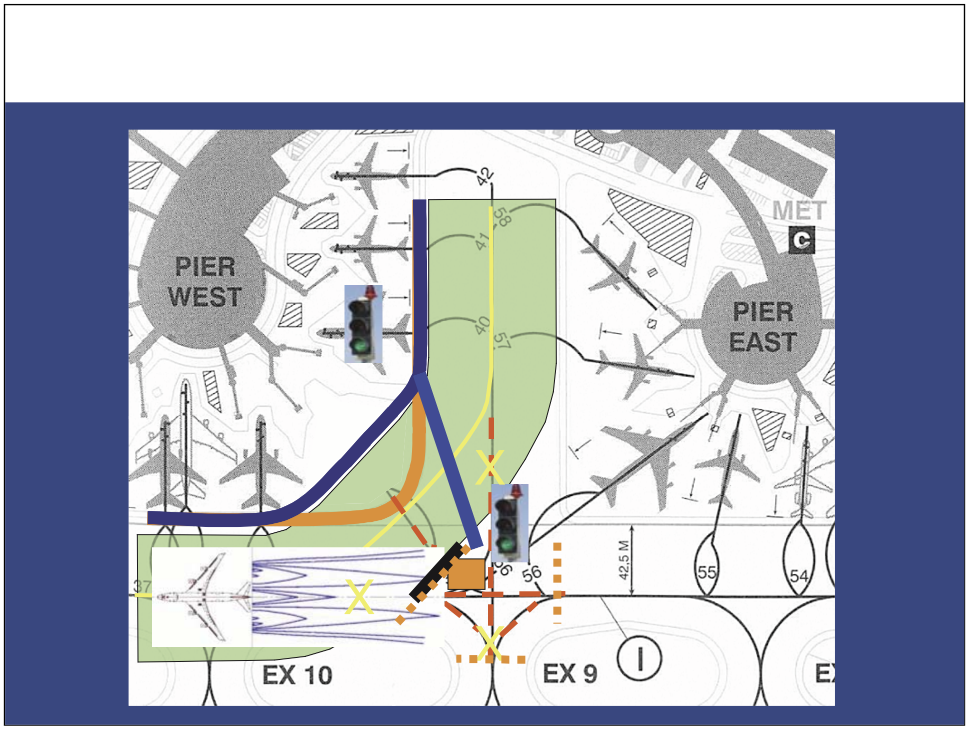


Details for repair works near the pier:

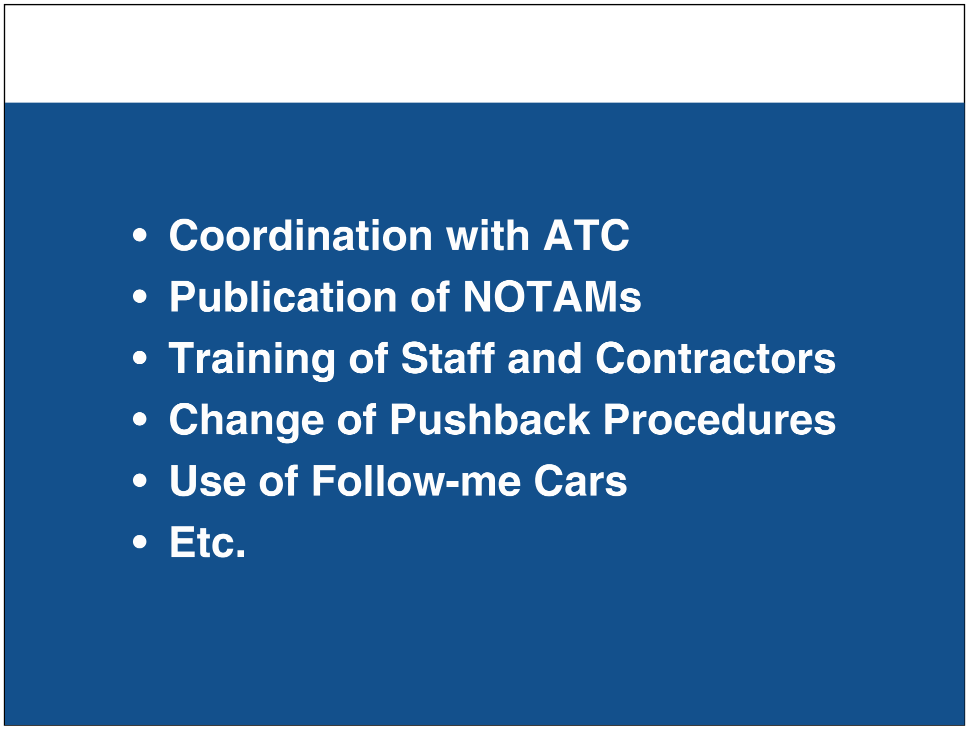
First of all, the use of parking positions between the piers must remain as unrestricted as possible.

Pos 39 will be used as an alternative routing.

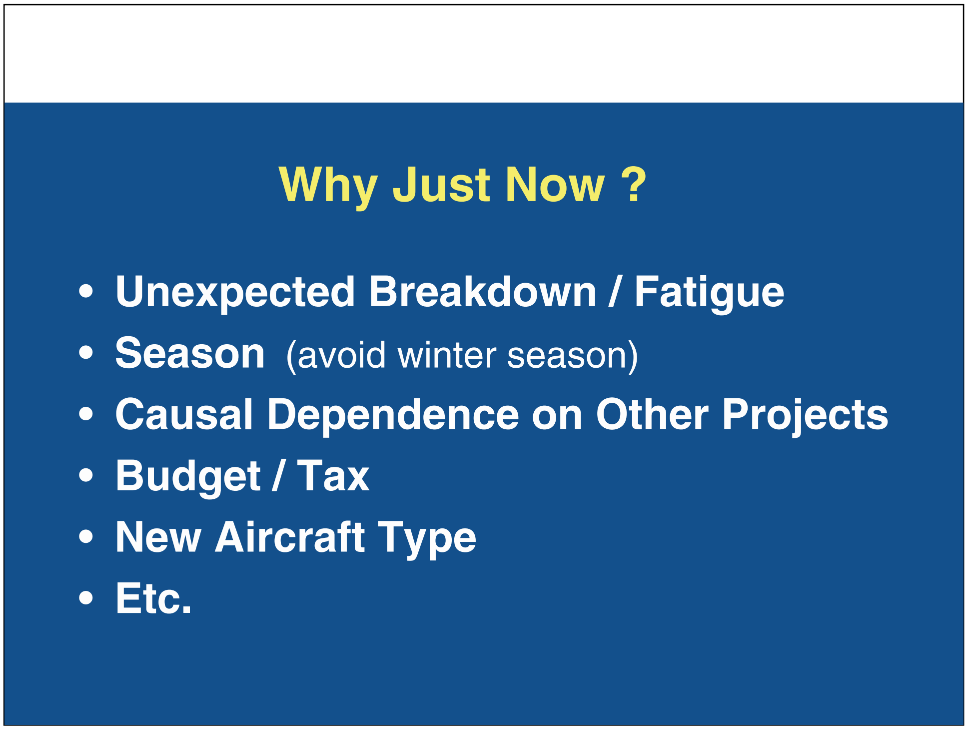
- Change of allocation of the pier positions in order to cope with the reduced capacity of the movement areas
- Relocation of aircraft centerline and road marking
- Publishing of NOTAMs indicating the new situation
- Airport internal publications
- Change of pushback procedures
- Training of staff and contractors



- Use of parking stand 39 as alternative routing
- Disabling of misleading centerline markings and centerline lights
- Road markings to guide workers to and from the construction area
- A traffic light is required to separate workers from aircraft movements
- Protection of workers from blast

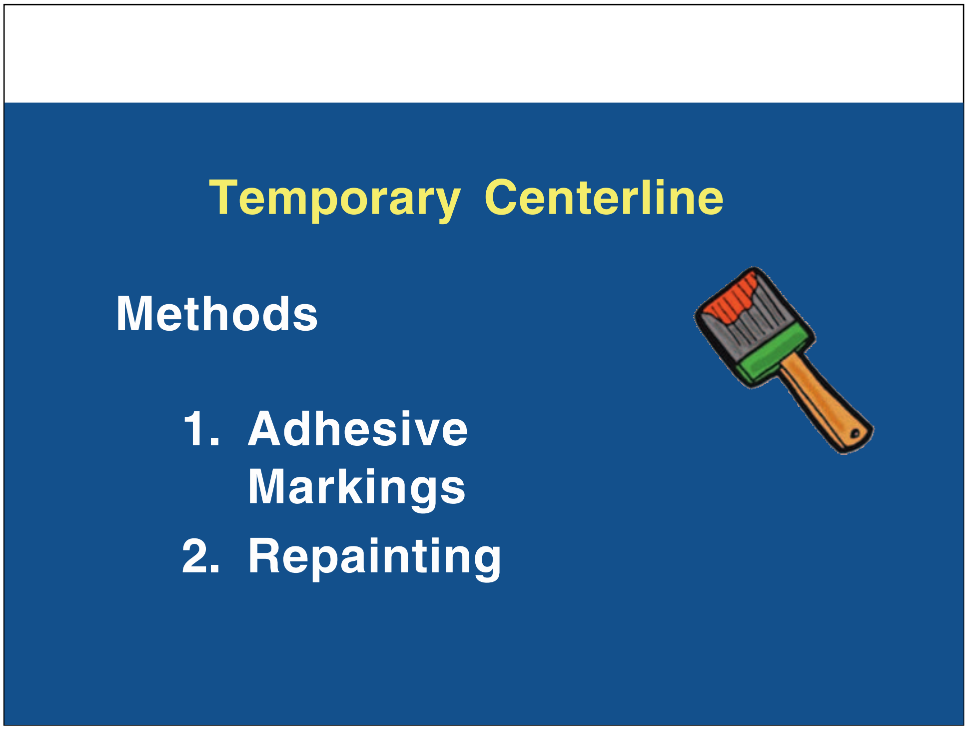


In addition to the construction activities on the site, further duties are required.



There is always the question, “Why just now?”

The construction schedule is determined by numerous factors, as shown above.



To relocate the original centerline, it is necessary to make the painting invisible and to paint a new line.

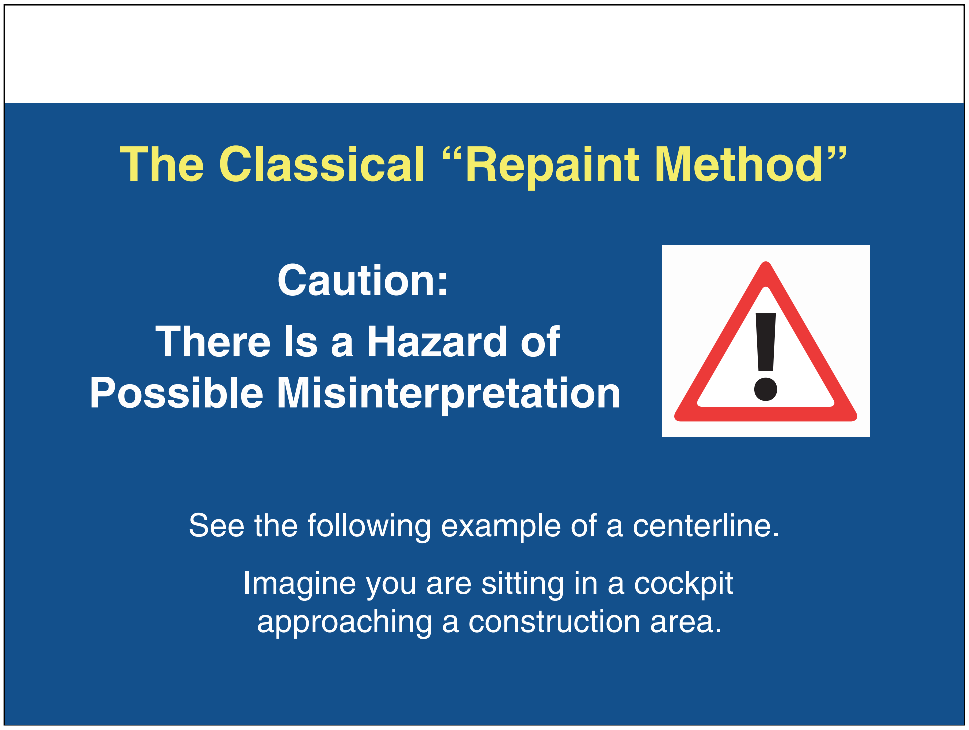
The temporary line must be removed again when construction is finished.

There is never a perfect solution for the problem of temporary markings.

Colored strips are fixed onto the surface.

These adhesive strips are made of special material and therefore are very conspicuous under critical conditions (e.g., night, rain).

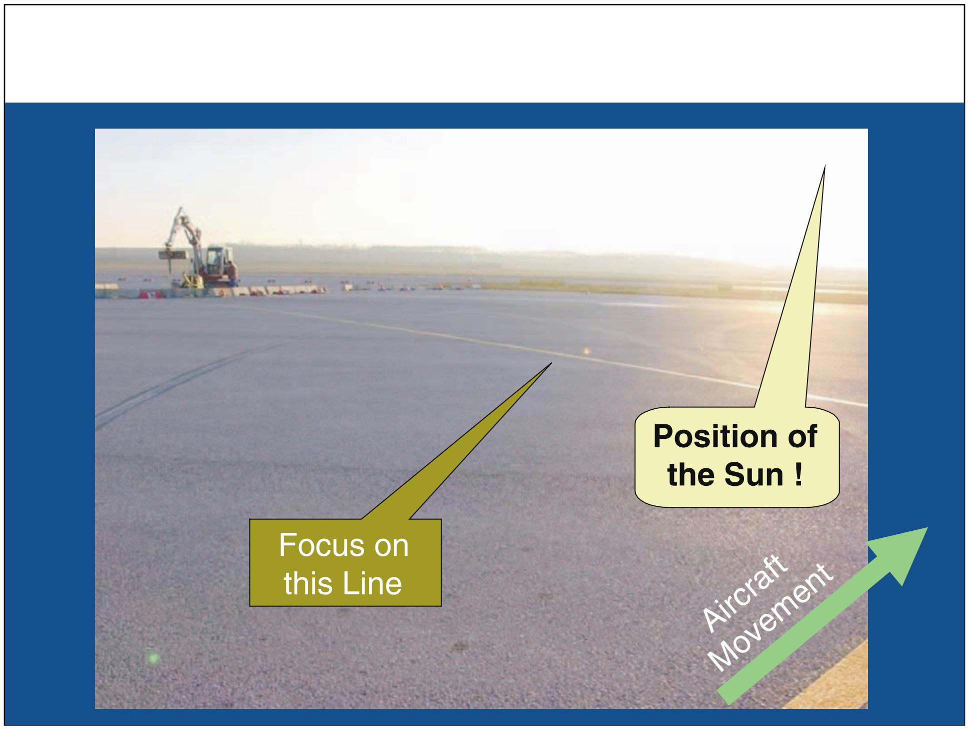
Unfortunately, these strips are quickly damaged by wheels of vehicles like tow trucks.



Surface markings appear different with change of light and surface conditions.

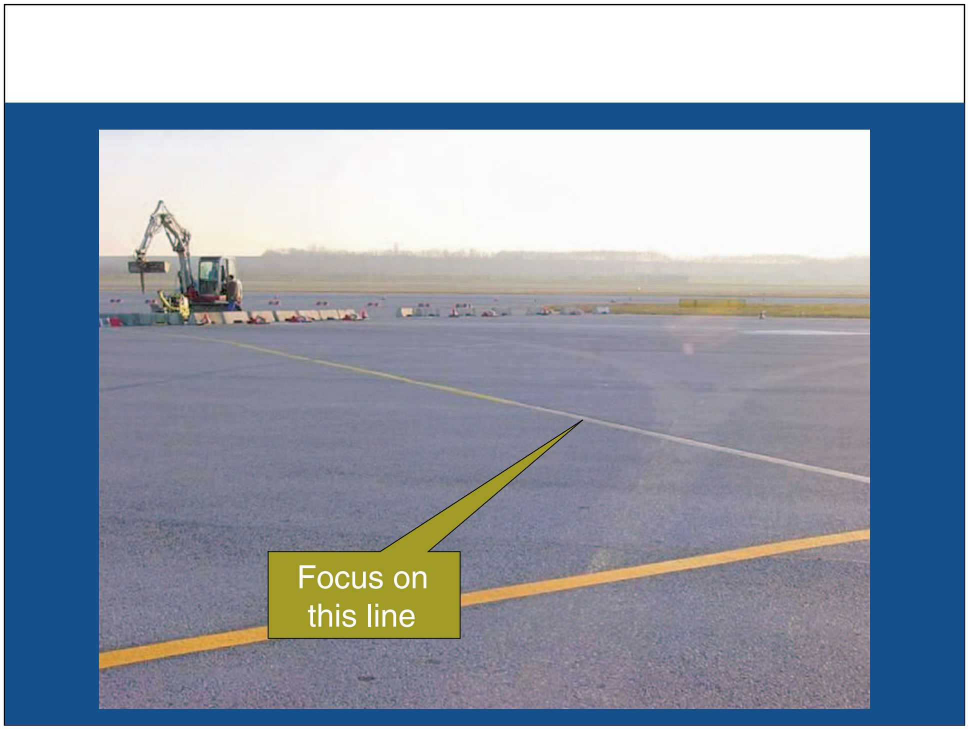
The color of the painting is invisible against the sun.

It will even be worse in the case of wet surface or during nighttime.

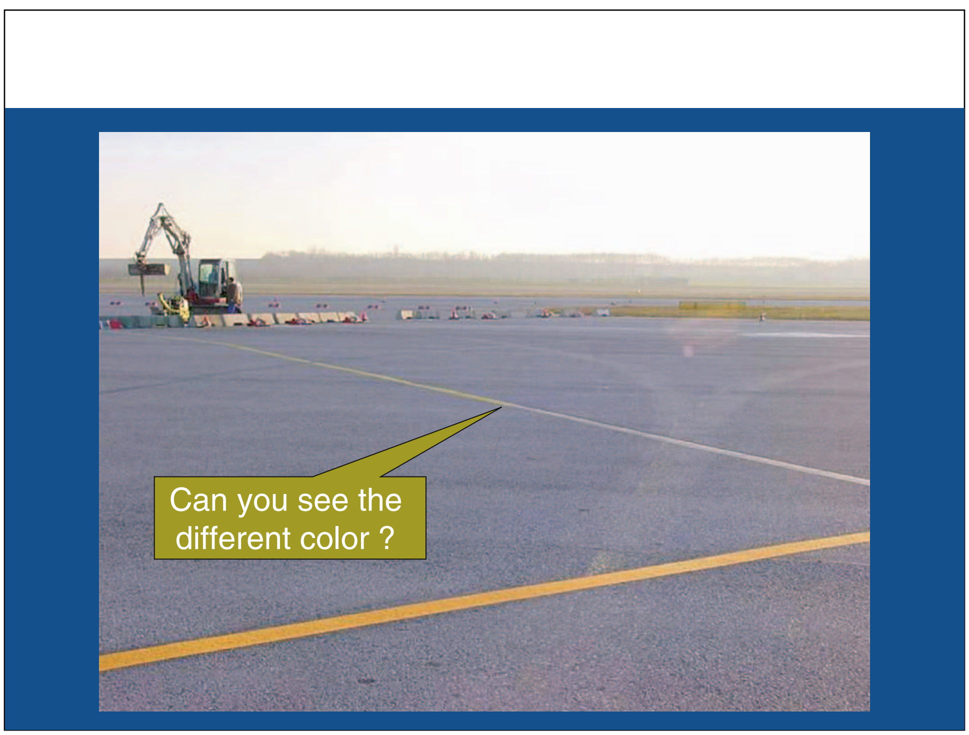


The yellow line indicated is painted black.

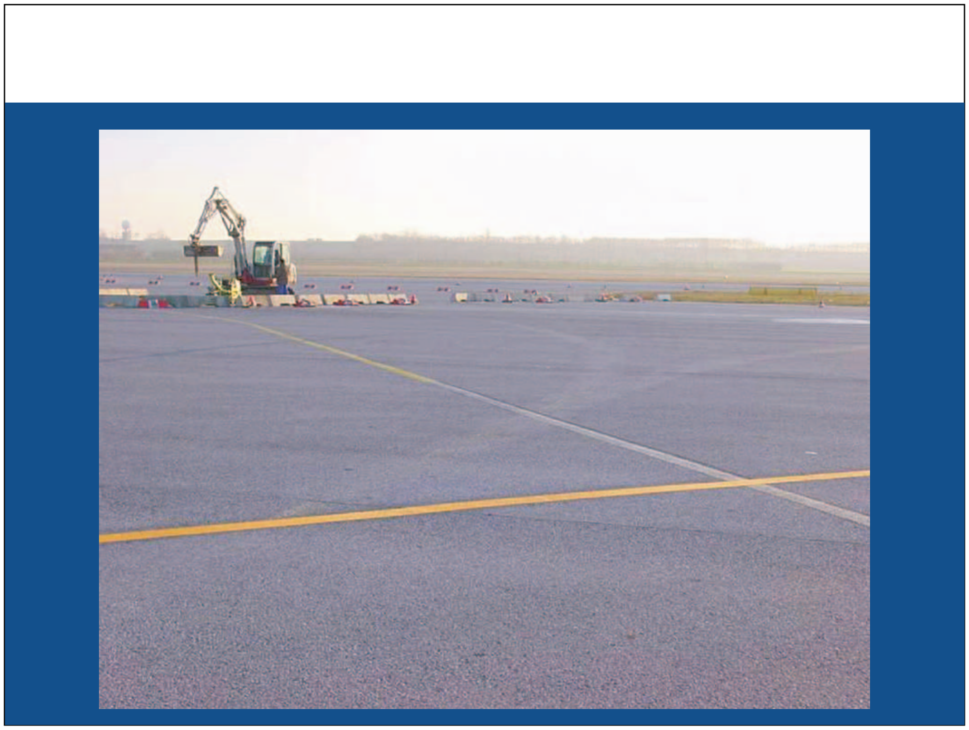
It is not visible from this position.



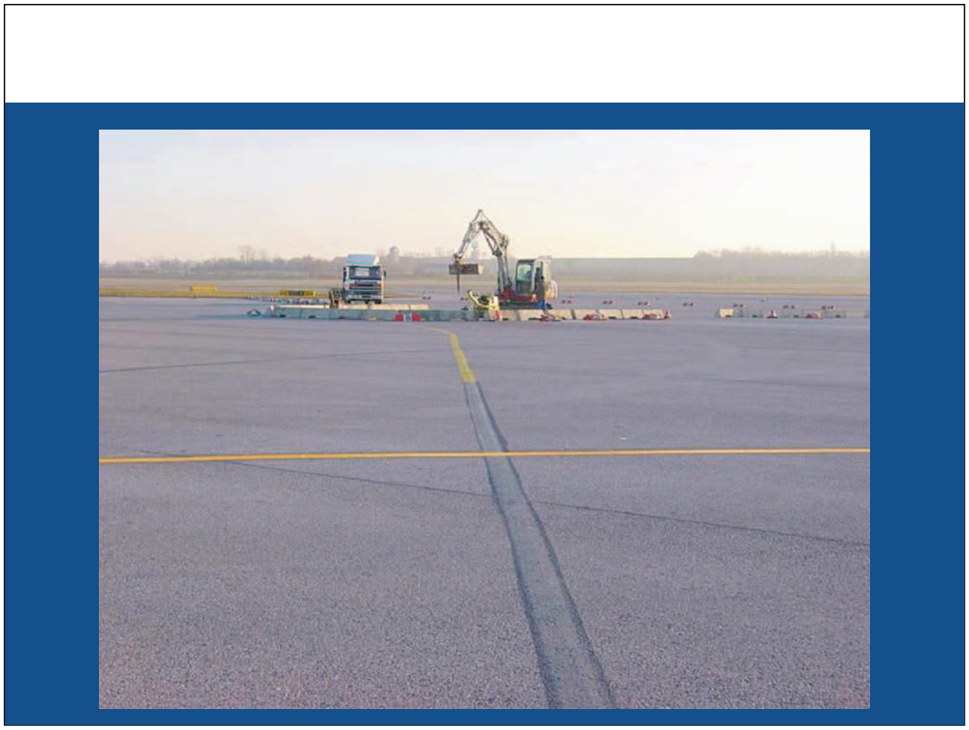
Getting closer.



The arrow indicates the change to the different color.



Now it becomes visible.



Now it can be seen:

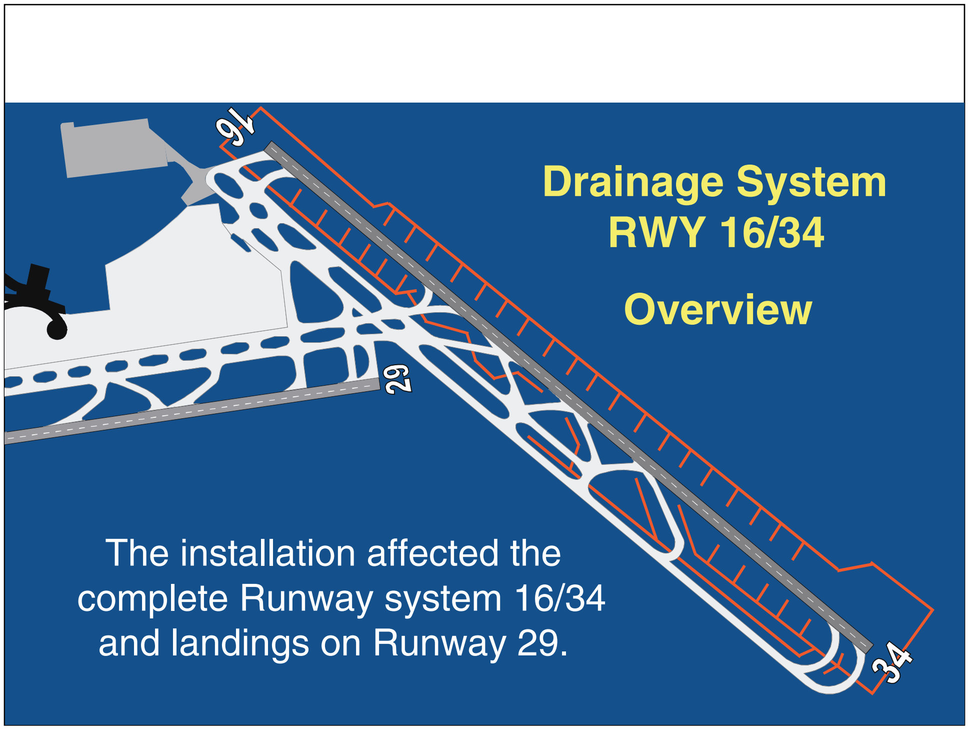
There is actually no yellow line in the lower part of the picture.

Procedure for removal of temporary markings:

Originally this was a centerline marking which was removed by using high pressure water.

This also causes erasure of the top layer of the pavement, creating a deepening, resulting in formation of water.

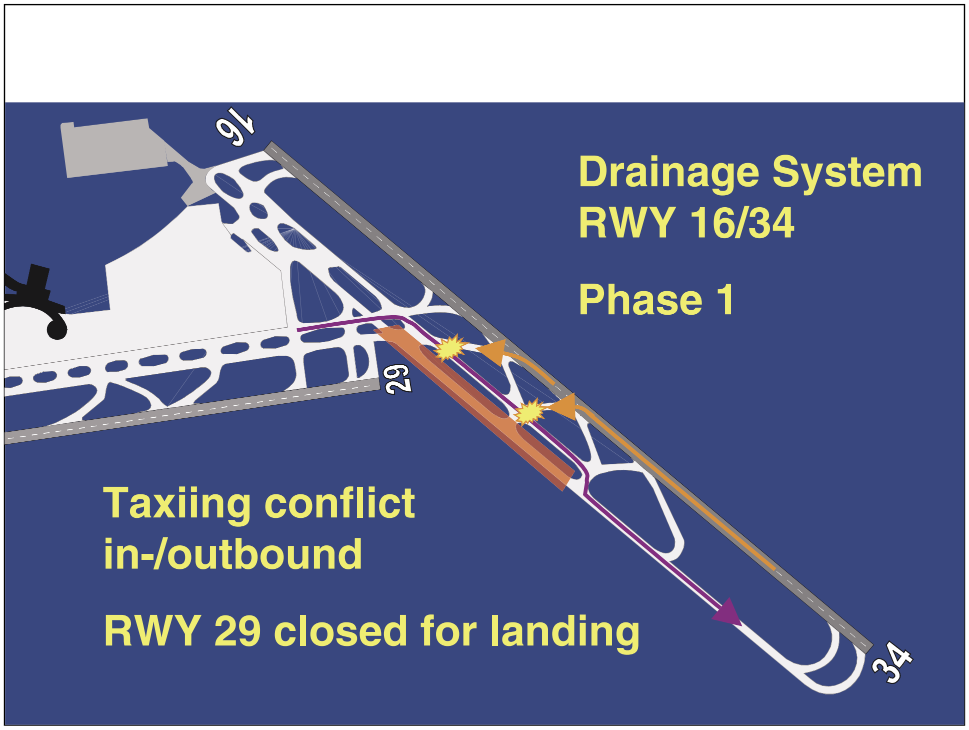

Example 2
Drainage System



Overview of the drainage system which was installed one year ago.

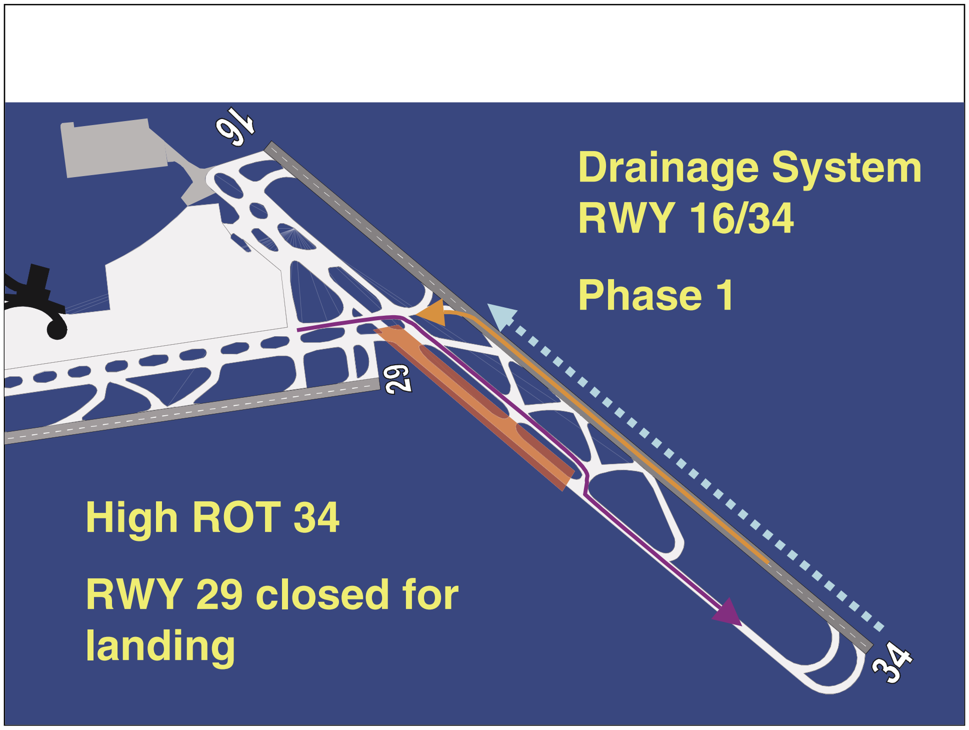
This became necessary due to environmental reasons.

This construction affected all taxiways of Runway 16/34 and also landings on Runway 29 during some construction phases.



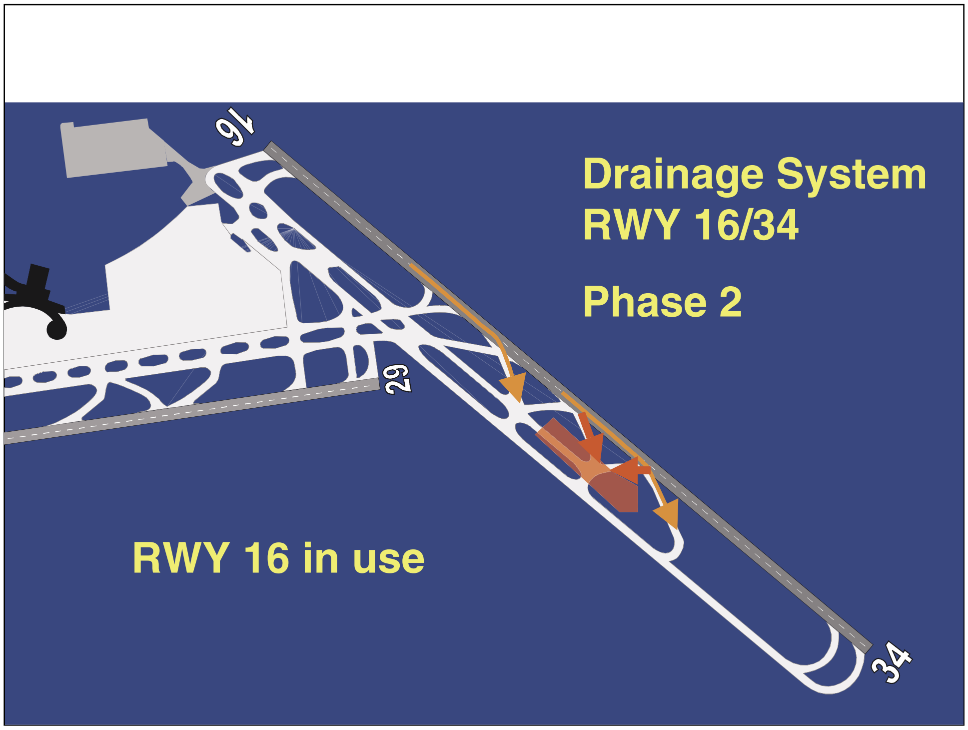
Due to the obstacles in the approach path, Runway 29 was closed for landings.

Aircraft leaving Runway 34 after landing were in conflict with aircraft taxiing to Runway 34 for takeoff.



Long taxiing on Runway 34 is required to avoid conflicts with aircraft taxiing to Runway 34.

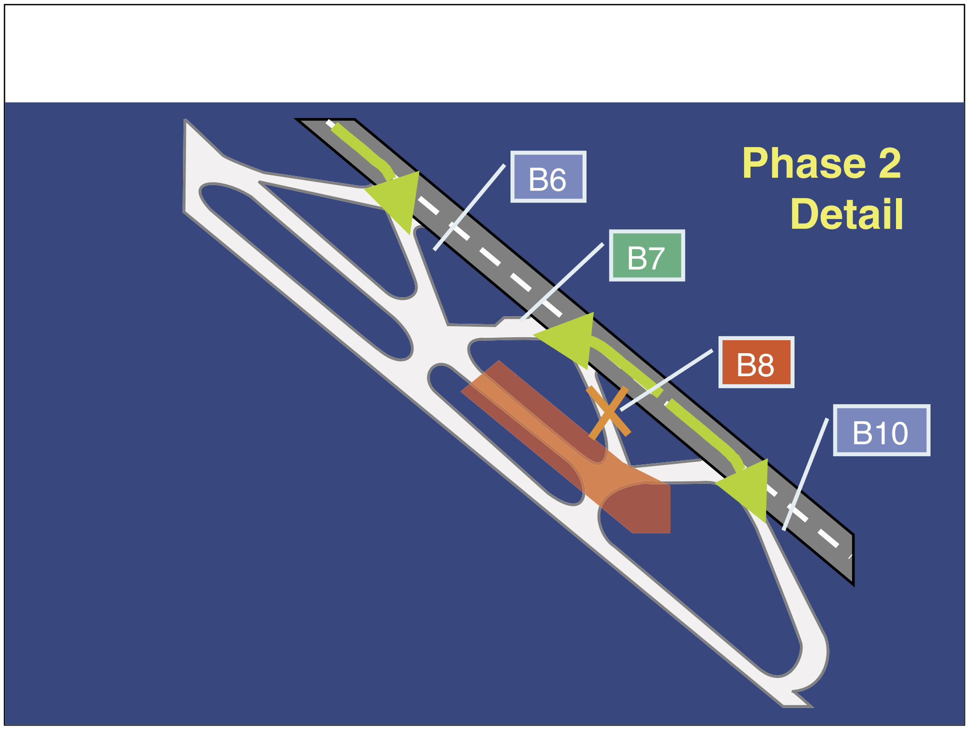
This results in a longer runway occupancy time, causing a decrease of capacity.



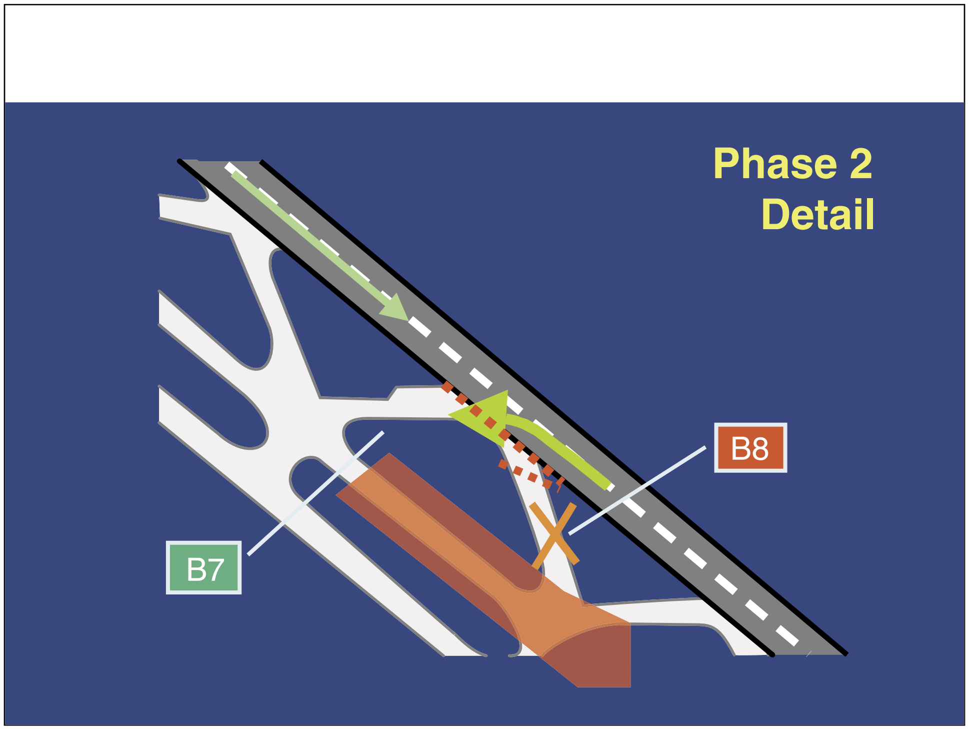
This construction phase had no major impact on capacity.

Just one rapid exit taxiway in each direction could not be used.

The problem was the fencing of the closed taxiways.



Because Taxiway B7 was used for landings on Runway 34, the physical barrier for the closed Taxiway B8 was not visible for pilots landing on Runway 16.



It was not possible to erect a physical barrier along the runway edge due to the use of Taxiway B7.

Therefore the closure of B8 was not visible for pilots landing on Runway 16.

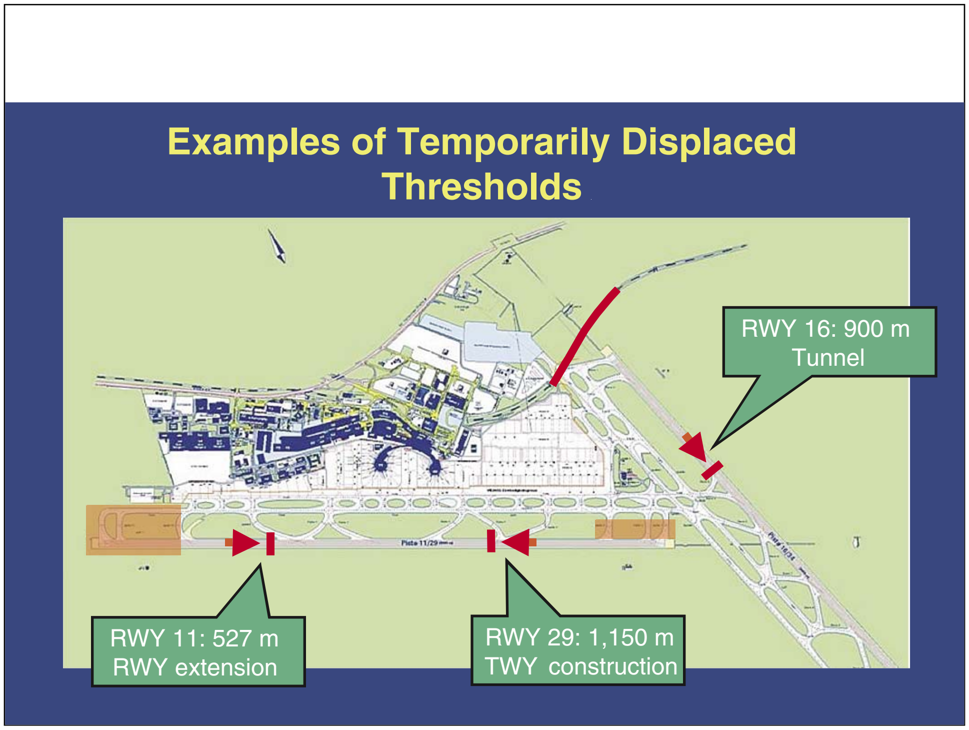
B767 ran into closed TWY B8

A Boeing 767 left Runway 16 via a closed Taxiway B8.

60-meter skid marks were visible, indicating heavy braking.

The closed taxiway was published by NOTAM and ATIS.

This is the displaced threshold on Runway 16 in 2004.



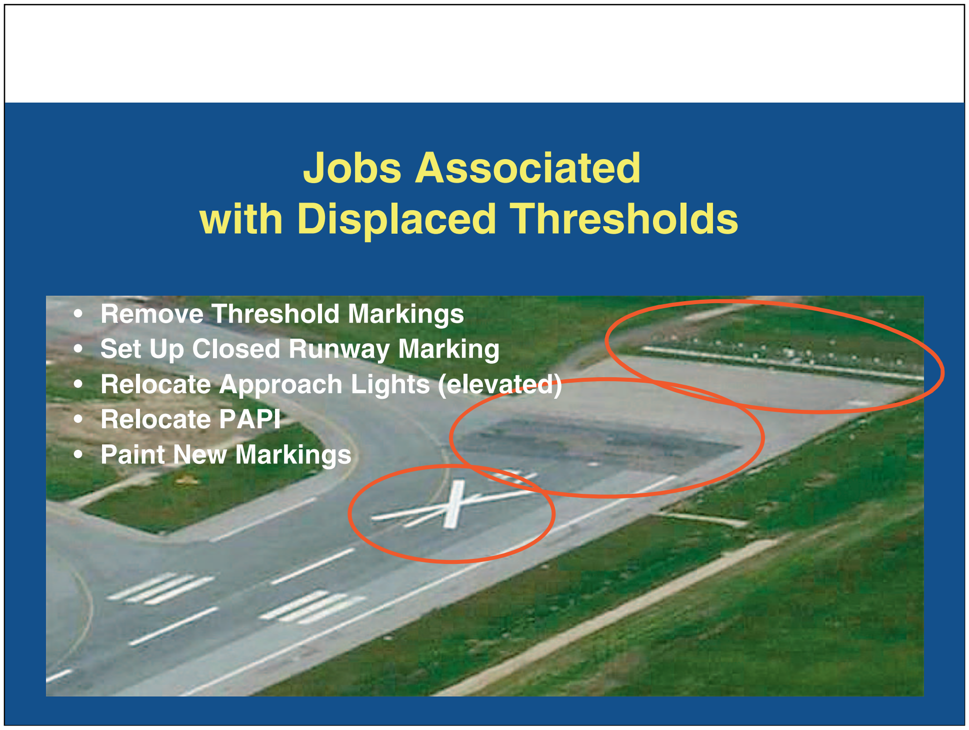
Temporarily displaced thresholds are required to maintain restricted operation on the remaining part of the runway.

Recent situations:

1997: Displaced threshold 11 – 527 m due to extension of Runway 11/29 500 m to the west.

2001: Displaced threshold 29 – 1150 m due to construction and repair of Taxiways A1, A2 and A3

2004: Displaced threshold 16 – 900 m due to construction of a railway tunnel



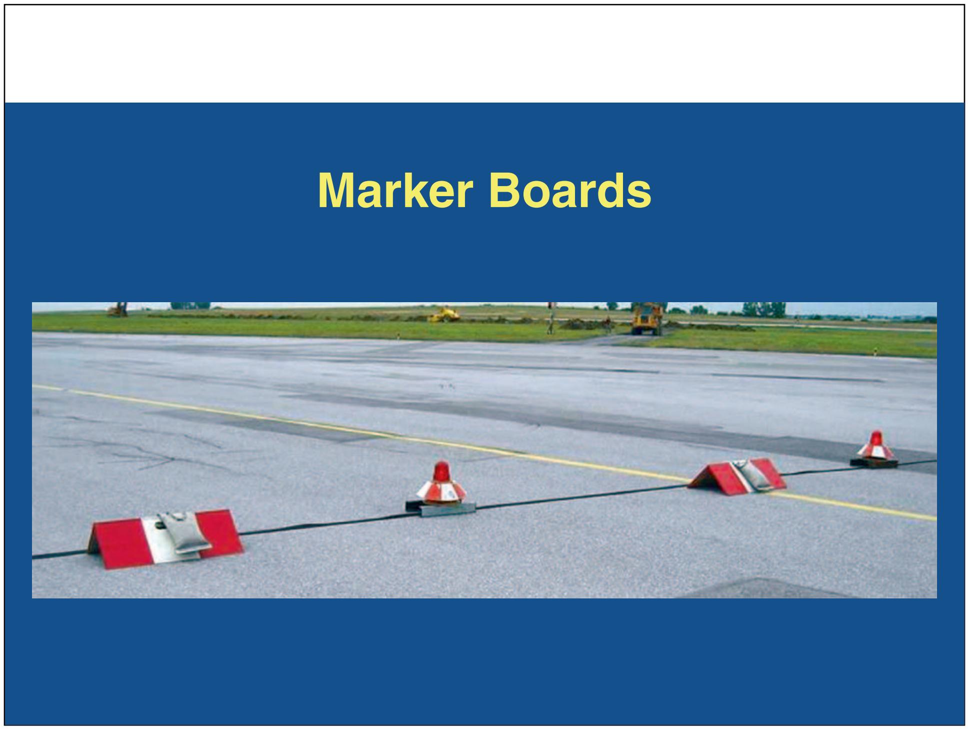
These are only some of the items which are necessary when relocating the threshold.

Reflecting balls will be sprinkled on top of the new markings to increase conspicuity.

Closed Runway Marking

Wooden closed runway markings are of 36 m length.

They indicate a runway (part) which is closed for operation.

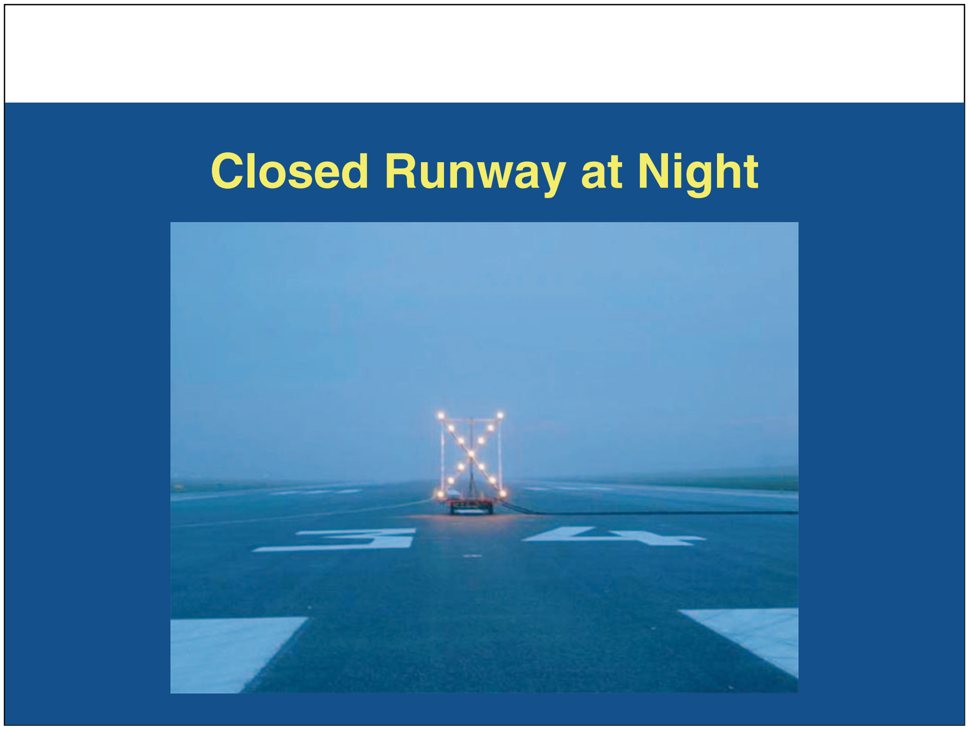


Unserviceability marker board in accordance with ICAO Annex 14 (item 7.4.7) is being used.

Colors are either red/white or orange/white with vertical stripes.

Unserviceability lights consisting of a red fixed light are used for nighttime marking (ICAO Annex 14, item 7.4.4).

Such lights can be either supplied with power by cables or battery-powered.

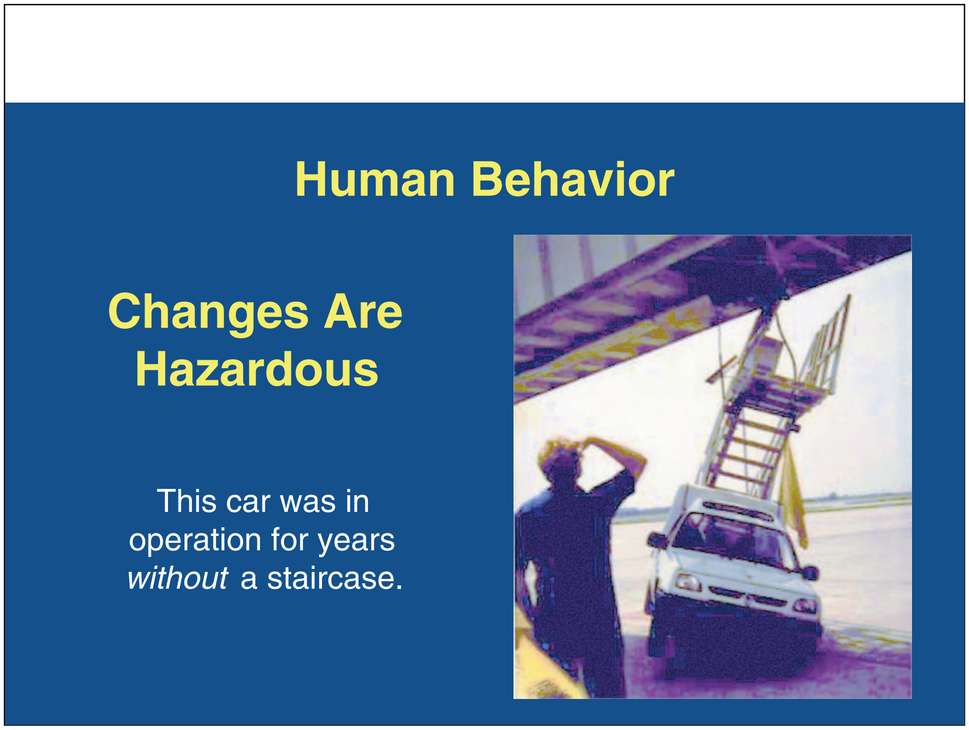


Illuminated closed-runway marking used at Vienna Airport for nighttime and low-visibility conditions.

Taxiway sign indicating that the relevant area is closed for operation.

The left photo shows the method of covering the full sign.

At Vienna Airport the signs are crossed out and therefore they can still be seen by the pilots for orientation purposes.



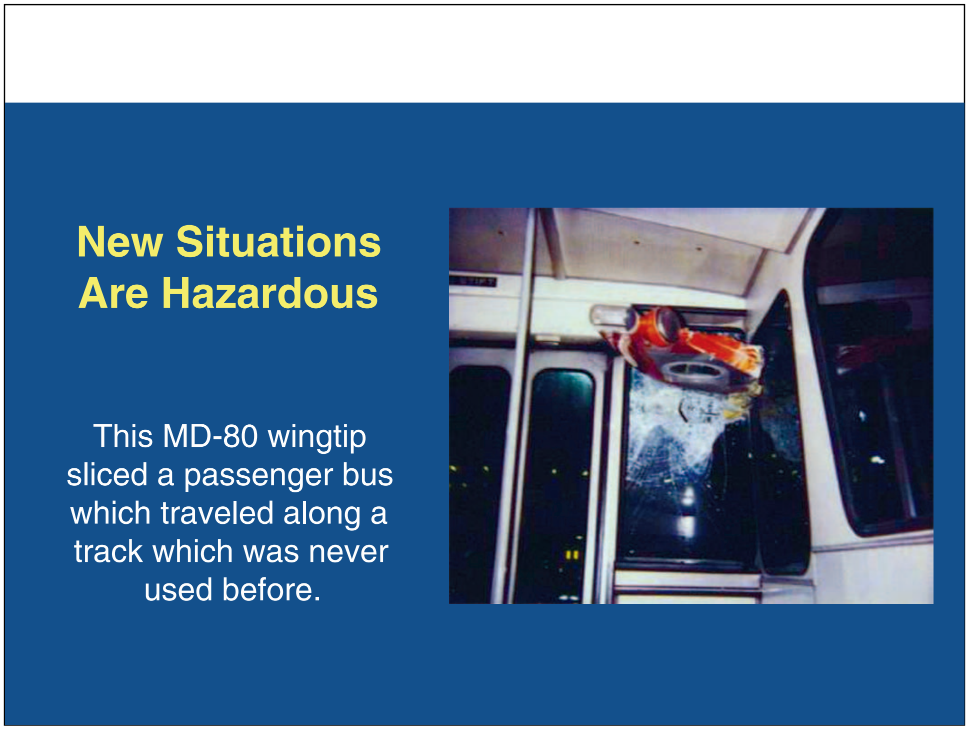
Human behavior is a big issue.

Any change of conditions is critical.

This applies for ground staff as well as for flight crews.

Two examples we had at Vienna Airport.

1. This is an aircraft maintenance car which received a staircase. Several accidents happened with different objects (e.g. passenger loading bridges, aircraft wings etc.).



2. New situations in combination with unfavorable conditions are hazardous (e.g., nighttime, back light, new staff, etc.).

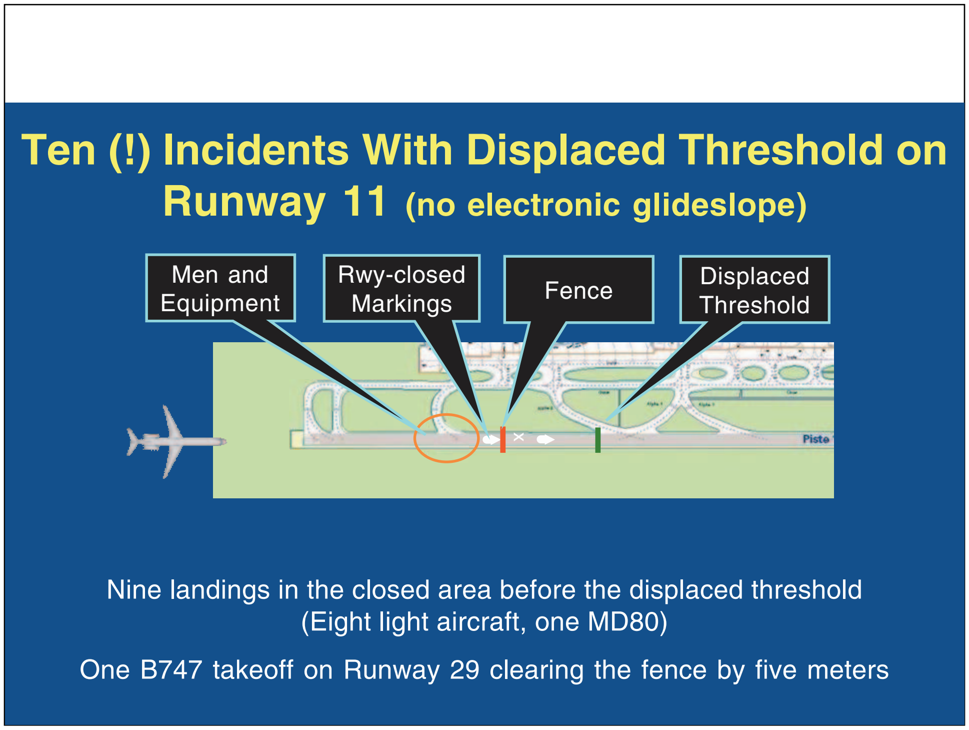
Bus transportation was required at the pier due to a breakdown of a passenger boarding bridge.

The bus driver — driving against back light —– followed a track which was never used before.

If the runway is not equipped with an electronic glideslope, there is a considerable chance that an aircraft will land well before the elevated displaced threshold lights.

A pilot will have a picture in mind (rubber deposit, runway layout, etc.) which will attract him to the original touchdown zone.

Even if the original threshold is not illuminated and not marked, you will have a tendency to go below the PAPI if the threshold is displaced.



Displaced THR Incidents:

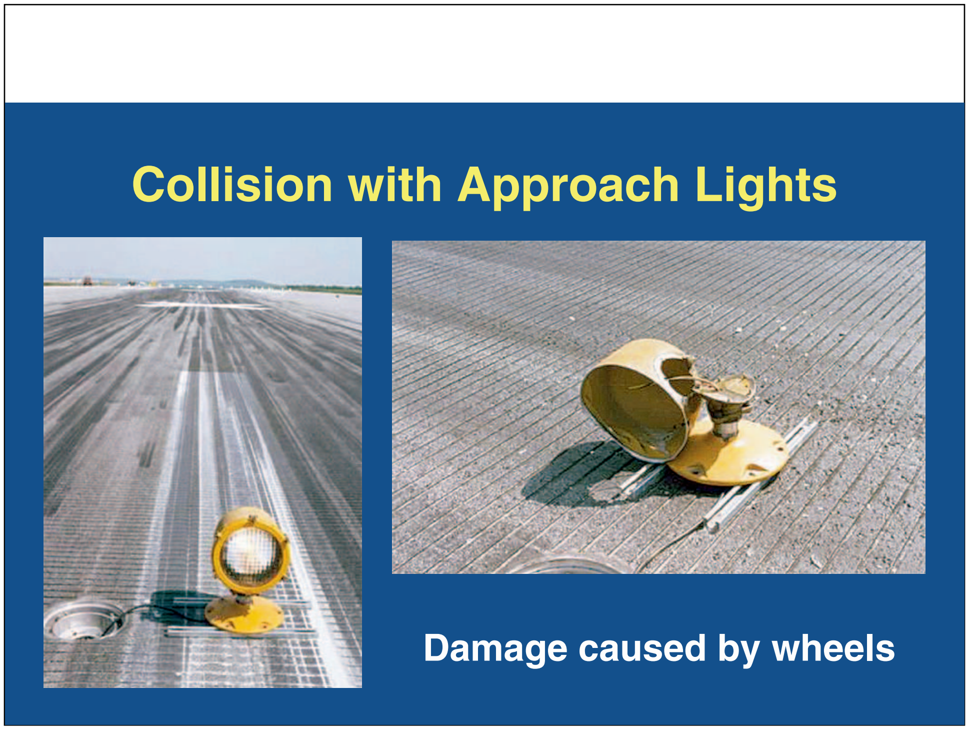
Ten incidents occurred within 12 weeks. All of them happened during daylight.

An instrument approach procedure (LOC-DME) was published.

One MD 80 landed well in front of the displaced threshold but could lift off again to avoid a collision with the elevated lights of the displaced threshold.

Construction areas are one of the main reasons for accidents during ground operations.

Quite often pilots are assuming normal conditions at the airport and are not aware of the restrictions.



A Piper PA28 landed well in front of the displaced threshold on Runway 11 and destroyed the temporarily installed elevated threshold lights.

Damage to Aircraft

This aircraft collided with the elevated approach lights because of the landing well in front of its displaced threshold.

To Be Safe

- Don’t assume that the airport will still be in the same condition as yesterday
- Check NOTAMs
- Check ATIS
- Keep your eyes open

Aviation is a fast growing business which requires continuous adaptation, extension and construction work to cope with the capacity demand.

Do not assume that the airport will still be in the same condition as yesterday.

Always be alert to possible changes and restrictions and check all available sources.

♦♦♦♦

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Serge Dassault
Chairman and CEO,
Dassault Aviation

R. Lamar Durrett
Past President and CEO,
Air Canada

Jeffrey Erickson
President and CEO,
Atlas Air

Fernando Flores
Past President,
Mexicana Airlines

Louis Gallois
Past Chairman and CEO,
Aerospatiale

Dr. Hannes D. Goetz
Past Chairman,
Swissair

Gerry Greenwald
Past Chairman,
United Airlines

Sigurdur Helgason
President and CEO,
Icelandair

Barron Hilton
Chairman,
Hilton Hotels Corp.

Clay Jones
Chairman, President and CEO,
Rockwell Collins

Herbert D. Kelleher
Past Chairman,
Southwest Airlines

Karl J. Krapek
Past President,
Pratt & Whitney

Joseph Leonard
Chairman and CEO,
AirTran Airways

Lord Marshall of Knightsbridge
Former Chairman,
British Airways

H.H. Sheikh Ahmed bin Saeed Al Maktoum
Chairman, Emirates

Wolfgang Mayrhuber
Chairman and CEO,
Deutsche Lufthansa

James McCrea
Past Managing Director,
Air New Zealand

James McNerney
Past President and CEO,
GE Aircraft Engines

Russell W. Meyer Jr.
Past Chairman and CEO,
Cessna Aircraft Co.

Robert A. Milton
President and CEO,
Air Canada

David R. Mueller
Chairman and CEO,
Comair

Leo F. Mullin
Past Chairman and CEO,
Delta Air Lines

Jean Pierson
Past Managing Director, Airbus

Fernando A.C. Souza Pinto
President and CEO,
TAP Portugal

Sir Ralph Robins
Past Chairman,
Rolls-Royce

Jürgen E. Schrempp
Chairman and CEO,
DaimlerChrysler

Gert Schyborger
Past President,
Saab Aircraft AB

Eugeny Shaposhnikov
Aviation Advisor to Russian President

Frederick W. Smith
Chairman, President and CEO,
FedEx Corp.

Jean-Cyril Spinetta
Chairman and CEO, Air France

Jan Stenberg
Past President and CEO,
Scandinavian Airlines System

Terry Stinson
Past Chairman,
Bell Helicopter Textron

James Strong
Past Managing Director,
Qantas Airways

Moritz Suter
Past Chairman of the Board,
Crossair

A.L. Ueltschi
Past Chairman and President,
FlightSafety International

Leo van Wijk
President and CEO,
KLM Royal Dutch Airlines

Theodore Vassilakis
Chairman and CEO, Aegean Airlines

Dipl. Ing. Jürgen Weber
Past Chairman and CEO,
Lufthansa German Airlines

Arthur Wegner
Past Chairman and CEO,
Raytheon Aircraft Co.

Stephen M. Wolf
Past Chairman, US Airways

Capt. Yang Yuanyuan
Minister, General Administration of
Civil Aviation of China

Flight Safety Foundation

Members*

Benefactor

Airbus
BAE Systems (Operations)
Boeing Commercial Airplanes
GE Aircraft Engines
Gulfstream Aerospace
Honeywell
SNECMA

Patron

Continental Airlines
Delta Air Lines
Northwest Airlines
Pratt & Whitney
Rockwell Collins
U.S. Federal Aviation Administration
United Airlines

Contributor

Altria Corporate Services
British Airways
Saudi Aramco
VARIG Brazilian Airlines

Subscriber

Air Canada
Air Line Pilots Association, International
All Nippon Airways
AT&T
Bank of America
BEA France
Bell Helicopter Textron
bmi
Bombardier FlexJet
Britannia Airways (U.K.)
China Airlines
Citigroup Corporate Aviation
Embraer
Evergreen International Airlines
ExxonMobil Corp.
FlightWorks
Global Aerospace
IBM Flight Operations
Japan Airlines
Kingfisher Airlines
Limited Brands
Lufthansa German Airlines
National Air Transportation Association
National Jet Systems Group
Pratt & Whitney Canada
Procter & Gamble
Rolls-Royce North America
Sonair
Swiss International Air Lines
U.K. Civil Aviation Authority
US Airways
UTFlight
Xerox Corp.

A

Abbott Laboratories
Access Air
Accident Investigation Board–Norway
ACI Pacific
ACM Aviation
Addison Jet Management dba Imaginaire
Adria Airways
AEA–Association of European Airlines
Aegean Airlines
Aer Lingus
Aero Asahi Corp.
Aero Asia
Aero California
Aero Zambia
Aeroflot–Russian Airlines
Aerolíneas Argentinas
Aeroméxico
Aeromexpress
Aeropostal Alas de Venezuela
Aerosweet Airlines
Aerovitro S.A. de C.V.
AFLAC
AfriJet Airlines
Afriqiyah Airways
Agenzia Nazionale per la Sicurezza del Volo
Agro Industrial Management
AIG Aviation
Air Algérie
Air Astana
Air Atlanta Icelandic
Air Austral
Air Baltic
Air Berlin
Air Bosna
Air Botswana
Air Caledonie
Air Canada
Air Canada Pilots Association
Air China International Corp.
Air Contractors
Air Corps Library
Air Europa
Air Force Academy, Education and Training Center for Aviation Safety (Taiwan)
Air France
Air Gabon

*As of September 2005

Air Gemini
Air Iceland
Air India
Air Jamaica
Air Jamaica Express
Air Japan
Air Koryo
The Air League–United Kingdom
Air Line Pilots Association, International
Air Line Pilots Association–Singapore
Air Luxor
Air Macau
Air Madagascar
Air Malawi
Air Malta
Air Marshall Islands
Air Mauritius
Air Moldova
Air Namibia
Air Nelson
Air Net
Air New Zealand
Air Nippon Co.
Air Niugini
Air Nostrum
Air One
Air Pacific
Air Routing International
Air Sénégal International
Air Seychelles
Air Star Helicopters
Air Support A/S
Air Tahiti
Air Tahiti Nui
Air Tanzania Co.
Air Traffic Navigation Services
Air Transat
Air Transport Association of America
Air Transport Association of Canada
Air Transport International
Air Vanuatu
Air Wisconsin Airlines Corp.
Air Zimbabwe
AirAsia
Airbus
Airbus North America Customer Services
Airbus North America Holdings
Airfast Indonesia, PT
AirFlite
Airkenya Aviation
Airline Professional Association Teamsters Local 1224
AirNet Systems
Airport Engineering and Services
Airports Council International
Airservices Australia
AirTran Airways
Alaska Airlines
Albanian Airlines
Alberta Government, Air Transportation Service
Alberto-Culver USA
Alcoa
Alertness Solutions
Alitalia
All Nippon Airways
Allied Pilots Association
Aloha Airlines
Alpi Eagles
Alticor
Altria Corporate Services
AMC Airlines
Amerada Hess Corp.
American Airlines
American Association of Airport Executives
American Eagle Airlines
American Electric Power Aviation
American Express Co.
American Jet International
Amgen
Amiri Flight–Abu Dhabi
AMSAFE Aviation
Amsterdam Airport Schiphol
Anadarko Petroleum Corp.
Angola Airlines (TAAG)
Anheuser-Busch Cos.
ANPAC (Associazione Nazionale Piloti Aviazione Commerciale)
Antonov Design Bureau
Aon Corp.
APCO Worldwide
Apex Aviation Corp.
Archer Daniels Midland Co.
Ariana Afghan Airlines
Arkia Israel Airlines
Armavia
Armenian International Airways
Armstrong World Industries
Malcolm “Mac” Armstrong
Capt. Angel Arroyo
Ashland
Asiana Airlines
ASPA de México
Associaçao dos Pilotos Portugueses de Linha Aerea
Association of Air Transport Engineering & Research
Association of Asia Pacific Airlines
Astar Air Cargo
AT&T
ATA Airlines
Athens International Airport
Atlantic Southeast Airlines
Atlas Air
Augsburg Airways
Austral
Australia Civil Aviation Safety Authority

Australian Defence Directorate of Flying Safety

Australian Federation of Air Pilots

Australian Transport Safety Bureau

Austrian Airlines

Avaya Aviation

Avensa

Aventis Pharmaceuticals

Aviacsa Airlines

Avianca Airlines

Aviateca

Aviation Global Services

Aviation Mobility

Aviation Personnel International

Aviation Safety Alliance

Aviation Safety Council

Aviation Safety Foundation Australia

Avicos Insurance Co.

Avionica

AvJet Corp.

Avolar

Azerbaijan Airlines

B

B&C Aviation

BAE Systems (Operations)

Capt. Bart Bakker

Ball Corp.

Bangkok Airways

Bank of America

Bank of Stockton

Barcinova y Gestion

Barnes & Noble Bookstores

Baron Aviation Services

Basin Electric Power Cooperative

Battelle Memorial Institute

Michael Baum

Baxter Healthcare Corp.

BEA France

Capt. Sheila Beahm

Bechtel Corp.

Belavia-Belarusian Airlines

Bell Helicopter Textron

BellSouth Corporate Aviation

Bellview Airlines

Robert O. Besco, Ph.D.

BHP Billiton

Biman Bangladesh Airlines

Binter Canarias, S.A. Unipersonal

Blue Cross Blue Shield of Tennessee

Blue Hawaiian Helicopters

Blue Panorama Airlines

Blue1

BMED

bmi

Boeing Commercial Airplanes

Bombardier

Bombardier Aerospace Business Aircraft

Bombardier Aerospace Corp.

Bombardier Club Challenger

Bombardier FlexJet

Bombardier Skyjet

Bowling Green State University

BP America

Jeffrey J. Brausch

Bristol-Myers Squibb Co.

Britannia Airways (Sweden)

Britannia Airways (U.K.)

British Airways

British European

Brunei Department of Civil Aviation

Brunswick Corp.

Budapest Airport

Business & Commercial Aviation

BWIA West Indies Airways

C

C&S Wholesale Grocers

C.A.L. Cargo Airlines

CAE SimuFlite

Calspan Corp.

Cameroon Airlines

Campbell Helicopters

Campbell Sales Co.–Flight Operations

Canadian Business Aviation Association

Cape Clear

Cape Verde Islands Airports & ATC Authority

Cargill

CargoJet Airways

Cargolux Airlines International

Caribbean Sun Airlines

Cat Aviation

Caterpillar

Cathay Pacific Airways

Cayman Airways

Cayman Islands Civil Aviation Authority

CCI Pilot Services II

CEFA Aviation

CENIPA–Brazil

Center of Aviation Safety and Technology, General Administration of Civil Aviation of China

Central Joint Aviation Authorities

Cessna Aircraft Co.

Champion Air

Chantilly Air

CHC Europe

ChevronTexaco Corp.

China Airlines

China Cargo Airlines

China Eastern

China Northern Airlines

China Northwest Airlines

China Southern Airlines

China Yunnan Airlines

Cigna Corp.

Cimber Air

Cingular Wireless

Citigroup Corporate Aviation
Cityjet
CityLine Simulator & Training
Civil Aviation Authority of Singapore
Coca-Cola Bottling Co. Consolidated
The Coca-Cola Co.
Colegio de Pilotos Aviadores de México
Colleen Corp.
Colombia Civil Aeronautical Authority
Comair
Commercial Airways
Compagnie Aérienne Corse Mediterranée
ConocoPhillips Global Aviation Services
Contact Air Flugdienst & Co.
Continental Airlines
Continental Micronesia
COPA
Corporate Angel Network
Corporate Aviation Service
Corporate Aviation Systems
Corporate Flight Alternatives
Corporate Flight International
Corse Air International
Costco Wholesale
Cox Enterprises
Cranfield University
Crescent Heights Flight Operations
Croatia Airlines
Crown Equipment Corp.
Cubana
Cummins
Cyprus Airways
Czech Airlines

D

DaimlerChrysler
DaimlerChrysler Aviation
Dassault Aviation
Dassault Falcon Jet
Deere & Co.
Defence Aviation Safety Centre–U.K.
Katia DeFrancq
Delta Air Lines
Denmark Aircraft Accident Investigation Board
Denmark Civil Aviation Administration
Department of Homeland Security, Immigration & Customs Enforcement
Anthony Destefano
Deutsche BA
Deutsche Lufthansa
Deutsches Zentrum für Luft-und Raumfahrt
DHL Air
DHL International
Dillard’s
Dominion Resources
The Dow Chemical Co.
Dow Corning Corp.
Dragonair
Drug Enforcement Administration–Aviation Division
Capt. Thomas A. Duke
Duncan Aviation
Dunell Aviation International
DuPont
Dutch Airline Pilots Association

E

Earth Star
East African Safari Air
Eastern Airways
Eastman Chemical Co.
Eastman Kodak Co.
Eaton Corp.
Eclipse Aviation Corp.
EG&G Technical Services
EgyptAir
EgyptAir Cargo
Egyptian Aviation Services
Egyptian Meteorological Authority
El Al Israel Airlines
Eli Lilly & Co.
Elite Air
Embassy of France (DGAC)–U.S.
Embraer
Embry-Riddle Aeronautical University–Arizona
Embry-Riddle Aeronautical University–Florida
Emerson Electric Co.
Emirates
Empire Airlines
ENAC–Ente Nazionale Aviazione Civile
Enron Corp.
Entergy Services
Epps Air Service
Era Helicopters
Estafeta Carga Aérea
Estonian Air
Estonian Civil Aviation Administration
Ethiopian Airlines
Etihad Airways
Eurocontrol
Eurocopter Deutschland
Eurocypria Airlines
European Air Express
European Air Transport
European Regions Airline Association
Eurowings Luftverkehrs
EVA Airways Corp.
EVASWorldwide
Evergreen International Airlines
Execaire
Express One International
ExxonMobil Corp.

F

Falcon Air
Far Eastern Air Transport Corp.
FedEx Express
FHC Flight Services
Finland Accident Investigation Board
Finland Civil Aviation Administration
Finnair
First Air
First Choice Airways
FirstFlight
FL Aviation
Flight Attendants' Association of Australia
Flight Data Services
Flight Safety Foundation International (Moscow)
Flight Safety Foundation–South Eastern Europe
Flight Safety Foundation–Taiwan
FlightSafety International
FlightWorks
Florida Power & Light Co.
Florida Wings
Flowers Industries
Flying Lion
Fokker Services
Ford Motor Co.
Forward Air International Airlines
Fraport AG–Frankfurt Airport Services Worldwide
Frontier Airline Pilots Association
Frontier Airlines
Fuqua Flight

G

Gael Quality International
Galaxy Aerospace Corp.
Gannett Co.
Garuda Indonesia
Gaylord Entertainment Co.
GB Airways
GE Aircraft Engines
Geico Corp.
General Communication
General Electric Co.
General Mills
General Motors Corp.
George Washington Aviation Institute
Ghana Airways
Ghana Civil Aviation Authority
Global Aerospace
Global Aviation
Global Crossing Aviation
Orin Godsey
Gol Linhas Aereas
Michael R.O. Grüninger
GTC Management Services
Guild of Air Pilots and Air Navigators
Gulf Air
Gulfstream Aerospace
Guyana Civil Aviation Authority

H

H. Beau Altman Corp.
H.J. Heinz Co.
Hahn Air Lines
Hainan Airlines Co.
Haiti Office National de L'Aviation Civile
Halliburton Co.
Jerry B. Hannifin
Hapag-Lloyd Flug
Harley-Davidson Transportation Co.
Harris Corp.
Helicopter Association International
Helios Airways
Hellas Jet
The Hellenic Air Accident Investigation and Aviation Safety Board
Hellenic Airline Pilots Association
Hellenic Civil Aviation Authority
Hemus Air
Heritage Flight
Hewlett-Packard Aviation
Hillenbrand Industries
Hilton Hotels Corp.
The Home Depot
Honeywell
Honeywell Engines, Systems & Services
Hong Kong Civil Aviation Department
HTS Worldwide
Huntsman

I

Iberia Air Lines of Spain
Iberworld Airlines
IBM Flight Operations
Icebird Airlines
Icelandair
Icelandic Civil Aviation Administration
IFSC–Italian Flight Safety Committee
IHS Aviation Information
Imperial Oil
IMS Health
Indal Technologies
Independent Pilots Association
Indian Airlines
Institut Français de Sécurité Aérienne (DCI/AIRCO)
Institute of Transportation, MOTC
Instituto Nacional de Aviação Civil
Inter Air
Inter American University of Puerto Rico, School of Aeronautics
Inter Assessoria Aeronáutica
Inter Hannover Scandinavian Branch
Interlaken Capital Aviation Services

International Air Transport Association

International Airports Projects–Saudi Arabia

International Federation of Air Line Pilots' Associations

International Federation of Air Traffic Controllers Associations

International Federation of Airworthiness

International Paper

International Society of Air Safety Investigators

Iran Air

Iran Aseman Airlines

Iraqi Airways

Ishikawajima-Harima Heavy Industries

Israel Aircraft Industries

Israir Airline and Tourism

J

Jackson Air Charter

JAL Express

JALways Co.

Japan Aircraft Pilots Association

Japan Airlines

Japan Asia Airways

Japan TransOcean Air

JCPenney Co.

Jeld-Wen

Jeppesen

Jeppesen Dataplan

Jet Airways

Jet Aviation

JetBlue Airways Corp.

jetCenters

Jetflite

Jetport

Johnson & Johnson

Johnson Controls

Dr. Daniel Johnson

Margaret A. Johnson

JP Morgan Chase

JSC Siberia Airlines

JSC Volga–Dnepr Airlines

K

K-Services

KaiserAir

KB Home

Kellogg Co.

Kenya Airways

KeyCorp Aviation Co.

Kingfisher Airlines

Kish Airlines

Kitty Hawk Aircargo

KLM CityHopper

KLM Royal Dutch Airlines

Knollwood Aviation

Koch Business Holdings

Korea Air Force Risk Management Agency

Korean Air

The Kroger Co.

Kuwait Airways

Kuwait Director General of Civil Aviation

L

La Réunion Aérienne

LACSA–Líneas Aéreas Costarricenses

Ladeco Airlines

Ladeco Cargo

Laker Airways (Bahamas)

Lan Ecuador

Lan Perú

LanChile

Lands' End

Lauda Air–Austria

Lauda Air–Italy

Level 3 Communications

Liñhas Aéreas de Moçambique

Liberty Mutual Group

Libyan Arab Airlines

Limited Brands

Líneas Aéreas Azteca

Líneas Aéreas Privadas Argentinas (LAPA)

Lithuanian Airlines

Litton Aero Products

Lloyd Aéreo Boliviano

LMA (Lloyd's Market Association)

Lockheed Martin Corporate Aircraft

Capt. W.R. "Bill" Long

LOT Polish Airlines

LTU

Lucent Technologies

Luftfahrt-Bundesamt

Lufthansa Cargo

Lufthansa CityLine

Lufthansa German Airlines

Luxair

Luxembourg Air Rescue

M

M&M Aviation Consultancy

M&N Aviation

Macedonian Airlines–Macedonia

Maersk Air (Denmark)

Magic Carpet Aviation

Mahan Airlines Services Co.

Maintenance and Ramp Safety Society

Malaysia Airlines

Malév Hungarian Airlines

Malmö Aviation

Wayne Malone

Malta Department of Civil Aviation

Mandarin Airlines

Marathon Oil Co.

Marsh

Martinair Holland

MasAir Cargo Airline

Masco Corp. Flight Department

John McCarthy

McCormick & Company

McDonald’s Corp.

Capt. Michael W. McKendry

McWane

MedAire

Merck & Co.

Meridiana

Metropolitan Aviation Group

Mexicana Airlines

MIAT Mongolian Airlines

MidAmerica Jet

Middle East Airlines

Midwest Airlines

Millennium Aviation

Milliken & Co.

Mission Safety International

MK Airlines

Monsanto Aircraft Operations

Montenegro Airlines

Motorola

Luis Moyano

Mutual of Omaha

MyTravel Airways

N

National Academy of Public Administration

National Aeronautic Association of the U.S.A.

National Aerospace Laboratory (NLR)–Netherlands

National Air Services–Aircraft Management

National Air Traffic Controllers Association

National Air Transportation Association

National Association of Flight Instructors

National Business Aviation Association

National Jet Systems Group

Nationwide Airlines

Nationwide Insurance Enterprise

Nav Canada

NAVIAIR

Netherlands Civil Aviation Authority

NetJets

NetJets International

NetJets Middle East

New World Jet

New Zealand Civil Aviation Authority

New Zealand House of Representatives

New Zealand Transport Accident Investigation Commission

Nigeria Airways

Nippon Cargo Airlines

Nissan Corporate Aviation

Norsk Helikopter AS

Northern Jet Management

Northwest Airlines

Norway Civil Aviation Authority

Norwegian Air Shuttle

Novartis Aviation

O

Steve O’Toole

Offshore Logistics

Olympic Airlines

Oman Air

Omni Air International

Omniflight Helicopters

Ellen Overton

Owens Corning

Owens-Illinois General

P

Pakistan International Airline

Palestinian Airlines

Pantanal Airlines

PAR Travel Tech

Parker Drilling Co.

Parker Hannifin Corp.

Partner Reinsurance Co.

Penske Jet

PepsiCo

Petroleum Air Services

Petroleum Helicopters Inc.

Pfizer

Pfizer AirShuttle

Phelps Dodge Corp.

Philippine Airlines

Phillips Aviation Alaska

Phuket Airlines

The Pictsweet Co.

Pillsbury Winthrop Shaw Pittman

Pilot Corp.

PLUNA Líneas Aéreas Uruguayas

Poland Civil Aviation Office

Polynesian Airlines

Portugália Airlines

PPG Industries

Pratt & Whitney

Pratt & Whitney Canada

Premier Air Charter Corp.

Priester Aviation

Robert L. Prince

Principal Financial Group

Printpack

PrivatAir–Switzerland

PrivatAir–U.S.

Procter & Gamble

Professional Aviation Maintenance Association

Progress Energy

Pulkovo Aviation Enterprise

Purdue University Aviation Technology Department

Q

Qantas Airways

Qatar Airways

QST Safe Skies

Quest Diagnostics

Quizno's Aviation Department

R

Rabbit-Air

Rainin Air

Capt. Costas Rapis

Raytheon Aircraft Co.

Raytheon Co.

Régional

Regional Airline Association

Regional Express

Republic of Singapore Air Force

Richmor Aviation

RJ Reynolds Tobacco Co.

Robertson Aviation

Capt. David Robertson

Rockwell Automation

Rockwell Collins

Rolls-Royce

Rolls-Royce North America

Rosemore Aviation

Royal Air Maroc

Royal Brunei Airlines

Royal Flight of Oman

Royal Jet

Royal Jordanian Airlines

Royal Norwegian Air Force

Royal Swazi

Royal Tongan Airlines

Rwandair Express

Ryanair

S

S.C. Johnson

SA Airlink

Saab Aircraft AB

Sabena Flight Academy

Safair

Safe Flight Instrument Corp.

Safegate Airport Systems

Safety Operating Systems

SAGEM

Sahara Airlines

Samara Airlines

SAS Braathens

SAS Flight Academy

SATA

Saudi Arabian Airlines

Saudi Aramco

SBC Communications

SCANA Corporation

Scandinavian Airlines System

Schering-Plough Corp.

Ronald Schleede

The Schwan Food Co.

Rusty Scioscia

Sears Holdings

SENER Ingenieria y Sistemas

Shamrock Aviation

Shandong Airlines

Shanghai Airlines

Shaw Communications

Shaw Managed Services

John Sheehan

Shell Canada

Shell Oil Co.

Shenzhen Airlines

Sierra Flight Operations

Sierra National Airlines

Signature Flight Support

SilkAir

Simat, Helliesen & Eichner

Simrik Air

Sindicato Nacional de Pessoal de Voo da Aviacao Civil–Portugal

Sindicato Nacional dos Aeronautas

Singapore Airlines

Singapore Airlines Cargo

Sirocco Aerospace International

Skycare Aviation Safety Society (India)

Skymark Airlines

SkyRiver Management

Skyservice Airlines

Skyways

SN Brussels Airlines

SNECMA

Solavia

Solomon Airlines

Sonair

Sony Aviation

South African Airways

South African Civil Aviation Authority

Southern California Safety Institute–Australia

Southern California Safety Institute–Kirtland

Southern Methodist University

Southern Winds

Southwest Airlines

Spanair

SPIDELA

Sprint Corp.

SriLankan Airlines

St. Paul Travelers

Statens Haverikommission

Steelcase North America

STK Skandinavisk Tilsynskontor

Sudan Airways

Sudan Civil Aviation Authority

Sundt Air, Norway

Sunoco

SunTrust Banks

SuperValu Aviation
Surinam Airways
Swedish Civil Aviation Authority
Swiss Air Ambulance
Swiss International Air Lines
Swiss Pool for Aviation Insurance
Swiss Reinsurance Company–FSBG
SwissAlpa–AEROPERS
Syndicat National des Pilotes de Ligne
Syrianair

T

TACA International Airlines
TAG Aviation USA
Taiwan Civil Aeronautics Administration, China
TAM Brazilian Airlines
TAME
Tampa Airlines
TAP Portugal
Target Corp.
TAROM Romanian Air Transport
Tassili Airlines
TeamLease
Teledyne Controls
Telstra Childflight
Tennessee Valley Authority
Texas Instruments
Thai Airways International
Thales Aerospace
The Boeing Co.
3M Aviation
Thomas Cook Airlines
The Timken Co.
TNT Airways
Torong Guyana Co.
Trans Mediterranean Airways
Trans-Exec Air Service
Transaero Airlines
TransAsia Airways
Transavia Airlines
Transbrasil Linhas Aereas
Transport Canada
Transportation Safety Board of Canada
Transportes Aéreos del Mercosur
Transportes Aeromar
Michael Alexander Tsantoulis
Tudor Investment Corp.
Tunisair
Turkish Airlines
Turkmenistan Airlines

U

U.K. Civil Aviation Authority
U.S. Air Force Headquarters–SE
U.S. Coast Guard–Washington, D.C.
U.S. Federal Aviation Administration
U.S. National Aeronautics and Space Administration Langley Research Center
U.S. National Transportation Safety Board
U.S. Naval Research Laboratory–Monterey
U.S. Naval Safety Center
Ukraine International Airways
Unione Piloti
United Airlines
The United Co.
United States Aviation Underwriters
United States Steel Corp.
UnitedGlobalCom
Universal Jet Aviation
Universal Underwriters Group
Universal Weather & Aviation
University Aviation Association
University of North Dakota
University of Southern California
UnumProvident Aviation Department
UPS Airlines
US Airways
USAA
USAirports Air Charters
USDA Forest Service
UTFlight

V

Valero Energy Corp.
The VanAllen Group
Vancouver International Airport Authority
VARIG Brazilian Airlines
Varig Logistica
VASP Brazilian Airlines
Vereinigung Cockpit–German Air Line Pilots' Association
Veridian
Verizon
Victory Aviation
Vienna International Airport
Vietnam Airlines
Virgin Atlantic
Virgin Blue Airlines
Virtual Flight Surgeons
Vladivostok Air JSC
Volare Airlines
David Vornholt

W

W.W. Grainger
Wachovia Corp.
Waitt Media
Washington Airports Task Force
WCF Aircraft Corp.
WestJet Airlines
Whirlpool Corp.
Widerøe's Flyveselskap
Willis Global Aviation
World Airways
World Class Charters
Wyvern Aviation Consulting

X

Xerox Corp.
Xiamen Airlines
Xpress Air

Y

Terry Yaddaw
Yemenia, Yemen Airways
Yugoslav Airlines (JAT)
Yum! Brands Aviation

Z

Zambian Airways
Zeno Air
Zimex Aviation
Zoom Airlines