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HISTORICAL MONOGRAPH NO. 4

DEVELOPMENT OF THE CORPORAL:
THE EMBRYO OF THE ARMY MISSILE PROGRAM

APRIL 1961

VOLUME II OF II

SUPPORTING DATA

DOCUMENTS 1 THRU 31

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APPENDIX

APPENDIX (Continued)

INITIATION OF THE JET PROPULSION LABORATORY

EXTRACTED FROM

THE HISTORY OF THE ORDCIT PROJECT

UP TO 30 JUNE 1946

arranged by

Richard C. Miles, Compiler

Research and Development Service Sub-Office (Rocket)
California Institute of Technology
Pasadena, California

[redacted]

INITIATION OF THE JET PROPULSION LABORATORY

"The GALCIT Rocket Research Project was initiated in 1936 more or less privately by the following research group: Frank J. Malina, Hsue-Shen Tsien, A.M.O. Smith, John W. Parsons, Edward S. Forman, and Weld Arnold. The early phases of the research were financed by a fund of $1,000 from Mr. Weld Arnold.

"The first activities of the research project as described by F. J. Malina[1] included a broad study of the various aspects of rocket propulsion.* A study of the flight performance of a sounding rocket propelled by constant thrust was made by F. J. Malina and A.M.O. Smith[2], a continuation of the study was made by H. S. Tsien and F. J. Malina,[3] who considered propulsion by successive impulses. The performance of a rocket plane was analyzed by William Bollay.[4]

"The problem of rocket motor design, based on the theory of perfect gases, was discussed by F. J. Malina.[5] J. W. Parsons and E. S. Forman[6] made an experimental study of the fast-burning powder rocket motor. The practicability of various substances as propellants for jet propulsion was investigated by J. W. Parsons.[7]

"In addition to the papers mentioned above, a number of reports were prepared for manufacturing concerns and government agencies by F. J. Malina, with the assistance of J. W. Parsons and E. S. Forman."[8]

The fundamental research of the GALCIT Rocket Project was conducted for the greater part amongst the delicate precision instruments of the Guggenheim Aeronautical Laboratory and in a test pit located just outside of the Laboratory. At the same time experimentation was being conducted on the Arroyo Seco Valley floor bordering the city limits of Pasadena. The Institute frowned upon the Project's work at Guggenheim mainly because of the proximity of delicate instruments which could easily be damaged by the gaseous propellant experimentation. Objection was also made to the noises which ensued from the test pit located outside. Likewise, the Arroyo Seco site was unfavorable, since permanent facilities could not be constructed and the ground used could not be leased. There was also the disconcerting possibility of inundation during heavy rains. Yet, despite the obvious disadvantages of the experimental stations, the work which was carried out produced the papers and reports listed above.

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* References are given at the end of this textual material.

[redacted]

When the preliminary theoretical and experimental work of the first phase was completed, the GALCIT Rocket Research Project was ready for expansion. "In 1938 General H. H. Arnold requested a special committee of the National Academy of Science for Air Corps Research to sponsor a program for the development of rocket units suitable for aircraft superperformance applications."[9] The National Academy of Science contacted the California Institute of Technology and requested that the Institute undertake all experimental work on propellants and jet propulsion. The Institute was quite willing to undertake this work and "on 1 July 1939 the Air Corps Jet Propulsion Research Project, GALCIT Project No. 1 was initiated."[9] Thus sponsored by National Academy of Science Contract W535-ac-15690 dated 26 September 1940, the Jet Propulsion Research Project commenced its operations under the able leadership of Dr. Theodore von Kårmån, chairman.

> "The program set as its objective the investigation of a number of basic problems connected with the development of jet propulsion for application to the superperformance of aircraft. The term superperformance is defined to include: (a) shortening the time and distance for take-off, (b) temporary increase of rate of climb, and (d) temporary increase of level flight speed. It was understood that the study of basic problems was to be carried to the point from which the Materiel Division of the Air Corps could proceed to practical developments.
>
> "The following research program was initiated on 1 July 1939:
>
> "1. Study of the characteristics of the constant pressure jet propulsor using gaseous propellants.
>
> "(a) Variation of the exhaust velocity with the chamber pressure.
>
> "(b) Effect of mixture ratio on the exhaust velocity.
>
> "(c) Study of materials to be used in the construction of the motor unit.
>
> "2. Study of the solid propellant jet propulsor to determine:
>
> "(a) If the burning of a large powder charge can be controlled to such an extent that preignition can be prevented.
>
> "(b) If a device containing such a powder charge can be operated with reasonably safety.
>
> "(c) Thrust weight, characteristics of the solid propellant propulsor.
>
> "3. Study of liquid propellants to determine:
>
> "(a) If liquid oxidizers are available or can be developed to replace liquid oxygen.

"(b) Injection methods for liquid propellants.

"(c) Cooling and insulation of the propulsor."[10]

Thus with the advent of the new program, construction of suitable facilities became necessary. On 13 August 1940, a formal lease for a period of 3 years of a narrow, irregular strip of land with an average width of some 60 feet, approximately 4.239 acres in area, was obtained through the Water Department of Pasadena, California. The site chosen was about 4 miles northwest of Pasadena, California, situated in the Arroyo Seco valley which forms a portion of the westerly city limits of Pasadena. The Air Corps Jet Propulsion Rocket Project was therefore consolidated for the first time in a new area with most of the objectional aspects of the previous research locations eliminated.

Construction of facilities followed quickly upon the formal signing of the lease. By February 1941 the Project possessed five major facilities with many additional buildings on the drafting board. The five buildings which were completed and in full operation at this time were as follows:

(a) A physical rocket problem laboratory which contained a test stand for measuring the various reactions of motors utilizing gaseous propellants and was also equipped for study of heat transfer, nozzle design, and other problems needing solutions in the development of liquid and solid propellant motors up to 1,000-pound thrust.

(b) A rocket propellant motor test stand and facilities connected thereto.

(c) A powder laboratory.

(d) A solid propellant rocket test stand and facilities connected thereto.[11]

The Project operated for nearly 2 years under the National Academy of Sciences, but was concerned with only the fundamental research on the application of rockets and jet propulsion; however, by the spring of 1941 the Air Corps deemed it advisable to negotiate a contract directly with the California Institute of Technology, inasmuch as the Institute had done all of the experimental work contracted to the National Academy of Sciences, and was, therefore, familiar with the work. Then, too, a contract would considerably expedite the administrative work between Wright Field and the contractor by eliminating the national agency, in this case, the National Academy of Sciences. At this time the California Institute considered itself far enough advanced with basic research to undertake practical developments in this field.

On 25 June 1941, a Letter of Intent was filed with the California Institute of Technology, and provided $115,500 to cover cost of research, pending receipt of formal contract. The contract as signed stipulated that the Contractor would furnish and deliver to the Government a report prepared in triplicate covering research in jet propulsion for airplanes. The report and experiments called for under the terms of this contract would include, but would not be restricted to the following:

(a) Flight test on the Ercoupe in cooperation with the Air Corps, Materiel Division.

(b) Development of 150-pound-thrust, single-jet, solid propellant units.

(c) Development of 1000-pound-thrust, single-jet, liquid propellant units.

(d) Design for 1000-pound-thrust, single-jet, liquid propellant prototype and construction of experimental units, possibly in cooperation with the Army Ordnance Department.

(e) Flight test on service-type airplanes conducted on the basis of descussion between the contractor and the Materiel Division, Air Corps, U. S. Army, Wright Field, Dayton, Ohio.

(f) Investigation of methods of quantity production of 1000-pound thrust and larger units.

(g) Motor design studies for items 2 to 4 using the existing gas propellant apparatus.

The impetus of work called for under Contract W535-ac-20260, now known as JPL-1, demanded additional land for expansion of existing facilities. Expansion to the east and south was not possible, for that property sloped down to the water basin, usually under water for short periods during the winter rains. To the north a ridge of high hills prevented any tendency to expand in that direction. To the west, however, property belonging to the Flint Ridge Realty Company was available, and this company was, in turn, approached for a lease. On 1 October 1941, a formal lease was secured from that company of some 3.5 acres.

The following 16 months proved to be a period of extremely rapid growth. With the declaration of war on 8 December 1941, the Project assumed an importance proportionate to the furor of war which swept the country. Additional personnel and facilities were added. By the spring of 1943 the critical shortage of facility space again hampered research. The Flint Ridge Realty Company was for the second time approached for a lease of adjoining land. Inasmuch as the Realty Company was in the process of liquidizing certain holdings, they would not consider a loan but would sell the property desired. The Board of Directors of the California Institute approved the idea of expanding the research project; hence on 27 May 1943 an area approximately 15.82 acres was purchased by the Institute. This purchase included also the land originally leased from the Flint Ridge Realty Company on 1 October 1941.

The next problem confronting the Project in its expanding tendency was the construction of a suitable water tower to the north and on the high ridge running east and west. The possibility of serious fires was a constant and ever increasing hazard with which the low-pressure city water supply could not cope. Small brush fires behind the test pits were on the increase, and a sprinkler system was definitely required. Upon investigation of suitable locations for the contemplated water tower, it was discovered that the only available land was owned by the city of Pasadena and was just to the north of property already leased from the city. Thus, in the renewal lease of city-owned property, negotiated on 20 July 1943, an additional 0.196 acre was acquired which included the water-tower site; thus the total of city-leased land was approximately 4.435 acres.

The Institute, planning further expansion of facilities at the Jet Propulsion Laboratory, made its final land purchase on 1 February 1944 when an additional 45.16 acres were purchased from the Flint Ridge Realty Company, including an easement of 1.36 acres which joined the Laboratory grounds with city-owned Oak Grove Drive. With this last purchase the total acreage of the Laboratory amounted to approximately 65.415 acres, including the 4.435 acres leased from the City of Pasadena.

At this point, it seems advisable to re-emphasize the fact that expansion of JPL with respect to both facilities and land was necessitated entirely by the work being undertaken for the Air Technical Service Command under Contract W535-ac-20260, initiated in 1940 but supplemented many times since then.

"The following list is representative of some of the accomplishments achieved by this project:

"(a) Performed the first take-off in the United States of an aircraft assisted by restricted-burning solid propellant units, on 12 August 1941, at March Field, California."[9]

"(b) Developed the asphalt-potassium perchlorate restricted-burning solid propellant known as GALCIT 61-C, which is the only successful restricted burning propellant in service use (used in the Navy JATO units).

"(c) Developed the first satisfactory theory on the operation of a restricted-burning solid propellant rocket unit.

"(d) Performed the first take-off in the United States of an aircraft assisted by liquid propellant rocket units, on 15 April 1942, at Muroc, California."[9]

"(e) Developed the red fuming nitric acid-aniline liquid propellant rocket unit.

[redacted]

"(f) Designed and tested the first high-performance liquid propellant rocket motor to operate at thermal equilibrium for a period exceeding 30 minutes.

"(g) Designed and tested the first regeneratively cooled monopropellant-type (nitromethane) rocket motor.

"(h) Designed and tested the largest thrust rocket motor so far operated in the United States (20,000-pound thrust)."[9]

The year 1944 marked the greatest advance of JPL in its aggregate undertakings. No fewer than five additional contracts were consummated during that year. The AAF and the Ordnance Department requested the Institute to undertake large-scale JPL research and development projects with contracts totaling approximately $2,500,000. The contracts were to be prepared to cover construction of buildings in the Institute's Arroyo Seco property, complete laboratory test facilities and supplies, and services for a 1-year period.

The Ordnance Department stepped into the field with a contract W-04-200-ORD-455 for research, investigation, and engineering of a long-range rocket missile with launching equipment. This contract became designated as JPL-4. The facilities (installation, purchase of equipment, etc.) for research to be conducted under JPL-4 was covered by separate contract W-04-200-ORD-703, designated as JPL-5. These two contracts constituted the ORDCIT program at the California Institute.

Work on the ORDCIT program, however, was not begun without difficulties. The AAF proposed that facilities and equipment for both ORDCIT and AAF be obtained through the Defense Plant Corporation (DPC) rather than through the Engineers. This came as a surprise to both the Ordnance Department and the Institute, inasmuch as by mid-July the Ordnance Department had already supplied the Institute with an engineering contract for the construction of a large portion of the facilities which would have enabled the Institute to proceed immediately with engineering work preliminary to actual construction. As a result of the stand of the Air Corps, this engineering contract was canceled. Both the Ordnance Department and the Institute agreed to the change of agency, as both were assured that there would be no delay involved.

Negotiations with DPC were commenced at once by all agencies involved. An extract from a letter written by W. R. Stott, assistant comptroller at the California Institute, to the Western Procurement District at 3636 Beverly Boulevard, Los Angeles 54, California, can best describe the confused situation as it existed on 26 August 1944--2 months after the letter order of intent of Contract ORD-455 was furnished the Institute:

"3. It has now been some six weeks since negotiations were started with the Defense Plant Corporation. During this

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period we have been unable to do any work on these facilities because of the legal restrictions imposed upon the Los Angeles office of the Defense Plant Corporation by law; it does not seem to us as though we can complete contractual arrangements with this agency in less than six to eight weeks, if at all.

"4. As you know, they have asked us to lease them the land for a period of twenty-five years, but are only willing to lease it back to us for a period of five years. Such an arrangement is not satisfactory, and, furthermore, the Institute would prefer to deal directly with the Army Air Forces without the necessity of going through a third agency, such as the Defense Plant Corporation. Our research work is being carried on for the Army Air Forces and the Ordnance Department, and it is our belief that it can best be carried on by dealing entirely with these two organizations, either separately or collectively.

"5. There are certain buildings already in existence on this property, which buildings were constructed under Contract No. W535-ac-20260. It is our understanding that these buildings must, of necessity, be transferred to the United States Engineers who would subsequently transfer these to the Defense Plant Corporation. It is then, we believe, proposed the Defense Plant Corporation would lease these same buildings back to the Institute. Inasmuch as the existing facilities valued at approximately $150,000 must be transferred to the United States Engineers, we believe that it is very advisable from our point of view to have the existing facilities and all the new facilities to be constructed handled by the United States Engineers. From what we know of their procedures, we could, within forty-eight hours after receipt of their orders from higher authority, start the final engineering plans for the constructing of these facilities. We, further believe that if it were possible for the Army Air Forces to arrange for the United States Engineers to handle this construction work, the facilities will be made available for research sooner than they would be if we continued on our present course.

"6. As stated previously, the Institute would prefer to have all contractual arrangements directly with the service that is requesting the research work. In this case this would mean contracts with the Army Air Forces and the Ordnance Department. It is our understanding that if the facilities were constructed by the United States Engineers this service would turn these facilities over directly to the Army Air Forces, who in turn could by contract furnish these facilities to us for purposes of research. This type of contractual arrangement is most satisfactory to the Institute.

[redacted]

"7. We, therefore, propose that arrangements be made whereby it would be possible for the United States Engineers to construct the facilities which are so urgently needed by the Army Air Forces and the Ordnance Department. If such an arrangement can be made we would propose to sell to the United States Engineers approximately twenty acres of land presently known as the GALCIT Project in the Arroyo Seco, Pasadena, California, for approximately $7,000; this amount being our actual cost. As far as the price is concerned, we would be willing to accept a fair appraisal by the Ordnance Department of the value of this property. In other words, we do not wish to have the negotiations over the price of the land to, in any way, interfere with the construction of these faciaities, notwithstanding the fact that we have our own funds invested in this property. In the area which we propose to sell there is already located the $150,000 in facilities already constructed by the Army Air Forces..."

The atmosphere was eventually cleared when on 6 September 1944 the AAF and Engineers appointed a Site Board to arrange for a lease of the necessary land for the JPL-Ordnance Project and the job was to go back entirely into the hands of the Engineers. By 19 September the Site Board report was approved by Washington, and the Engineers were ready to begin construction. As a result, on 2 October 1944 the Engineers' letter order W-04-353-Eng-1056 became effective. The project became known as RSC Project 486-A-3 and covered labor, materials, tools, machinery, equipment, and facilities. This enabled the work to go ahead, but the delay had been serious; the 3 months wasted over unconstructive bickering might have been used in profitable experimentation.

In November 1944 the need for additional facilities was encountered. Small experimental structures were necessary which could not be financed out of experimental money, as funds of both JPL-4 and JPL-5 were considered. It was not likely that such structures could be built under Engineers Contract 1046. Colonel Leslie A. Skinner, the Ordnance Department Liaison Officer at the California Institute, suggested on 24 November to the San Francisco Ordnance District that it prepare a new contract of a fairly small amount--$35,000 to $40,000--which would be specifically for experimental construction on approval of local engineers. The net result of this suggestion was the consummation of a miscellaneous construction contract ORDCIT-RAD Project No. 2685 for $75,000, effective 23 March 1945.

One ever present and annoying obstacle confronting the Laboratory since its inception at the Arroyo Seco site has been the status of the small parcel of land leased from the city of Pasadena. Inasmuch as this piece of land was the location of the early Laboratory, many buildings were constructed thereon under Air Corps officers. The initial construction was done by Institute labor, the cost of materials being charged against Air Corps Contract 20260. Also a considerable number of buildings were constructed through purchase orders, again charged against Air

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Corps Contract 20260. Unfortunately, a great number of the buildings were constructed on city property leased to the Institute for a period of 3 years only. Such a situation could not long exist.

It was estimated that the cost of transferring and rebuilding facilities which could not be moved to land belonging to the Institute would amount to between $20,000 and $30,000 and cause delay in operation amounting to at least 6 months. Likewise, the operation of facilities on city-owned land would be handicapped because of shutdown of common facilities. Another factor having direct bearing on the problem was the fact that additional facilities to be constructed would be used in connection with facilities existing on city-owned land, and it was imperative that additional facilities be constructed on contiguous land in order that the research work assigned be carried on successfully.

To remedy the bad situation, the Materiel Center at Wright Field as early as April 1943 requested that a 25-year lease for the land be obtained from the city. Condemnation proceedings had been instituted by the Facilities Division of the Army through the Attorney General's office in Los Angeles, but for some reason the condemnation did not materialize. The city manager of Pasadena, in a letter to the California Institute on 21 April 1943 rejected any offer which involved the city in a 25-year lease "in view of the fact that the city had an obligation to the people who built their homes in the vicinity away from the din and noise of city life--some of the property having been bought from the city." He further added that, if he were to agree to the establishment of a "plant such as the Institute in operating, it would be a violation of his word of honor that when the war ceased the plant would be removed from the city's property" and also that such a plant would be "violating the first principle of proper zoning in residential territory." The only offer on which the Board of City Directors and the city manager would commit themselves was a lease for 3 years, or for the duration plus 1 year thereafter. Finally, on 6 November 1945, the existing lease on the property was terminated. The change of policy by the city became necessary in order to avoid condemnation proceedings threatening in earnest again. In order to place the responsibility for all land with the Government the U. S. Engineers arranged for a new lease with the city of Pasadena for a period of approximately 25 years, thereby relieving the Contractor of such lease responsibility as was presently spelled out in Contract W535-ac-20260, and likewise relieve the Government of rehabilitation liability.

The negotiated lease W-04-193-Eng-5914 JPL was effective on 1 April 1945 and will extend to 30 June 1970. Though the long-term lease was consummated, the fact still remains that Government buildings exist on non-Government property, a situation which knows few precedents.

Another problem of similar nature but not so difficult of solution was acquisition by the Government of remaining land upon which Government buildings had been and were being erected. This land, it will be remembered, was purchased by the Institute and constituted some 60.98

acres, not including the city-leased land. In a letter to the Site Board, AAF Western Procurement District, Los Angeles, California, dated 7 September 1944, the Institute expressed a willingness to lend or sell this property to the Government. The Institute offered to accept a Government appraisal figure, although the total cost of this land to the Institute was approximately $7,000. In any event, whether the Government bought or leased the land, the California Institute was willing to allow AAF immediate access to the property in order to allow construction of much needed facilities to proceed immediately.

With this cooperative attitude, it took a little over a month to conclude the transaction. On 19 October 1945, a total of 31.5 acres of land was sold to the United States, the cost to the Government being approximately $164 per acre.

By March 1946 the Laboratory with all its installations was worth approximately $3,000,000. The prospects for the future were bright. To augment a solidarity with the Armed Forces, it undertook in December 1945 a theoretical study of a high-altitude rocket test vehicle for the Navy. All facilities of the Laboratory are used jointly, making it a cooperative enterprise and emphasizing the harmonious relations which can exist between the Services on a project of this nature.

As far as the Institute is concerned, JPL facilities and equipment are owned in their entirety by the Federal Government. They are operated by the Contractor for the benefit of the Government in carrying out the research under the eight general contracts now in effect. The Contractor has no intention of making use of these facilities at any time other than for operation solely for the benefit of the Government on a nonprofit basis.

It should be noted that the initial structures at JPL were built entirely with CIT labor and materials; later, when expansion was more rapid, CIT Purchase Orders with outside contractors were resorted to. Funds for such construction were obtained from the Research Contract W535-ac-15690, sponsored by the National Academy of Science. With the sale of the JPL site to the U. S. Government on 19 October 1945, subsequent construction of buildings and facilities were handled entirely by the U. S. Engineers under Contract 1056. In addition to the facilities at JPL/CIT, a special test station was constructed at the Army Air Force Muroc Flight Test Base, California, since the test pits at JPL could handle rockets only to a 2,000-pound thrust. This large test station at Muroc, built by Army Engineers and turned over to JPL/GALCIT in April 1945, was designed to operate a motor of 20,000-pound thrust for the CORPORAL missile in a vertical position for durations somewhat larger than 1 minute.

As an addendum, it may be stated that the Research and Development Service Sub-Office (Rocket) located at the California Institute of Technology, Pasadena, California, was established primarily to maintain close liaison between the ORDCIT Project at JPL/GALCIT, and the U. S. Army Ordnance Department.

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ACQUISITION OF LAND FOR ORDCIT PROJECT RANGE FACILITIES

Designated

White Sands Proving Ground

Later Redesignated

White Sands Missile Range

EXTRACTED FROM

DEVELOPMENT & TESTING OF ROCKETS & MISSILES

at

White Sands Proving Ground

1945 - 1955

by

Brown et.al.

Historical Information Branch

WSMR, New Mexico

1 October 1959

ARMY SERVICE FORCES
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON

CE 601.53 (El Paso, Texas - ORDCIT) 8 February 1945
ref CM 108603A SPELR

SUBJECT: Acquisition of Land for ORDCIT Range Facilities

TO: The Commanding General, Army Service Forces

1. Based upon the request of the Chief of Ordnance, by 1st Indorsement dated 4 January 1945, the approval of your Headquarters, by 2nd indorsement dated 11 January 1945, and the recommendation of the Division Engineer, Southwestern Division, by 2nd Indorsement dated 31 October 1944, a military necessity exists for the joint use of certain existing reservations and for the acquisition of additional land, as set forth below:

a. BRIEF DESCRIPTION OF THE LAND: All Federal, state and private lands within an area approximately nine (9) miles in width of the south boundary, thirty-seven (37) miles at the north boundary and one hundred and forty (140) miles in length, located in Dona Ana, Socorro, Lincoln, and Otero Counties, New Mexico, and El Paso County, Texas, as outlined in green on the inclosed map dated 27 October 1944, marked "Directive Map - Original" and entitled "Real Estate - ORDCIT Project, Area #3". The above area includes certain War Department controlled facilities shown in blue on the map and described as follows:

(1) The Fort Bliss, Texas, Anti-Aircraft Firing Range, now under the jurisdiction of Army Ground Forces, containing approximately 400,000 acres of which 299,520 acres were acquired by transfer and approximately 100,480 acres have been leased at an annual rental of $67,359.00.

(2) The Dona Ana Target Range, under the jurisdiction of Army Ground Forces, containing approximately 8,500 acres of land acquired by transfer.

(3) The Castner Target Range, under the jurisdiction of Army Ground Forces, containing approximately 8,500 acres of land acquired in fee in 1928.

(4) The Alamogordo Bombing Range, under the jurisdiction of Army Air Forces, containing approximately 1,242,000 acres of land acquired by lease and suspension agreements at an annual rental of $16,035.00.

b. PROPOSED USE: Rocket Range.

c. APPROXIMATE AREA:

War Dept. Controlled:	1,696,500 acres
To Be Acquired :	974,500 acres
Total Area	2,671,040 acres

SUBJECT: Acquisition of Land for ORDCIT Range Facilities.

d. IMPROVEMENTS: There are no towns, railroads, cemeteries or other public facilities, except U. S. Highway #70 which traverses the area. Approximately 90 ranch units, and the Sierra Tal Company mine, which has outstanding oil leases upon which Moratorium Agreements may be secured if necessary.

1st Ind.

War Department, Headquarters Army Service Forces 8 February 1945

TO: The Under Secretary of War (THRU: The Assistant Secretary of War for Air)

1. The Secretary of War directs that you be informed that a military necessity exists for the acquisition of the land as outlined in the basic letter.

2. All papers necessary for the acquisition of this land are hereby removed from SECRET status.

FOR THE COMMANDING GENERAL:

s/t F. M. SMITH
Colonel, General Staff Corps,
Asst. to the Chief of Staff, A. SL F.

3 Incls. n/c

For W. D. STYER
Lt. Gen., U. S. A.
Chief of Staff

2nd Ind.

Office of the Under Secretary of War 20 February 1945

TO: The Chief of Engineers

Approved for acquisition of land and improvements as outlined in basic letter in accordance with AR 100-61.

By Direction of The Under Secretary of War:

3 Incls. n/c

s/ Herbert A. Friedlich
Colonel, J.A.G.D.
Assistant.

ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE DIVISION ENGINEER
SOUTHWESTERN DIVISION
1114 Commerce Street
Dallas, Texas

SWDRO

22 May 1946

SUBJECT: White Sands Proving Ground - Intermittent Closing of United States Highway No. 70

TO: Commanding Officer,
White Sands Proving Ground
Las Cruces, New Mexico

The attached photostat of Special Use Permit authorizing intermittent use of White Sands National Monument, New Mexico, by the War Department for Military Purposes, is for the files of your office.

FOR THE DIVISION ENGINEER:

1 Incl
Photostat of Special
Use Permit

LEONARD M. COWLEY
Lt Col, CE
Chief, Real Estate Division

UNITED STATES
DEPARTMENT OF THE INTERIOR

SPECIAL USE PERMIT AUTHORIZING INTERMITTENT USE OF
WHITE SANDS NATIONAL MONUMENT, NEW MEXICO,
BY THE WAR DEPARTMENT FOR MILITARY PURPOSES

The Secretary of War is hereby granted a permit, operative from and after March 1, 1946, revocable at will by the Secretary of the Interior, to use at periodic intervals and upon the giving of notice as hereinafter provided in paragraph numbered 4, all of the lands lying within the exterior boundaries of the White Sands National Monument, New Mexico, as shown on the map (National Park Service Map No. NM-WS 7002, revised October 29, 1942) attached hereto as Exhibit "A" and made a part hereof, in connection with the experimental bombing range known as the ORDCIT Project.

This permit is granted subject to the following provisions and conditions:

1. Physical use of the Monument area is not desired by the War Department and the said area will merely be in the path of projectiles with the point of impact some distance outside of the Monument boundaries.

2. On each occasion that firing occurs, United States Highway No. 70 and all roads leading to the Monument shall be closed and the public adequately warned by the War Department. Such warning shall be in advance of the firing and Highway No. 70 shall be adequately posted as to the duration of the firing period.

3. The War Department shall (a) render harmless and remove all duds and unexploded shells or bombs which may fall or be deposited upon lands within the Monument and (b) shall take all reasonable precautions to prevent and suppress brush or grass fires.

4. The War Department shall cause to be delivered to the Custodian of White Sands National Monument, personally at his official headquarters, written notice setting forth the exact date and the duration of each period that the use of the Monument area is desired by the War Department. In each case, the notice shall be delivered to the Custodian at least ten days prior to the first day of each period such use is desired. A similar notice shall be given to the Monument concessioner, grazing permittees, and any others who may be occupying Monument lands.

5. Subject to the availability of funds, the War Department shall reimburse the National Park Service of the Department of the Interior for any and all expenses that may be occasioned such Service by reason of the use of the Monument area by the War Department, excepting for all

services hereinafter stated to be furnished by the War Department. Such reimbursement shall be handled by the execution of United States Form 1080, but shall not include compensation to be paid by the War Department to grazing permittees and/or the concessioner who hold or possess valid rights or privileges upon Federal land included in the White Sands National Monument. In the event of any damage to the land, improvements and/or other property of the National Park Service, Department of the Interior, occasioned by or through the use of Monument lands by the War Department, the Department shall compensate the Department of the Interior for such damage or restore such land, improvements, or other property to the condition prior to the issuance of this permit in a manner satisfactory to the Director of the National Park Service, at the option of the Secretary of the Interior, and without cost to the Department of the Interior.

6. Subject to the availability of funds, the War Department shall furnish the necessary transportation to and from the Monument area and quarters and meals which shall be satisfactory to the Custodian, without cost, to employees of the National Park Service and members of their families, at the Army Air Field, Alamogordo, New Mexico, during all the times that the said employees and members of their families are required to be absent from White Sands National Monument, but with the understanding that in the event all said expenses are paid by the War Department, said employees of the National Park Service and members of their families will make no claim for per diem or mileage as the result of their evacuation from the Monument.

7. The War Department, acting by and through the Corps of Engineers, will negotiate directly with individuals holding grazing permits in the area included in White Sands National Monument, insofar as the use by the War Department will interfere with the use granted to said permittees by the Department of the Interior, and for the payment for any losses or damage sustained by such permittees attributable to the War Department's use of the Monument area.

8. This permit shall be accepted with the understanding that any privileges granted therein are subject to all outstanding and existing rights or privileges for grazing and for concessions granted by the Department of the Interior. Subject to the availability of funds, the War Department will also make adequate provision and effect appropriate arrangements with the concessioner to compensate him for any losses or damages sustained that are attributable to the War Department's use of the Monument area.

Dated this Sixth day of March, 1946.

s/ Oscar L. Chapman
Acting Secretary of the Interior

Accepted this 30th day of April, 1946.

s/ Robert P. Patterson
Secretary of War.

NEW MEXICO
STATE HIGHWAY DEPARTMENT
DISTRICT NO. 2

T. B. White
District Highway Engineer

ROSWELL, N. M.
November 15, 1948

Captain Hopson, Provost Marshal
White Sands Proving Grounds
Alamogordo, New Mexico

Re: Patrol 21A

Dear Sir:

In session October 29, 1948, the State Highway Commission took the following action:

"Consideration was given to request of Capt. Hopson, Provost Marshal, White Sands Proving Grounds, for permission to declare a portion of U. S. 70 a military highway during the time rockets are being fired, and the following action was taken:

IT IS HEREBY ORDERED that permission be granted to the military authorities to declare that portion of U.S. 70, from the entrance of the White Sands National Monument to the entrance of the White Sands Proving Grounds, a military highway during the time rockets are being fired on the White Sands Proving Grounds; provided that the firing will take place during daylight hours and that the maximum length of time of closing the road is to be one hour."

Yours very truly,

s/ T. B. White
District Engineer

TBW:ch

cc: J. R. Nelson
T. H. Card

HEADQUARTERS
ARMY SERVICE FORCES
WASHINGTON, D.C.

SPX 680.1 (9 Jul 45)
OB-I-SPMOC

12 July 1945

SUBJECT: Establishment of White Sands Proving Ground Las Cruces, N. M.

TO: Commanding General, Eight Service Command
Chief of Ordnance
Chief of Engineers

1. Effective as of 9 July 1945, the White Sands Proving Ground is established in Dona Ana and Otero Counties, New Mexico, as a Class IV activity under the control of the Chief of Ordnance, with railhead and post office at Las Cruces, New Mexico.

2. The newly acquired lands and facilities to be utilized by this activity will become a part of the Fort Bliss Military Reservation. The Alamogordo Bombing Range will remain under the jurisdiction of the Commanding General, Army Air Force.

3. The Commanding Officer, Fort Bliss, Texas, will be responsible for administrative and supply services to this activity, with the exception of technical administrative and operational functions.

BY COMMAND OF GENERAL SOMERVELL:

s/t Otto Johnson
Adjutant General

WHITE SANDS MISSILE RANGE 18 June 1958

Land Composition

Historical Background

Plans for Army Ordnance test facilities for guided missiles and related materiel were first begun during World War II. The general area presently called the White Sands Missile Range was selected and the Corps of Engineers issued Real Estate Directive 4279 dated 8 February 1945, which declared the use of the general areas to be a military necessity. The areas already under War Department control were itemized in the directive as follows:

"(1) The Fort Bliss, Texas, Antiaircraft Firing Range, now under the jurisdiction of Army Ground Forces, containing approximately 400,000 acres of which 299,520 acres were acquired by transfer and approximately 100,480 acres have been leased at an annual rental of $67,359.00.

"(2) The Dona Ana Target Range, under the jurisdiction of Army Ground Forces, containing 46,000 acres of land acquired by transfer.

"(3) The Castner Target Range, under the jurisdiction of Army Ground Forces, containing approximately 8,500 acres of land acquired in fee in 1928.

"(4) The Alamogordo Bombing Range, under the jurisdiction of Air Forces, containing approximately 1,242,000 acres of land acquired by lease and suspension agreements at an annual rental of $16,035.00. This directive was amended, 10 May 1945, stating that a military necessity no longer existed for the acquisition of approximately 69,000 acres for the ORDCIT project.

The first construction (temporary) began June 1945 in the present Army Missile Test Center area and the testing project was established as a Class IV Activity, under control of the Department of the Army, Office, Chief of Ordnance, by Army Service Forces Circular No. 268, Hq, Army Services Force 9 July 1945. Letter Order dated 12 July 1945, signed by the Adjutant General, Washington, D.C., formally established the White Sands Proving Ground (now White Sands Missile Range) as a Class II Activity. First troops arrived in August and the first rocket (called TINY TIM) was tested the following month of 1945. Effective 16 September 1948, by Department of the Army General Order No. 59, dated 8 September 1948, the installation became a Class II Activity under the control of the Chief of Ordnance at Ft. Bliss.

The Corps of Engineers began immediately to negotiate with federal, state and private interests. Fifty-two co-use and full-use agreements, covering 815,172.07 acres of land, in the Ordnance-California Institute of Technology, subsequently known as ORDCIT, had been completed by August 1947. Lands within the area under the control of Air Force, known as the Alamogordo Bombing and Target Range, had previously been negotiated for by the Air Force, and the lands within the area known as the Fort Bliss Antiaircraft Firing Range, had been previously acquired by the Corps of Engineers for the Department of the Army. Division of this latter area between White Sands Missile Range and Fort Bliss was outlined in the Secretary of Defense Memorandum, subject: Plan of Operation, dated 19 August 1952. Another Memorandum from the same office under date of 18 July 1952 had provided that there would be no transfer of property and facilities between military services but that the Commanding General, White Sands Missile Range, would have operational control of the area North of the line of demarcation, and Fort Bliss would retain control over the portion lying South.

By 1948 it became necessary to terminate all co-use agreements with private interests in order to relieve the government of the responsibilities which might result from activities of White Sands Missile Range. On 3 March 1949, a joint military acquisition directive was issued by the Department of the Army and the Department of the Air Force calling for the reacquirement on an exclusive control basis. Also, the closing of Highway No. 70 periodically to the public became necessary. This had to be coordinated with the New Mexico state officials and with the federal officials of the White Sands National Monument. Also, Memorandum of Agreements were entered into with the Department of Agriculture, Jornada Experimental Range and with the Department of the Interior, National Park Service, White Sands National Monument for special uses of lands under their jurisdiction.

Under the date of 21 May 1952, the Secretary of the Interior issued Public Land Order 833, which withdraws all public lands, subject to valid existing rights, from all forms of appropriation under the public land law, including the mining and mineral-leasing laws, and reserved these public lands for the use of the Department of the Army for military purposes. The areas described included both public and non-public lands, aggregation approximately 2,394,384 acres. Of this, less than half of it fell within the now White Sands Missile Range boundaries. Other than to further guarantee the interests of the Department of the Army, it had no immediate effect on White Sands Missile Range, insomuch as leases had already been negotiated for exclusive use on all land being used, except for 74,986 acres under the jurisdiction of the White Sands National Monument and 83,430 acres under the control of the Department of Agriculture, Jornada Experimental Range.

According to the records maintained in the Albuquerque District Office, Corps of Engineers, there are 2,215,450.07 acres under the jurisdiction of White Sands Missile Range. However, 1,219,560 acres of this remains under the property control of the Air Force, and leases, property records, and actual payments to lease holders are the responsibility of the Air Force. This divided responsibility makes it more difficult for the Corps of Engineers to keep up with the current status of that area.

Also, the 167,974.70 acres of the Fort Bliss Antiaircraft Firing Range allocated to White Sands Missile Range, represent a map calibration rather than a physical survey. Thus, until an actual physical audit has been completed, acreages quoted represent paper totals. Present information indicates that the physical composition of White Sands Missile Range is as follows:

	Acres
Air Force Accountability (Alamogordo Bombing Range)	
Leased from State of New Mexico	266,499.77
Leased from other Federal agencies	902,447.94
Transferred from other Federal agencies to Air Force	37,729.74
Leased from Patent Holders	33,843.88
Owned in Fee by Air Force	2,996.79
	1,243,518.12
Army Accountability (ORDCIT)	
Leased from State of New Mexico	98,027.10
Special use agreement with White Sands National Monument	75,628.54
Special use agreement with Jornada Experimental Range	83,430.00
Leased from other Federal Agencies	513,100.66
Leased from Patent Holders	44,985.77
Fee Simple from State, Federal and Patent Holders	167,974.70
	2,226,664.89
Less Tracts disposed of as not required	11,214.82
Total White Sands Missile Range	2,215,450.07

Doc 3

ORDCIT PROJECT

The following information summarizes the purpose and objectives of the ORDCIT Project, Contract Nr W-04-200-ORD-455, ASF Ordnance Department, with the California Institute of Technology, under which Contract JPL/CIT undertook certain research in the field of rocketry and its related areas. This information also summarizes progress on this contract to 17 March 1947, as set forth in ORDNANCE DEPARTMENT GUIDED MISSILE PROGRAM, Rocket Development Division, Research and Development Service, Office, Chief of Ordnance, 13 March 1947.

ORDCIT PROJECT

A. CONTRACT COVERS:

The Ordnance Department contract with the Jet Propulsion Laboratory of the California Institute of Technology covers research, development, and engineering work on long range rocket missiles and ramjets and on associated guidance and launching equipment. Specifications and basic engineering data for these missiles and equipment are to be furnished, and prototype missiles are to be constructed (by subcontractors selected by the contractor) and fired. Complete evaluations are to be made of all proof data obtained. Experimental research and development are also to be carried out on propellants and materials that might possibly be used in rockets and ramjets. Special equipment required for all these investigations is to be designed, constructed, and furnished by the contractor.

In addition to monthly progress reports, comprehensive reports are to be furnished by the contractor on:

1. Possible range and bombing load of large size rockets and ramjets.

2. Stability and aerodynamic control of such devices.

3. Characteristics of adequate propulsion systems.

4. Characteristics of various launching systems.

B. SCOPE OF PRESENT WORK:

1. Basic Research

The chief emphasis under this project is placed on fundamental investigations underlying the broad fields of jet propulsion and guided missiles, rather than on the development of specific missiles to meet tactical or strategic requirements. The following give an indication of the major fields on which attention is being focused.

a. Aerodynamics and Performance. Here are included theoretical analyses and wind tunnel tests of stability, control, and performance of specific missiles, as well as of various types of thermal jet propulsion systems. Theoretical studies of the fundamentals of supersonic flow using the most modern techniques of Applied Mathematics are especially emphasized.

b. Materials. Attention is here centered on the development of ceramic materials, high melting point metals, metal-ceramic combinations, and porous metals for sweat cooling. The latter three fields are all based on the techniques of power metallurgy which have been intensively developed at the JPL-GALCIT.

c. Fluid Mechanics. Three broad fields are included under this heading. The first might be characterized as hydraulic and is concerned with liquid propellant supply systems, injection, atomization, etc. The second is that of heat transfer with special emphasis on film and sweat cooling, and the third covers combustion and aerothermodynamic problems particularly in relation to ramjets.

d. Liquid and Solid Propellant Rocket Motors. Basic propellant studies are carried out under a joint Army-Navy contract. Further application to actual motor design is investigated under this section of the ORDCIT program.

e. Remote Control, Guidance, Telemetering. Specific studies related to the CORPORAL, WAC, and RAFT (Rocket Airfoil Tester) test vehicles are being made. In addition, basic investigations of the long-range guidance problem are contemplated.

f. Laboratory Instrumentation. This field is self-explanatory.

2. Experimental Research

Although the major emphasis of the project is on basic research, certain development activities are also being carried on. It should be remembered that the dividing line between basic and development research is often very hazy, and that many investigations involve both type of activity. The ORDCIT Project is concentrating its development research in the four following fields:

a. Liquid Rocket Motors. Light weight WAC and CORPORAL type motors are being developed, and new motor design ideas already initiated will be further investigated.

b. Ramjets. The results being obtained in Section B, 1c (above) are being applied to ramjet construction and test. The ducted rocket which has already been studied is to be further investigated.

c. Propulsion System Components. Propellant supply systems, including turbine-pumps and gas generation, light weight pressure tanks, jet vanes, and electrical accessories are being studied.

d. Test Vehicles. A series of rockets generally progressive in size and complicacy have been and are being constructed and fired as experimental or study missiles to check the conclusions being reached as a result of the continuing research studies. Certain components of these experimental missiles have been used in the design of tactical missiles being developed by other projects, while one of the experimental missiles, the WAC CORPORAL, is being adapted to meet a requirement for a high altitude meteorological rocket. Further work is contemplated on such test vehicles as the BUMPER combination, a controlled

[redacted]

WAC, an improved CORPORAL, and a solid propellant step rocket.

C. PROGRESS:

1. PRIVATES A and F. A limited number of PRIVATE A and PRIVATE F missiles have been constructed and all development tests and test firings completed. The data obtained are being used in further research and development under the ORDCIT and other guided missile projects.

2. WAC CORPORAL. Firings of the booster unit for the WAC CORPORAL commenced at White Sands Proving Ground in September 1945, with the first complete missile being fired in October 1945. A total of seventeen (17) of the complete missiles (including booster) have been fired to date. In addition, seventeen (17) of the booster rocket units, some with and some without dummy WAC CORPORAL missiles, have been fired. Firing of the last three missiles was conducted by the first AAA Guided Missile Battalion. Initial development tests are now considered to be complete. Twenty-five (25) of the missiles are to be made for the Signal Corps, and an additional fourteen (14) are to be constructed for further ORDCIT test requirements. Preparation of drawings for this production is now underway at Douglas Aircraft Company.

3. CORPORAL. Fabrication and testing of the components of the No. 1 prototype of this missile are being pushed to enable the first round to be fired in May of this year. The critical components continue to be the tanks. The first unit of telemetering equipment for the missile has been completed and is now being calibrated. Sixty-three (63) motor and vane test runs have been made, the last test being of the motor which will be used in the Number 1 missile. This motor performed satisfactorily and showed no signs of erosion at the throat.

4. RAFT. The RAFT (Rocket Airfoil Tester), which consists of an airfoil, measuring gages, and telemetering system mounted in the mose of a 5" Navy rocket (HVAR), provides an inexpensive method of obtaining aerodynamic information on airfoil sections. The RAFT's fired in April and October 1945 proved unsatisfactory, and this project was temporarily dropped. It was later resumed and modified RAFT measuring and telemetering components were successfully tested in the WAC CORPORAL firings of December 1946 and February 1947. Modified RAFT's will again be tested at Inyokern, California, in July 1947.

5. Ramjet Research. Various tests on fuel types, fuel injection, ignition, and combustion have been carried out in three inch and eight inch diameter combustion chambers, with valuable data being obtained in many cases. A thrust jack for calibration of fuel flow versus thrust developed by a rocket has been constructed. The mixing section of the induction test tunnel has been set up and calibrated, and a diffuser will be installed in the very near future. This will enable investigations to be made of the shortest mixing chamber length for good diffusion. Wind tunnel tests of RAMCIT No. 1 (California Institute of Technology Ramjet) will soon be underway.

[redacted]

6. Propellants. Tests are continuing on polysulfide base propellants, on ignition time, burning rates, stability of burning, chamber pressures, temperature limits, sensitivity, effect of variations in curing, and on various new propellant compositions.

7. Materials. Considerable work has been and is continuing to be done on the development of porous metals for sweat cooling. Various porous metals, including sintered materials, have been prepared and tested. Recent reports in this field which have been written by ORDCIT cover:

a. Preparation and properties of porous stainless steel for sweat cooling.

b. Relative merits of porous stainless steel, porous nickel, and porous copper in the sweat-cooling process.

c. Effect of gas temperature and velocity on material specimen temperature and flow of coolant, as surveyed in the high velocity testing equipment.

d. Test of several commercially available porous metals for hydraulic characteristics, using nitrogen as the test fluid.

Recent investigations on refractory chamber liners included tests of 3/8-inch-thick liners of stabilized zirconia, thoria, carbon, and two grades each of porous carbon and porous graphite. These tests were made in a 750-lb.-thrust motor using RFNA-Aniline propellant.

D. RATE OF EXPENDITURE:

Current rate of expenditure for the ORDCIT Project is $150,000 per month (excluding cost of missiles).

STATISTICAL SUMMARY OF PRIVATE A

EXTRACTED FROM

HANDBOOK OF GUIDED MISSILES

Prepared by

Guided Missiles Committee of the Joint Committee
on New Weapons and Equipment

Joint Chiefs of Staff

1 July 1945

and

Other Sources

STATISTICAL SUMMARY OF PRIVATE A

DESCRIPTION

WEIGHT--NOMINAL

PRIVATE A--Missile only

Weight of rocket unit (propellant and motor)	400 pounds
Weight of fin-tail assembly	56 "
Weight of nose (with all weights present)	71 "
Total weight of missile	527 "
Weight of propellant	192 "

PRIVATE A--Auxiliary launching rocket assembly

Total weight	149 pounds
Weight of propellant	19 "

BODY

Aerojet Model X30AS1000
Jet motor

AIRFRAME

None. Missile was a fin-stabilized rocket with four conventional tail fins and the following nominal dimensions: length, 92 inches; diameter, 10 inches; diameter across fins, 33½ inches; length of fin, 20 inches.

GUIDING SYSTEM

None.

PROPULSION

PRIVATE A missile only: Restricted-burning, solid-propellant rocket; thrust, 1,000 pounds (nominal) for 30 seconds, using GALCIT 61-C fuel having a specific impulse of 184 lb sec/lb; nominal over-all dimensions of charge: length, 50 3/4 inches; diameter 8 3/4 inches.

PRIVATE A auxiliary launching rocket assembly: For each missile, 4 unrestricted-burning, solid-propellant rockets, manifolded together to minimize the possibility of non-axial thrust. The rockets used were the motors from the Army 4.5-inch T22 Rocket. Average thrust 22,000 pounds for 0.18 second, using AXS 719 fuel with a specific impulse of 206 lb sec/lb.

WARHEAD

None. Payload was represented by 60 pounds of lead weights mounted in the conical nose section.

FUZING AND ARMING SYSTEM

None.

LAUNCHING

Launched from a 4-rail, box-type steel launcher 35 feet long, with a door on the top side of the lower end, through which door the missile was loaded. The launcher was adjustable in elevation only. Since no parts were expended other than the electrical firing connections, this launcher could be used repeatedly.

The booster rocket was placed in the launcher so that the forward end of the booster assembly was butted against a large external nut threaded on the exhaust nozzle of the missile. After having served its purpose, the booster fell free, and the missile proceeded on its way. The booster accelerated the missile at 33 g, and the missile was launched at 190 ft/sec.

MODIFICATIONS AND INSTALLATIONS REQUIRED TO EMPLOY THE MISSILE

This section not applicable. The missile was launched from a ground installation only.

CHARACTERISTICS

This was an experimental missile developed as a first step in the development of long-range guided missiles. Specifically, it was intended for the study of aerodynamic design, launching, and radar tracking.

TESTS AND OPERATIONAL USE

DEVELOPMENTAL TESTS

The initial firing of 27 rounds of this missile during the period 4 December to 15 December 1944 showed the performance of both the booster rockets and the missile rockets as entirely satisfactory.

SERVICE ACCEPTANCE TESTS

Not applicable.

THEATER OPERATIONAL USE

Not applicable.

FUTURE TESTING PROGRAM

This missile was primarily intended to provide a means of checking the theoretical trajectory predictions for this type of missile and to develop a satisfactory launching device designed to provide accurate aim and smooth performance. This phase of research was necessary, as the trajectory calculations previously developed were for either no propulsive force (shells) or for propulsive force applied for a very short time interval (then current military rockets).

The research program to obtain this information was tentatively set as follows:

A. Theoretical Trajectory Calculations

1. Computation of trajectories under standard conditions.
2. Differential corrections for variations in weight of missile, atmospheric conditions, and propellant performance.

B. Firing-Range Tests

C. Coordination of Theory and Experiment

TRAINING PROGRAM

Not applicable.

ASSEMBLY, MAINTENANCE, AND TEST EQUIPMENT

Not applicable.

PACKAGING AND SHIPPING

Not applicable.

AVAILABILITY

Not applicable.

COST

Not applicable. PRIVATE A was an experimental item produced in only experimental quantities, with modifications as needed.

DATES

Program started 12 May 1944.

FURTHER DEVELOPMENT

Information obtained from the development and testing of this missile was to be used in the over-all, long-range guided missile program. Further development of this missile was not planned.

PRIORITY

Development--ASF 1-C.
Production--Not applicable.

SECURITY

Development--SECRET (World War II was on at the time.).
Production--Not applicable.

DEVELOPMENT AGENCIES INVOLVED

Jet Propulsion Laboratory, California Institute of Technology.

RESEARCH IN PROCESS AFFECTING PROJECT (as of 1 July 1945)

ORDCIT Program at CIT.

SIMILAR DEVICES

None.

HEADQUARTERS ACTIVITIES AFFECTING ROCKETS

Office, Chief of Ordnance, Rocket Development Division, Research and Development Service.

STATUS OF PRIVATE A

As of 1 July 1945, status of PRIVATE A was that it could be used for the purpose for which it was designed.

WIND TUNNEL TESTS OF ORDCIT MODELS

The following tables of wind tunnel tests of ORDCIT models were extracted from Puckett, Allen E., BRL/APG Report Nr 548, SUPERSONIC WIND TUNNELS LABORATORY Problem Nr SS-2, WIND TUNNEL TESTS OF ORDCIT MODELS, Ordnance Research & Development Center, Aberdeen Proving Ground, Maryland, 25 May 1945.

WIND TUNNEL TESTS OF ORDCIT MODELS

In Table I is given a list of the models tested, with the wind tunnel model number, and the notation used for quick identification.

In Table II are given the critical dimensions of the principal models. The dimensions here given are measures of the actual models which differed slightly from the original designs due to shop inaccuracies. The actual models were small, with body diameters of 1.062" and lengths varying from 10.25" to 14.75", so that very close machining tolerances would have been necessary to maintain accuracy of the models.

The vertical fins were identical with the horizontal fins for all models except the PRIVATE F, (MR-20), and its modifications as indicated in Table II. The normal fin and wing incidence settings for basic models were 0°, with the exception of the horizontal fin surfaces of the PRIVATE F, which were set at -2°.

Variations of the basic CORPORAL model and the low-aspect-ratio CORPORAL model included deflected elevators on the horizontal fins. The elevators consisted of constant-chord sections extending the full width of the fins. The elevator chords, in fractions of the fin root chords, were:

Basic CORPORAL	0.294
Low-Aspect-Ratio CORPORAL	0.300

Photographs of nine models are given in the textual volume, Chapter II "PRIVATE A."

TABLE I

Index of Models

MODEL	NOTATION	NAME
MR-18	S_A	PRIVATE A
MR-19	S_A - HV	PRIVATE A minus tail surfaces
MR-20	S_F	PRIVATE F
MR-21	S_F - W	PRIVATE F minus wing
MR-22	S_F - HV	PRIVATE F minus tail
MR-23	S_C	Basic CORPORAL (long body)
MR-24	S_C - HV	Basic CORPORAL minus tail
MR-25	S_B	CORPORAL, intermediate body
MR-26	S_B - HV	CORPORAL, intermediate body, minus tail
MR-27	S_D	CORPORAL, short body
MR-28	S_C (7°)	Basic CORPORAL, 7° nose angle
MR-29	S_C (15°)	Basic CORPORAL, 15° nose angle
MR-32	S_C ($e = 8^\circ$)	Basic CORPORAL, elevator setting 8° down
MR-33	S_C (L AR)	Basic CORPORAL, low aspect ratio tail
MR-34	S_F ($i = 2^\circ$)	PRIVATE F, wing incidence = 2°
MR-35	S_F ($i = 2^\circ$)-HV	Same, minus tail
MR-38	S_B (7°)	CORPORAL, intermediate body, 7° nose
MR-39	S_D (7°)	CORPORAL, short body, 7° nose
MR-40	S_B (15°)	CORPORAL, intermediate body, 15° nose
MR-41	S_D (15°)	CORPORAL, short body, 15° nose
MR-42	S_C ($e = 8^\circ$)	Basic CORPORAL, elevator setting 4° down
MR-52	S_F ($i = 0^\circ$,) ($H = -4^\circ$)	PRIVATE F, horizontal tail at -4°

Indix of Models (Continued)

MODEL	NOTATION	NAME
MR-53	$S_F \begin{matrix}(i = 2^\circ,) \\ (H = -4^\circ)\end{matrix}$	Same, with wing incidence - 2°
MR-54	$S_C \begin{matrix}(L\ AR\ ) \\ (e = 4^\circ)\end{matrix}$	CORPORAL, low aspect ratio tail, elevators 4° down
MR-55	$S_C \begin{matrix}(L\ AR\ ) \\ (e = 8^\circ)\end{matrix}$	Same, elevators 8° down

TABLE II

Principal Model Dimensions, as Constructed
(Linear dimensions in body diameters;
fin thicknesses as fraction of chord)

MODEL	BODY LENGTH	AREA	ROOT THICKNESS	TIP THICKNESS	ASPECT RATIO	ROOT CHORD	TIP CHORD
		HORIZONTAL FINS					
MR-18	9.65	5.41	0.0993	0.0113	1.24	2.08	2.08
MR-20	9.65	6.31	.1092	.0194	4.09	1.64	0.824
		VERTICAL FINS					
MR-20		2.71	.0978	.0090	2.47	2.09	2.09
		WINGS					
MR-20		2.07	.105	.017	3.09	0.824	0.824
		HORIZONTAL FINS					
MR-23	13.90	4.72	.1005	.0758	1.91	1.932	1.144
MR-25	11.68	4.72	.1005	.0758	1.91	1.932	1.144
MR-27	9.65	4.72	.1005	.0758	1.91	1.932	1.144
MR-33	13.90	4.73	0.0988	0.0903	0.557	2.93	2.44

UNCLASSIFIED

RESULTS OF PRIVATE A FIRINGS

During the period of 1 December - 16 December 1944, the test program for the PRIVATE A Missile, a research test vehicle developed under the Ordnance Department basic research contract with California Institute of Technology, was successfully carried out at Camp Irwin Reservation near Barstow, California. Twenty-four rounds were fired in all, including four rounds of dummy PRIVATE A to test the operation of the launcher and boosters, two rounds of one-third-duration charged PRIVATE A to test the launching procedure and stability of the missiles, and eighteen rounds of fully charged PRIVATE A for record test data.

The PRIVATE A booster rockets and missile rockets performed satisfactorily. An average range for the fully charged rocket was 18,000 yards.

From the PRIVATE A firings experience was gained in the operation and instrumentation of guided missile tests. A study of the results of these tests provided valuable information in this research project.

Firing results were summarized from:

JPL Report Nr 4-3

FIRING TESTS OF "PRIVATE A"

at

LEACH SPRING, CAMP IRWIN, CALIFORNIA

by

S. J. Goldberg

JPL/GALCIT, CIT

14 March 1945

UNCLASSIFIED

RESULTS OF PRIVATE A FIRINGS

Research Agency: California Institute of Technology

Missile No.	Date	Range or Altitude	Remarks
1	Between 1-16 Dec. 1944	R 371 yds.	PRIVATE A dummy, cleared launcher satisfactory, booster separated correctly.
2	"	R 385 yds.	Same as above.
3	"	R 3,510 yds.	PRIVATE A with one-third thrust duration. Booster did not separate and made entire flight. PRIVATE thrust burning time 11 seconds.
4	"	R 410 yds.	Dummy PRIVATE A to test booster action. Separation was satisfactory.
5	"	R 2,990 yds.	PRIVATE with one-third thrust duration charge. Boosters failed to fire. PRIVATE made completely self-propelled flight.
6	"	R 4,800 yds.	Fully charged PRIVATE with booster. Booster failed to separate. PRIVATE continued to burn after impact.
7	"	R 460 yds.	Same as Rounds 1, 2, and 4. Purpose to test shear pin under booster action. Action satisfactory.
8	"	R 17,000 yds.	First successful flight of 30-second duration PRIVATE. Firing sequence of PRIVATE and booster successfully accomplished.
9	"	R 17,300 yds.	First fully charged PRIVATE (First record round) Launcher at 76° elevation. PRIVATE burning time 34.2 seconds. Flight duration 78 seconds.
10	"	R 18,975 yds.	Same as No. 9, burning time 32.4 sec., duration of flight 32.4 sec.
11	"	R 17,800 yds.	Same as above, burning time 34.6 sec., duration of flight 80 sec.

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Missile No.	Date	Range or Altitude	Remarks
12	Between 1-16 Dec. 1944	R 16,250 yds.	Same as above, burning time 36 sec., flight duration 69.5 sec.
13	"	R 16,200 yds.	Same as above, burning time 39 sec., flight duration 70 sec.
14	"	R 17,800 yds.	Same as above, burning time 35.5 sec., flight duration 68.8 sec. Burning time of propellant charge was noted to greatly affect range.
15	"	R 19,100 yds.	Same as above, burning time 34.5 sec., flight duration unobserved.
16	"	R 18,075 yds.	Same as above, burning time 34.6 sec., flight duration 78 sec.
17	"	R 17,750 yds.	Same as Round No. 9. Burning time 34 sec., flight duration unobserved.
18	"	A 5,000 ft.	Night firing of full-charged PRIVATE A with no booster. Purpose was to get a streak trajectory on photographic plate. Smoke obscured view, no plate obtained.
19	"	R 19,000 yds.	Same as Round No. 9. Burning time 32.8 sec., flight duration 83 sec.
20	"	R 19,350 yds.	Same as Round No. 9, and last of standard PRIVATE A rounds fired during above series. Longest range achieved. Burning time 32.5 sec., flight duration 90 sec.
21	"	R 19,300 yds.	Lead weights in PRIVATE nose replaced with camera. Burning time 34 sec., flight duration 87 sec. Camera destroyed on impact; however, rate of spin was determined to be 1 revolution in 0.8 sec. or 75 rpm.
22	"	R 18,950 yds.	Duplication of Round No. 21. Burning time 33 sec., flight duration 84 sec. Camera badly damaged on impact. Rotation determined to be 60 rpm.

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Missile No.	Date	Range or Altitude	Remarks
23	Between 1-16	R 16,900 yds.	PRIVATE fired at 60 lbs. reduced weight with center of gravity shifted to 33" forward of nozzle exit to achieve maximum range. Burning time 35 sec., duration of flight unobserved. Round did not perform according to expectation.
24	"	R 20,000 yds.	Duplication of Round No. 23, launcher elevated to 80.5^{o}. Burning time 35 sec., duration not observed. Round went beyond mountain range and beyond observation.

UNCLASSIFIED

STATISTICAL SUMMARY OF PRIVATE F*

EXTRACTED FROM

HANDBOOK OF GUIDED MISSILES

Prepared by

Guided Missiles Committee of the Joint Committee
on New Weapons and Equipment

Joint Chiefs of Staff

1 July 1945

and

Other Sources

* In addition to those items applying equally to both PRIVATE F and PRIVATE A, for which see Doc 4: STATISTICAL SUMMARY OF PRIVATE A, this summary supplies additional information pertaining almost wholly to PRIVATE F.

STATISTICAL SUMMARY OF PRIVATE F

DESCRIPTION

WEIGHT

Approximately the same as that of PRIVATE A for both the missile and the booster.

AIRFRAME

None. PRIVATE F was a fin-stabilized rocket with small forward wings. There were two diametrically opposite tail fins in the horizontal plane and one tail fin in the vertical plane. The vertical fin was entirely above the longitudinal axis of the missile. Both the wings and the horizontal fins had a predetermined dihedral and incidence angle.

BODY

Aerojet Model X30AS1000 Jet Motor (as was case with PRIVATE A).

LAUNCHING

PRIVATE F was launched from an experimental launcher which was adjustable in elevation only. The unit was made for testing this missile only. The launcher could be used repeatedly, since no parts were expended other than the electrical firing connections.

The booster rocket was placed in the launcher so that the forward end of the booster assembly was butted against a large external nut threaded on the exhaust nozzle of the missile. After having served its purpose, the booster fell free, and the missile proceeded on its way. One booster assembly was expended per round. The booster accelerated the missile at 33 g, and the missile itself was launched at 190 ft/sec.

CHARACTERISTICS

This was an experimental missile using the PRIVATE A motor and having small forward wings added, together with the change of the tail configuration already described, these modifications having been based on the theory that additional range over that of PRIVATE A could be thereby obtained.

This stabilizing system of forward wings and a three-fin tail proved unsatisfactory. The missile was very unstable in flight, especially at supersonic speeds.

TESTS

Firing Tests conducted in April 1945 bore out the results of wind tunnel tests of PRIVATE F models at Aberdeen Proving Ground conducted earlier in 1945. The missile was unstable after passing supersonic speeds.

STATUS AS OF 1 JULY 1945

Further work on PRIVATE F was not planned. Information obtained was to be incorporated in future missiles of this type, if any.

RESULTS OF PRIVATE F FIRINGS

Firing tests of the PRIVATE F Missile developed under ORDCIT Project were carried out at Hueco Range, Fort Bliss, Texas, between 1 April and 13 April 1945. A total of 17 rounds were fired including two dummies to test operation of the launcher and boosters. Tests were conducted for the purpose of investigating some of the problems of winged missiles, particularly aerodynamic problems of stability and drag at high speeds and to check on the feasibility of extending the range of a missile by the use of wings. When the missiles were fired, in no case was satisfactory steady flight produced. A steady rolling motion developed in every case about ten seconds after launching. Small changes were made in the fins during the test program but no really satisfactory results were obtained. From study, it was determined that the unsatisfactory behavior of the PRIVATE F in flight was caused by aerodynamic moments produced by asymmetries in the wing and tail construction. It was concluded that small high-speed missiles must either be constructed with extraordinary precision or be equipped with an auto pilot.

Firing results were summarized from:

JPL Report Nr 4-7

FIRING TEST OF "PRIVATE F"

at

HUECO RANGE, FORT BLISS, TEXAS

APRIL 1 TO APRIL 13, 1945

by

S. J. Goldberg

JPL/GALCIT, CIT

10 May 1945

RESULTS OF PRIVATE F FIRINGS

Research Agency: California Institute of Technology

Firing	Date	Description of Round	Range or Altitude	Remarks
1	Apr 1-13, 1945	PVT. F Dummy	R 375 yds.	Only booster fired to check launcher. Separation was satisfactory. Launcher satisfactory at 20° elevation.
2	"	" " "	R 400 yds.	Same as above. Launcher satisfactory at 40° elevation.
3	"	1/3 Thrust PVT. F	R 1,100 yds.	Missile slow-rolled to left and dived into ground.
4	"	" " " "	R 950 yds.	PVT. F motor had very slow start and missile made unpowered flight. Unstable as above.
5	"	Full Charged PVT. F	R 1,300 yds.	Missile rolled and spiraled. Observers blamed excessive vertical fin.
6	"	" " " "	R 2,000 yds.	4" cutoff vertical fin. Missile made slow rolling oscillations and then into barrel roll.
7	"	" " " "	R 1,350 yds.	6" cutoff vertical fin. Similar flight as above with more violent spiraling.
8	"	" " " "	R 2,225 yds.	Vertical fin removed. Missile rolled rapidly after firing.
9	"	" " " "	R 1,400 yds.	5" cut from vertical fin and 4" of end of horizontal surface tips bent up at 45°.
10	"	" " " "	Misfire	Round booster was blown out of breach and missile burnt out in launcher.
11	"	" " " "	R 2,900 yds.	Using the tail of Round No. 10. Round stable at first, then went into spin.

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Firing	Date	Description of Round				Range or Altitude	Remarks
12	Apr 1-13, 1945	Full	Charged	PVT.	F	R 1,450 yds.	6" removed from vertical fin, 6" of horizontal surface bent at 45°. Flight characteristics unchanged.
13	"	"	"	"	"	R 1,650 yds.	5" removed and balance as in Round 12. Flight characteristics unchanged.
14	"	"	"	"	A	A 25,000 ft.	PVT. A was modified to fit PVT. F launcher. Launched at 80° Missile was stable to 25,000 ft. and then changed course 45° and disappeared over mountains.
15	"	"	"	"	F	R 5,075 yds.	Vertical front fin 5" long welded on nose. Rear fin left unchanged. Horizontal surfaces bent at 45° as before. Missile stable in pitch and yaw but unstable in roll.
16	"	"	"	"	"	R 2,150 yds.	Front fin increased to 11". Round very erratic in flight.
17	"	"	"	"	"	R 2,050 yds.	Compromise in specification between rounds 15 and 16. Round very erratic.

Firings Carried out at Hueco Firing Range, Ft. Bliss, Texas.

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STATISTICAL SUMMARY OF WAC CORPORAL MISSILE AND TINY TIM BOOSTER

EXTRACTED FROM

Ordway, Frederick J., III, and Wakeford, Ronald C.

INTERNATIONAL MISSILE AND SPACECRAFT GUIDE

New York, Toronto, and London

McGraw-Hill Book Company, Inc.

1960

STATISTICAL SUMMARY OF WAC CORPORAL MISSILE AND TINY TIM BOOSTER

	WAC CORPORAL	TINY TIM
Length, ft.	16	5
Diameter, in.	12	12
Span, ft.	3	4
Weight, lbs.	(Weight varied)	
Loaded	665	546
Empty	292	400
Propellant	346	146
Payload, lbs.	25	
Altitude, miles		
Boosted	45	
Unboosted	19	
Velocity, mph		
Booster burnout	1,700	
Missile burnout	2,800	
Thrust, lbs.	1,500	50,000
Burning Time, sec	45	0.6
Specific impulse, lb /lb-sec	195	202
Chamber pressure, psi	300	
Exhaust velocity, mph	4,250	4,425
Propellants	Nitric acid-aniline	Solid--ballistite--Unrestricted-burning

WAC CORPORAL DEVELOPMENT

Work began on WAC CORPORAL rocket in December 1944 at JPL under the ORDCIT Program. Army Ordnance desired that a feasibility study be conducted leading to the development of an upper-air sounding rocket capable of lifting a 25-pound payload to about 20 miles. As it turned out, however, the performance was considerably better than originally planned.

In carrying out the program, JPL first developed a small, 1/5-scale model of the design they had selected for the WAC. This small version was called BABY WAC and was tested at Goldstone Ridge, California, 3-4 July 1945. The successful results of these firings confirmed that a 3-finned, boosted missile was satisfactory.

WAC CORPORAL's rocket-motor development program was given to Aerojet Engineering Corporation, which soon provided a bi-propellant, regeneratively cooled unit ignited hypergolically. Compressed air was used to pressurise the tanks to cause propellant flow, and propulsion was initiated following the operation of an inertia value, which was incorporated in the compressed-air circuit. As the missile was accelerated by the booster, the valve opened, and air pressure was transmitted to the propellant tanks and at the same time actuated the piston of the main propellant valve.

The booster was a TINY TIM rocket whose fins and nose were modified. Thrust was increased from 30,000 to 50,000 pounds, and burning time was decreased from 1 to 0.6 second.

Launching was from a 102-foot-high steel tower that had 3 guide rails inside, spaced at 120 degrees from one another and having an effective length somewhat less than 80 feet. The first WAC CORPORAL was fired from such a tower at WSPG on 26 September 1945, and tests continued through 25 October 1945. The first missile reached an altitude of 43½ miles, or more than twice that originally specified. This excellent performance was very largely due to the powerful booster.

The WAC CORPORAL was originally developed to carry out upper-air sounding tasks, but by the time it was ready for research firings V-2 had been converted into a high-altitude research vehicle, and WAC was soon all but forgotten. It did, however, contribute to the BUMPER Program as the second stage and was of value toward the JPL surface-to-surface missile development.

UNMODIFIED TINY TIM

TINY TIM		Range, miles	1
Length, feet	10¼*	Velocity, mph	550*
Diameter, inches	11 3/4	Thrust, pounds	30,000
Span, feet	3	Burning time, Seconds	1
Weight, pounds			
Loaded	1,284*	Propellant	Ballistite
Payload	590 (including 150 pounds TNT)		

* 9½ and 9 3/4-inch versions were developed, weighing 1,169 and 1,261 pounds, respectively. Velocity was increased to 600 mph.

SUMMARIZED HISTORY OF TINY TIM

Work began on this large Naval airplane rocket at CIT (Projectile, Propellant, and Production Sections, National Defense Research Committee) in February 1944. The motor was rapidly developed and, when completed, consisted of a tube with 4 solventless-extruded ballistite grains, together weighing nearly 150 pounds. A multinozzle arrangement was featured, with 24 nozzles symmetrically placed around the center nozzle. Static testing began at the Naval Ordnance Test Station, Inyokern, California, and in April 1944, the rocket was first fired from a ground launcher. Two months later, on 22 June 1944, the first firing took place from a TBF Avenger airplane.

The Marine Air Group 51, with F4U equipment, was the first combat unit supplied with the 4-finned TINY TIM, and during the Battle of Okinawa TINY TIM was first fired in action. Because of the great number of other weapons used, it was not possible to evaluate fully the effects of TINY TIM. By the time World War II was over, the United States had in this missile a powerful, if not fully combat-tested, rocket weapon, and when the Korean War began, TINY TIM was used with excellent results.

RESULTS OF WAC CORPORAL FIRINGS

The following tables summarize the results of the different stages, or phases, of WAC CORPORAL firings at White Sands Proving Grounds and include firings of the TINY TIM booster alone. These tables were compiled from various documents and synthesized into a composite summary of these firings.

MISSILE PROJECT: TINY TIME (Booster Only)

Round Number	Date Fired	Fired By	Altitude (in feet)	Purpose of Test	Remarks
A	26 Sep 45	ORDCIT	14,000	Booster only fired to check launcher, radar tracking, camera crews, etc.	Launcher proved satisfactory, and booster operated as planned
B	26 Sep 45		Average		
C	26 Sep 45				
D	27 Sep 45				
11	7 May 46	ORDCIT	No record		
13	20 May 46	ORDCIT	No record		
14	23 May 46	ORDCIT	"		
15	23 May 46	ORDCIT	"		
16	24 May 46	ORDCIT	"		
17	24 May 46	ORDCIT	"		
18	26 May 46	ORDCIT	"		
19	26 May 46	ORDCIT	"		
20	29 May 46	ORDCIT	"		
21	2 Dec 46	ORDCIT	"	To test glass chute.	Normal take-off. Chute operated successfully. Good instrumentation obtained.
27	17 Feb 47	ORDCIT	"	Carried 680 pounds lead ballast.	Fired successfully. Burning time and acceleration data obtained.

MISSILE PROJECT: WAC CORPORAL

Missile Number	Date Fired	Fired By	Altitude (in feet)	Purpose of Test	Remarks
1 2	27 Sep 45 28 Sep 45	ORDCIT ORDCIT	 8,000	Dummy WAC CORPORAL with booster, fired to check launching velocity, launcher, booster-missile separation in free flight.	Radar tracking tended to lock on booster after separation; all other results very satisfactory.
3 4	1 Oct 45 2 Oct 45	 ORDCIT	 28,000	To check launcher operation (fueling, etc.) flight performance. Quarter-charged WAC w/booster.	Launching operation (fueling, etc.) satisfactory. Flight performance for both rounds satisfactory. Nose release mechanism failed in both rounds. Difficulties were encountered in tracking with radar. Over-all missile operation very satisfactory.
5	11 Oct 45	ORDCIT	235,000	Fully charged WAC CORPORAL.	Launching operation and flight characteristics very satisfactory. Radar tracking failed, and nose release again failed to function. Radiosonde equipment did not function.
6	12 Oct 45	ORDCIT	235,000	Fully charged WAC CORPORAL. To test radar tracking.	Round No. 6 identical with round No. 5 except that "radar window" was included in nose to assist in tracking. Over-all operation satisfactory. No signal from radiosonde equipment. No radar track. M-2 optical trackers proposed for assisting in tracking on following rounds.

MISSILE PROJECT: WAC CORPORAL

Missile Number	Date Fired	Fired By	Altitude (in feet)	Purpose of Test	Remarks
7	16 Oct 45	ORDCIT	90,000	Fully charged WAC CORPORAL.	Nose release prematurely functioned at 90,000 ft. when missile went into spinning flight. No radiosonde signals received.
8	19 Oct 45	ORDCIT	235,000	Fully charged WAC CORPORAL. Radiosonde equipment replacement check. Equipment replaced with seven lbs. of lamp black (Black-WAC) set to produce a cloud at zenith of flight. To increase smoke trail 4% potassium nitrate added to oxidizer.	Nose released prematurely. Radar tracking was obtained.
9	25 Oct 45	ORDCIT	No record	Fully charged WAC CORPORAL.	Fuel leak occurred during charging and missile was fired with only partial air charge. No record.
10	25 Oct 45	ORDCIT	No record	Fully charged with booster. Fired at night. Radiosonde replaced with T-90, 100,000 candlepower flare to be released at zenith of flight.	Nose release failed to function. Radar tracking obtained. All other operation satisfactory.

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GENERAL CONCLUSIONS AFTER SERIES OF FIRST 10 WAC CORPORAL FIRINGS

1. WAC CORPORAL at this stage was capable of reaching 230,000 feet in vertical flight.
2. Flight control equipment was not required if missile were launched from launcher at velocity 400 ft/sec.
3. Over-all mechanical design of missile was satisfactory.
4. Booster rocket used proved satisfactory.
5. Nose release mechanism was not satisfactory.
6. Tracking by radar proved difficult without use of manual trackers; radar signal above 90,000 feet proved too weak for recording.

WAC CORPORAL FIRINGS

White Sands Proving Ground, New Mexico

Between 11 and 29 May 1946

Firings conducted during this period were performance tests of the TINY TIM Booster. Inasmuch as the purpose of these firings was to check major components, specific data of each item fired is not tabulated.

During this series, one WAC CORPORAL with booster was fired on 10 May 1946 as a demonstration round for visiting dignitaries. This demonstration was successful; however, no data were recorded

Between 2 and 13 December 1946

When firings were resumed on 2 December 1946, except for one round of WAC A remaining from the September - October 1945 firings, the newly designed WAC B was the vehicle launched, plus one TINY TIM round, for a total of six rounds.

Between 17 February and 3 March 1947

One TINY TIM and three WAC B rounds were fired during February - March 1947.

12 June 1947

On 12 June 1947, one WAC B was launched.

RESULTS OF ORDCIT FIRINGS

Research Agency: California Institute of Technology

Missile Number	Date	Altitude (in feet)	Description of Round	Remarks
Booster	2 Dec 46		TINY TIM with glass chute.	Normal take-off. Chute operated successfully. Good instrumentation obtained.
11	3 Dec 46	94,600	WAC A with glass chute & beacon.	Lost three fins in flight. Short burning time caused by failure of aniline tank. Unstable flight. Chute opened, but missile broke away.
12	6 Dec 46	92,000	WAC B with 14 ft ribbon chute & beacon	Chute operated successfully. Missile lost fin in flight, causing instability and reduced altitude.
13	12 Dec 46	105,000	WAC B with 10 ft glass chute & beacon. Reinforced fins.	Beacon did not function. Chute operated successfully. Fins remained intact, but missile was damaged on impact.
14	12 Dec 46	160,000	WAC B with 8 ft nylon chute & telemetering. Reinforced fins.	Telemetering unit lowered successfully by parachute. Good instrumentation obtained.
15	13 Dec 46	175,000	WAC B with 10 ft glass chute & telemetering. Reinforced fins.	Normal flight. Parachute fouled and failed to open. Only fair instrumentation obtained. Telemetering functioned satisfactorily.
Booster only.	17 Feb 47		TINY TIM with 680 lbs lead ballast.	Fired successfully. Burning time and acceleration data obtained.
16	18 Feb 47	144,000	WAC B with beacon & 21 ft silk ribbon chute and special nose cone.	Velocity lower than normal. Beacon and chute operated satisfactorily. Missile lowered gently and recovered nearly intact, but chute was burned by acid fumes. Excellent instrumentation.
17	24 Feb 47	240,000	WAC B with beacon and 10 ft glass chute.	Chute failed to open. Missile not recovered. Good instrumentation.

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Missile Number	Date	Altitude (in feet)	Description of Round	Remarks
18	3 Mar 47	206,000	WAC B with 10 ft glass chute.	Chute opened successfully. Good instrumentation. Missile recovered nearly intact.

An additional round was fired in June 1947.

Missile Number	Date	Altitude (in feet)	Description of Round	Remarks
19	12 Jun 47	198,000	WAC B with 10 ft silk chute and beacon.	Nose cone blow-off operation and chute opening satisfactory, but chute torn loose from missile and neither recovered. Goof instrumentation.

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THEORETICAL CALCULATIONS OF TRAJECTORIES
FOR THE PROPOSED V-2/WAC CORPORAL MISSILE

EXTRACTED FROM

JPL Memorandum Nr 4-16

PRELIMINARY CONSIDERATIONS REGARDING THE
PROPOSED V-2 WAC MISSILE

JPL/GALCIT/CIT

16 August 1946

TRAJECTORIES OF THE V-2 WAC MISSILE

	Case 1	Case 2	Case 3
WAC characteristics			
Gross weight (lb)	700	627	570
Propellant weight (lb)	370	370	370
Burning time (sec)	47	47	47
Specific impulse (sec)	226	226	226
At V-2 end of burning*			
Altitude (ft)	123,000	124,000	124,000
Elevation angle (°)	79.4	79.4	79.4
Speed (ft/sec)	5,047	5,047	5,047
Time (sec)	65	65	65
At WAC end of burning			
Altitude (ft)	309,000	326,000	346,000
Elevation angle (°)	76.5	76.5	77.0
Speed (ft/sec)	8,936	9,916	11,076
Time (sec)	112	112	112
At WAC summit			
Time (sec)	382	412	437
Altitude (ft)	1,474,000	1,767,000	2,151,000
Altitude (miles)	279	335	407
At 100,000 ft on the way down			
Speed (ft/sec)	9,400	10,350	11,500

*The Hermes Project Monthly Summary, No. 15, May 1, 1946, pp. 6 and 7, trajectory No. 2.

BUMPER (V-2/WAC CORPORAL COMBINATION) FIRINGS

at

White Sands Proving Ground, New Mexico

and at

Long Range Proving Ground, Cocoa, Florida

EXTRACTED FROM

JPL Combined Bimonthly Summary Nr. 5 & 20, February 1948 to 20 April 1948; *Ibid.*, Nr. 6, 20 April 1948 to 20 June 1948; *Ibid.*, Nr. 8, 20 August 1948 to 20 October 1948, JPL/CIT, 15 May 1948, 15 July 1948, and 15 November 1948, respectively.

Long Range Proving Ground Division

Patrick Air Force Base

Cocoa, Florida

Document 12

29 September 1950

BUMPER (V-2/WAC CORPORAL COMBINATION) FIRINGS* AT WSPG AND AT LRPG

FIRINGS AT WSPG**

Rd Nr	Date Fired	Altitude in Miles	Veloc FPS	Purpose of Test	Remarks
1	13 May 48	V-2 69.70	4010	To test separation mechanisms under flight conditions; to test Doppler instrumentation; preliminary fin and spin stability information. Dummy WAC having short-duration, solid-propellant motor.	First large two-stage rocket to be launched in Western Hemisphere. Firing considered successful in all details. Separation completed prior to 68.7 seconds. Doppler followed WAC down to 10,000 ft.
2	19 Aug 48	V-2 8.28 WAC 8.10	1250	Same as above.	First-stage failure, presumably caused by premature closure of alcohol preliminary valve of V-2, due to failure in controlling circuit.
3	30 Sep 48	V-2 WAC 93.40	1280	Live BUMPER WAC propelled by acid-aniline motor, but partial charge (32 sec burning time). Ballast used to simulate weight of full charge so trajectory would duplicate first part of trajectory of fully charged rounds.	WAC exploded prior to separation after successful launching and excellent behavior of V-2 in flight.

* All firings conducted by General Electric.
** See Document 13 for detailed descriptions of BUMPER Round 5 firing at WSPG and Document 14 for similar account of Rounds 7 and 8 at LRPG.

Rd Nr	Date Fired	Altitude in Miles	Veloc FPS	Purpose of Test	Remarks
4	1 Nov 48	V-2 WAC 3.00	1280	Same as Rd Nr 3. First round to incorporate burst diaphragm over exhaust nozzle to preserve ground atmospheric pressure for start of motor preceding separation.	Failure in V-2 due to break in alcohol piping result in explosion of V-2 tail section. Telemetry failed. Beacon signal disappeared.
5**	24 Feb 49	V-2 63.00 WAC 244.00	3850 7553	First fully tanked WAC. Instrumented to measure upper air temperatures. (45 sec burning time). Second round to have burst diaphragm over exhaust nozzle. WAC carried telemetry to transmit technical data pertaining to conditions encountered during flight to ground stations.	V-2 attained speed of 3,600 mph 30 sec after takeoff. WAC reaches 5,150 mph, greatest velocity and highest altitude ever reached by man-made object. First time radar ever operated at such extreme altitudes.
6	21 Apr 49	V-2 WAC 31.00	2600	Fully tanked WAC. Nose cone instrumented to record data on cosmic radiation at altitudes greater than could be reached by other missiles.	Performance normal for 47.5 sec. Cutoff relay operated prematurely due to some malfunction in V-2's control system, presumably caused by excessive vibration due to structural changes to accommodate WAC CORPORAL. Failures of Rounds 2 & 4 were possibly due to same type malfunction.

** See Document 13 for detailed descriptions of BUMPER Round 5 firing at WSPG and Document 14 for similar account of Rounds 7 and 8 at LRPG.

FIRINGS AT LRPG**

RD Nr	Date Fired	Altitude in Miles	Veloc FPS	Purpose of Test	Remarks
7	19 Jul 50			First attempt to launch unsuccessful due to accumulation of moisture in missile after 9 hours in launcher due to delays occasioned by a series of equipment failures. Round 7 returned to hangar for drying and rechecking.	
8	24 Jul 50	V-2 WAC		Fully charged WAC. Experiment called for relatively low trajectory, with separation angle approximately 20 degrees from horizontal, objectives to test separation at missile altitudes approaching horizontal and skin temperatures in dense atmosphere. To determine high velocity, low altitude, temperature pressure, and heat-transfer characteristics from Teflon nose of WAC.	Precession increased program angle, & separation angle was about 13 degrees. Separation occurred, but WAC failed to accelate afterwards. Spin rockets ignited. Optical coverage impaired by clouds. Doppler & WAC telemetry performed well, but Doppler signal was lost soon after separation. Missile beacon performed well.
7	29 Jul 50	V-2 WAC	8213	Same as above.	Precession increased program, & separation angle was about 10 degrees. Separation occurred, and despite error in trajectory WAC CORPORAL attained velocity of Mach 9, the highest sustained speed that had ever been reached in earth's atmosphere. Separation altitude only

Rd Nr	Date Fired	Altitude in Miles	Veloc FPS	Purpose of Test	Remarks
					48,000 feet. Doppler & WAC telemetry records obtained throughout its flight almost to impact. HERMES telemetry & optical records good.

RESULTS OF BUMPER FIRINGS

Through BUMPER firings, it was learned that the speed of a rocket or missile could be increased with each successive stage. Step-rockets, fired when the assistant rocket was at maximum velocity, imparted to the final rocket a speed equal to that of all stages combined. Innumerable problems connected with rocket motor ignition at high altitudes and attachment and separation of successive stages were solved satisfactorily, providing a basis for later missile designs requiring similar experiments, among them being AEROBEE, the direct lineal descendant of WAC CORPORAL. The burst diaphragm was incorporated in the CORPORAL motor design.

[redacted]

[redacted]

[redacted]

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Doc 13

DETAILED LAUNCHING ACCOUNTS

BUMPER Round 5

EXTRACTED FROM

Report No. R50A0501, Project HERMES, PROGRESS REPORT ON BUMPER VEHICLE -- A TWO-STAGE ROCKET-POWERED TEST VEHICLE, Special Projects, A & O Systems, General Electric Company, Schenectady, New York, February 1950, by R. P. Haviland

and

BRL Memorandum Report Nr 504, AN ANALYSIS OF SPIN ERRORS IN THE DOVAP SYSTEM FROM THE RECORD OF BUMPER ROUND NO. 5, Ordnance Department, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, February 1950, by R. B. Patton, Jr.

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[redacted]

THE HAVILAND ACCOUNT

Following is the detailed account of the launching of BUMPER Round 5 at WSPG on 24 February 1949. The success of the whole BUMPER Program was due to the efforts of personnel of the following agencies, activities, and organizations:

- Ballistic Research Laboratory, Aberdeen Proving Ground
- Douglas Aircraft Company
- Frankfort Arsenal
- General Electric Company
- Jet Propulsion Laboratory, California Institute of Technology
- Ordnance Department, United States Army
- Signal Corps, United States Army
- White Sands Proving Ground.

The final preparation and firing schedule for the first BUMPER with a liquid-propellant WAC is given below. There were variations between the two liquid-propellant WAC's, but this schedule was generally followed in all cases:

COUNT-DOWN TIME		REMARKS
Hours	Minutes	
0115	X-360	Start preliminary tests
0215	X-300	Install WAC air dump squib
0255	X-260	Install Doppler
		Test Doppler
		Remove WAC nose line
		Install V-2 batteries
0315	X-240	Start alcohol loading in V-2
		Current transfer
		Close V-2 sectors 2, 3, and 4
0340	X-215	End alcohol loading
		Final weather check
0350	X-205	Start acid loading in WAC (Clear all persons from gantry except persons working on acid loading.)
0450	X-145	Start oxygen loading in V-2
0515	X-120	Start radio silence
0525	X-110	Complete oxygen loading
		Start peroxide and permanganate loading
0530	X-105	Connect WAC spin matches and battery
		Connect warhead detonators
		Throw safe-arm switch in WAC firing circuit
		Close V-2 sector 1
		Connect WAC to V-2 plug (Circuits to WAC starting and dump valves)

COUNT-DOWN TIME Hours	Minutes	REMARKS
		Close access port in V-2 nose
		Install and connect WAC starting squib
		Close access port to WAC
0610	X-65	Replace WAC pressurizing and doppler blowoff line
		Check O-ring in Wiggins plug
		Raise gantry platform
0615	X-60	Check command circuit
0630	X-45	Close road blocks
		Clear launching area of visitors
0635	X-40	Gantry in motion
		Final vane balance
		Connect V-2 igniter
0645	X-30	Clear rocket
		Turn on beacon
		End of radio silence
		Open WAC airline at pithouse
0647	X-28	Open WAC airline in blockhouse (One man on manual valve, other operating solenoid switches)
0650	X-25	Pressurize WAC (Continue to monitor pressure until X01).
0700	X-15	Fire red flare
0710	X-5	Turn on relay motor, ARW-37
		Place doppler and V-2 telemetry on external power
0712	X-3	Rocket clear
		Calibrate doppler temperature telemetry
0713	X-2	Fire red star shell
		Sound post siren
		Place doppler and V-2 telemetry on internal power
0714	X-1	Check clearance light from relay motor, ARW-37
		Monitor pressure in WAC air tank and drop WAC blowoff line
0714:35	X-25 sec	Preliminary stage
0715	X-0	Firing time

Upon arrival at WSPG, the WAC had been taken to the NIKE hangar and given a complete cleaning, checking, and testing. Burstable diaphragms had been installed. After reassembling, the WAC was tanked with aniline and was installed in the nose of the V-2 before erection of the V-2.

Flight Performance of BUMPER Round 5

BUMPER V, the first fully fueled round, was launched at 1514 hours on 24 February 1949, after a delay of about seven hours due to cloud coverage and to failure of a lead through the A4 (V-2) midsection.

The performance of the vehicle was fully satisfactory. The 8-ton stage signal was given at 61 seconds, and the WAC start signal at 63.8 seconds. A4 (V-2) shutdown and separation occurred at 64.5 seconds. The WAC spin motors operated satisfactorily. WAC burnout occurred at 107 seconds.

Performance data are:

	A4 (V-2)	WAC
Maximum velocity	3850 ft/sec	7553 ft/sec
Maximum altitude	63 miles	242 miles
Range of impact	21.5 miles N 5.7 miles E	Not known
Takeoff weight	28297 pounds	621 pounds

Performance of the vehicle was slightly below rated value. The A4 (V-2) velocity was about 150 fps below the integrator setting. This appeared to be due to combined effects of integrator error and slightly low thrust, which introduced an added error. The WAC performance was probably adversely affected by the fact that separation occurred below design altitude, with resulting thrust decrease and drag increase.

During the separation period, the WAC combustion pressure started up within 0.1 second after the start signal and reached 250 pounds within 0.3 second. Peak recorded pressure was 285 pounds, which was not the final value, since movement of the WAC removed the gauge supply load. The WAC moved approximately one inch in the first 0.1 second after the start signal, three inches in the next 0.1 second, and three inches in the next 0.05 second. Motion thereafter was too rapid for the resolution of the telemetry system.

The problems of winds aloft was particularly troublesome for this round, due to the high values of winds existing during the spring of the year. The lateral velocity predictions showed that the vehicle would drift to the east during powered flight. For part of the flight the drift was expected to exceed the allowable limits set by the size of the proving ground, but the valocity at separation was expected to be safe. Up to approximately 50 seconds the average acceleration was to the east, thereafter shifting sharply to the west. The west component maintained until cutoff. Data for calculating the effect of side winds were obtained by differentiation of doppler position data. The reversal of direction at 50 seconds was very apparent. During and immediately after the period of separation, the lateral velocity remained essentially constant.

The changes in lateral valocity between 70 and 100 seconds were not in accord with expectations. The corresponding altitudes were 115,000 and 270,000 feet, so that aerodynamic forces should have been almost negligible. Further, winds at these levels are probably from east to west, so that the WAC, being arrow-stable, would have headed eastward, or into the wind. This possibly accounted for the peak at 80 seconds, and the subsequent westward motion was possibly due to some other factor.

The telemetry equipment aboard the A4 (V-2) functioned well until separation. Signal modulation was lost at this time, due to a short on the 10-kc supply lead, the short having probably occurred when the supply lead to the WAC combustion pressure gauge pulled off.

The doppler unit performed well. Solid signals were received from takeoff until 662 seconds. It appeared that the WAC broke up at this time due to re-entry into the atmosphere.

The doppler telemetry unit did not perform satisfactorily. The signal strength experiment was lost, apparently due to commutator failure. Data from the temperature experiment were recorded.

The impact of the WAC was accidentally located in September 1949. Unfortunately, photographic records of the impact were spoiled in developing. Verbal descriptions indicated that the WAC must have fallen in a flat spin, since impact did not produce an appreciable crater. Air flask and doppler unit were not recovered. They were presumably broken off during descent. The leading edge of the fins showed erosion due to the elevated temperatures encountered during flight. Examination of the WAC motor disclosed that it had burned through at the throat. This was probably the major reason for the below normal WAC performance experienced.

THE PATTON ACCOUNT

Development of a double-unit manifolded spin rocket was discussed in the text. BRL/APG was interested in the effects of a spinning rocket (in this case, the WAC) on the DOVAP (Doppler Velocity and Position) system. Report Nr 504 analyzed such effects; this is the account of the BUMPER Round 5 flight with technical details omitted.

Measurements of position, velocity, and acceleration were made for this round by several independent systems through the burning period. Only DOVAP, however, was capable of tracking the WAC missile after burnout. The latter system consisted essentially of a transmitter fixed on the ground, a transceiver in the moving vehicle, and three or more ground receiving stations. Radiation at a frequency of 38.5 megacycles was broadcast from the ground transmitter to the missile transceiver where the signal was received, doubled in frequency, and re-broadcast to the ground receiving stations. This approximate 77 megacycle signal was then heterodyned with the original transmitted ground signal, which was likewise doubled in frequency. The resulting doppler cycles, together with a suitable time standard, were recorded on 35 millimeter film. . . .

Excellent signals were received from the time of launching through 662 seconds of flight by the six antennae which had been set up on the ground. The supply of film in the recording cameras was, however, sufficient for only 614.5 seconds of the run. In addition to this record, obtained for all six antennae, the data for four receivers, for the interval from 614.5 to 662 seconds, were originally recorded on magnetic tape and later transferred to 35 millimeter film.

DISCRIPTION OF THE MISSILE'S FLIGHT

The first stage of burning covered the time interval from launching to 65.5 seconds, when the WAC missile separated from the A-4 (V-2) at an altitude of 18.3 miles. At this instant, the trajectory velocity was 3895 ft/sec. In the next half-second interval, the WAC missile commenced spinning and by 66.5 seconds had attained a spin rate of 7.1 revolutions per second (rps). The spin rate continued to increase to a maximum value of 7.9 rps at the time of the WAC burnout, then decreased to 7.7 rps, and remained constant thereafter until the missile re-entered the atmosphere on the downward leg of the trajectory. Following separation, only the WAC was tracked by the DOVAP system. Burnout for this missile was observed to occur at 108 seconds at an altitude of 61.8 miles and with a maximum velocity of 7553 ft/sec. The vertical deceleration, however, remained slightly less than the value of g over the next 20 seconds of flight, suggesting a small amount of residual burning. The WAC attained its maximum altitude of 243.7 miles above the X-Z coordinate plane (244.1 miles above the earth's surface) 368.5 seconds after launching. The surveyed point of impact for the WAC missile was 572,200 $\pm$ 500 feet north of the launcher and 19,900 $\pm$ feet west of the launcher.

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BUMPER MISSILES NO. 7 & 8

EXTRACTED FROM

Technical Report Nr 1

The V-2/WAC CORPORAL combination to constitute the BUMPER Missile was the first missile firing conducted at Long Range Proving Ground, Cocoa, Florida. The account of that firing follows.

Long Range Proving Ground Division

Patrick Air Force Base

Cocoa, Florida

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BUMPER MISSILES NO. 7 & 8

PURPOSE OF BUMPER FIRINGS NOS. 7 AND 8

After the completion of the first phase of the BUMPER Program, it was decided to utilize BUMPER Missiles No. 7 and 8 to conduct aerodynamic investigations in the vicinity of Mach 7 at relatively low (120,000 - 150,000 ft) altitude. This decision predicated that the missiles, after take-off, would be guided to essentially a horizontal flight path. It was for this reason that facilities of the LRPG with its available impact area at a range of 250 miles were required. The tests were to be conducted within certain limits of Mach number, dynamic pressure, and Reynolds number to obtain aerodynamic data that could be measured in the WAC with the minimum of internal instrumentation development. Objectives of the LRPG phase of the BUMPER Program were (1) to prove the separation technique at missile attitudes approaching the horizontal and (2) to determine high velocity, low altitude, temperature pressure and heat-transfer characteristics from the Teflon nose of the WAC.

GENERAL

Activity at the LRPG in preparation for these BUMPER flight tests began in September 1949 with preliminary planning and determination of requirements. Because these were the first firings at the LRPG, 95% of the required facilities, personnel and equipment, were not immediately available and had to be obtained for the launchings. At this time, the firings were scheduled for January. However, many postponements resulted when necessary funds were not made available. Most of the training, requisitioning, preliminary clearing of the launching area and installation of communications was accomplished prior to the release of these funds. In April, the funds became available and the dates of the 19th and 26th of July were selected for the firing of BUMPERS No. 7 and 8, respectively. These dates proved to be realistic although the Korean War and the resulting loss of many specialists hampered operations. System check-outs and operational dry runs were conducted during X-2 and X-1 weeks, and all agencies were ready for the first firing on the 19th of July.

Flight Test Operations

On 19 July, the first attempt to flight-test BUMPER No. 7 resulted in a failure to launch, after nine hours on the stand. This was found to be the result of excessive moisture which impaired the electrical insulation of the main fuel valve control electromagnet. It was decided to return BUMPER No. 7 to the base, re-service the entire propulsion system, and attempt another firing of No. 7 after the firing of BUMPER No. 8. The failure of BUMPER No. 7 to launch resulted in a much closer firing schedule. It was mandatory that both firings be accomplished by 1 August because of prior commitments of personnel and equipment elsewhere

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after that date. It was decided that, with concentrated effort, BUMPER No. 8 could be launched on 24 July and BUMPER No. 7 on 29 July. Both of these launchings were completed on schedule. In general, the operating procedures established prior to the firings proved satisfactory. The communications system utilized in the firing was designed for field conditions but proved adequate for the operation. The difficulties experienced in the first attempted launching of BUMPER No. 7 were corrected prior to the later launchings. Range clearance operations were highly successful and no serious delays were encountered because of a foulded range at the scheduled launching time. Technical difficulties and equipment failures, particularly in the instrumentation system, caused most of the delays, as was expected. However, all operations and all preparations improved materially between each launching. Summary of the flight test follows:

FIRING	LAUNCHING TIME Scheduled	Actual	DELAY
BUMPER No. 7 (1st attempt)	0800	1720	+9:20
BUMPER No. 8	0800	0928	+1:28
BUMPER No. 7	0700	0644	- :16

Results

Results of the firings in general were very satisfactory. A qualitative summary of both firings follows:

1. V-2 performance was normal; launching was stable, propulsion was satisfactory.
2. The V-2 pre-set guidance system in general functioned satisfactorily. In azimuth, missile varied less than three degrees. In pitch, programming was excessive by about 10 per cent. This caused a separation altitude several thousand feet less than predicted. This was, in general, true for both firings.
3. Separation occurred in both firings, but the V-2 apparently became slightly unstable and oscillated during the separation periods. The magnitude of the oscillation was approximately two degrees. An apparent failure of the WAC missile in BUMPER No. 8 occurred soon after separation. The failure may have been due to effects imparted during separation, or to instability of the WAC.
4. During the flight of BUMPER No. 8, ignition of the WAC and apparent spin were noted, but probable structural failure in the WAC nose caused a rapid deceleration and loss of all instrumentation. During the flight of BUMPER No. 7 performance was normal, the WAC burned almost to the calculated burn-out time. However, velocity was considerably below that predicted, primarily because of the high drag at low flight altitude.

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5. External instrumentation functioned successfully. Doppler and Askania data were obtained at the ground stations. The tracking telescope on the optical ship provided good data on separation. The results from the internal instrumentation were negative, because the conditions for which the internal instrumentation was designed were never attained in flight. From preliminary analysis, this failure was primarily attributed to the increased pitch program and to the resulting lower altitude and increased drag.

PREPARATIONS FOR FIRING

Preparations for the firing at the LRPG can be divided into two general phases: the preliminary phase, beginning with the initial planning and ending with the arrival of the agencies at the LRPG and the final phase, including those preparations following the arrival of the participating agencies.

Preliminary Preparations

In June 1949, the request to fire BUMPER Nos. 7 and 8 at the LRPG was initiated by the Ordnance Corps through the Joint Long Range Proving Ground Group in Washington, D. C. The first general plan for the firings was made at a conference held at the LRPG on 28 August 1949. Detailed plans were made at two subsequent conferences of the principal participating agencies. These conferences were held at the White Sands Proving Ground and LRPG in October 1949 and January 1950, respectively.

In the fall of 1949 LRPG initiated preparations for the organization and training of personnel required to carry out the firings. Key personnel were sent to White Sands Proving Ground to familiarize themselves with the flight test operations of missiles similar to BUMPER. Upon their return, these personnel conducted detailed training programs for LRPG employees who were to take an active part in the firings. A general orientation program was also carried out for all base supporting activities because over 90% of the Proving Ground personnel had had no previous experience with operations of this type.

The major participating agencies which were associated with the program from its inception were The Ordnance Corps, Ballistic Research Laboratories of the Aberdeen Proving Ground, General Electric Company, Douglas Aircraft Company, California Institute of Technology, Signal Corps Engineering Laboratories and the LRPG. As the latter activity did not have all the personnel necessary to undertake this program, arrangements were made to obtain experienced personnel from White Sands Proving Ground and other agencies to assist in the handling, launching, and in-flight safety operations. In addition, arrangements were made for instrumentation ships and for personnel to perform many range clearance functions.

Procurement and supply of necessary items of equipment presented a major problem in this phase. Supply action had to be initiated on practically all items of technical materiel as none were available.

Installation of facilities required in the launching area was initiated early in January 1950. The installation of communications equipment was begun 1 February 1950. Preparation of the launching site and construction of facilities to house the instrumentation equipment were accomplished with the personnel and monies available. Contracts were let in April for construction of the necessary launching pad and access road. Construction of a temporary block house suitable for the two launchings was begun in May.

During this period, the General Electric Company was assembling the V-2's at White Sands Proving Ground, and instrumentation for the WAC at Schenectady. The Douglas Aircraft Company was fabricating the WAC. The Ballistic Research Laboratories were developing and packaging the necessary instrumentation equipment at Aberdeen and White Sands Proving Ground, and The Signal Corps Engineering Laboratories were completing the necessary modifications to the SCR-584 radars and associated plotting boards.

Final Preparations

Final preparations for the launchings got under way with the first arrival of the participating agencies at the LRPG. These preparations included equipment installation, system check-outs, and operational check-outs. These preparations were, for the most part concurrent, and no attempt will be made to discuss them here in detail. However, they are chronologically summarized below.

8 June - Installation of BRL instrumentation equipment began.

15 June - Construction of temporary blockhouse completed.

18 June - Arrival of WSPG convoy with V-2's and arrival of WAC missiles by air transport.

19 June - Missile check-out began in assembly hangar.

20 June - Construction of launching pad completed.

30 June - Initial erection and test of the gantry stand at base completed.

2 July - Blockhouse to launching pad hook-ups completed and circuit check-outs began.

5 July - Range Clearance Center in operation.

6 July - First high-altitude weather run using hypsometers. (Altitude of 110,113 ft. attained). First AEW search operations of range danger area.

9 July - Installation of BRL shipboard instrumentation completed.

10 July - Range clearance boat arrives. Ground search radar (AN/CPS-5) operating group arrives.

11 July - Hangar interference checks with BUMPER Nos. 7 and 8. All installations for in-flight safety completed. Arrival of in-flight safety operational personnel and remainder of missile handling crew from WSPG. All BRL ground instrumentation checked out.

12 July - All communications installed. Telemetry and optical ships on station off Canaveral.

13 July - First operational dry run. (coordinated check-out of communications, timing, instrumentation, range clearance, and in-flight safety operations.) Final assembly of BUMPER No. 7. Critique of first dry-run.

14 July - Second operational dry-run. Pad and block house installations completed and checked out. Erection of working stand completed at launching pad. Temporary access road completed. Critique of second operational dry-run. Pre-launching conference for BUMPER No. 7.

15 July - Third operational dry-run.

17 July - BUMPER No. 7 moved to launching pad and erected.

18 July - Launching pad interference checked and completed. Final rehearsal for firing BUMPER No. 7.

DESCRIPTION OF TESTS

Flight tests operations included those relating to the actual launching of the BUMPER missiles and were conducted during the period 19 to 29 July 1950 as summarized below.

19 July - First attempted launching of BUMPER No. 7 operations were terminated at 1720 hours.

20 July - Fuel unloaded from BUMPER No. 7.

21 July - BUMPER No. 7 returned to assembly hangar.

22 July - BUMPER No. 8 moved to launching pad and erected. Repair and check-out of BUMPER No. 7 begun.

23 July - Interference check. Final rehearsal for firing BUMPER No. 8.

24 July - Launching of BUMPER No. 8 at 0928 hours.

26 July - Critique of BUMPER No. 8 launching and pre-launching conference for BUMPER No. 7.

27 July - BUMPER No. 7 moved to launching pad and erected.

28 July - Individual operational check-outs of external and missile-borne equipments.

29 July - Launching of BUMPER No. 7 at 0644 hours.

First Attempt - BUMPER No. 7

The launching was scheduled for 0800, but a series of equipment failures delayed a launching attempt. Altogether there were ten delays, resulting in an accumulated delay of over nine hours. Two oxygen refills were required before the launch signal was given at 1720. At that time, the oxygen had been in the missile for over seven hours.

Preparations at the launching pad began at 0001 (X-8) hours. The missile propulsion system checked out satisfactorily. There were several delays in the fueling operations because of a leak in the alcohol truck. Later an acid over-flow occurred which required a detailed inspection of the missile for damage. Failure of the WAC spin rocket firing circuit resulted in a considerable delay, but it was finally decided to launch without the spin rockets.

Range clearance operations were initiated at X-3 hours. These operations proved quite effective and successful. During the entire twelve-hour period when positive range clearance operations were taking place, there were only two occasions when the range was unsafe for a launching. Of these, a short delay resulted when a ship was not removed in time from the impact area.

All external interference had been eliminated in the system in operational check-outs prior to the firing. The internal equipment interference, which had been noticed before launching, and which was reflected in the communications system was undesirable, but had no serious effect on the flight-test operation. However, atmospheric noise began to build up at about 1500 hours and would undoubtedly have had an adverse effect on Doppler data acquisition, had the missile been launched. Weather conditions favorable to firing prevailed throughout the day.

External instrumentation equipment checked out initially, but the missile's Doppler unit had to be replaced at abour X-4 hours, resulting in some delay. Communication between all instrumentation sites was, in general, satisfactory; however, the radio links to ghe instrumentation ships, particularly to the telemetry receiving ship stationed two hundred miles from the launching pad, were the cause of considerable difficulty, thus necessitating a relay between the two ships. However, this did not cause any delay in the preparations schedule, because timing and Doppler signals were received and the count-down was relayed. The most serious failure occurred after the firing had already been postponed four hours; when the Doppler 19-25 megacycle reference transmitter failed. This caused a delay of approximately five hours. The difficulty was finally corrected and the launching was rescheduled for 1715. Two other minor delays occurred because of instrumentation failures; failure of a telemetry recording camera and failure of the cut-off test equipment. However, these delays were negligible.

The firing signal was finally given at 1720. Ignition occurred, but preliminary burning ceased after two seconds because of the failure of a main fuel valve. It is perhaps fortunate that failure at this time did occur, for had the missile launched, other failures in the propulsion system, or circuitry would have been highly probable as considerable condensation had taken place in the missile's interior compartments. This resulted from the liquid oxygen having been in the missile for seven hours.

BUMPER No. 8

In general, the procedures and preparations schedule for BUMPER No. 7 was only slightly modified for the launching of BUMPER No. 8 on 24 July. It had been proved in the first attempted launching that, barring unreasonable delays, the time allotted for the various operations was sufficient. The one major change in procedure was re-scheduling the fueling time for oxygen after all other missile preparations had been completed, except for the arming of the destructor unit and the final vane balance. This allowed a minimum of time for condensation within the missile to take place.

The launching was scheduled for 0800. The pre-launching preparations proceeded on schedule, except for a failure of the HERMES telemetry transmitter which had to be replaced, and for a failure of the fuel cut-off receiver in the missile. Cloud coverage was approaching fifty per cent when the final count-down was initiated.

The missile was launched successfully at 0928, and appeared to follow the prescribed trajectory. However, a later investigation of the records disclosed that the programming was excessive, causing a low separation altitude and the resultant low separation velocity. The WAC separated, but did not accelerate after separation. There was evidence of ignition of the spin rockets.

Optical coverage was impaired somewhat by the cloud coverage, but considerable data was obtained. The optical ship provided considerable evidence of the cause of failure of the Doppler signal. HERMES telemetry functioned very satisfactorily during flight. Doppler and WAC telemetry performed well. However, the Doppler signal was lost soon after separation. This was presumably due to a structural failure of the WAC nose. Missile beacon performance was excellent. The V-2 was tracked through peak to impact. Because of the low altitude and velocity, no significant variations in the internally measured quantities within the WAC were recorded.

BUMPER No. 7

BUMPER No. 7 suffered no damage as a result of the failure to launch on the 19th of July. The missile was thoroughly baked out and complete re-checks of the propulsion and electrical systems were made in the assembly hangar. Since the apparent structural failure of the WAC during the flight of BUMPER No. 8 probably occurred at the junction of the WAC nose with the main fuselage, this junction was considerably strengthened prior to the second launching of BUMPER No. 7.

It was also reasoned that possible recovery of any parts of the missile after impact would aid considerably in analysis should another failure of the WAC occur; therefore, recovery was to be attempted and spotting was to be simplified by placing green dye in the instrument compartment of the V-2 which would be dispersed upon impact.

The missile was slightly damaged structurally in loading it on the meillerwagon on X-2 days. However, after a thorough investigation, it was decided that the missile could still withstand the lateral loads expected. This analysis proved correct. The scheduled time for launching was changed to 0700. This change was predicated on forecasts of unfavorable weather beginning in late morning on X-day, and of the prospect of poor optical coverage if the firing took place after 0900. Prelaunching operations proceeded very well. The cut-off receiver failed during preliminary checks, but was replaced and caused no delay. There were no delays in the preparation schedule. Operations at the launching pad had improved to the point where the time allotted for certain operations, particularly acid loading was in excess of that required. Therefore, it became possible to advance the entire firing schedule. This was particularly desirable because of the pending unfavorable weather.

BUMPER No. 7 was launched successfully at 0644. V-2 performance was satisfactory, with the exception of excessive programming. Separation of the WAC was normal, but the separation altitude was only 48,000 feet. In this flight, the WAC performance was good with approximately rated thrust being developed until burn-out at 103 seconds. The separation angle was only 12 degrees. The high drag forces encountered limited the maximum velocity of the WAC to about 4800 feet per second, based on preliminary data. Spin rockets functioned properly.

Instrumentation results were excellent. Doppler and WAC telemetry records were obtained throughout the flight almost to WAC impact. In addition, HERMES telemetry and optical records were good. However, most of the high speed data to be measured in the WAC were not obtained because of the low velocity obtained. Again radar tracking of the V-2 to impact was effected. The dye pool at the impact point was discovered by range clearance aircraft within three minutes after V-2 impact, but the only remaining parts found were small pieces of wood. No remains of the WAC could be found.

PARTICIPATING AGENCIES

The test program of BUMPER Missiles Nos. 7 and 8 was conducted through the combined efforts of the following Agencies:

1. U. S. Army

   a. CHIEF OF ORDNANCE, sponsored and had overall supervision of the BUMPER program. BUMPER is one of several missiles being developed by the Ordnance Corps under the HERMES project.

   b. BALLISTIC RESEARCH LABORATORIES (Aberdeen Proving Ground, Aberdeen, Md.) were charged with the overall responsibility for instrumentation used in observing and recording the flight tests and for the reduction of data obtained therefrom.

   c. WHITE SANDS PROVING GROUND (Las Cruces, N.M.) furnished general technical assistance for in-flight safety and for the accumulation of technical weather data.

   d. SIGNAL CORPS ENGINEERING LABORATORIES (Ft. Monmouth, N.J.) were responsible for the necessary modifications, installation and operation of tracking radar system used for in-flight safety operations.

   e. PROVISIONAL COMMUNICATIONS DETACHMENT, SIGNAL CORPS (Ft. Monmouth, N.J.) installed and operated the communications system throughout the launching area and its associated facilities in support of the BUMPER flight tests.

   f. 1st GUIDED MISSILE BATTALION, (Las Cruces, N.M.) assisted in the preparation of the missile for launching and also assisted SCEL in the operation of tracking radars during the firings.

   g. COMPANY C 15th INFANTRY REGIMENT, (Ft. Benning, Ga.) assisted in the security of the launching area and its facilities, together with certain buildings at the main base area.

2. U. S. Navy

   a. OPERATIONAL DEVELOPMENT FORCES, (U. S. Naval Station, Key West, Fla.) furnished ships for off-shore instrumentation and AEW aircraft (from Development Squadron 1) for range clearance operations.

3. U. S. Air Force

   a. LONG RANGE PROVING GROUND DIVISION (Patrick Air Force Base, Cocoa, Fla.) furnished technical and operating personnel, certain facilities and equipment and the general coordination of all participating agencies in the conduct of the BUMPER program.

b. 307th BOMB Wing, (Mc Dill Air Force Base, Tampa, Fla.) provided the crash boat and crew for off-shore range clearance.

c. 550th GUIDED MISSILE WING (Eglin Air Force Base, Valpariso, Fla.) provided a B-29 aircraft and crew for interference monitoring and "polly" aircraft and crews for range clearance operations.

d. 502d TACTICAL CONTROL GROUP (Pope Air Force Base, Ft. Bragg, N.C.) furnished operating crews for the AN/CPS-5 search radar used in range clearance.

4. Contractors (Sponsored by the Army Ordnance Corps)

a. GENERAL ELECTRIC COMPANY, (Schenectady, N.Y.) had overall responsibility for the conduct of the flight test, internal WAC instrumentation and preparation of the V-2 for launching.

b. DOUGLAS AIRCRAFT CORPORATION (Santa Monica, Calif.). This organization fabricated the WAC, made necessary modifications to the V-2 and prepared the WAC for launching.

c. CALIFORNIA INSTITUTE OF TECHNOLOGY-(Pasadena, Calif.). In direct support of General Electric and Douglas, this institution conducted the theoretical investigations required for the modification of the V-2 and WAC missiles in their integration as a two-step vehicle.

EARLY MILITARY CHARACTERISTICS EXPECTED OF
THE DRAWING-BOARD CORPORAL

and the

ESTIMATED PERFORMANCE OF THE ORDCIT CORPORAL
SERIES OF GUIDED MISSILES

EXTRACTED FROM

JPL Memorandum Nr 4-12

THE ESTIMATED PERFORMANCE OF THE ORDCIT CORPORAL
SERIES OF GUIDED MISSILES

Jet Propulsion Laboratory, GALCIT
California Institute of Technology
Pasadena, California

30 November 1945

and the

THE HISTORY OF THE ORDCIT PROJECT
UP TO 30 JUNE 1946

Research and Development Service Sub-Office (Rocket)
California Institute of Technology

n.d.

by

H. J. Stewart and W. Z. Chien - Richard C. Miles, Compiler
respectively

EARLY MILITARY CHARACTERISTICS EXPECTED OF THE DRAWING-BOARD CORPORAL

The definitive contract W-04-200-ORD-455 was entered into on 16 January 1945, generally in accordance with the following objectives:

1. Missile was to have a minimum weight of highly explosive payload of 1,000 pounds.
2. Maximum weight of missile was not to exceed weight consistent with good design and maximum payload.
3. Range of missile was to extend up to 150 miles.
4. Dispersion at maximum range was not to exceed 2 per cent, or it was to be a missile suitable for direction by remote control.
5. Velocity of the missile was to be sufficient to afford protection from fighter aircraft.

On May 23, 1945, Colonel Phillip R. Faymonville sent a memorandum to the Chief of Ordnance, Attention: SPOTU, regarding the military characteristics for guided missiles, with a request that all agencies engaged in the development of guided missiles evaluate their development programs in terms of these suggested characteristics:

MILITARY CHARACTERISTICS FOR A GROUND TO GROUND GUIDED MISSILE

1. General. These characteristics described a self-propelled guided missile for use against ground targets. A suitable fire control system and launching equipment were to be included. The requirements listed herein were to be considered as desirable but not restrictive, since the state of development did not permit establishment at this time of detailed characteristics.

2. Missile. The missile was expected to incorporate the following features:

a. Self-propulsion at high speed.

b. Ability to carry at least 500 pounds of explosive or incendiary filler. Ability to carry up to 2000 pounds was, however, more desirable.

c. A maximum effective range of at least 50,000 yards. A maximum effective range of 200,000 yards, however, was desirable.

d. Delay fuze, time fuze, impact fuze, proximity fuze, and continuously controllable fuze.

3. Control. Control of the missile was to include the following features:

a. Continuous control up to the moment of impact and continuous control of detonation to override the time and proximity fuze functions.

b. Flexibility in control to provide internal, external, or predetermined control of the course.

c. Accuracy such as to obtain the least possible errors in range and deflection. Accuracy sufficient to obtain probable errors of not more than 0.25 per cent of range was desirable.

d. The highest degree of security against interference or enemy countermeasures.

4. Miscellaneous.

a. The highest practicable rate of launching was desired.

b. Launching equipment, control equipment, and all accessories were to be transportable by motor vehicles.

c. The period of time required to assemble the equipment for operation after it has been transported was to be as short as practicable. A period of not more than four hours was desirable.

d. Flash and smoke at the time of launching was to be held at a minimum.

Since JPL/GALCIT was engaged under the ORDCIT contract in the development of guided missiles, in particular the CORPORAL series of missiles, JPL conducted the suggested study. The ORDCIT group was carrying out the development of one basic guided missile, the CORPORAL; however, several modifications of this basic missile's power plant were being considered, including:

1. The CORPORAL E, which used a compressed air propellant pumping system, was in an advanced stage of engineering design, and fabrication of missiles was under way.

2. The CORPORAL F, which used a turborocket propellant pumping system, was in an early stage of engineering design, and fabrication of some components had been initiated.

3. The CORPORAL G, which used a gas-generation propellant pumping system, was to be carried only through a paper study by the ORDCIT Project.

As a result of this study, it was expected that the performance of the CORPORAL would be considerably better than the minimum performance specified in the above list of military requirements, although not quite so good as the desired performance. The control system of the CORPORAL met all the suggested requirements.

WEIGHT AND PERFORMANCE ESTIMATES

Since the making of preliminary estimates of the performance of the CORPORAL, the engineering design of the CORPORAL E had proceeded to a point where fairly realistic estimates of the weight, the most important quantity which had been previously somewhat uncertain, could at this time be given. In addition, sufficient basic information was available so that the modifications required by the CORPORALS F and G could reasonably be estimated. The results of this weight study are summarized below:

Missile		CORPORAL E	CORPORAL F	CORPORAL G
Propellant Weight (lb)		6453	6453*	6453
Gross Weight (lb)	500 lb payload	10842	9761	9795
	2000 lb payload	12342	11261	11295
Propellant Weight ÷ Gross Weight	500 lb payload	0.595	0.661	0.659
	2000 lb payload	0.523	0.574	0.572

*There is an additional 200 lb of propellants for operating the turbine fuel pumping system in the CORPORAL F. This is included in the gross weight but not in the propellant weight.

The weight estimates included, besides the payload, an allowance for the radio control equipment. The CORPORAL was considered to be a laboratory test vehicle; hence, the payload it was expected to carry was composed of special instruments for obtaining flight and control characteristics. A similar missile carrying a warhead of the same weight, however, would have had the same performance.

Previous estimates of the CORPORAL's performance were based on a propellant weight of 6000 pounds; the expected performance on a direct weight basis should have been better, according to revised estimates of propellant weights. The expected maximum ranges for the CORPORALS follow:

Missile		CORPORAL E	CORPORAL F	CORPORAL G
Maximum Range (yd)	500 lb payload	135,000	210,000	208,000
	2000 lb payload	80,000	117,000	115,000

The method used for correcting for the increase in propellant weight overestimated the effect of drag on the missile and was thus somewhat conservative. Moreover, several minor aerodynamic improvements in the external shape of the CORPORAL had been introduced after the first estimates were made as to performance. A revised maximum range calculation gave the following result:

Missile		CORPORAL E	CORPORAL V	CORPORAL G
Maximum Range (yd)	500 lb payload	153,000	270,000	246,000
	2000 lb payload	95,000	140,000	123,000

It may be noted that the expected performance of the CORPORALS was markedly better than the minimum performance (500-pound payload and 50,000 yards range) suggested in the appended list of military characteristics; however, the desired performance (2000-pound payload and 200,000 yards range) was not quite attained. It may also be noted that the CORPORAL G was expected to have a performance almost as good as that of the much more intricate and costly CORPORAL F.

CONTROL SYSTEM

The control system planned for the CORPORAL was very complete and was expected to fulfill all of the functions set forth in the list of desired characteristics except that, being a laboratory missile, it had no provision for any type of warhead or fuze. The control system embodied a complete autopilot, which could be set for any desired trajectory within the maximum range limits. In addition, there were provisions for overriding controls in both pitch and yaw so that manual control from the ground control station was possible. The maneuverability was sufficient to attain the desired accuracy of 0.25 per cent of range for a fixed target. The radio control was carried out by means of a coded radar link and could thus be expected to have a very high degree of security against enemy countermeasures.

LAUNCHING SYSTEM

The launching system for the CORPORAL was similar to that used on the V-2; that is, the missile was to be set up on a small support in any convenient open space, serviced, and then fired. It was planned to use a standard Aerojet Service Trailer to service the missile, and this process was not expected to require longer than approximately two hours.

For a laboratory missile, such as the CORPORAL, the firing rate was, of course, expected to be very low, as all the special equipment had to be checked and calibrated before firing.

CONCLUSIONS

1. The expected performance of the CORPORAL was considerably better than the minimum performance specified in the attached list of military characteristics, although it was not quite so good as the desired performance.

2. The control system of the CORPORAL fit all the requirements given in the attached list of military characteristics.

ESTIMATED PERFORMANCE OF THE ORDCIT CORPORAL SERIES OF GUIDED MISSILES

(U) As discussed in the text, Dr. von Kármán and his associates in the GALCIT Project had been investigating propulsion and propellants since 1936. He and some of this group several months before the initiation of the ORDCIT Project (27 July 1943) published a study of the substitution of pumps for a pressure-tank system as a metter of weight limitation:

> "When the work on the jet motor for long duration was started, it became evident that the point of view of weight limitation that the propellants would have to be fed by propellant pumps instead of the standard pressure-tank system. The question then arose as to the magnitude of the motive power necessary to drive these pumps and its source. A preliminary estimate showed that the necessary power to drive the propellant pumps for the projected 2,000-pound-thrust motor was 37 hp, provided the motor chamber pressure were 550 psi. Among the suggested methods of furnishing this amount of horsepower was one originated by Dr. Theodore von Kármán. It consisted of utilizing the ejector action of the motor jet to drive an air turbine. Air was to be drawn through the air duct before entering the guide bucket. After leaving the guide bucket, the air was to drive a rotating turbine wheel. The air was then to mix with the exhaust, which was to maintain the flow by ejector action, and leave the system." (Ref von Kármán, Theodore, Tsien, Hsue-Shen, and Canright, Richard B., A STUDY OF THE POSSIBILITY OF USING THE EJECTOR ACTION OF THE JET AS A SOURCE OF POWER FOR DRIVING PROPELLANT PUMPS, p. 1, Air Corps Jet Propulsion Research, GALCIT Project Nr 1, CIT, 27 July 1943.)

(S) The above is an example of the theoretical studies made in the field of propulsion systems. The CORPORAL F TURBOROCKET did not, however, fit into that category. The experimental work was performed on the CORPORAL 20,000-pound-thrust scale. Aniline-furfuryl alcohol (80%-20%) and 6½% NO_2 (FNA) were used as propellants. Experimentation evolved a successful turbopump which proved itself in static firings. The specific requirements of the CORPORAL program did not, however, warrant additional development of the turborocket system. As a consequence, no additional experimental work on the turbopump system was performed after 1948. (Ref JPL Rpt Nr 20-100, op. cit., pp. 77-78.)

(U) A somewhat oversimplified explanation of this feed system is that it consisted of a pair of centrifugal pumps to deliver the propellants to the motor. These pumps were powered from a turbine driven by gases generated from the propellants themselves.

(C) Although the use of compressed air was adopted to force propellants to the CORPORAL's engine, experiments were never suspended in an effort to develop a satisfactory gas-generation liquid-propellant-pumping system. Weight reduction of the missile, increased efficiency, a shorter-length missile, and simplification of logistics in the matter of not having to supply compressed air in the field were all claimed for the system. Experiments and tests eventually led to the development of a dual gas-pressurized propellant-pumping system. The experiments were advanced to the point of carrying out two firing tests, utilizing modified CORPORAL missiles. The first round was fired on 17 November 1955 and reached a range of 124.8 kilometers. On 13 March 1956, the second round attained a range of 126.8 kilometers. It was concluded that both rounds demonstrated successfully the dual-generated gas-propellant-pumping system. These two field tests completed the flight evaluation of the gas-generation system. (Ref JPL Rpt Nr 20-100, op. cit., pp. 78-82; Dunn, Louis G., Meeks, Paul J., Denison, Frank G., Jr., ORDCIT Project Memorandum Nr 4-59, PRESENT STATUS OF THE CORPORAL DEVELOPMENT, JPL/CIT, 17 March 1950; Dunn, Louis G., Director, JPL/CIT, "The Development of the CORPORAL Missile (XSSM-G-17)," SHORT-RANGE SURFACT-TO-SURFACE MISSILES, Presented to the Committee on Guided Missiles, R&D Board, Department of Defense, 25 and 26 January 1951 and 7 June 1951.)

UNCLASSIFIED

Doc 16

ORDCIT Project

Contract No. 04-200-ORD-455-RAD, 2865-1

ASF ORDNANCE DEPARTMENT

EXTRACTED FROM

ORDCIT Memorandum No. 2

RESEARCH PROGRAM FOR THE SECOND TYPE OF LONG-RANGE JET PROPELLED MISSILE

(XF30L20,000)

by

Theodore von Kármán, Director

Guggenheim Aeronautical Laboratory

JET PROPULSION LABORATORY
GALCIT

California Institute of Technology
Pasadena, California

August 20, 1944

UNCLASSIFIED

RESEARCH PROGRAM FOR THE SECOND TYPE OF LONG-RANGE JET PROPELLED MISSILE

(XF30L20,000)

Missile XF30L20,000 was to be a test missile to be used as a means of carrying out basic development work on controls and launching. The missile's tentative specifications follow:

Gross weight	10,000 pounds
Rocket thrust	20,000 pounds
Rocket duration	60 seconds
Specific propellant consumption	0.005 lb/sec/lb thrust
Average operating altitude of rocket unit	15,000 feet
Range	30-40 miles
Diameter	30 inches
Launching acceleration	6g
Maximum flight acceleration	6g
Launching velocity	160 fps
Launching length	100 feet
Launching thrust	140,000 pounds
Stabilization and control	Fins

Using as propellant combination red fuming nitric acid and aniline, Model XF30L20,000 was at this time expected to have turbine-driven propellant pumps, using combustion gases from the combustion of its own fuel to furnish the motive power for her feed-propellant pumps. The missile was being planned as a turborocket, in other words.

The preliminary weight breakdown of the missile follows:

Total propellant weight	6,500 pounds
Propellant tanks	800 pounds
Missile structure	1,000 pounds
Rocket unit (turborocket)	1,000 pounds
Remote control equipment	700 pounds
Total	10,000

Two turborocket designs were envisaged:

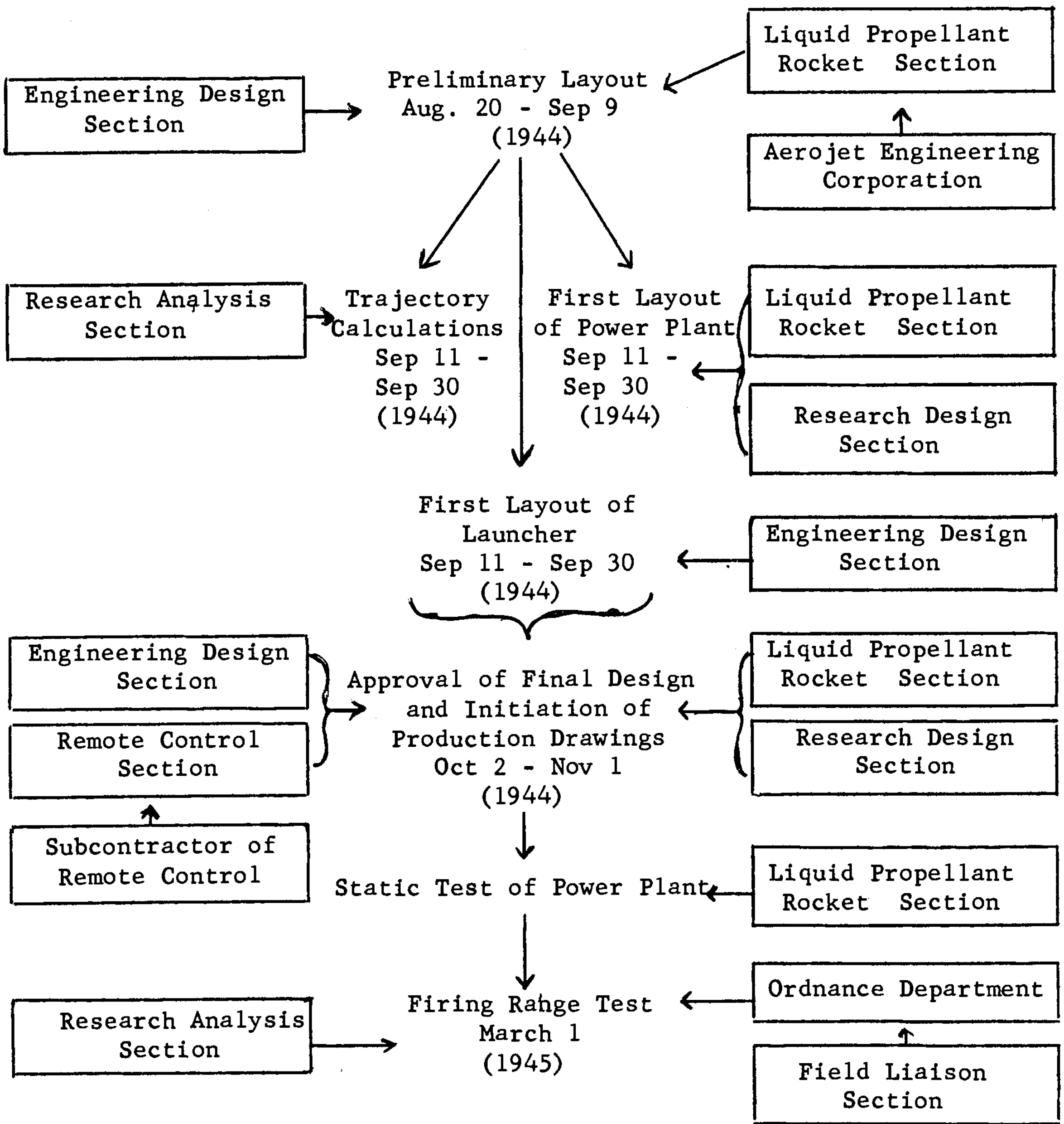
Design I.	F -- Aerojet 3,000-pound thrust motors		
	Chamber pressure	=	310 psi
	Feed pressure	=	510 psi
	Mixture ratio	=	3
	Turbine horsepower	=	240
	Pump rpm	=	15,000
Design II.	1 -- 20,000-pound thrust motor		
	Chamber pressure	=	500 psi
	Feed pressure	=	700 psi
	Mixture ratio	=	3
	Turbine horsepower	=	300
	Pump rpm	=	15,000

Design I would have used already developed Aerojet rocket motors of 3,000-pound thrust. It had the advantage of utilizing a proven motor. The second design had the advantage of lower propellant consumption, but delay in its development could be expected because of lack of experience in constructing a large rocket motor of 20,000-pound thrust.

The following highly optimistic (as later developed) tentative time schedule was set for designing and constructing the XF30L20,000:

TIME SCHEDULE FOR DESIGNING AND CONSTRUCTING THE XF30L20,000

To carry out the design and construction of the XF30L20,000, the following tentative time schedule is set:



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Doc 17

INITIAL DEVELOPMENT OF THE CONTROL SYSTEM OF CORPORAL E

by

SPERRY GYROSCOPE COMPANY, INC.

Miles, Captain Richard C., Compiler

(Captain Miles was at the time of compilation of the above history one of the liaison personnel assigned to this sub-office.)

The History of the ORDCIT Project up to 30 June 1946

Research and Development Service Sub-Office (Rocket)
California Institute of Technology
Pasadena, California

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SPERRY GYROSCOPE COMPANY, INC.
GREAT NECK, LONG ISLAND, N. Y.

GROUND ARMAMENT RESEARCH DEPARTMENT
Mail Station 6N0507

Reference: Our 5253.18038 April 22, 1946.

Army Service Forces,
Research and Development Service Sub-Office,
Office of the Chief of Ordnance,
California Institute of Technology,
Pasadena 4, California.

Attention: Lieutenant R. C. Miles.

Dear Sir:

As requested in your letter of March 8, 1946, we are forwarding to your attention a historical account of the connections of this Company with the ORDCIT Project.

This report has been prepared in strict chronological form and no attempt has been made to separate the various incidents into subdivisions such as contractual negotiations, engineering, manufacturing, etc., as we were not certain of the practicality of this presentation from the viewpoint of its later use.

Much of our actual manufacturing work with this Project has thus far been concerned with modification and adaptation of existing standard instruments; however, a few items which are new are mentioned in our summary.

Your letter invites comment on sources of delay to the Project. There have been many small delays, but they are largely attributable to the pressure of other war work and to the natural re-assessments at the end of the war. There seemed to be undue delay in completing contractual arrangements but this did not greatly hold up the Project since engineering work was carried on at a normal rate pending the formal agreements.

There was some difficulty in learning what reports were available on related projects during the preparation of our study reports. This difficulty is no doubt a universal one, and we will be heartily in favor of any technical index or abstract service which could be made effective.

[redacted]

[redacted]

We hope that the historical outline will prove satisfactory as submitted and that you will advise us of any further requirements in this regard.

Very truly yours,

SPERRY GYROSCOPE COMPANY, INC.

s/t G. E. WHITE

Encl: Prog. Report 5-15-45
Historical Summary
cc: O. A. Vielehr.
GEW/RBN: jt

[redacted]

[redacted]

HISTORY OF THE ORDCIT PROJECT AT THE SPERRY GYROSCOPE COMPANY TO 31 JANUARY 1946

SUMMARY

The participation of the Sperry Gyroscope Company in the ORDCIT Project to date may be divided into four parts. These are:

(a) The design and manufacture of automatic control components for the CORPORAL E rocket, including analysis and research on new servo motors and signal systems.*

(b) An over-all study, submitted in the form of a report, of control systems for guided missiles.

(c) The design of automatic control components for the CORPORAL F rocket, now under way.

(d) A study and report of a possible command control system for the CORPORAL F rocket, now being prepared.

Of the above phases, (a) and (b) are complete (except for some mofification work in conjunction with the CORPORAL E equipment and the actual flight tests yet to be held). Phases (c) and (d) are now in progress. In addition to the active work outlined above, members of this company have endeavored to keep abreast of current trends and developments by witnessing firings of the PRIVATE and WAC CORPORAL rockets, by attending conferences and symposiums on subjects related to our work, and by visiting other concerns and agencies which are occupied with work of a similar nature.

Under (a), several new instruments were required, which are referred to in Progress Report No. 4-14.*

(a) A radically new pneumatic servo of very small weight and high power.

(b) A special signal "mixer" (pneumatic amplifier) for controlling the servos.

(c) Special pneumatic pickoffs for gyros to give gyro signals to the mixer.

(d) Design of a special rate gyro for stabilization.

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*Harris, H., Harcum, W. M., and White, G. E., "Control System for the CORPORAL E Missile," Progress Report No. 4-14, Jet Propulsion Laboratory, GALCIT, 10 May 1945.

[redacted]

(e) Design of a pitch schedule control.

(f) Design of an angular rate telemetering unit.

CHRONOLOGY

The original conversations on the ORDCIT Project were held between personnel of the California Institute of Technology and the Sperry Gyroscope Company in late July 1944. In a letter to Sperry dated 8 August 1944, Dr. Clark B. Millikan stated in part:

> "The California Institute, with its own staff, is primarily concerned with the propulsion, launching, and design problems of these missiles. However, in the over-all picture the problem of remote control occupies a very essential role. The California Institute has agreed to accept the responsibility for this phase of the work as prime contractor. It is proposed, however, that the actual development work on the necessary servo-control mechanisms and the electronic or other instruments required for the remote control of these missiles be carried out by other qualified organizations under subcontract with the Institute.
>
> "The Ordnance Department has suggested that we correspond both with you and with the Massachusetts Institute of Technology in this connection.
>
> "The control problem is that of furnishing guiding and control for such missiles with as great an accuracy as possible. Both weight, size, and insensitivity to acceleration will, of course, be of fundamental importance in connection with the control mechanism."

Further talks were held between CIT, Ordnance, and Sperry during the ensuing months. The outcome of these conversations was a proposal from Sperry on 11 October 1944 to undertake an engineering investigation covering a period of approximately 3 months.

The principal product of this investigation was to be a report which would include:

(a) A recommendation of a control system for the CORPORAL missile (later the CORPORAL E) made up of available components where possible, for early experiments on the first test models.

(b) Initial steps in the procurement of components.

(c) An outline indicating how the continued development of missile controls and associated ground devices might proceed.

On 10 October 1944, Sperry personnel visited the Union Switch and Signal Company and the Gulf Development and Research Company in Pittsburg to investigate the control principles of AZON and RAZON. On 19 October 1944, a visit was made to Wright Field for the purpose of studying the control mechanism from a captured German V-1 robot bomb.

By 11 November 1944, informal engineering plans for control of the CORPORAL provided for continuous stabilization in rooo, control in pitch during the burning time only, and control in yaw by radio signals from the ground. Pneumatic gyro and servo units were contemplated at this time.

A letter order from CIT dated 16 November 1944 called for ten control systems for the CORPORAL. This letter followed closely the suggestions made in the Sperry proposal of 11 October.

Sperry personnel held conferences with CIT and Ordnance personnel and witnessed firings of the PRIVATE at Pasadena and Leach Lake, California, from 29 November to 11 December 1944. At this time, the understanding reached as regards equipment to be supplied by Sperry for the CORPORAL rockets was as follows:

(a) Gyros and control amplifiers for the automatic pilot.

(b) Servo motors (possibly four per unit) for the control surfaces.

(c) Gyros to give telemetering information (probably separate from the pilot).

(d) The transmitter-receiver unit for external trajectory control.

(e) Power supplies and internal plumbing for the control equipment where necessary.

(f) Ground checking equipment for the pilot for design testing.

At this time, approximately six CORPORAL models were being planned, each containing variations in power plants, instrumentation, or control surfaces.

In addition to the above equipment plans were made to submit two reports. The first would cover specific plans for the CORPORAL series of missiles, while the second would present our opinion on the subsequent system developments which might be expected.

By 3 January 1945, it had been decided to use an electric pilot system in the CORPORAL. It was planned to use two gyrosyn gyroscopes to obtain the control signals in the roll and pitch axes and an A-12 pilot vertical gyro for the yaw axis control signal. Four electric servos from the A-7 pilot were to be located in the tail, one being used for each movable fin.

On 12 January 1945, Sperry requested that CIT consider issuing a letter purchase order authorizing the expenditure of a stated amount pending the execution of a definitive contract. It was also requested that the contract include provisions for revising the price upward or downward on the basis of actual experience at the time when approximately 40 per cent of the proposed work was done.

A letter from CIT on 25 January 1945 stated that the number of CORPORAL units of the gas pressure type had been increased to ten. This would require delivery of ten automatic steering controls by the end of June 1945. It was requested that Sperry submit a proposal covering the production of these ten units. It was also pointed out that the transmitter-receiver unit for external trajectory control would be supplied by CIT rather than by Sperry.

A letter order dated 25 January 1945 from CIT called for "services consisting of research, investigation, and engineering in connection with the development of methods and devices for the remote control of long-range missiles as outlined in your letter of 11 October 1944, and for complete reports, drawings, and specifications describing all work done in connection therewith for a fixed price payable upon completion of the work as outlined in said letter."

The required copies of this letter order were signed by Sperry and returned to CIT in a letter dated 7 February 1945. In this same letter, receipt of CIT's letter of 25 January, which increased the number of CORPORAL missiles to ten, was acknowledged and it was pointed out that the change in quantity would add to the difficulties of our facilities and would require further study prior to our proposal.

Purchase Order No. 119778 dated 19 February 1945 from CIT confirmed a previous telegram authorizing a stated expenditure for miscellaneous parts, etc., as required to fabricate ten CORPORAL units.

A letter from Sperry to CIT dated 21 February 1945 stated that the increase in number of pilots to ten would prevent Sperry from meeting the desired delivery schedule (complete in June 1945) if electric components were used. It was therefore stated that a change from electric to pneumatic pilots would be necessary to meet the above schedule.

A letter from CIT dated 16 March 1945 stated that the change from electrical to pneumatic components was acceptable to CIT.

On 30 April 1945, Sperry submitted a brief progress report on the status of control equipment for CORPORAL E. (This report has been issued as Progress Report No. 4-14 by the Jet Propulsion Laboratory, GALCIT.)

A letter dated 7 May 1945 from Sperry to CIT made a proposal for the manufacture of ten control systems as ordered, plus one estra system and a set of ground test accessories. The items to be supplied were listed as follows:

Item	Quantity	Description
		Control systems for the CORPORAL comprising:
1	11	(a) Servos and gyro equipment, etc., for an automatic pilot as required.
2	1	(b) Gyros and pickoffs for telemetering set of accessories for ground test and checking of system.
3		Engineering reports, including such information of instructional nature as may be essential, and also complete sets of photographs of the various subunits of the control system.
4		Set of vandyke reproductions of schematics, flow diagrams, assembly drawings, and certain details as used for engineering and manufacture. Included shall be the services of an adequate number of engineers to assist during installation of equipment, set-up, field test, and firing operations.

It was proposed that delivery should start in June and be completed in July 1945.

A telegram followed by a letter from CIT, both dated 15 May 1945, advised Sperry that the revised estimated dates of delivery required for the CORPORAL E controls were as follows:

One automatic pilot (for tests at JPL-GALCIT)	1 July 1945
Five automatic pilots	1 September 1945
Five automatic pilots	15 October 1945
One servo unit (for Muroc tests)	1 August 1945

The letter also stated that the Sperry proposal submitted on 7 May 1945 was being studied.

Purchase Orders No. 11977-S (Supplement 1) and 17130-S were received on 23 May 1945 from CIT for material outlined in the Sperry proposal of 7 May 1945.

A letter dated 5 June 1945 from CIT pointed out delays in completing the subcontract because of difficulty in obtaining adjustments in the prime contract to cover the terms of the subcontract.

On 26 June 1945, one complete ORDCIT pilot was sent to CIT. Also included was the required telemetering system as agreed upon previously.

Sperry representatives attended the guided missile conference at the Aberdeen Proving Grounds from 25 June to 6 July 1945.

On 13 August 1945, Sperry suggested by letter to CIT that the suplementary purchase orders should be superseded by a supplement to the base subcontract. A recommended revision of certain pertinent articles of the subcontract was also suggested. It was pointed out that it would be necessary for CIT to execute the subcontract returned on 26 April 1945 before a supplement could be prepared. It was further requested that the date of completion of the study report surveying control methods for guided missiles be postponed from 30 June to 30 September 1945.

Sperry personnel visited the Applied Physics Laboratory at Silver Spring, Maryland, and the Ballistics Research Laboratory at Aberdeen, Maryland, during 23 and 24 August 1945, for the purpose of becoming acquainted with related guided missile projects.

A letter dated 25 August 1945 from CIT to Sperry stated that a supplement to the related prime contract had been received permitting CIT to execute the subcontract with Sperry with the revisions previously agreed upon.

During the month of August 1945, Sperry and CIT personnel conducted tests to investigate the feasibility of driving a servo motor by means of gases generated by a burning charge. The tests were unsuccessful since the soot given off during burning caused the servo motor to become inoperable after a few seconds. Nevertheless, there was general optimism as to the future of this method of energy storage.

During the month of October 1945, Sperry engineers witnessed firing tests of the WAC CORPORAL missiles at the White Sands Proving Ground, Las Cruces, New Mexico. During these visits, it was decided that Sperry would submit a proposal for the design and manufacture of ten sets of controls for the CORPORAL F rocket. It was decided further that we would inform CIT of the approximate size and scope of the reports to be prepared by Sperry so that a decision could be reached as to whether Sperry or CIT would do the reproduction work.

During the visit of Sperry personnel to CIT during October 1945, it was decided to develop a contact air speed switch to turn on the pitch mechanism after a given air speed had been reached.

A letter dated 2 November 1945 from Sperry to CIT outlined the scope of the various reports which this company planned to make as previously agreed upon at White Sands.

The list of reports was as follows:

> "Preflight Checks and Operations for CORPORAL E Controls," about 3 pages.

"Report on Controls for CORPORAL E," about 30 pages.

"Proposals for Future Development of Control Components for Guided Missiles," about 5 pages.

"Study of Control Systems for Guided Missiles," about 40 pages.

On 19 November 1945, Sperry sent to CIT a draft of the proposed preflight checks and operations for CORPORAL E controls.

It should be pointed out that throughout the period covered by this history, engineering liaison between CIT and Sperry was continuously maintained. This liaison was in the form of letter correspondence, telephone contacts, and personal visits by both parties. Because of the number of contracts involved and the detailed nature of their subject matter, all but a few have been omitted from this outline.

On 30 November 1945, Sperry, preparing to make a proposal covering the control equipment for the CORPORAL F missile, asked CIT certain questions for the purpose of clarification of basic aims and policies. The information desired included:

(a) The dates of final design freeze, first installation, and firing of the CORPORAL F.

(b) Whether final design of CORPORAL F components was dependent upon results of CORPORAL E firings.

(c) Whether the CORPORAL F program was one of basic research as was the case with earlier programs where the main objectives were the accumulation of test data rather than the convergence of final manufacturing designs.

(d) Who was to be responsible for telemetering.

The answers received to the above queries by telephone were as follows:

(a) Based on the results of the CORPORAL E firings, the design of the CORPORAL F would be worked over and frozen about July 1946. The first models of CORPORAL F would be ready for installation about November 1946. The firing dates were yet to be determined.

(b) It was believed that test data and information on the CORPORAL E should be obtained before setting final design constants for the CORPORAL F controls. The completion dates of CORPORAL E were scheduled for April or May, with firings in June 1946.

(c) The CORPORAL F program was still one of basic research.

[redacted]

(d) It was agreed that Sperry would make a separate proposal on telemetering when more definite information on requirements become available.

On 6 December 1945, a letter was received from CIT stating that the air speed switch model seemed satisfactory but that final decision would await the results of wind tunnel tests. It was further stated that changes in the tail structure of CORPORAL E required locating the rate gyros within the body of the missile rather than in the tail, but that the mixer valves and servo motors would ramain in the fins. The transfer valve and low-pressure regulator would be mounted in a space near the motor nozzle.

A letter dated 7 December 1945 from CIT acknowledged Sperry's letter of 2 November 1945 on the subject of intended reports and stated that the general outline of the reports was satisfactory. A reporting standards memorandum was also sent for guidance during preparation of the reports. The reports were assigned numbers as follows:

"Report on Controls for CORPORAL E," Report No. 4-15.

"Study of Control Systems for Guided Missiles," Report No. 4-16.

It was requested that Report No. 4-15 be prepared on vellum and sent to CIT for reproduction while Report No. 4-16 was to be printed by Sperry.

On 4 January 1946, Sperry received estimated trajectory plots from CIT for rounds 1 and 2, and 3 to 10 of the CORPORAL E.

During 3 and 4 January 1946, Sperry personnel attended a symposium on the guidance and launching of supersonic missiles at the Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland.

On 25 January 1946, Sperry sent to CIT a proposal for work to be done in connection with control equipment for the CORPORAL F missile. Eleven sets of control equipment for the CORPORAL F were proposed, including the following:

(a) Test equipment and fixtures required for use in installation and field test work.

(b) One hundred copies of report covering work done during design and manufacture.

(c) One hundred copies of report covering installation and operation. (These reports to be delivered at the time of assembly of the first set of controls for CORPORAL F.)

[redacted]

(d) One set of vandyke reproductions of drawings used in manufacture.

(e) Field engineering assistance as required during installation and firing.

(f) Investigation of power supplies utilizing rocket fuels in collaboration with CIT.

In addition to the above, it was proposed to make a study of automatic ground control for the CORPORAL F. This study was for the purpose of providing data as to the practicability of introducing automatic control mechanism between the radar tracker and the missile.

It was further proposed that a price revision clause be included in the contract authorizing a price redetermination either upward or downward based upon cost experience after the shipment of the first four sets of control equipment.

A further chronology is being prepared for events after 31 January 1946.

Signed: G. E. White

G. E. White
SPERRY GYROSCOPE COMPANY, INC.
April 22, 1946.

SUPPLEMENT TO THE
HISTORY OF THE ORDCIT PROJECT

at the

SPERRY TYROSCOPE COMPANY, INC.

1 February 1946 to 31 March 1946

A meeting was held at Sperry on 14 February 1946 between CIT and Sperry personnel. At this time, CIT pointed out that the latest calculations showed an unexpected roll instability when CORPORAL E missile passes through the trans-sonic region. Sperry was asked to investigate means of obtaining additional roll torque from the control system. It was estimated that two CORPORAL E missiles would be ready for firing in July 1946. Sperry was further requested for budget reasons to separate the work to be performed in connection with CORPORAL F into two parts; (1) preliminary engineering and laboratory work up through the CORPORAL E firings, and (2) the design and manufacture of the necessary controls.

On 19 and 20 February, Sperry personnel attended the guided missile telemetering conference at Princeton University.

On 21 February 1946, Sperry outlined in a letter to CIT three methods of increasing roll stabilization torques. These methods were listed in order of practicality:

(a) Operate the servos at double the air pressure of 100 pounds per square inch and redesign the gear boxes to allow double the torque output.

(b) Have the roll signal operate all four control surfaces instead of two surfaces as with the previous design.

(c) Design roll trim tabs into the missile structure.

On 21 February 1946, one hundred copies of Report No. 4-16, "Study of Control Systems for Guided Missiles," were shipped to CIT.

A letter from CIT dated 28 February 1946 stated that it would be necessary both to increase the servo air pressure from 100 to about 165 pounds per square inch and to install an additional mixer and transfer valve so that the rudders as well as the elevators would serve to correct any rolling torque, especially the high torque caused by slight fin misalignment which is expected when passing through the trans-sonic region. It was requested that an effort be made to increase the torque available at each control surface by approximately a factor of 3.

As a result of the above letter, the following steps were immediately undertaken by Sperry:

(a) Increasing the strength of the output gears from the servos. (Former gears would fail at about 70 foot-pounds and an output torque of 100 foot-pounds was now required.) In addition, the gear ratio in the servo was reduced from 206:1 to 125:1, in order to maintain approximately the same over-all gear ratio between the air servo and the control surface.

(b) Procurement of the required additional transfer valves from Navy surplus stock. A decision was made to cut up the present block of three transfer valves and to install an extra transfer valve so that separate elements might be installed in each fin near the corresponding servo.

(c) Procurement of additional mixers as required.

(d) Minor changes in the plumbing system.

Operation of the servos at 300 pounds per square inch was believed necessary. It was believed that if no unforeseen problems arose, the 15 May 1946 delivery date might still be met.

From 13 March to 16 March 1946, Sperry personnel attended an aeronautical symposium on problems of the upper air at CIT.

Signed: G. E. White
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EARLY TROUBLES ENCOUNTERED BY THE OUTSIDE FABRICATION DEPARTMENT, JPL/GALCIT, CIT, AND THEIR SOLUTION

EXTRACTED FROM

The History of the ORDCIT Project up to 30 June 1946, Research and Development Service Sub-Office (Rocket),

by

Richard C. Miles, Compiler

Since the development of the CORPORAL Missile System from the drawing-board PRIVATE A through deployment of the CORPORAL as a tactical missile has been delineated as having performed an educational function in addition to the traditional function as a weapon, early problems confronting actual fabrication are herewith presented. It will be noted that JPL personnel and private fabricators were being "educated" concurrently.

California Institute of Technology
Pasadena, California

n.d.

[redacted] UNCLASSIFIED

THE OUTSIDE FABRICATION DEPARTMENT*

The translation of any ORDCIT design into a completed material unit rightly begins with the arrival of the combined drawings and approved production schedule in the joint office of the ORDCIT machine shop and Outside Fabrication Department, and thereby establishes the point where any history of the production aspects of the project also must begin. In that office, a swift survey to determine the essential factors of what is required, how many are required, and when, usually canalizes any job immediately either to the machine shop or to the Outside Fabrication Department, which are closely coordinated under the same supervision. Each is enabled in that way to supplement and reinforce the fabrication experience of the other, and frequently can share the responsibility for a completed assembly.

The machine shop was established during the early days of the Jet Propulsion Laboratory primarily to furnish that specialized apparatus and equipment, not available commercially, which were necessary to basic and original research. Initially, it was concerned almost exclusively in turning out experimental devices never previously designed or fabricated; that tradition still dominates the shop's activities. Gradually, it has been equipped with the best obtainable machine tools along certain lines, and has been manned with a superior staff of experienced machinists. Theoretically, and if possible, the first experimental unit of any new design is still fabricated within the machine shop, not only to test the soundness and practicality of the design but also to apprehend any new fabricating technique which might assist any subsequent outside vendor.

However, the ORDCIT machine shop did very little fabrication work on the ORDCIT missiles, chiefly because it possessed neither the extensive facilities nor the large manpower required, and also because the fundamental technical principles involved had already been established by previous research, and in every case only additional and amplifying data were now desired.

In the Outside Fabrication Department, the main emphasis quite naturally lies in the expert detection of outside vendors, whose experience, equipment, and talents fit them preeminently for the precise requirements of an individual job. In most cases, the smaller specialized concerns were found the most satisfactory for ORDCIT needs. The use of larger firms was generally impossible, because of ORDCIT inability to obtain a manpower priority; thus any ORDCIT work in the larger firms was compelled to retreat indefinitely before production orders for the Armed Forces. In some instances, this became a serious handicap. Moreover, most of the large corporations during the war were confronted not only with an immense backlog of high priority orders, but also with the

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* Compiled by the ORDCIT Outside Fabrication Department (Jason Walker, Anthony Tocco, Robert Ogg, Ted Steere, and Walter Carsten); arranged and edited by David Jamison; corrected and approved by R. E. Moulton.

constant and inexorable pressure of a high overhead. Many firms quite frankly admitted their willingness to escape the usual routine by tackling some of ORDCIT's difficult experimental problems, but obviously they could neither ignore the rigid caste system of priorities nor risk their overhead against the comparatively small and unrepeated orders from ORDCIT.

On the other hand, the first-class smaller shops invariably had intelligent, imaginative, and progressive management, which was stimulated by demands for ingenuity in solving any difficult and unprecedented fabrication problems. In addition, the smaller shops were able not only to give closer and better supervision to ORDCIT work even on routine jobs, but also to reduce red tape to a minimum and enable the Outside Fabrication Department freely to inspect, advise, and accelerate all ORDCIT jobs in progress. Day-by-day and, when necessary, hour-by-hour coordination was thereby possible with an intimacy which would have been impossible in the larger establishments. Necessity, first, and experience, later, formulated eventually the Outside Fabrication policy to prefer the smaller, specialized concern, if it was equipped thoroughly to handle the job.

Getting down to actual cases, the detailed chronicle of ORDCIT fabrication first becomes interesting with the inception of PRIVATE A, code name for the initial ORDCIT solid propellant missile. The motor parts for this missile were secured from Aerojet Engineering Corporation, and conformed in principle and design to those developed by JPL solid propellant research. PRIVATE F, the second ORDCIT solid propellant missile, was essentially a replica of PRIVATE A, plus the installation of forward wings or fins (made by Consolidated Steel Corporation, Maywood) to obtain greater range. However, the fabrication problems of both of these earlier missiles were so orthodox that no special discussion needs to be made.

The third ORDCIT missile, the WAC CORPORAL, utilized a liquid propellant and consequently required considerable variation from the previous missiles, both in design and in engineering details. However, just as the Outside Fabrication Department was settling down to tackle in earnest these new problems, an abrupt interruption came one morning with the announcement of the BABY WAC, one-fifth the size of the WAC CORPORAL, for preliminary test purposes and scheduled for launching just 20 days after the instigation of the design. This meant that the Outside Fabrication Department had approximately 10 days for the procurement of materials, and fabrication and assembly of all the parts demanded. Fortunately, no serious or difficult machining problems were involved; the principal demand upon the department and the various vendors was simply for high-speed cooperation without violating the close tolerances desired. Noteworthy in this instance was the work of Western Drilling Company which, by assigning all three shifts to this job, was able to complete the 20-foot launcher in the record time of 5 days. The deadline for all the parts was successfully and rather breathlessly met, because of the phenomenal efforts of a loyal group of small specialized concerns, among which Howell-Sherburne Company, Hollywood Tool and Die Company, and Kenneth Holloway were outstanding.

Returning now to the WAC CORPORAL proper, the fabrication of the nose cone, for instance, presented several difficult problems. The specified material, JIA magnesium, had to be formed around a mandrel and welded. The necessary mandrel was designed by Mr. Bennett of Research Welding Company and consisted of a hardwood cone with a stainless-steel longitudinal inlay for welding the long seam. Upon forming, the magnesium sheet hardened considerably but this condition was overcome by annealing the material twice during the wrapping operation. After wrapping, the sheet was held in place by several mild-steel rings bored to a 7° taper, spaced approximately 8 inches apart on the mandrel. After considerable experimentation, the welding method which proved most satisfactory was heliarc with argon gas and JIA magnesium rod. The rings held the edges parallel during the tacking and welding, so that a continuous bead could be started at the cone base, and as it progressed, the rings removed one by one. Next a skin (12 inches OD) of the same material was formed on a separate mandrel, welded together, and then attached to the cone section by a circumferential seam, maintaining a common center line. The nose cone assembly was then completed by welding caps, clips, and a solid magnesium tip to the cone, by some final minor straightening and weld grinding, and by a protective coat of wax applied over-all to hold the finish.

The tail section assembly of the WAC CORPORAL, consisting of aft shell, thrust ring, tail ring, fin mounts, and fins, was constructed by Presidential Silver Company. This job required exceptional workmanship since each section had to be laid out and developed individually in order to compensate for errors inherent in the shells. The limited number of units made regular production tooling too costly and impractical; thus temporary tooling had to be improvised. Since the entire missile was assembled by orientation from the faced diameter of the tail casting, the relation of this casting to the shell was most critical, and necessitated the machining of a set of castings for each shell to compensate for variations in co-axiality of shell and frustum. After delivery to the project, three units, selected at random, were subjected to rigid dimensional inspection as well as static loading in compression, and all the units withstood the field tests at White Sands, including high booster impact during the launching. These results testified to expert workmanship with such light material.

The main contract for the construction of the WAC CORPORAL propellant tanks was given to Southwest Welding Company, and during the progress of this work several unpredictable problems arose. Because the material specified (4-6 chrome) apparently had never before been used in the fabrication of light-gage, high-pressure vessels, much experimental testing had to be done at various stages of the building procedure. For instance, approximately twenty different welding techniques were tested in order to select the one most successful in forming an airtight vessel capable of withstanding pressure as high as 3000 pounds per square inch. Heliarc and acetylene gas welding were not as acceptable as electric arc welding with 4-6 chrome rod. Also, the correct heat treatment for the completed tanks had to be determined by eliminative testing, and a number of test specimens were made by Southwest Welding Company for critical analysis by Mr. Spade of Allegheny-Ludlum Steel Corporation and Mr. Sandberg of ORDCIT.

In addition, the tanks had to be set again in a lathe and checked for concentricity not to exceed ¼ inch, because the maintenance of roundness and straightness had been almost impossible during heat treatment at 1725°F. Eventually, that problem was solved by providing a continuous support cradle which permitted the vessel to seek its own level at elevated temperatures. And, since pressure of at least 10 pounds had to be held in each compartment during heating, to prevent collapse, a special apparatus of water columns and piping had to be developed by the vendor.

The heavy-weight (Type 1) motor for the WAC CORPORAL presented no special machining or fabrication problems, with the exception of the intricate helix requirements for the inner shell, which were successfully solved by the ingenuity of Special Tools and Machinery Company.

The light-weight (Type 2) motor for the WAC CORPORAL, however, offered fabrication difficulties much more complicated and puzzling. The inner shell was hot-rolled over a mandrel without trouble, but trials were experienced from the start with the stamping requirements of the outer shell. The design was rejected by the experts of several large stamping companies as completely impossible, but Alloy Diecraft Company was persuaded to make an attempt, and revealed most commendable perseverance in executing the job successfully. The most baffling portion of the outer shell called for a two-lead round thread form, the entire length of the motor, stamped to conform with the venturi contour. This form normally necessitates an elongation of approximately 34 per cent, but unfortunately deep-drawing steel was not available, and hot-rolled SAE 1010 to 1020 carbon steel, with a practical elongation of only 20 per cent had to be substituted. Therefore, some method had to be invented by which the shell could be built up through partial formations without any stretch. This was finally achieved by feeding the material into one end of the die, a thread at a time, using a modified thread form in the started die, and opening the die up to a 90° tangent to the periphery of the outer shell, thus cutting down the elongation to approximately 16 per cent.

The first two light-weight motors were copper-brazed, but the results were unsatisfactory, because the lightness of the outer shell prevented tight enough contact with the inner shell. Eventually Solar Aircraft Company of San Diego perfected a process for the electrical-resistance seam welding of the two shells, and all the resultant motors passed a 650-pound hydrostatic pressure test with flying colors.

Concluding with the WAC CORPORAL, the launcher for this missile was made by Consolidated Steel Corporation, Maywood, which by working in day-to-day accord with the Engineering Design Section and Outside Fabrication Department of ORDCIT, fabricated a difficult assembly with remarkable speed. The launcher was 137 feet high from base to top, and the three riding tracks, each 80 feet in length, had to be held straight and plumb within 1/16 inch. Each track was provided with adjusting jacks at both ends and at the center of each section, and screw jacks were installed on the tripod base to permit adjustment of the launcher to $1/10^{\circ}$. Consolidated Steel Corporation also displayed admirable efficiency and zeal in meeting such complementary demands as for erection prints, for installation of water piping, sheaves, winches, and handling bars, and for the final field erection.

In designing CORPORAL E, the largest ORDCIT missile to date, a new method of fabrication and assembly had to be introduced to conform with the more strenuous requirements. As a preliminary test for this new design, 1000-pound thrust scale motors were instigated. The original forgings for these motor parts were made by Lacy Manufacturing Company from a section of seamless tubing welded to two cones, one of 15°, each 4½ inches long. But early in the stages of fabrication it became apparent that, because of the sharp angles and short length, these cones and tubes could not be held to the desired concentricity.

Following the suggestion of machinists at Pearne and Lacy Machine Company sections of seamless tubing and pieces of solid round stock were faced off, welded together, and stress-relieved for machining, thereby saving valuable time, eliminating the welding on the cones, and making feasible the required dimensions. The machining of these inner shells by Pearne and Lacy was a delicate piece of precision work, calling for a 1¼ thread lead, meantime holding a uniform wall thickness at the base of the threaded passage to 0.125 and keeping the throat bore to 1.767, plus zero, minus 0.002, after chrome plating. Comparatively speaking, as much time and effort were spent in mastering the machining problems of the first unit as later went into the fabrication of the remaining nine units.

The outer shells also presented a complicated machine job by requiring a uniform wall thickness of ¼ inch the entire length of the shell, holding the inside diameter bore to the exact contour dimensions of the inner shell. The most provocative and ticklish task of all was to fasten together successfully and firmly the inner and outer shell. Numerous methods, such as plug-welding, slot-welding, and metal-to-metal contact, were tried, but the only acceptable results were achieved by the intricate process of cutting a groove along the top center of the threads to take a piece of 0.025 soft copper wire, fitted flush with the thread surface, then fastening the split outer shell over the inner shell with a welded butt strap across the longitudinal seams, before brazing the assembly together in a natural atmosphere furnace at Warner Manufacturing Company.

Some of the lessons learned from these preliminary 1000-pound motors were incorporated into the design for the CORPORAL E 20,000-pound heavy-weight (Type 1) motors, the original forgings for which were likewise made by Lacy Manufacturing Company. The inner shells were from rolled and formed $1\frac{1}{2}$ inch mild steel plate, welded, X-rayed, and stress-relieved, while the outer shells were from 1-inch plate treated the same. The machine requirements of these shells posed the problem of finding a subcontractor who not only was capable of handling such a precision job but also possessed equipment large enough and in good enough condition to do the work. Many lathes large enough to handle the shells were inspected but none were in good enough repair to hold the exacting tolerances required. Finally Pearne and Lacy reworked and set up a special lathe to machine the first motor, where manifold problems arose in the initial stages. The cutting of a quintuple thread with a $6\frac{1}{2}$ inch lead, on the inner shell, with an angle progression from 30° to 15° at exceedingly close tolerances, was a machinist's nightmare. Until the final finish cut was made, the slightest slip of the tool would ruin the entire job, because after the cutting tool was in the threaded section, it could not be removed until the cut was finished.

In addition, the passage at the base of the thread at the injector end of the shell, called for a wall thickness of 0.160 inch, and at the exhaust end of the shell, a wall thickness of 0.140 inch, with progressive varying gradations in between, which had to be held uniform from the throat center line for the entire length of the shell, 41-11/16 inches. Then the inside bore of the outer shell had to be machined to the exact outside diameter of the inner shell at all points.

The second unit of this 20,000-pound motor part was machined at Allen Machine and Tool Company, where the technical knowledge and inventive ability of Mr. Clark Allen furnished the project with the first completely satisfactory motor of this design. Other vendors, such as Pearne and Lacy, and Baash-Ross Tool Company, were able to profit immensely by Mr. Allen's experience in the fabrication of this unit, both by reducing considerably the production time and also by using the Allen templates to achieve the desired fit.

The inner and outer shells of the first two completed units were fastened together by using E-Z Flo silver solder ribbon, 0.005 thick, laid on top of the inner shell threads contacting the split outer shell, whose two longitudinal seams were then welded up, and the entire unit brazed together at 1350°F in an electric, controlled-atmosphere furnace at White Heat Treating Company.

In the third and fourth units, an improvement in the bonding process was achieved by spraying the silver solder 0.005 thick on top of the inner shell threads, and 0.002 thick on the inside of the outer shell, which was quartered instead of halved to insure a closer fit. Then the unit assembly was welded and brazed as before.

After brazing all units were returned to Lacy Manufacturing Company where exhaust manifolds were added as well as a closing ring at the injector and before having the inner surface of the inner shell hard-chrome plated. Los Angeles Plating Company constructed special electrodes to plate the irregular shape of the venturi and did an outstanding job on each motor sent to them. Lacy Manufacturing Company then welded on the piping and the injector head they had constructed, using special equipment to maintain the injector head and the motor level and plumb to each other.

The light-weight (Type 2) motor for CORPORAL E, now in the process of fabrication at Solar Aircraft Company in San Diego, presents somewhat the same production problem as the WAC CORPORAL light-weight motor, inasmuch as it calls for eight parallel cooling passages to be stamped in the outer shell. Because of its greater elasticity, 18-8 stainless steel instead of low-carbon steel has been used for this design, and the outer shell has just been successfully stamped in quarter-circle segments. Low-carbon steel was retained, however, in the inner shell, which has also just been stamped in half-circle segments. The chief difficulty ahead in the inner shell appears to lie in the weldment forming the injector head and the aniline and acid inlet tubes, because of the required exact alignment of the flanges and the precise impingement location of the orifices.

In conclusion, the relationship between ORDCIT and the many subcontractors was almost unanimously on a high and trustworthy level. Exceptions there were, of course, as well as variations in degree of cooperation and in quality of service, dependent often upon circumstances and exigencies beyond control. Sometimes the personal equation was a factor, but usually the prestige of the project and its backers was more than sufficient to ensure the most willing assistance. In that connection, there remain four first-class specialized machine shops not emphasized earlier, whose record of whole-hearted cooperation and invariably exacting standards of performance entitle them to the highest accolade possible for ORDCIT vendors. Whenever the Project needed unswerving loyalty on an unexpected rush job, as well as ingenious and superior performance on any design, large or small, the ORDCIT Outside Fabrication Department always could call with confidence upon any one or all of these four:

Allen Machine and Tool Company

Hollywood Tool and Die Company

Howell-Sherburne Company

Special Tools and Machinery Company

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RESULTS OF CORPORAL E FIRINGS

Carried Out At

White Sands Proving Ground

EXTRACTED FROM

"Army Ordnance Department Guided Missiles Program," 1 January 1948; Dunn, Louis G., Meeks, Paul J., and Denison, Frank G., Jr., JPL Memorandum Nr. 4-59, "Present Status of the CORPORAL Development, JPL/CIT, 17 March 1950; Dunn, Louis G., and Meeks, Paul J., JPL Report Nr. 4-45, "A Brief Resume of the CORPORAL E Program," JPL/CIT, 17 February 1948; JPL Report, "Status Report on CORPORAL Guided Missiles," JPL/CIT, 22 September 1952; JPL Combined Bimonthly Summary Nr. 1, June 20, 1947, to August 20, 1947, JPL/CIT, 15 September 1947; Nr. 2, August 20, 1947, to October 20, 1947, ibid. 15 November 1947; Nr. 3, October 20, 1947, to December 20, 1947, ibid., 15 January 1948; Nr. 4, December 20, 1947, to February 20, 1948, ibid., 15 March 1948; Nr. 5, February 20, 1948, to April 20, 1948, ibid., 15 May 1948; Nr. 6, April 20, 1948, to June 20, 1948, ibid., 15 July 1948; Nr. 7, June 20, 1948, to August 20, 1948, ibid., 15 September 1948; Nr. 8, August 20, 1948, to October 20, 1948, ibid., 15 November 1948; Seifert, Howard S., JPL Publication Nr. 22, "History of Ordnance Research at the JPL, 1945-1953," JPL/CIT, 29 July 1953.

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U.S. ARMY ORDNANCE CORPORAL E GUIDED MISSILE

DEVELOPED UNDER CALIFORNIA INSTITUTE OF TECHNOLOGY PROJECT ORDCIT

The CORPORAL E guided missile was designed as a result of progress made under the U. S. Army, Ordnance Department, ORDCIT Project with the California Institute of Technilogy. The ORDCIT contract was basically a research contract covering fundamental investigations underlying the broad fields of jet propulsion and guided missiles. This contract called for the design and fabrication of test missiles progressively increased in size and complexity that would prove in practice theory advanced with regard to aerodynamics, general performance, materials, fluid mechanics, liquid and solid propellants, remote control, guidance, telemetering, motor design, etc., as a result of the latest laboratory achievements.

CORPORAL E was the first of the ORDCIT test missile series incorporating command guidance. It was propelled by an acid-aniline liquid-fuel motor, and was launched vertically from a launching platform.

Initial stabilization was maintained by the use of four carbon vanes located in the exhaust gas stream of the motor. Stabilization in flight was controlled by four external vanes located along the trailing edge of each fin.

Performance Data Round No. 1
Fired 22 May 1947

	Calculated	Actual
Altitude	102,000 ft.	129,000 ft.
Flight Time, Total	200 sec.	227 sec.
Flight Time, To Burn-out	66 sec.	71 sec.
Altitude, To Burn-out		13 mi.
Flight Time, To Zenith	116 sec.	126 sec.
Weight of Missile, Total Including Fuel	11,700 lbs.	Not Obtained
Center of Gravity from Aft End, Ready for Firing	206.25 ins.	
Horizontal Ground Range from Block House		64$\frac{1}{4}$ mi.
Maximum Altitude		24$\frac{1}{2}$ mi.
Maximum Velocity		2695 ft/sec

RESULTS OF CORPORAL E FIRINGS

Carried Out at White Sands Proving Ground

Research Agency: California Institute of Technology

Firing Round	Date	Range (Miles)	Altitude in feet	Remarks
1	22 May 47	63	129,000	Take-off was excellent. This vehicle, the first completely designed, engineered and fabricated, surface-to-surface, American guided missile performed well above expectations. At the beginning of flight the missile was 12° off due north course but after 30 seconds of flight, course was corrected by autopilot to 6°. After 160 seconds of flight a radar control signal was given to deflect the missile toward the left. The missile executed this maneuver.
2	17 Jul 47	Malfunction; See Remarks.		Fuel ignition did not occur immediately upon the firing signal. After the elapse of several seconds, ignition was noted. It appeared to be weak and incomplete. After approximately 90 seconds of this weak and incomplete burning with the missile in place at the launching platform, sufficient fuel having been consumed to equalize weight of test vehicle with thrust, CORPORAL slowly began to rise, attaining a height of 50 feet, toppling to the east, and moved over the test pit, where it fell to the ground. After impact, CORPORAL was thrust along the ground for about 100 yards by continuing combustion. It was concluded that the following items were at fault for the malfunctioning: 1. The propellant blade valves did not completely open. 2. Regulation of air pressure to the propellant tanks functioned improperly.

Firing Round	Date	Range (Miles)	Altitude in feet	Remarks
3	4 Nov 47	14	66,000	Objectives of this test were in general to test further the design and construction of a supersonic, controlled missile and specifically to check the air-regulator system which malfunctioned in Round 2. Takeoff was excellent, but CORPORAL veered off in azimuth. Performance up to the first 45 seconds of flight was somewhat better than expected, but burning suddenly ceased at 45 seconds. Early in-flight, control signals were transmitted to CORPORAL, correcting its course in azimuth to the extent of bringing CORPORAL within safe limits of WSPG. Yaw signals were also successfully applied later in flight. Telemetering results were generally good,sufficient records having been obtained to assure analysis of flight. Round 3 was last round utilizing semi-monocoque construction throughout and also last round employing the heavy (650-pound) motor having helical coils for circulating fuel coolant.
4	7 Jun 49	14	66,000	Round 4 was the first to have the new lightweight (125-pound), axially cooled motor and also the first of the redesigned 7 Douglas-production models (Ref. test, Chapter VII). This was first CORPORAL to be launched from the newly designed, 4-strut, supporting launcher, which operated successfully (Ref. test, Chapter VII). Airframe had truss-type construction wherever possible. Forward to aft were nose cone, air-pressure tank, fuel tank, oxidizer tank, motor, tail with surface controls (jet vanes and 4 trapezoidal fins with attached movable trailing control surfaces). Earlier boattail design was replaced by straight, cylindrical aft end, and rotary air motor and gear box in control system by pneumatic piston. CORPORAL veered to left of vertical almost immediately after takeoff, beginning to roll at about 15 seconds. At 23 seconds radio cut-off was effected as a safety measure. Telemetering records

Firing Round	Date	Range (Miles)	Altitude in feet	Remarks
				showed that control system's performance had differed radically from that anticipated. Static tests of exact model of aft end revealed jet-vane moment 4 times greater than expected; also that flame had entered control mixer, burned away some of the pneumatic tubing, & softened springs on control system mixing bar. Decision was that mechanical autopilot being used was adversely affected by vibration. Indications were that new motor & propulsion system would function satisfactorily.
5	11 Jul 50	51.2		Nose cone was vacated; telemetering and other electronic gear formerly housed in nose cone were transferred to stowage compartment aft of nose cone. All-pneumatic control system abandoned & JPL-designed electro-pneumatic autopilot incorporated. Static tests prior to firing indicate vibration as a factor causing mechanical failures. Rounds 5 & 6 carried portions of control system under development at JPL. This tactical guidance system consisted of electronic automatic pilot driving air-operated servo motors, an overriding radar control for the climbing leg of trajectory, doppler cutoff, and integrating accelerometers for descending leg of trajectory. Although CORPORAL's propulsion system operated satisfactorily and the flight was considered successful, failure of the disconnect air coupling, designed to bleed air from the air tank, reduced propellant flow rates, thereby cutting down overall performance of the missile. Round 5 carried a Doppler transponder and an AN/DPW-1 radar beacon, modified in accordance with HERMES A-1 missile requirements.

Firing Round	Date	Range (Miles)	Altitude in feet	Remarks

The important policy decision was made after firing of Round 4 that a new all-electronic autopilot, less vulnerable to mechanical vibration, would be developed with JPL carrying out the development in order to integrate the propulsion and control systems. At the same time, the decision was reached in Washington for CORPORAL to assume the role of precision weapon capable of tactical employment against small targets, rather than to remain a mere test vehicle for propulsion and airframe development. This decision made it necessary to evolve a complete command guidance system, capable of determining the impact point of the missile to within a few hundred feet.

Just a little over a year later (11 July 1950) Round 5, incorporating the new JPL-designed electronic autopilot and some elements of the command guidance system, was flown successfully. This round marked the end of the era of CORPORAL test-vehicle development and the beginning of the greatly accelerated program in the tactical version of CORPORAL, although 5 more firings were to ensue before CORPORAL E passed from the stage. The vehicle bore various designations during transition into CORPORAL Type I: CORPORAL, CORPORAL E, RTV-G-2, and XSSM-A-17, indicating respectively its progress through drawing-board, research, preliminary development, and production phases.

6	2 Nov 50	35.9		Impact approximately 35 miles short. Later static tests demonstrated apparent dome-loader regulator failures had occurred in both Rounds 5 & 6, causing overrich mixture ratios. Moreover, failure of airline disconnect coupling had caused loss of air. In Round 6, the radar beacon was used to provide azimuth overriding guidance, operating satisfactorily until the flight beacon transmitter failed at 36 seconds. The Doppler beacon was provided to initiate shutoff of propellant flow to rocket motor when missile had achieved velocity calculated to carry it to target in ballistic trajectory. CORPORAL failed to attain velocity sufficient to effect propellant shutoff at predetermined velocity. Furthermore, Doppler beacon itself failed at 24 seconds. Finally, telemetering equipment ceased functioning at 48½ seconds. All electronic equipment of CORPORAL E Round 6 failed, apparently because of extreme vibration inherent in flight environment.

As of 31 December 1950, an additional 20 missiles (less control system equipment) were being fabricated by Douglas Aircraft Corporation for further flight testing in conjunction with development by JPL of tactical guidance and control system. Expected accuracy on that date was ± 100 feet in azimuth and ± 500 feet in range of 26 to 75 nautical miles. These 20 missiles were the first of the CORPORAL I type.

Firing Round	Date	Range (Miles)	Altitude in feet	Remarks
7	Jan 51	63.85		Five miles short of target. This was first round to have inflight propellant shutoff. Also, CORPORAL E Round 7 first employed new multi-cell (19 cells) air tank and new air-disconnect coupling, thereby greatly improving reliability of propulsion system. Control & guidance system had been developed to point of reliability. But the number of equipment malfunctions indicated that over-all missile reliability would continue a significant problem and that more information concerning operating environment would be required before necessary corrections could be made. CORPORAL started to roll at 40 seconds, due to failure of connection between central power supply and autopilot. Ground radar furnished some erroneous information to control & guidance system, thereby accounting for 2 of the 5 miles' target-shortage.
8	22 Mar 51			Round 8 impacted about 4 miles short of its target.
9	12 Jul 51			Round 9 impacted some 20 miles beyond target, due to failure of Doppler transponder & absence of propellant shutoff.
10				CORPORAL E Round 10 was not launched.
11	10 Oct 51			Round 11 was cut down. CORPORAL E Round 11 was the first to carry the newly developed delta fins; it comprised the basic configuration of the generations of CORPORALS to follow--the tactical version; it was capable of carrying a 1,500-pound warhead in a newly designed nose cone. At

Firing Round	Date	Range (Miles)	Altitude in feet	Remarks
				takeoff, the central power supply frequency regulator failed. Control-loop stability was disrupted, and CORPORAL followed a nearly vertical trajectory that carried the missile over the Organ Mountains in a westward direction instead of northward as programmed. CORPORAL was cut down by the range safety radio link and made to impact between WSPG headquarters area and City of Las Cruces, striking about 15 miles west of the launching site.

CORPORAL I ENTERS THE STAGE

Flight 11 (Round 12) was fired on 6 December 1951, second flight of the new series having the delta fin configuration and the first with elements of warhead equipment. All missile components except the range computer and azimuth programmer had been developed and flight-tested. The ground system was beginning to take shape in the form of prototype equipment. Prototype radar, doppler, and computer equipments were employed in Round 11.

Between January 1952 and December 1952, 26 CORPORAL rounds were fired by JPL. Sixteen of these firings were conducted with missiles produced on a job-shop basis by Douglas Aircraft Company; ten were from Firestone Tire and Rubber Company's production line. During that period, an experimental UHF Doppler system and azimuth programmer were satisfactorily demonstrated. The first two sets of prototype ground equipment were completed by January 1952. CORPORAL was in business.

TABULATION OF ORDCIT TEST VEHICLE AND CORPORAL FIRINGS

at

White Sands Proving Ground, New Mexico

EXTRACTED FROM

Brown et. al.,
Development & Testing of Rockets &
Missiles at White Sands Proving Ground, 1945-1955,

Appendix

Historical Information Branch, WSMR, New Mexico,

1 October 1959

[redacted]

TABULATION OF ORDCIT TEST VEHICLE AND CORPORAL FIRINGS

White Sands Proving Ground, New Mexico

Year	Missile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1945	TINY TIM Booster									4				4
	WAC Dummy									2				2
	Quarter Charge WAC & Booster										2			2
	WAC CORPORAL A										6			6
	TOTAL									6	8			14
1946	WAC CORPORAL A					1								1
	WAC CORPORAL B												6	6
	TINY TIM			9										9
	TOTAL			9		1							6	16
1947	WAC CORPORAL B		3	1			1							5
	WAC CORPORAL E*					1		1						2
	TOTAL		3	1		1	1	1						7
1948	BUMPER					1			1	1		1		4
1949	WAC CORPORAL					2								2
	CORPORAL E						1							1
	BUMPER		1		1									2
	TOTAL		1		1	2	1							5
1950	CORPORAL E							1				1		2
1951	CORPORAL	1		1				1			1		1	5
1952	CORPORAL Research	2		3	2	3	2	3	3	2	1	4	3	28

[redacted]

Year	Missile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1953	CORPORAL Engineering	1		1		1	1						1	5
	CORPORAL Research	2	3	1	3	3	1	3	4	4	5	2	3	34
	TOTAL	3	3	2	3	4	2	3	4	4	5	2	4	39
1954	CORPORAL	5	2	4	3	6	6	5		10	4	2	3	50
1955	CORPORAL	5	1	3	4	2	5	9	6	7	10	8	9	69
	GRAND TOTAL	16	10	23	13	20	17	23	14	30	29	18	26	239

* After the fifth CORPORAL E firing, the remaining six CORPORAL E rounds were listed under CORPORAL.

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EXTRACTED FROM

Publication No. 64

THE CORPORAL MISSILE

ARMING PHILOSOPHY

by

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JET PROPULSION LABORATORY
California Institute of Technology
Pasadena 3, California

February 16, 1956

UNCLASSIFIED

[redacted]

THE CORPORAL MISSILE

ARMING PHILOSOPHY

Questions have recently been raised regarding proper use of the Computer Group condition selector switches for arming, these questions resulting from firings where the computer decision has been to NOT ARM under conditions which appeared favorable to arming. Accordingly, the Jet Propulsion Laboratory has extensively investigated the overall problem. A reassessment of the basic arming philosophy, with particular regard to the requirements placed upon it by the Military Characteristics, has made a mandatory change in arming circuitry necessary. The Laboratory's recommended hardware changes have already been documented for Ordnance, and procedure revisions by others will be issued in time for field modifications. It is the purpose of this communication to explain the arming philosophy and its practical implications.

Ideally, warhead arming should occur whenever the missile impacts within enemy territory out of lethal range of friendly troops. At first glance this would appear easy to accomplish, at least when the targets were deep in enemy territory. More investigation, however, brings to light many considerations which affect the arming decision.

Of primary importance in the arming circuitry design is the Military Performance Characteristic which states unequivocably that the probability of a nuclear explosion occurring over friendly troops shall be less than 1 in 10,000.

It is obvious that if accurate determination of missile position throughout the flight were possible, the arming decision would be made just before impact. Due to practical considerations, CORPORAL arming election takes place approximately at the peak of the trajectory, and the decision can be made at that time only on the predicted impact point. What factors, then, affect the accuracy of the predicted impact point at the time of the designated arming decision?

Again, there are many practical considerations, such as simplicity, which dictate the inherent equipment design for missile components and associated ground guidance. For example, range correction depends on a linear computer based on the assumption of small deviations from standard values. In addition, some of the input data to this computer saturates if the actual conditions vary by more than a fixed amount from their standard or expected values. It will be seen, therefore, that if flight conditions vary considerably from a set of standard values there will be significant higher order errors in the output of this computer.

Similarly, the azimuth impact prediction is based on the radar antenna azimuth error signal, this signal having a limited linear range; in fact, an S curve shape so that for large errors the signal returns to zero. Obviously, then, there are limitations to both predicted range and azimuth accuracies when flight measurements deviate markedly from expected or standard values.

Certain failures can occur which cause or allow the missile to deviate from the target, but, at the same time, cause the predicted impact point to be within a specified safety limit. Because, generally speaking, these failures would cause certain other critical flight path measurements to deviate significantly from their expected values, the reliability of the arming decision can be improved by requiring that certain trajectory measurements be within prescribed tolerances.

An added requirement is that no arming will take place unless a range correction trigger impulse from the Radio Set to Computer Group occurs prior to arming decision time, and that an arming signal, by way of the doppler link, is received by the missile within certain tolerances of the expected time of receipt. Thus this signal will fall within the allotted period, unless either there has been an equipment failure or the trajectory is quite non-standard. As a matter of information, the arming circuitry change documented to Ordnance actually expands one prescribed trajectory tolerance in that the range correction trigger impulse will occur six seconds earlier. This allows the required 25 volt output of Amplifier A-7 to occur up to six seconds earlier and still permit arming. Thus in the future, arming can take place on flights similar to recent apparently good flights where arming was not effected because the 25 volts from A-7 occurred too early.

There are tactical situations, such as a target deep in enemy territory, where it would be desirable to have warhead arming no matter how far the impact point was beyond the intended target. The system employs azimuth and range computers for determining predicted impact point, and additional requirements of prescribed trajectory standards are introduced into the arming election circuitry. But the fact remains that nowhere in the system is there sufficiently accurate information for arming as to whether or not the missile will impact in enemy territory with the all important reliability assurance of 10,000 to 1.

As an extreme example of possible errors, an experimental CORPORAL, due to a programmer failure, flew an approximately vertical trajectory. Obviously, the flight trajectory conditions were far from standard, but the range computer, operating as designed on the input data it received, actually predicted that impact would be far long, whereas actual impact was far short of the target. Only a short safe limitation had been set into the arming selector for this particular flight, and the arming elector decision was to arm. However, the warhead would not have been armed in this case, since the same programmer failure which caused the missile to fly the vertical trajectory also prevented the missile from receiving the arming signal. Actually, other failures could have occurred which would have caused the trajectory to be near vertical and at the same time not have prevented the receipt of an arming signal.

It is, therefore, necessary to employ arming limits on all four sides of every target, even though tactical situations would seem to permit a reduced number of limits. It is recognized that this philosophy must inevitably increase the number of duds; however, it is believed that the percentage increase should be small as these extra arming decision functions will prevent arming only when the flight conditions are considerably non-standard, and as such the probability of impacting near the target is quite low.

The above arming philosophy, which is dictated by the requirements of the Military Characteristics, simply makes mandatory the setting of parameters for both long and short range, and both left and right azimuth, for every target.

A target problem example with diagram is set forth below to explain the ARMING SELECTOR in the Computer Control C-1424/MSA-6 (Control Unit II). Firing Tables CORPORAL B-1 Missile, GM, XSSM-A-17a are used.

An assignment classification of a small, tough target "T" is given for the CORPORAL missile attack. From nuclear warhead tables a warhead is selected compatible with the target requirements and CORPORAL CPE Military Characteristics.

Considering the arming selection problem, square "M" on the diagram represents the minimum arming area possible, 600 meters long or short in range, 600 meters right or left in azimuth. Areas "OA" plus "A" indicate the maximum selective arming region about the target, 3000 meters long or short in range, 5000 meters right or left in azimuth. Increments of 200 meters between the 600 and 3000 or 5000 meters can be selected as situations dictate.

Again referring to the diagram, the corners of the chosen arming area marked "EXA" indicate the maximum deviation from the target, based on the predicted impact point, under which a warhead arming decision can occur. Normally, of course, the final re-entry maneuver would direct the missile toward the target within the designed maneuvering capabilities.

There is a possibility, that after the irrevocable arming decision had been made with predicted impact point at "EXA", that failures causing wrong-polarity hard-over maneuvers in both range and azimuth could occur creating an additional 3000 meter area "AM" as shown.

Due to the lethal range of any warhead, a safety limit "SL" is required around the area in which armed-warhead-impact could occur. The nuclear warhead tables specify this safety limit as 6430 meters for the particular warhead selected necessary for the assigned target.

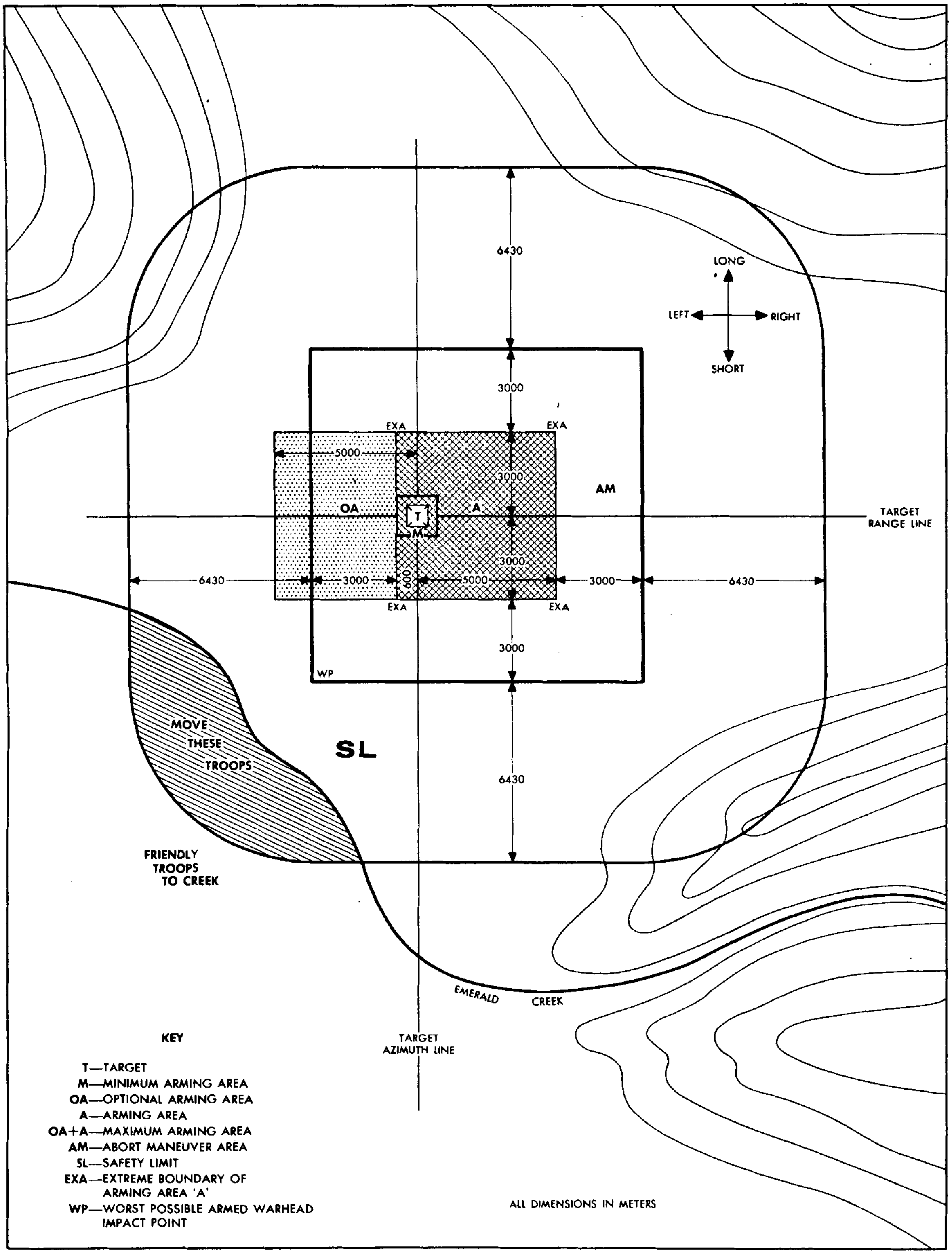
If friendly troops occupy the area bounded by Emerald Creek as indicated, some of these will be within the safety limit. It is mandatory to relocate the marked troops in order to meet safety requirements.

[redacted]

If the maximum arming area permitted by the missile system ("OA" plus "A") had been chosen, it is readily apparent that the troops occupying an additional area 4400 meters to the left would require relocation as dictated by the leftward movement of the possible ("WP") impact point with warhead armed.

A larger yield warhead selection, permitting a shift of azimuth line to the right within the new warhead C.P.E. limitations, cannot be considered because of the higher order troop safety limit requirements.

[redacted]



LONG
LEFT
RIGHT
SHORT
6430
3000
EXA
5000
3000
AM
OA
A
T
M
TARGET RANGE LINE
6430
3000
600
5000
3000
6430
EXA
EXA
3000
WP
SL
MOVE THESE TROOPS
6430
FRIENDLY TROOPS TO CREEK
EMERALD CREEK
TARGET AZIMUTH LINE
KEY
T—TARGET
M—MINIMUM ARMING AREA
OA—OPTIONAL ARMING AREA
A—ARMING AREA
OA+A—MAXIMUM ARMING AREA
AM—ABORT MANEUVER AREA
SL—SAFETY LIMIT
EXA—EXTREME BOUNDARY OF ARMING AREA 'A'
WP—WORST POSSIBLE ARMED WARHEAD IMPACT POINT
ALL DIMENSIONS IN METERS

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MILITARY CHARACTERISTICS,
STATUS OF CORPORAL, AND CORPORAL I FIRINGS
to 22 September 1952

EXTRACTED FROM

STATUS REPORT ON CORPORAL GUIDED MISSILES

and

ADDENDA CONCERNING CORPORAL TYPE I FIRINGS
TO 30 JUNE 1955 AND ADDITIONAL MILITARY CHARACTERISTICS

California Institute of Technology
Jet Propulsion Laboratory
Pasadena, California

September 22, 1952

[redacted] UNCLASSIFIED

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MILITARY CHARACTERISTICS,

STATUS OF CORPORAL, AND CORPORAL I FIRINGS

to 22 September 1952

1. INTRODUCTION

*   *   *   *   *

1.1 Military Characteristics

Extracts from the proposed military characteristics of the CORPORAL follow:

Warhead: 1,500 pounds

Range: 25 to 80 nautical miles

Speed: Supersonic

Accuracy: 1,500 feet circular probable error

Location of Guidance Center: Up to 2,000 feet off target line

Anti-Jamming Features: Shall be incorporated

Internal Guidance: Shall be sufficiently accurate to cause impact within 3 miles of target after a computed on-course shut-off.

Target: May be selected within 120° sector

Reliability: After 6 months storage 75% of missiles must pass all pre-firing checks. Of those which pass these checks, 95% must launch successfully. Of those launched successfully, 95% shall land within 4 probable errors of the target.

Check Out and Test Procedure: Shall be operated under field conditions 3 to 5 miles back of the launcher. Check out tests at the launcher shall be of the go and no-go type and shall occupy less than 20 minutes. These checks shall also be capable of being performed with the missile vertical.

Fueling: Fueling procedures shall stress safety and ease of operation.

Readiness: After fueling, warhead attachment, erection, and orientation, the missile shall be capable of being fired on 20 minutes notice. It shall also be capable of standing for 72 hours.

[redacted]

<u>Rate of Fire</u>: A maximum of 3 rounds per hour per guidance center on either of 2 targets shall be maintained.

<u>Emplacement</u>: Not more than 4 hours shall be required to emplace and fire the first missile given a prepared position, and not more than 1 hour shall be required to knock down and travel.

<u>Temperature Limits</u>: Operations shall be possible from -25^{o} to +125^{o} F.

<u>Surface Winds</u>: Launching shall be possible in 35 mph surface winds and 50 mph gusts.

<u>Launcher Altitude</u>: Launching shall be possible from sites having altitudes up to 10,000 feet.

<u>Storage</u>: Missile shall be capable of storage as follows:

Warehouse Storage	- 3 years
Field Storage	- 6 months
Uncrated	- 1 month

1.2 General Description

The missile has a length of 45' 4" and a diameter of 30". The takeoff weight is 11,250 pounds, of which 2,100 pounds is fuel (aniline) and 4,370 pounds oxidizer (RFNA). The warhead weight is 1,500 pounds. The missile is launched vertically and takes off with an acceleration of about 1g. The rocket motor has a thrust of 20,000 pounds. Four seconds after takeoff, the missile is titled about 3 degrees in the direction of the target. Thereafter it flies approximately on a ballistic (zero lift) trajectory to the target. Control is effected by an autopilot of more or less conventional design. Guidance is by command from a guidance center located about a mile from the launcher. Radar is used to map the position of the missile in space, and doppler radio is used to measure its velocity. These data are given to a computer which then sends appropriate commands to the missile by the radar link. Upon attaining the correct velocity to reach the target, the rocket motor is shut off by a command sent over the doppler radio. Later, near the zenith of the trajectory, an expected range error is computed and this information given to the missile to be used during the last 20 seconds of flight to make a range correction maneuver. The missile reaches the target with a velocity lying between about 1,500 and 2,500 feet per second, depending on the range.

Firing operations require two areas, the firing area and the service area, about five miles apart. The firing area contains an assembly of launchers and a guidance center. The service area provides facilities for uncrating, testing, and fueling the missiles. Missiles are transported to the launcher and placed thereon by an erector vehicle.

2. STATUS OF THE PROGRAM

2.1 Flight Tests

A summary of test flight results is presented below:

Missile Test Flight Summary

Round	Date	Range Error (Ft.)	Azimuth Error (Ft.)	Factors Affecting Target Errors
11-10	10/10/51	-	-	(This was actually the last round of CORPORAL E and the first to have the delta wing.) Central power supply frequency regulator failed. Missile unstable in roll, vertical flight. Cut down by range safety.
12-11	12/6/51	16,632 Long	36,560 Right	Command unit failed at X-4 seconds, no command guidance possible.
14-12	1/24/52	9,500 Short	4,116 Right	Aft section flame damage.
15-13	1/29/52	8,100 Short	23 Right	
17-14	3/12/52	19,330 Long	7,176 Right	Loss of central power supply just before shut-off.
18-15	3/17/52	9,750 Short	196 Right	Aft section flame damage.
19-16	3/21/52	-	-	Loss of central power supply before shut-off caused roll and missile break up.
21-17	4/24/52	-	-	Failure of check valve caused aniline tank explosion.
22-18	4/29/52	3,510 Long	4,350 Right	Command unit failure near zenith of flight.

[redacted]

Round	Date	Range Error (Ft.)	Azimuth Error (Ft.)	Factors Affecting Target Errors
23-19	5/12/52	3,750 Short	7,800 Right	Ground computer power supply failure caused hard right command for 50 seconds.
*24-20	5/16/52	6,950 Short	1,510 Right	Warhead detonated at 20,000 ft. for Chemical Corps experiment.
25-21	5/23/52	1,960 Short	3,270 Right	Ground Computer power supply failure caused hard right command for 10 seconds.
26-22	6/19/52	22,900 Short	354 Right	Incorrect setting in shut-off computer.
*27-23	6/24/52	11,000 Short	1,143 Left	Warhead detonated at 30,000 ft for Chemical Corps experiment.
28-24	6/27/52	7,070 Short	260 Right	Missile drag apparently high.
29-25	7/11/52	5,300 Short	1,740 Left	High missile drag, terminal maneuver.
13-26	7/17/52	8,644 Short	1,240 Left	High missile drag, terminal maneuver.
30-27	7/28/52	5,155 Long	2,725 Left	Errors in tactical prototype computer ground station.
33-28	8/7/52	48,000 Long	716 Left	Shut-off failure.
31-29	8/12/52	13,986 Short	158 Right	High missile drag.
36-30	8/27/52	39,625 Long	5,508 Right	Shut-off failure.
37-31	9/12/52	9,707 Long	1,900 Left	Shut-off failure, doppler failure before range correction point.

* Actual impact points were not very meaningful, since missile became unstable after detonation of warhead.

[redacted]

2.2 Missile Production

Four of the Firestone missiles had been fired (see above). It should be noted that these missiles had received approximately a two-month check at JPL before firing. During this period the missile was carefully inspected for mistakes and poor workmanship, and also a number of modifications were made as required by the R & D program. As was expected, these first production missiles required a considerable amount of rework before they could be flown. The flight performance of the missiles was satisfactory except for the fuel shut-off operation. This failed on three of the four rounds. The reason for the failure was still unknown as of 22 September 1952.

Production missiles having serial numbers 8, 9 and 10 were then at the Laboratory. These rounds represented a second stage in the production, with workmanship improved as much as possible as a result of experience with the first rounds. The Laboratory found an improvement, but much remained to be done.

Missile components not yet in production included:

1. Range correction system
2. Warhead arming circuits
3. Tactical doppler (airborne)

Item (1) had been delayed because of difficulties encountered in R & D. Prototype models were being flight-tested and production release was expected before the end of the calendar year.

Item (2) was a part of item (1) and was to be released simultaneously.

Item (3) was being flight-tested. Production was expected to be released before the end of the calendar year.

2.3 Ground Equipment Production

2.3.1 Ground guidance center

Prototypes of all units of the ground guidance center had been in operation at WSPG. The Laboratory was procuring four complete guidance centers. The second complete center was expected to be delivered to the JPL field test section at WSPG on November 1, 1952. After a field checkout, it was to be delivered to WSPG for use in their engineering test program. The third and fourth sets were to follow at about six-week intervals. The tactical doppler, as distinct from the training doppler then in production for the first two batallions, was to be released for production in six to nine months.

2.3.2 Mechanical components of ground equipment

The prototypes of the tactical erector and launcher were first used on the firing of September 12. Operation was quite satisfactory. Delivery of prototypes to WSPG was to be concurrent with other ground equipment.

2.3.3 Miscellaneous items of ground equipment

The prototype service checkout truck had been in operation at JPL and was to be shipped to WSPG for further test and evaluation about the end of September.

3. CURRENT PROBLEMS, LIMITATIONS OF PRESENT EQUIPMENT, AS OF 22 SEPTEMBER 1952

3.1 Reliability

The satisfactory performance of a system as complex as a guided missile required that all components of the system have an exceedingly high reliability. In practice the desired reliability was still not attained. Field tests to date indicated about one failure per flight. Fortunately, because of the CORPORAL system, most of these failures still permitted the missile to impact in the target area.

The Laboratory was placing a great deal of emphasis on its reliability program and significant improvements in component performance were expected.

3.2 Terminal Maneuver

The test flights had demonstrated repeatedly that at the time of re-entry into the atmosphere the missile trajectory was within about 100 feet of the desired azimuth plane; however, during the last 20 or 30 seconds of flight, the missile had frequently made violent maneuvers in pitch or yaw or both. On these flights the guidance system had been disconnected and the missile had roll control only. The tests had shown clearly that during re-entry there was appreciable bending of the missile which gave rise to large aerodynamic lift forces.

Although this effect had been the chief cause of azimuth dispersion on recent tests, it would presumably be solved by using accelerometer control during this part of the flight. Accelerometers had not been used on recent tests because of instabilities which were found on the first accelerometer tests. However, Laboratory experiments on the vibration modes of the missile, and REAC simulation of the accelerometer-controlled missile flights, had shown the reasons for the early difficulties and complete accelerometer control was to be flown shortly.

[redacted]

The most recent test flight, Round 37-31, showed very satisfactory performance of the pitch accelerometers in the range correction system and indicated that the accelerometer problem appeared to have been solved.

3.3 Drag Measurement

The range accuracy of the CORPORAL was critically dependent upon a knowledge of the drag coefficient of the missile at all parts of the trajectory. This could only be obtained by a careful analysis of the test flights. The data seemed to show an anomalous increase in drag near the end of the flight and a larger variation of drag coefficient from missile to missile than had been expected. Both of these effects contributed to range inaccuracy; however, at this time no definite conclusion as to the amount had been reached.

3.4 Fuel Shut-Off

The fuel shut-off system gave excellent results with the Douglas missiles, but three of the first four Firestone missiles failed to shut off on command. The first failure was almost certainly due to a short circuit in a cable, but the other two were probably not electrical failures. The complete shut-off system of the Firestone missile was being carefully examined for the difficulty, but no definite cause had been found.

3.5 Tactical Handling and Servicing

A complete demonstration of the tactical handling and servicing of the missile had not yet been attempted. However, as units of the system became available, they were put to immediate use.

3.6 Range Correction System

A series of test flights to evaluate the range correction system was just getting started. The system appeared to be satisfactory, but further tests were needed.

3.7 Azimuth Program

The missile had not yet been flown with an azimuth maneuver at takeoff of more than 120 feet. The short-range firings scheduled for the next four rounds were to increase this to 290 feet. The tests showed that the azimuth program was operating correctly, but demonstrations at larger off-sets were indicated.

[redacted]

3.8 Counter - Countermeasures

The missile as presently produced was subject to enemy countermeasure action, particularly in the doppler radio link. A new doppler system operating on a higher frequency and with greater security had been tried in recent flight tests and found to meet technical requirements. The new equipment was being engineered for production and was recommended to be used on all tactical missions.

3.9 Environmental Limitations

Tests had been satisfactorily conducted in all climatic conditions encountered at WSPG, but the effects of extreme cold or extreme humidity were still unknown. Actual field tests in extreme environments were necessary before the environmental limitations could be determined.

4. FISCAL HISTORY OF THE CORPORAL

* * * * *

5. RECOMMENDATIONS FOR FUTURE PROGRAM

During the coming year, 1953, the test-flight rounds were to be used for the continued development of the missile system. Development of the over-all CORPORAL system had progressed at a reasonable rate. Flight tests had shown that the system as originally conceived would be able to meet the military requirements. However, it was clear that numerous problems still remained to be solved before the system could be considered suitable for tactical use. One of the most serious problems was that of component reliability. It was only through the accumulation of flight-test data that a realistic evaluation could be made of the environmental conditions in the rocket during flight. Sufficient data had been obtained to permit the writing of a set of environmental specifications which were representative of actual flight conditions. JPL's reliability test program was showing that many components as originally designed would not meet these more rigid specifications. Further design and development work was necessary.

The aerodynamic design phase of the CORPORAL appeared to be almost completed; however, sufficiently accurate drag information still had to be collected to permit the computation of reliable trajectories and the construction of firing tables.

Work on the propulsion components, the guidance and control system, and the telecommunication system, during the next year, was to consist of (a) the completion of unfinished tasks and (b) development as required to provide for safe, reliable missile operation under tactical conditions.. In addition, test-flight operations designed to train military personnel in the operation and maintenance of the CORPORAL were to be continued.

By the end of 1953 nearly seventy CORPORAL rounds were to have been test-flown by this Laboratory. The rounds delivered in 1953 were to be used for the continued development of the guidance system, tactical field equipment, and warhead installations, as well as for establishing the field reliability of components.

Special studies were to be continued as required on such problems as the following:

(1) The effect on guidance of deviations in parameters such as drag, weight, and motor performance.

(2) The effect of missile alignment and aeroelastic phenomena on guidance and control.

(3) Effects of vibration.

(4) Propulsion-system stability.

JPL TEST-FIRINGS

As of 30 June 1955, 30 pre-production and 69 CORPORAL Type I production missiles had been fired by JPL. Twenty-six Type I production missiles had been fired in Engineer-User tests and 23 in training and user evaluation.

An analysis of the R&D firings (Ref Jet Propulsion Laboratory GUIDED MISSILE SUMMARY Nr 47, dated 15 May 1955) shows the following progression of Type I system in flight reliability during the R&D test program:

Flight Numbers	Inflight Reliability*
10-30	43.5%
31-54	46.2%
55-89	47.0%

*NOTE: Reliability determined by finding the per cent success of each major component, such as propulsion system, radar, etc., during flights and applying formula P overall = P_1 X P_2 X P_3 X P_4, etc.

Accuracies demonstrated in the R&D flight program are as follows:

Flight Numbers	% Within 300 Meter Circle	% Within 900 Meter Circle
10-30*	0%	0%
31-54	18.2%	63.7%
55-89	33.4%	69.8%

*NOTE: Rounds 10-30 did not contain final range correction guidance equipment.

ADDITIONAL INFORMATION CONCERNING MILITARY CHARACTERISTICS

The following additional information concerning military characteristics was extracted from Technical Report, ORDNANCE GUIDED MISSILE & ROCKET PROGRAMS, Vol. III, CORPORAL FIELD ARTILLERY GUIDED MISSILE SYSTEM, INCEPTION THROUGH 30 JUNE 1955:

The military characteristics for the CORPORAL system were prepared after the development was well under way. The military characteristics were transmitted to the Department of the Army Staff G-4 from G-3 by D/F file Nr G-3 471.94, dated 13 November 1952, Subject: "Interim Military Characteristics for CORPORAL Missile." Summarized below are important statements which were extracted from this document:

> Military characteristics set forth (herein) are those whose fulfillment are deemed necessary to make the CORPORAL missile system an acceptable missile system for use by the Army Field

Forces. Many features which would be desirable in an ultimate missile system are not included.

The CORPORAL missile is considered primarily as a carrier for an atomic warhead to be used to attack, for the purpose of destruction or neutralization, all profitable surface targets within range. The order of accuracy indicated as desirable may also render the CORPORAL an effective weapon system in carrying the following types of warheads:

Fragmentation Cluster
Chemical Cluster
GB
Incendiary
Biological
Radiological
General purpose and/or high explosives

The CORPORAL missile shall be capable of carrying a 1,500-pound warhead approximately 30 inches in diameter. The atomic warhead shall include the safety features required to give the highest possible assurance that a nuclear explosion will not occur over friendly troops. The probability of such an explosion shall be less than 1 in 10,000.

The CORPORAL system shall be capable of engaging targets at all ranges from approximately 25 to 80 nautical miles from the launching site. The missile shall fly at supersonic speeds from shortly after launch to impact or detonation.

The CORPORAL system shall have the maximum accuracy attainable within the following boundaries: assuming that the exact range and azimuth to recommended ground zero are known, it is required that at least 50% of those missiles which are launched impact within 300 yards of ground zero.

The reliability of the CORPORAL system should be such that: at least 75% of the missiles removed from six months storage must pass all preflight checkout tests; of the missiles which pass the checkout tests, no more than 5% may fail to launch at the designated time; those missiles which launch must have an inflight reliability of 95%.

All equipment of the CORPORAL system shall be mobile. No more than 4 hours shall be required to emplace the ground control equipment and the launcher in a prepared position and to fire the first missile. The ground control equipment and the launcher shall be capable of going out of action and into traveling position in not more than 1 hour. All equipment in the CORPORAL system shall be capable of transport without damage by air in Phase IV operations.

The equipment shall be designed to have acceptable performance within an air temperature range extending from -25°F to +125°F. The equipment shall be designed and constructed so as to permit launching in surface wind speeds up to 35 mph, with gusts up to 50 mph. The equipment shall be constructed to perform its intended function at all relative humidities up to 100% at all temperatures below 90°F.

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ANTICOUNTERMEASURES

EXTRACTED FROM

REPORT NO. 20-100

THE CORPORAL

A Surface-to-Surface
Guided Ballistic Missile

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

March 17, 1958

UNCLASSIFIED

[redacted]

ANTICOUNTERMEASURES

Early in the development of the CORPORAL radio-guidance system, it was recognized that electronic countermeasures (ECM) could constitute a threat to successful use of the system. However, the CORPORAL program was considered to be a "crash" project, and the philosophy of adapting readily available techniques and equipment dominated early system planning, with the objective of demonstrating a workable system of adequate accuracy at the earliest possible date. Selection of a modified SCR 584 radar and a modified AN/DPW 1 radar beacon, and adaption of the VHF DOVAP range instrumentation system (which in turn was based on the German V-2 Doppler velocity measuring scheme), were logical expedients. It was believed that ECM would not be a serious problem in the planned 1954 to 1960 era if a pulse-coded radar transmission and the ultimate narrow bandwidth of the Doppler system were used, combined with a low-maneuverability (near ballistic) guidance philosophy.

In Round 5, flown in July 1950, the basic radar and Doppler equipment was employed and the pattern was set for the eventual CORPORAL radio-guidance system.

In late 1952, an anticountermeasures (ACM) group was established at JPL to study the CORPORAL guidance system ECM vulnerability, with the objective of making proposals and developing techniques for the institution of those changes of a relatively minor nature to the existing radar and Doppler systems which would reduce the probability of effective enemy jamming. By March 1954, some (although by no means complete) jamming tests had been run on all elements of the CORPORAL radio-guidance systems, and the need for a few modifications had been indicated. Throughout 1954 and 1955, system evaluation and various modification development efforts continued, resulting in improvement of certain ECM vulnerability characteristics and in several recommendations for future improvements. Much of the specific improvement engineering required was accomplished by the groups responsible for the subsystem involved.

In addition to the Jet Propulsion Laboratory, other organizations were actively involved in the CORPORAL ECM vulnerability problem, notably Gilfillan, the Electronic Defense Laboratory, and the Operations Research Office of Johns Hopkins University. In general, the ACM evaluation program indicated that it would be technically practical, or under some assumptions rather easy, for a properly prepared enemy to jam the CORPORAL radio-guidance system, even as modified. Ultimately, however, the seriousness of any ECM vulnerability (or the worth of any ACM modification) depended upon the whole logistics and tactics situation, both friendly and enemy, which would prevail at the time when a system was employed. It is not necessarily true that the CORPORAL would, in fact, be neutralized by ECM, if employed tactically between 1954 and 1960.

Resistance to ECM is determined both by the fundamental design of the system and by the detailed performance of subsystems and individual circuits. By the time an active ACM effort was underway, the CORPORAL system fundamentals had long been fixed, and an accelerated effort was underway to get the system into production. This situation made it difficult to incorporate other than relatively minor changes; and even these changes were at times problematical.

Countermeasures vulnerability is part of the over-all reliability problem: ECM constitutes an environment, or potential environment, for any radio system. In any new missile system, early flight tests clearly indicate any lack of sufficient integrity to endure at least the basic mechanical environment encountered in flight. Thus, emphasis on mechanical environment specifications, mechanical design, and mechanical environmental testing comes early. On the other hand, true ECM environment is not "natural" during the development period, but must be provided. (Indeed the opposite usually occurs, and radio silence in critical frequency bands is demanded by developing agencies during early flight tests.) To provide jam-resistant systems, it appears necessary to specify a countermeasures environment early in system planning, to employ this specification as a boundary condition during system development and as a type-approval hurdle, and to use it as a basis for inspection and maintenance testing throughout production and use of the system. The requirement to continue the influence of a countermeasures specification throughout system life arises because ECM resistance almost always requires more nearly ideal behavior of circuits or components than is required for normal nonjammed system operation; hence continued satisfactory system operation in the absence of ECM is by no means proof that the ECM resistance level has been maintained.

In the following references to individual portions of the CORPORAL system, it is assumed that the reader is familiar with the subsystem concepts and the terminology commonly employed therewith.

A. COMMAND UNIT

The first portion of the CORPORAL system to receive attention from the ACM group was the command unit (CU) or radar beacon. Initial tests were conducted early in 1953, using both GE and early model CU54 beacons. The command unit continued to receive considerable attention throughout the program, in part because it was at times a conspicuous offender, and in part because it went through several model changes.

In the early tests, the pattern was established of interrogating the beacon closed loop (nonradiating) with standard CORPORAL test equipment and of adding jamming signals to the beacon input. The first jammer used for these tests was a high-power noise-modulated magnetron provided and operated by the Signal Corps Engineering Laboratories; later tests employed JPL-designed noise-jamming signal generators, as well as various CW and pulsed signal generators.

At various times several basic problems which existed in the command units significantly affected their ECM characteristics. Typical examples are the following:

1. THE "AGC CAPTURE" PHENOMENON. Proper AGC voltage is derived only when proper interrogation is occurring. Short-term interference with proper interrogation allows AGC to disappear, hence drives IF gain to its highest value and allows IF saturation on all but the weakest signals. The result is that all but the weakest signals appear to have the same amplitude to the beacon detector and video circuits. Once this sequence occurs, a weak jamming signal could be as effective as a powerful one of the same form and could continue to block the beacon receiver. This jamming could be mechanized by combining high-peak power pulses (at near the radar PRF) with high average power noise. Significant improvement was obtained in beacon performance by providing a dual time constant AGC system: fast to reduce beacon IF gain when interrogation is properly made, but slow to increase IF gain when interrogation is blocked.

2. LIMITING IN IF AMPLIFIERS. An AGC linearity problem occurred in certain beacons, which resulted in severe limiting in their IF amplifiers at moderate to high signals. As in the case of the AGC phenomenon just described, the result was to make a small-amplitude jamming signal as effective as a large one. This problem was a good example of the need for continued ACM testing, even during production, since beacons suffering from the condition worked ideally under nonjammed conditions. The trouble was found to result largely from an uncontrolled parameter in a tube type used in the AGC circuit, and redesign was able to cure the problem to a large extent. Trouble with limiting occurred several times during the program.

3. BLOCKING OSCILLATOR. Original beacon circuitry provided a blocking oscillator ahead of any coding protection circuits. Almost any signal of sufficient amplitude would trigger the blocking oscillator, and, until it could recover (approx. 25 sec), the beacon could not be interrogated. Replacement by a pulse-forming circuit substantially reduced this dead time (to about 5 sec).

Numerous other problems of varying magnitude were uncovered and attacked with varying success. However, certain fundamental problems remained:

1. It was not possible with any simple modification to protect the CU against interrogation by even a relatively simple code breaker.

2. Even a moderate increase in interrogation rate could have severe results, both in noisy command information in the missile and in degradation of the reply pulse to the ground radar (due to severe detuning of the beacon transmitter at the increased duty factor.

The significance of these two items is that hybrid PRF or jittered PRF will not protect the beacon from a code breaker.

Several investigations proposed for improving the command unit ECM vulnerability situation included the following:

1. Improve the airborne antenna pattern to favor the friendly transmitter. Several db might be gained by this improvement.

2. Require coincidence of all five pulses of the ground transmission to "unlock" the beacon. This change would somewhat increase the code breaker problems.

3. Provide an inverse time delay filter (matched filter) for a pre-coincidence-decision filter. (This improvement would be much more effective for pulse groups having larger numbers of pulses.)

4. Use discriminators of the phase-locked oscillator type for demodulation of commands.

5. Modify the system to incorporate a pseudonoise jittered pulse position in the ground transmission, and a suitably similarly jittered tracking gate in the beacon. This pseudo-random pulse (PRP) system has been studied at the Jet Propulsion Laboratory, and it is believed that it would substantially improve the CORPORAL system anticountermeasures performance.

B. DOPPLER SYSTEM

Two versions of a Doppler system have been employed as a part of CORPORAL guidance. The Mark I Doppler, adapted from the VHF DOVAP range instrumentation system, was originally intended for feasibility demonstration only. Since it was not considered tactical by this Laboratory, no significant amount of ACM effort was applied. The Mark II Doppler, a UHF system, was developed for tactical use and was examined much more thoroughly for ECM vulnerability.

1. DOPPLER GROUND STATION. The Mark II Doppler ground station (DGS) received considerable attention because it was discovered quite early that an extreme vulnerability existed in the velocity measuring process, as initially designed. Either noise or CW jamming was effective and some evidence indicated that even inherent system noise was causing excessive error. Fortunately, very substantial improvement is possible through the use of a phase-locked loop type of narrow-band tracking filter, with as much as 30 to 50 db improvement having been demonstrated under certain conditions.

In December 1954, two types of research model tracking filters were tested passively at WSPG, using the prototype (R&D) DGS, during CORPORAL flights 91 and 92. Phase-lock was achieved on all tests, and accuracy of operation was satisfactory. Jamming tests were conducted with the complete transponder/ground station loop, both with and without the filters installed, with very encouraging results. Later, tests were repeated, using a Gilfillan production type-II ground station and a Mark IIA Doppler transponder.

CW jamming tests of the Doppler ground stations were also conducted with the tracking filters installed. It was found that, unless the CW jamming signal was within approximately 1 kc of the Doppler signal, synchronization of the tracking filter with the Doppler tone was not dropped until an input signal-to-jamming ratio of -28 db into the Doppler transponder unit (DTU) or -55 db into the ground station was reached. If the CW tone happened to fall within approximately 1 kc of the Doppler tone, a signal-to-jamming ratio of about unity seemed sufficient to cause the loop to drop synchronization.

During the early part of 1955, a program was initiated to introduce the tracking filter into the type-II Doppler system. Two experimental tracking filters were built by the Laboratory and were evaluated to determine applicability to the CORPORAL system. The tests were aimed (a) toward familiarization of locked-loop systems and components and (b) toward evaluation of the two experimental units. By judicious packaging, the system could be mechanically interchangeable with the existing audio amplifier and filter assembly (whose function it replaces) and could be issued as a plug-in field modification for the existing type-II command centers. Additional field tests were made with the following objectives in mind:

1. Differences in field-test anti-jam performance between the vacuum tube and transistor versions of the lock-loop.

2. All preliminary tests had been conducted employing either a research and development or a preproduction prototype discriminator. However, in view of the indications that detailed discriminator performance might influence the jamming margin, all further tests used a production discriminator rather than the research and development or preproduction discriminators.

On 13 March 1956, CORPORAL Round 1413 was successfully flown, primarily as a gas-generation experiment, but also as a vehicle for field-testing a prototype of the Doppler tracking filter. Only autopilot guidance was employed, in order to simplify the electronic system. A type-I Doppler unit provided shutoff and DOVAP tracking. A separate type-II Doppler was flown in conjunction with the tracking filter experiment. A type-II radio (Doppler) set comprised the ground terminus for the tracking filter equipment. The shutoff signal received by the missile was telemetered and recorded on the ground, where the tracking filter input and output were both recorded on magnetic tape. The ground station was set up in a normal manner except that the shutoff frequency was set 150 cps low to insure a shutoff indication. Although the filter experienced two failures during the week prior to the flight, it operated satisfactorily during flight. A second prototype tracking filter was built by the Electronic Engineering Company. Tests indicated that its characteristics were essentially the same as the JPL prototype. This unit was submitted to Ordnance as a model for production.

2. FLIGHT DOPPLER. The Mark II flight Doppler transponder unit was examined for ECM vulnerability characteristics on several occasions, the first tests occurring in September 1953. There are two aspects of DTU vulnerability: first, jamming effects on the shutoff (or arming) relay closure decision made in the DTU, and, second, jamming effects on the retransmitted signal, in turn affecting the Doppler ground-station velocity measurement. The first aspect could be examined rather easily, using standard system test equipment to simulate the ground-station transmitter with various experimental jamming signals added from convenient signal generators. To explore the second aspect required development at this Laboratory of unique signal simulation equipment, involving considerable time and effort.

Effect of jamming on the shutoff relay closure was first examined, using an early Mark II DTU. It was found that noise (approx. equal to the DTU bandwidth) 0 to 5 db below the transmitter signal would falsely trigger the relay, and further that a properly two-tone modulated jamming carrier would trigger the relay when it was 15 or 20 db below the transmitter signal. This condition was related to the fact that in the absence of jamming only a very small percentage of the proper tone modulation of the transmitter carrier was required to cause shutoff relay closure. Also, it was determined that, with a 100% modulated carrier, the range of modulation tone frequency which would be effective was very wide, in some cases several kc.

The basic problem was that the final decision threshold for shutoff relay operation was very low. There are several reasons tending toward selection of a low threshold:

1. To eliminate undesired (or unknown) gain changes in the system, due to imperfect AGC, poor amplifier stability, detuning of filters, and other causes.

2. To allow the legitimate transmitter to cause shutoff, even though some otherwise ineffective jamming is present. Clearly a dilemma exists; the proper threshold setting depends upon the jamming environment expected. Later tests on Mark IIA units indicated that the threshold level had been raised to the point that noise alone was insufficient to cause false triggering.

Improving security of the shutoff relay closure appears to be a difficult problem. One basic approach is to set the threshold decision level in the shutoff decoder automatically on the basis of the total audio signal plus noise after the receiver second detector. This is an adaption of the British CODAN noise suppression idea. Such a system would correct for normally imperfect IF amplifier AGC, and would also correct for some of the suppression of apparent modulation level induced by the jamming signal. A second approach that could be followed would be a brute-force reduction of all the DTU bandwidths, primarily in the audio decoder filters.

It was determined that the RF reply signal to the Doppler ground station contained many spurious signals when the DTU input was contaminated by jamming. Further, the output amplitude of the desired signal was reduced, or suppressed from its normal unjammed value. In addition, quantitatively, all of these effects were levelsensitive. The most serious discovery was that the suppression effect on the desired output component was very large, the power of the desired output component decreasing as the fourth power of the DTU input jamming-to-signal power under some conditions. Analysis of the situation is difficult or (thus far) impossible, depending upon the system model chosen for study. The system is highly nonlinear in various ways, depending upon input level. Experimental models at the audio frequency of different combinations of limiters and frequency doublers were tested, with results that duplicate many of the effects found in the transponder. In general, it was found that limiting, either before or after a doubler was undesirable, and that a quadratic (or square-law) doubler was more desirable than a linear one (or a full-wave rectifier). At very low input-signal levels, the transponder behaved very much like a quadratic doubler, with linear amplifiers ahead and following. At higher input levels this was not true, and behavior was less satisfactory. An obvious step to improve the DTU RF output characteristics was to linearize its amplifiers and to enforce a squarelaw doubler operation; however, this improvement has not been effected. As previously mentioned, the phase-locked type of tracking filter in the DGS aids greatly in reducing the effects of transponder jamming.

Proposals for ECM improvement of the flight Doppler system include the following:

1. Remove DTU limiting. This step demands some sort of AGC criteria; perhaps output power would be a good choice.

2. Install a square-law frequency doubler in the DTU.

3. Narrow the bandwidth of the audio decoder filters.

4. Set the keying threshold on the basis of signal plus noise output of the second detector.

5. Improve airborne and ground antenna patterns.

6. Design an RF phase-locked DTU, thus overcoming the doubler threshold problem, as well as providing a narrower noise bandwidth for the audio detector.

Significant Ground-Radar Changes

Flight No.	Ground-Radar Changes
5	dual G.E.—Signal Corps radars employed; no guidance loops closed; 8-ft reflectors used
6	azimuth-guidance loop closed
7	first JPL experimental model radar employed; shutoff system used; 10-ft reflector used
8	elevation system employed
9	antenna shimmed in collimation
10	automatic frequency control employed for local oscillator, circularly polarized antenna, and stabilized R_0 range unit
11	automatic frequency control abandoned
12	radar brought up to Model-I status for first time; parallel tracking with second radar for training of field personnel
18	range-correction system employed
19	reverted to use of 6-ft reflector; beam-entry system used
22	pedestal removed from top of van and relocated on 40-mm gun carriage for stability
24	necessary to use emergency control box for first time
25	coriolis tilt employed for first time
27	first operation with programmed beam entry; first attempt to reduce ground reflections into antenna
34	first prototype model-I radar employed in parallel; 10-ft reflector used on experimental model for data on ground reflections
36	preset acquisition employed
40	6-ft reflector employed
41	prototype Model-I radar employed; emergency control box abandoned
42	10-ft reflector experiment
44	standard decoder employed
47	new 6-ft dish and feed to reduce side lobes employed; pulse rate altered to reduce interference
48	operation with linearly polarized missile antenna
49	radar employed different magnetron
50	first use of potentiometer for R_0 range information
55 & 56	operation with two missiles in 2 hr
67	new averaging boresight procedure employed for removing bias due to ground reflections
68	operated with wide transponder pulse to stabilize angle-error-signal scale factor
70	operation Bondoque: simulated tactical situation; type-I production radar employed

C. GROUND RADAR

The ground radar has been studied perhaps the least of the major elements of the CORPORAL guidance with regard to ECM characteristics, partly because of the unavailability of ground radar systems for test, but primarily because of the belief that the ground radar was less vulnerable to direct jamming than the rest of the system. Primary susceptibility is believed to be loss of beacon return. One early experimental examination was conducted on so-called type-I radars late in 1953 and early in 1954; several recommendations resulted, among which were the following:

1. Depending on IF gain, limiting in the video under noise or CW jamming could cause dropout of automatic range tracks long before an operator lost the signal on an A scope. AGC, hence limiting characteristics, appeared to vary greatly from one radar to another. There appeared to be no adequate procedure to assure correct adjustment under AGC. Use of the manual gain control could improve the situation by as much as 20 db.

2. The use of IF amplifier gating in the ground radar generated pulses out of CW or near CW interference. This could cause spurious signals to confuse the range and angle tracking systems. The use of video gating might be helpful.

3. Many things appear to happen simultaneously when the radar is jammed. Only well-trained operators could hope to be effective in regaining control. This fact suggested the possibility of a "jammer-trainer" to acquaint operators with jamming effects and proper manual-recovery techniques.

In addition to the early tests by the ACM group, the radar system group undertook two ACM efforts: the hybrid PRF and the tunable magnetron studies. The hybrid PRF scheme, incorporated successfully in JPL firings, consisted of alternately switching the transmitted pulse group spacings between those pulse group-to-pulse group spacings corresponding to two different PRFs. This insured that the beacon would not be blocked on any more than two successive interrogations by emission from a jamming ground radar using any normal and steady PRF. Use of hybrid PRF greatly alleviated interference problems at WSPG.

Application of a tunable magnetron to the ground radar transmitter was explored, but never incorporated in the field. A continuously tunable system would have increased to a small extent the complexity of a jamming station. Most significant would have been the ability to avoid portions of the spectrum known to be crowded.

It should be noted that no organized ACM tests of the type-II CORPORAL radar have been made.

[redacted]

Various proposals which have been presented include the following:

1. Replace the present 6-ft-D antenna with a 10-ft-D or larger unit, and increase transmitter power. These changes would help in marginal situations.

2. Convert to a full-track system in azimuth, instead of the locked azimuth system. This conversion would reduce the amount of limiting required in the command-unit receiver video.

3. Employ a side-lobe protecting screen if direct jamming of the ground radar occurs.

4. Remove or reduce the limiting in the ground radar receiver, and standardize the gain set-up procedure.

5. Employ the PRP system. (See CU recommendations.)

D. OVER-ALL RADIO SYSTEMS

The early ACM tests clearly demonstrated the difficulty of attempting to add jamming resistance to a system which had not considered such resistance in its original design. In many ways, the original design was directly opposed to the basic principles of interference rejection. Subsystems were used whose components were wekk-known to the enemy. Extreme sensitivity was designed throughout the system.

As a consequence, this Laboratory began an independent program whose goal was a tightly integrated, highly jam-resistant radio system capable of satisfying the basic needs of ballistic missile guidance. This research effort rapidly showed the advantages of pseudo noise coding, phase-lock systems, and precision simultaneous lobing antenna configurations. The program was directly inspried by the needs demonstrated in the CORPORAL system for a radio link capable of high accuracy and high jamming resistance.

The most direct result of this additional research program to the CORPORAL was the derivation of the theory and technique of phase-lock loops which were employed in the Doppler tracking filter. Later results included Microlock for extreme range telemetering, the CODORAC system for JUPITER missile guidance, and phase-lock discriminators for telemetering.

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GLOSSARY FOR "ANTICOUNTERMEATERS"

ACM - Anticountermeasures

AGC - Automatic Gain Control

CODAN - A carrier - operated anti-noise receiver

CODORAC - Coded Doppler Radar Command, used in JUPITER not in CORPORAL

Collimation - Refers to radar's "line of sight"

cps - Cycles per second

CU - Command Unit, or radar beacon

CW - Continuous Wave

db - Decible, the usual unit for measuring the relative loudness of sounds

DGS - Doppler Ground Station

DOVAP - Doppler Velocity and Position

DTU - Doppler Transponder Unit

ECM - Electronic Countermeasures

GSE - Ground Support Equipment

IF - Intermediate Frequency

Magnetron - A vacuum tube containing an anode and a heated cathode, the flow of electrons from cathode to anode being controlled by an externally applied magnetic field;
Anode: the positive pole, or electrode, of the vacuum tube.
Cathode: the negative pole, or electrode, of the vacuum tube.

MC - Megacycle

msec - Millisecond

NACA standards - National Advisory Committee for Aeronautics standards, referring in JPL reports to speed of sound, atmospheric viscosity, and other "standard" atmospheric conditions

PRF - Pulse-Repetition Frequency

PRP - Psendo-Random Pulse

RF - Radio Frequency

Servo - An electrically operated, pneumatically actuated device used for converting electronic guidance commands into movement of missile control surfaces

SET - Service-Evaluation Telemetering

UHF - Ultra High Frequency

VHF - Very High Frequency

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DEVELOPMENT OF CORPORAL GROUND HANDLING EQUIPMENT

EXTRACTED FROM

REPORT NO. 20-100

THE CORPORAL

A Surface-to-Surface
Guided Ballistic Missile

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

March 17, 1958

UNCLASSIFIED
[redacted]

DEVELOPMENT OF CORPORAL GROUND HANDLING EQUIPMENT

The Jet Propulsion Laboratory was originally requested to direct the development of handling and launching equipment for the CORPORAL missile system late in 1950. Because of the limited number of personnel available at JPL for investigation of launching and handling problems, the Office of the Chief of Ordnance advised this Laboratory to solicit proposals from those industrial firms which had capabilities in this field. The International Derrick and Equipment Company (IDECO), which had specialized in missile handling equipment, was asked by JPL to prepare a study of CORPORAL tactical handling equipment. Ordnance advised JPL that the study of handling equipment and methods of tactical operation of the CORPORAL field artillery missile paralleled a similar study for the Hermes missile system and requested that the IDECO study be coordinated with the Hermes study in progress by Barnes and Reinecke in order that as much interchangeability as possible could be developed between the two systems.

Two separate but parallel contracts for the development of similar guided-missile handling systems were approved. IDECO was to work under subcontract to JPL in developing equipment expressly for CORPORAL, and Barnes and Reinecke was to work under subcontract with G.E. in developing Hermes equipment. The latter contract included studies of the possibility of adapting Barnes and Reinecke equipment to the CORPORAL system. Reports by this company as late as 1953 confirmed that they had given serious consideration to the CORPORAL requirements, but termination of the G.E. contract before any CORPORAL missiles were operated with the equipment did not allow evaluation of that effort. JPL negotiated a cost-fixed-fee contract with IDECO to design and fabricate a complete set of launching and handling equipment for the CORPORAL missile. The contract, approved on 18 May 1951 by Ordnance, assigned responsibility for all system ground-equipment design to IDECO, with one exception: this Laboratory retained responsibility for the development of necessary fueling vehicles because of the specialized problems in that area.

At this time, the decision was made to include the following items of handling and launching equipment in the CORPORAL system:

1. The erector - a self-propelled vehicle to perform a dual function of transporting the missile to the launcher and of erecting the missile to the vertical position from which it would be fired.

2. The launcher - a device to support the missile in a vertical position for the firing.

3. An air-supply truck - an air container able to pressurize the missile air tanks for firing.

4. A truck-mounted air compressor - an adequate high-pressure air supply for the air-supply truck.

5. Truck-mounted propellant servicers - devices to mount fuel and oxidizer containers for filling the missile propellant tanks.

6. A shipping container - compatible with the handling gear.

7. A special device, necessitated by the extreme height of the missile - to service missile components in the guidance section, nearly 40 feet above ground level when the missile was erected.

Continued JPL evaluation of IDECO designs as development progressed led JPL to become more and more critical of the erector and launcher proposals. However, the servicing platform, air compressor, and air-supply trucks were considered to be progressing satisfactorily. When JPL concluded that IDECO was not achieving a design that best satisfied missile handling requirements, that portion of the contract was halted, and another subcontractor was selected. All other items of equipment that were developed under the IDECO subcontract ultimately reached the operating prototype stage. Within 2 years after the initiation of the equipment studies, all prototypes were in operation in tests at White Sands Proving Ground.

A. PROTOTYPE HANDLING AND LAUNCHING EQUIPMENT

Design features of the prototype handling and launching equipment were established at this stage and were changed very little through 4 years of production of the service weapon.

1. TRUCK-MOUNTED AIR COMPRESSOR. A truck-mounted air-compressor unit capable of being operated at a working air pressure of at least 3000 psi was dictated by requirements of the missile air tank. The missile air tank had to be pressurized to at least 2500 psi at takeoff in order to fulfill the combined functions of forcing propellants through the system and of operating pneumatic valves and controls.

The IDECO survey of the various types of available compressors capable of performing this job resulted in the conclusion that only one would satisfy the demands. A Clark Brothers lightweight high-speed air-cooled compressor, originally developed for the Chemical Corps as a part of a mobile flame-throwing apparatus, had been found to be a reliable unit in oil-field applications.

The problems of applying the Clark compressor to CORPORAL system requirements were many. A suitable gasoline engine prime mover had to be connected to the compressor, and high-quality filtering and drying units had to be added to the compressor outputs. A suitable 6-cylinder gasoline engine was adapted to drive the compressor, and a silica-gel twin-tower dryer unit and filter kept the compressed air supply clean and dry to standards far beyond the usual definition of "clean and dry".

All particles larger than 50 microns in diameter (0.005 mm) were filtered out, and the dew point of the air could bekept so low that moisture condensation would occur only when the air reached -80°C. The air compressor could operate at a rate of 90 cu ft/min when charging the truck-mounted air-supply tanks.

The air compressor was mounted on a 5-ton truck chassis. The installation included the necessary piping and adapters to connect it to the truck-mounted air supply.

2. TRUCK-MOUNTED AIR SUPPLY. All high-pressure air-supply bottles available in the spring of 1951 were studied by IDECO with an eye toward possible use in the CORPORAL system. The best available bottles were the laminated steel bottles made by the A. O. Smith Company. These bottles, 18-inch cylinders 14 feet long, were constructed of multiple layers of low-alloy steel. The advantage of the laminated construction was purported to be a high resistance to shattering in case of penetration by gunfire.

The truck accommodated four of the air-supply tanks manifolded together. Each of the tanks could be charged in unison and discharged separately in any desired order. Pressure gauges in the manifold were provided to measure the pressure of each tank independently, as well as the manifold pressure. A manually operated reel installed on the truck-mounted air supply carried 600 feet of special high-pressure steel-braid-reinforced Aeroquip hose.

3. TRUCK-MOUNTED SERVICING PLATFORM. Commercially available devices capable of lifting an operator to the level of the nose of an erected CORPORAL missile were studied by IDECO. The Hi-tender, manufactured by Stemm Brothers for work in the apple orchards in Washington, featured two hydraulically actuated folding booms. The commerical model would not reach the heights desired for the CORPORAL application, but the increased lifts required could be attained by limited redesign.

The necessary redesign and the mounting of the boom unit on a 5-ton truck chassis resulted in a servicing device that would enable an operator to reach the components in the nose of the erected missile.

4. SELF-PROPELLED ERECTOR. As a result of the difficulties that IDECO had experienced in the design of items directly associated with the handling of the missile, R. G. LeTourneau was asked to submit a proposal to the Laboratory for a vehicle capable of transporting the missile and erecting it on the launcher.

Le Tourneau accepted the task and in 1 month submitted proposals to JPL describing an all-electric-drive vehicle on which all wheels drove and all wheels steered. The most attractive feature of the electric drive was the precise positioning capability of the missile on the launcher, as well as a feature that would allow the hoisting of the missile from a horizontal position on or near the ground. All boom motions, missile-supporting clamp action, and steering were to be electrically powered or actuated.

LeTourneau's proposed erector was to be capable of holding the missile by split clamping rings attached to an erecting boom. The boom pivot point would in itself be capable of generous vertical movement. About the pivot point, the boom could be swung in a 180-degree vertical arc. The forwardmost point of the arc would position the missile horizontally over the erector for travel. At the mid-point in the arc, the missile and boom would be extended vertically in position for mounting the missile on the launcher. At the aftwardmost point of the arc, the missile and boom would be extended horizontally for fueling and servicing, with clear waist-high access to all parts of the missile. A gasoline-engine-powered ac and dc generator furnished all vehicle power.

The combination of all proposed features was sufficiently attractive that LeTourneau was given the task of building the erector and launcher. The construction phases of the IDECO erector and launcher contract were cancelled. At this time, because of certain doubts as to the suitability of the launcher design that LeTourneau proposed, JPL went ahead with a launcher design of its own.

5. MOBIEL LAUNCHER. The CORPORAL launcher had to be capable of supporting the missile at four points on the aft end of the oxidizer tank, of holding it in a vertical position, and of rotating the missile to firing azimuth; in addition, it had to be mobile. The JPL launcher prototype supported the missile on four pivoted arms that engaged hooks on the aft end of the oxidizer tank, midway between the planes of the stabilizers. Two steadying pins engaged holes in the aft support of the missiles, and the air line and electrical cable connections were provided. The launcher support arms, as well as the steadying pins, were mounted on a turntable structure which could rotate through 6400 mils. The turntable was in turn mounted on a welded steel box-section base that functioned also as a trailer frame. On each corner of the square base were pivoted folding outriggers that incorporated leveling jacks. The launcher could be towed behind a standard truck.

6. PROPELLANT SERVICER. The hazards of handling and transferring or pumping the propellants for CORPORAL led to the early decision that the only acceptable scheme would provide propellant transfer by gravity. Adequate flow rates could be achieved only by holding the storage tanks at a greater height than the missile when the propellant transfer was taking place. With the missile held horizontal and just above ground level by the erector, there was a sufficient height differential between the missile and propellant tanks mounted on the body of a standard truck to achieve adequate transfer times. The fumes which would have been evolved if the missile tanks were vented to atmosphere during the filling with red fuming nitric acid (RFNA) would have presented a definite problem. Hence the decision was made to vent the missile tanks to the

filling tank in such a manner that, as the missile tanks filled with acid, the fumes and air within the missile tank would be displaced into the original acid container. A sealed closed-transfer system was used. The flow was controlled by tipping the tank so that it was possible to eliminate valves. The hoses were separated after the transfer operation had taken place; hence virtually no acid fumes were vented.

One of the major problems associated with the development of the fueling equipment was the selection of a suitable transfer hose. Because of the small gravity head available, it was necessary to utilize transfer hose having as large a diameter as possible. This hose had to be quite flexible, yet resistant to the effects of RFNA. The hose selected was one constructed of spiral wraps of polyethylene tape and stainless-steel wire, approximately 2 inches in diameter. The propellant truck was capable of carrying either four aniline containers or two acid containers. Mounted in the center of the truck body was a swinging crane, which was capable of picking up the containers from ground level and placing them in the special holding racks on the truck body. One aniline tank and one acid tank comprised a fuel charge for one missile.

With the completion of the design fabrication and proof testing of each of the individual items of launching and handling equipment, the units were sent to WSPG to be used in an actual missile firing.

During the use of the equipment at WSPG, one significant major failure occurred. This was the collapse of the prototype Stemm Brothers servicing platform. While being operated by Army personnel, the middle joint in the boom assembly failed; the operator's cage fell approximately 15 feet to the ground, and the men in the cage sustained slight injuries. An investigation revealed that the design was inadequate in spite of the satisfactory performance on proof-test loading of the servicer. After a thorough check of the characteristics of the particular design, it was this Laboratory's conclusion that a new type of servicer should be considered. A survey of the available commercial servicer units was again conducted.

The best solution appeared to be an adaptation of an orchard spray unit made by the Miller-Robinson Company. This unit consisted of a multiple-stage hydraulic ram which extended vertically to sufficient distance for the necessary servicing operations. For travel, the multiple stage ram was folded forward and down to reduce the over-all height. With the exception of some difficulties with hydraulic-fluid leakage at the joints of the telescopic cylinder, the unit was entirely satisfactory. Functionally, however, there was a disadvantage in that the operator's cage was approximately 15 feet from the ground at its lowest point, which meant that any equipment or tools to be used for servicing the missile first had to be carried to the platform from the ground level.

B. FIRESTONE CONTRACT

As a result of the demonstration in tests by the Laboratory of all the basic elements of the CORPORAL launching and handling equipment, Firestone was awarded a contract to produce these items. Firestone was to redesign the equipment to incorporate changes required as a result of deficiencies found in field tests, and also to incorporate such changes as would make the equipment more suitable for production. In addition, the Firestone design responsibilities included the creation of satisfactory Ordnance documentation of the designs. The Laboratory acted in its position as technical consultant to Ordnance during this phase of the development of the handling equipment by serving as an agent for Ordnance in approval of the designs submitted by Firestone.

After design, production, and field test of the type-I CORPORAL ground equipment, Firestone was advised of the shortcomings of all of the equipment then produced in order that Firestone could redesign for production, by remedying those deficiencies that could readily be corrected, and provide for documentation of all of the equipment. A resume of the deficiencies was forwarded to Firestone prior to their implementation of the type-I contract. Those design changes incorporated by Firestone are listed as they apply to each item of equipment.

1. GUIDED-MISSILE LAUNCHER XM-1

1. Instead of the complicated mechanisms for retracting and extending the missile support arms, a simple screw jack and coil spring retractor was incorporated.

2. The over-all structure was simplified.

3. The original torsion-bar axle suspension was omitted in favor of a straight single-axle assembly with no springing.

4. The launcher air line and electrical cable servicing methods were greatly simplified.

2. PROPELLANT TRUCK.

1. Definite deficiencies in the design of the rotary drive for the propellant truck crane were remedied in the Firestone redesign.

2. Other details in the design to make the truck more producible were included by Firestone.

3. GUIDED-MISSILE ERECTOR XM-1

1. LeTourneau heavy-equipment manufacturers, working with Firestone, extensively redesigned the type-I erector.

2. The missile handling-rang grasping linkage was modified to allow remote, positive handling-ring engagement and disengagement.

3. The over-all width of the erector was decreased.

4. New electrical drive motors were installed to enable the erector to travel at greater speed.

5. The erector operator was provided with a remote-control box to enable precise positioning of the missile on the launcher. The remote-control box, used by an operator only inches from the missile, allowed each small movement to be detached during the operation.

4. TRUCK-MOUNTED AIR COMPRESSOR XM301E1.

1. The capacity of the air compressor to 3500 lb/sq. in. was increased.

2. All of the compressor piping, the filter assembly, and the drying towers underwent redesign.

3. The method of mounting the air compressor on the truck body was changed in order to effect savings in dimensions and weight.

5. TRUCK-MOUNTED AIR SUPPLY SM350:

1. The capacity of the air supply to 3500 lb/sq. in. was increased.

2. Because of the increase in working pressures, it was possible to shorten the laminated steel storage bottles.

3. Total air volume was decreased since the working pressure was increased.

4. The method of interconnecting the air bottles was changed in order to provide greater resistance to leakage.

6. SERVICING PLATFORM SM280E1:

1. The extension capability of the outer boom was restricted in such a manner that the maximum load limit could not be exceeded.

2. The over-all boom structure was redesigned to furnish a higher factor of safety.

3. The details of the boom joints were changed in order to achieve greater strength.

C. SHIPPING CONTAINERS

No provisions were made for any method of shipment of the CORPORAL missile components until the original missile production contract was under way. Neither was the shipping container included as part of the original missile-handling-equipment contract with JPL.

It was very evident that some means of shipment must be produced. Firestone asked that the aircraft division of Lyon Van and Storage Company submit a design study for the CORPORAL shipping container. JPL considered that the results of the Lyon container study were entirely inadequate. The next container, a result of a design collaboration between Firestone and JPL, was intended as an interim shipping means only.

Briefly, the interim shipping container could be described as a large plywood box structure that contained missile supports at the forward end and near the aft end of the missile-body aft section. Each support had four rubber shear mounts. The missile structure was protected from the adverse effects of humidity by a composite plastic and aluminum foil bag designed by Firestone. The design of the plywood box was accomplished by JPL, and Firestone designed the means of support and the protective covering.

The inadequacies of the wooden shipping containers were found to be as follows:

1. The wooden container had many bolts that had to be removed before removal of the missile from the box.

2. The shock and vibration isolation system was not adequate to protect the container contents from a 36-inch drop.

3. The details of the attachment of the shock and vibration mounts were such that no convenient means for picking up the missile remained.

4. The aluminim foil bag covered with a plastic material was not adequate for moisture protection.

The wooden shipping container was not redesigned to alleviate the faults listed. Ordnance contracted with JPL to design and fabricate a reusable metal shipping container after a design study by Rheem Manufacturing Company proved unacceptable. The metal container alleviated all of the original objections to the wooden container.

The metal shipping container XM351 was designed by Sandberg-Serrell Corporation because of manpower limitations in this field at the Laboratory. An acceptable design was received within 3 months. This container consisted of a cylindrical metal shell with a removable end cap. The missile was supported by cables attached to torsion bar suspension devices and could be released by removing the end cap, attaching a track section, lowering the missile to grooved wheel dollies, and rolling it out of the container. The missile-body aft section was shipped in the pressurized container in a completely assembled condition, with the sole exception of the installation of the fins. Three of the original, or prototype metal containers, were manufactured by JPL and tested.

D. OVER-ALL REVIEW OF DESIGN

At the time that the CORPORAL program was conceived, the Ordnance Corps did not have prior experience in the design, development, or use of any guided-missile system. On the other hand, the developers of the system, namely, the Jet Propulsion Laboratory, had no prior experience with the tactical usage of a guided-missile system. The German V-2 program did not paralled the intended use of the CORPORAL, due to the fact that the CORPORAL was to be a battlefield weapon, whereas the V-2 was not a tactical missile. However, certain similarities did exist between the CORPORAL system and the V-2. The missile was transported from the test site to the launcher on a trailer. In both systems the missile was raised by an erecting device to a vertical position on a separate launching platform. In addition, the basic V-2 concept resulted in an awkward system having many separate component units.

Compounding the lack of experience was a sense of urgency. At the time of the Korean action, the world situation was so unsettled that the utmost importance was attached to immediate production of a guided-missile weapon system of the short-range ballistic type. This urgency precluded any redesign of the basic features of the CORPORAL missile which dictated certain handling equipment requirements; hence all ground equipment had to work around a then-existing design that had not taken into consideration the problems resulting from field-handling operations.

1. TYPE-II GROUND EQUIPMENT. All deficiencies of the first production type-I equipment were listed by both Army groups and JPL. Firestone was given the sole responsibility for the design and production of the type-II ground-equipment contract. JPL did not participate in this effort.

The only contribution by this Laboratory was to report system malfunctions such as those that occurred during the SANDSPIT tactical field operation conducted by the Laboratory at WSPG; JPL responsibilities for the type-II CORPORAL system were limited to missile components, missile electronics, and ground-guidance units. The limited design approval retained by this Laboratory in the case of the type-I system was not extended to type II. Therefore, JPL had no ground-equipment responsibility for type-II equipment.

Illustrations of the type-II erector and launcher are included in this Report for information purposes, as all JPL operations of the type-II system at WSPG utilized these units.

2. MAJOR DEFICIENCIES. The CORPORAL launching and handling equipment had three major deficiencies both in the prototype gear built by JPL and in the operational systems designed and built by Firestone. The first major deficiency resulted from the lack of integration of transporting, storing, servicing, erecting, and launching equipment for the missile; these devices were not properly integrated with each other, nor with the missile. The second major deficiency resulted from the use of a very complicated nonstandard vehicle, the erector. Although the erector was a reasonably reliable device, it was of such complexity and so different from anything with which the Army had had experience that almost insurmountable problems resulted whenever malfunctions occurred. The third set of deficiencies resulted from miscellaneous small details of equipment design that made the gear very difficult for Army personnel to operate. Not enough consideration was given to the mechanical aspects of the designs.

a. Lack of integration. Those integration faults previously mentioned resulted from the need of transferring the missile from one special piece of gear to another. It was possible to face six different situations of this type. In general, the missile could arrive in two types of containers; it could then be transferred either to the handling stands or to the contrainer tracks; and, finally, it could be picked up by the erector and placed on the launcher. Removal from the launcher or the container, in case of a cancelled firing, added to the difficulty.

Because of insufficient understanding of the requirements inherent in an operation with many transfers, the system suffered. Field operations required a flexibility in intervehicle relationships that was not possible. In order to provide even the flexibility necessary to make the various pieces of gear work with each other, complications were introduced in the equipment. Typical of the complications was as simple an item as the missile handling rings. An outgrowth of the factory handling rings which were used to clamp the missile firmly, yet allowed it to be rotated during assembly and tests, the handling rings were the common ground that existed between containers, storage racks, and erectors. The original wooden container lacked sufficient space to allow the installation of the handling rings while the missile remained in the support crate. The handling rings, because of the limitations in the fore and aft movement of the erector clamps that engaged them, had to be placed in a precise location on the missile before the erector could raise the missile. Precise location of the rings was difficult because of their weight. Further, to simplify the erecting operation, some means of removing the rings from the missile had to be provided; consequently, the once-simple split rings bolted together with flange bolts had to incprporate features that would allow the erector clamps to hold them firmly when the missile was released.

When the metal container was produced, one of the limitations on the design was imposed by the necessity of making the track compatible with the missile, the handling rings, and the erector. Even then, incompatibilities existed that made it difficult to gain access to all missile compartments for tests or maintenance.

When the type-II erector incorporated new handling rings intended to eliminate the need for the precise location of the rings on the missile, the need for coordinated design became apparent. Because of the location of the permanently installed handling rings in the type-II e erector boom, alternate handling-ring positions were necessary when the missile was taken out of the container and tested on the track. Every operation required two sets of handling rings. Then Firestone, acting on an Ordnance request, designed some lightweight handling rings to alleviate the physical labor inherent in the installation of the several-hundred weighty items. Their aluminum alloy handling rings were adequate, but were not entirely compatible with the container tracks.

b. Use of nonstandard erector. Another category of problems arose as the result of the use of the erector, a large, complicated and non-standard vehicle. The use of the liquid propellants and the requirement for the utmost in simplicity in order to achieve safe operation dictated that the missile be placed in a horizontal position during the propellant-filling operation. To hold the missile horizontally in any sort of erecting vehicle while filling the propellant tanks was not too difficult, but to hold it near the ground in order to be able to utilize gravity propellant flow became more of a problem. With full propellant tanks the missile weighed approximately 11,000 pounds. This 5-ton weight had to be lifted to a vertical position and moved into accurate alignment with the launcher-support points. All of the requirements then were such that no standard vehicle or crane would be able to fulfill them. The size and weight of the missile necessitated a special-purpose vehicle.

Factors that were considered in the selection of erecting vehicles were: quick availability, apparent functional suitability, and construction-equipment level of reliability. One manufacturer, LeTourneau, apparently could fill these needs and, in addition, was able to provide a proven, easily controlled, electrical motor-drive system. The LeTourneau erector was selected for initial prototypes.

After early devices were produced and tested, it was apparent that the electrical drive system in the LeTourneau design was not in as advanced a state of development as had been supposed. In addition to shortcomings evident in the electrical drive system, the Army did not set up proper maintenance procedures for so unusual a vehicle. Frequently occurring malfunctions pointed up the lack of proper maintenance on the electrical drive.

c. Problems of equipment design. The class of faults that plagued the whole system might to attributed to two reasons: (1) the designers did not appreciate the problems that inevitably result from field use of any weapon. (2) Not even an incomplete testing program, aimed at eliminating the difficulties resulting from field use of the weapon, was initiated early enough in the development to have determined the existence of such difficulties. The deficiencies might be considered individually as relatively minor, but their aggregate effect on the usability of the CORPORAL ground equipment was major in significance. Regardless of any detailed reasons for the existence of the previously mentioned faults or major problem areas, the underlying reason is found in the inexperience of both designers and users. Neither the developers nor Ordnance knew enough about the problems to evolve a system without some shortcomings.

The military characteristics requirement was not in existence until all individual elements of the system had been designed; lack of time to conduct studies of the system was also a factor. For instance, the only studies that were made before the system was well outlined in its present form took only 2 months from inception to presentation. Comparative studies on parallel systems take more than 2 years. Because of time limitations, the major emphasis on design was to get something that worked, a production item if at all possible. No particular stress was put on making the design work well because that would have caused an immediate extension of the time required to go into production, even of prototypes.

FISCAL HISTORY OF CORPORAL

INTRODUCTORY EXPLANATION

The first four CORPORALS (CORPORAL E rounds) were custom-built at JPL between 1945 and 1949. The air frames of the next seven (Rounds 4-11) were built by Douglas Aircraft Company during 1949; propulsion and guidance were added at JPL. Douglas was awarded a contract for the air frames and propulsion systems of the next 20 (Rounds 12-31), to be built during 1950 and early 1951. By this time, it was apparent that greater numbers would be needed, and in January 1951 JPL created an industrial planning section to assist in formulating and "freezing" complete missile specifications for submission to possible contractors. This was a most difficult task for an item still in the early development phase, since many compromises had to be made between the manufacturers' need for fixed specifications and the development engineers' desire to incorporate recent improvements.

In mid-1951, specifications were sent out for bid to General Motors, Continental Can, Douglas Aircraft, Vendo Corporation, and Firestone Tire and Rubber Company. The initial cost-plus-fixed-fee contract for 200 CORPORALS (CORPORAL Type I) was let to Firestone in July 1951. In July 1952, this number was increased by 120, making a total of 320 Type I missiles. About half these missiles had been delivered by mid-1953, but they required certain modifications (suggested by the JPL research staff) before they could be flown.

An additional contract was let to Firestone in mid-1953 for 465 "ORD-437" missiles (designated Type II CORPORAL), production to start in mid-1954. The ORD-437 was a "cleaned-up" version of the CORPORAL and involved no major system changes but a number of minor revisions in the interest of efficient production. The electronics subsystems were subcontracted by Firestone, who held the prime contract on missile equipment, and by the Gilfillan Corporation, who held the prime contract on all electronic ground equipment. Several dozen subcontractors were involved under the two prime contracts.

Table I:	JPL Expenditures by Fiscal Years
Table II:	History of Contract Structure of Jet Propulsion Laboratory to July 1953, Including Ordnance, Navy, and Air Force
Table III:	California Institute of Technology Contracts Directly Relating to ORDCIT Project
Table IV:	Summary of CORPORAL Contract Costs for Major Contracts Executed through 30 June 1955

TABLE I: JPL EXPENDITURES BY FISCAL YEARS

The tabulated information listed below was extracted from STATUS REPORT ON CORPORAL GUIDED MISSILE, JPL/CIT, 22 September 1953. Expenditures by JPL on the CORPORAL Program, including the FY 1953 estimate, were as follows:

FY 1946		$ 245,000.00
FY 1947		588,200.00
FY 1948		643,371.00
FY 1949		383,250.00
FY 1950		646,200.00
FY 1951		2,644,630.00
FY 1952		4,957,222.00
FY 1953	Estimated	5,500,000.00

TABLE II

HISTORY OF CONTRACT STRUCTURE OF JET PROPULSION LABORATORY TO 29 JULY 1953, INCLUDING ORDNANCE, NAVY, AND AIR FORCE

JPL No.	Government No.	Starting Date	No. of Supplements	Termination Date	Total Funds	Purpose
1	W-535-ac-20260	6-25-41	19	6-30-52	$ 3,156,264.00	liquid and solid rockets, JATOS
2	W-33-038-ac-4441	6-14-44	7	4-15-47	280,975.00	hydrobomb and solid rocket
3	W-33-038-ac-4320	9- 1-44	18	6-30-52	1,149,037.00	ramjet and combustion
*4	W-04-200-ORD-455	6-22-44	44	10-31-50	12,338,249.00	long-range rockets
*5	W-04-200-ORD-703	6-22-44	14	10-31-50	1,138,765.00	facilities and equipment
*6	W-04-353-ENG-1056	10- 2-44	3	5- 7-47	317,500.00	buildings
*7	W-04-363-ENG-1698	7-30-45	3	11-15-45	4,716.00	preliminary 20-inch supersonic wind tunnel
8	a(s)-7913	12-12-45	2	7-13-46	15,000.00	satellite study (Navy)
*9	W-04-200-ORD-1482	5-29-46	25	10-31-50	907,233.00	basic propellant study
10	N6-ONR-244	10- 1-46	3	6-30-47	16,031.00	Mugu range instrument study (Navy)
*11	W-04-353-ENG-1957	12- 3-46	12	12-31-50	691,000.00	construction of 20-inch supersonic wind tunnel
*13	W-04-200-ORD-1501	5-13-47	2	8-30-48	65,000.00	50-lb solid-propellant rockets
15	W-33-038-ac-18709	9-26-47	2	6-30-50	159,750.00	evaluation of AF contracts
17	(NORD-10448)	6-15-49	8	active	281,842.00	liquid gun development
18	(N123a-57251)	12- 1-48	2	7-31-50	44,440.00	Mugu sea range study

The information listed was extracted from Seifert, Howard S., JPL Publication Nr 22, HISTORY OF ORDNANCE RESEARCH AT THE JET PROPULSION LABORATORY, 1945-1953, JPL/CIT, 29 July 1953.

TABLE II (Cont)

JPL No.	Government No.	Starting Date	No. of Supple-ments	Termina-tion Date	Total Funds	Purpose
19	NOa(s)-10068	6-30-49	2	6-30-51	$ 121,725.00	liquid rocket combustion
*20	DA-04-495-ORD-18	10- 3-50	15	9-30-53**	21,392,500.00	missile development
*21	DA-04-353-ENG-299	6- 1-50	2	6-30-51	7,500.00	master plan for JPL
22	AF-33-038-14535	-------	-------	6-30-51	11,900.00	Air Force property inventory
*23	DA-04-495-ORD-18	5- 8-51	1	12-31-52	926,590.00	CORPORAL training program
24	NOas-52-455c	11-12-51	1	11-30-52**	136,640.00	rocket-motor combustion

* The W-04 and the DA-04 contracts included those pertaining particularly to CORPORAL and also those supporting other research projects as well as the CORPORAL. The remarks under "Purpose" are self-explanatory.

** Active as of 29 July 1953.

TABLE III

CALIFORNIA INSTITUTE OF TECHNOLOGY CONTRACTS
DIRECTLY RELATING TO ORDCIT PROJECT

EXTRACTED FROM

Miles, Captain Richard C., compiler, THE HISTORY OF THE ORDCIT PROJECT UP TO 30 JUNE 1946, Research and Development Service Sub-Office (Rocket), California Institute of Technology, Pasadena, California, nd.

Although JPL-3 was not directly related to the direction development of CORPORAL followed, original plans did contemplate the possibility of developing a ramjet-type test vehicle. That contract is therefore included:

JPL-3

Contract Nr	:	W33-038-ac-4320	
Subject Work	:	Services and reports; theoretical analyses of ram-jet propulsion and its application.	
Effective	:	1 September 1944 to 15 November 1946.	
Definitive Contract	:	$160,875.00	6-30-45
Supplement Nr 1	:	160,875.00	9- 1-45
Change Order Nr 2	:	160,875.00	2-28-46
Change Order Nr 3	:	195,875.00	2-28-46
Supplement Nr 4	:	591,875.00	11-15-46

INTRODUCTORY EXPLANATION

Ordnance work which became JPL-4 and JPL-5 began under Letter Order Nr W-04-200-ORD-396 (for $25,000.00) to cover preliminary plans. Pending execution of a definitive contract, the research was begun under a series of Letter Orders, designated on Institute records as JPL-4.

The facilities (purchase and installation of equipment, etc.) for the research to be conducted under JPL-4 were covered by a separate contract, Nr W-04-200-ORD-703, designated as JPL-5.

In two instances, funds were transferred between JPL-4 and JPL-5, in accordance with demands of each contract: JPL was reduced by $250,000 in Supplement Nr 12, and JPL-5 was increased by that amount in Supplement Nr 1; Supplement Nr 13 decreased JPL-4 by $100,000, which appears as an increase under Supplement Nr 3 of JPL-5. The decrease of $91,234.89, covered by Supplement Nr 2 of JPL-5 was initiated by the Ordnance Department on the grounds that "due to termination of hostilities in the present war /World War II/, the adjustment by the Government of certain allocations of funds has been made necessary."

JPL-4

Contract Nr :	W-04-200-ORD-455
Subject Work :	Research and investigation and engineering re long-range rocket missile and launching equipment.
Effective :	29 June 1944 to 30 June 1946.
Letter Order Nr 1	(Letter Order was placed with CIT on 22 June 1944 and accepted by CIT on 29 June 1944.)
through Nr 6:	Provided for preliminary research work to be conducted for the period 29 June 1944 through 15 January 1945, pending execution of Definitive Contract.
Supplement Nr 7 :	Was never issued.
Supplement Nr 8 :	Extended the Letter Order from 15 January 1945 to 15 February 1945, pending execution of Definitive Contract.
Supplement Nr 9 :	Was the Definitive Contract, in the amount of $1,600,000; it carried a termination date of 22 December 1945.
Supplement Nr 10 :	Modified the patent clauses, only.
Supplement Nr 11 :	Brought the total funds to $3,600,000. The termination date was extended to 30 June 1946.
Supplement Nr 12 :	Provided for a decrease of $250,000, reducing the total funds to $3,350,000. The termination date remained 30 June 1946.
Supplement Nr 13 :	Provided for a decrease of $100,000, reducing the contract total to $3,250,000, with no extension of the termination date, which remained 30 June 1946.

SPERRY-GYROSCOPE SUBCONTRACT UNDER JPL-4

This subcontract was dated 23 August 1945 and provided $33,000 to cover cost of research, investigation, and engineering. Final report was due 31 March 1946, which was the expiration date for the contract as set by Supplement Nr 2 thereto.

DOUGLAS AIRCRAFT COMPANY SUBCONTRACT UNDER JPL-4

This subcontract, dated 16 June 1945, covered labor and materials to be furnished by Douglas for the assembly of articles developed under the prime contract and also the manufacture by Douglas of component parts for these articles.

JPL-5

Contract Nr : W-04-200-ORD-703

Subject Work: Facilities in connection with JPL-4.

Effective : 22 June 1944 to 31 March 1946.

Definitive Contract provided funds amounting to $275,000 and carried a termination date of 31 March 1945. As stipulated in this contract, CIT had the power to extend the termination date; therefore, CIT advanced the date to 30 June 1945, without supplement to the contract.

Supplement Nr 1: Provided an increase of $250,000, bringing the total funds to $525,000. CIT again extended the termination date, making it 30 September 1945.

Supplement Nr 2: Provided for a decrease of $91,234.89, reducing total funds to $433,765.11. The termination date was advanced to 31 March 1946.

Supplement Nr 3: Provided for a transfer of $100,000 from JPL-4 to JPL-5, thereby increasing JPL-5 funds to $533,765.11. The termination date remained 31 March 1946.

Another contract of considerable interest, in view of the development of the WAC CORPORAL and the BUMPER Project, was designated:

JPL-8

Contract Nr : NOa(s)-7913.

Subject Work: Theoretical study of a high-altitude rocket test vehicle.

Effective : 17 December 1945 to 31 May 1946.

Definitive Contract provided $15,000 to carry the contract through 31 May 1946.

SUMMARY OF CORPORAL CONTRACT COSTS FOR MAJOR CONTRACTS EXECUTED THROUGH 30 JUNE 1955

The following information was extracted from Technical Report, "Ordnance Guided Missile & Rocket Programs," Vol. III, "CORPORAL Field Artillery Guided Missile System, Inception Through 30 June 1955," pages 39-63, 169-201, where procurement and related matters are treated in considerable detail. Only the major contracts are included in this summary. The costs, moreover, do not include the following: Ordnance administrative costs; arsenal, proving ground, and other governmental agencies research, engineering, and procurement support costs; costs of items listed on TO/E other than contractor-furnished and basic research. Field Service costs are not broken down into individual contracts. In general, Field Service Contracts covered services in connection with the maintenance support of CORPORAL equipment and field modification of the equipment.

TABLE IV

SUMMARY OF CORPORAL CONTRACT COSTS FOR MAJOR CONTRACTS EXECUTED THROUGH 30 JUNE 1955

Contractor	Contract Number	Date	Item	Contract Totals 30 June 1955
SECTION A, RESEARCH AND DEVELOPMENT				
California Institute of Technology	DA-04-495-ORD-18	5 Oct 50	Research and Development	$28,296,868.00
Douglas Aircraft Company, Inc.	DA-04-495-ORD-21	9 Oct 50	Test Vehicle	1,414,645.00
Gilfillan Brothers, Inc.	DA-04-495-ORD-468	11 Jun 53	Redesign of guidance equipment	6,063,618.53
SECTION B, INDUSTRIAL				
Firestone Tire & Rubber Company	DA-04-495-ORD-159	16 Jul 51	CORPORAL Type I Missiles	26,348,037.62
Firestone Tire & Rubber Company	DA-04-495-ORD-355	24 Jun 52	Ground Handling Equipment	19,402,128.56
Firestone Tire & Rubber Company	DA-04-495-ORD-437	26 Feb 53	CORPORAL Type II Missiles	39,625,101.16
Firestone Tire & Rubber Company	DA-04-495-ORD-681	29 Jun 55	CORPORAL Type III Missiles	10,235,582.19
Firestone Ture & Rubber Company	DA-04-495-ORD-688	29 Jun 55	CORPORAL Missiles for United Kingdom	7,739,287.98
Firestone Tire & Rubber Company	DA-04-495-ORD-700	29 Jun 55	Ground Equipment for United Kingdom	2,253,354.95
Gilfillan Brothers, Inc.	DA-04-495-ORD-350	23 Jun 52	CORPORAL Ground Guidance & Control Systems	30,154,987.13
Gilfillan Brothers, Inc.	DA-04-495-ORD-692	29 Jun 55	CORPORAL Ground Guidance & Control Systems for United Kingdom	2,682,267.00

TABLE IV (Cont)

Contractor	Contract Number	Date	Item	Contract Totals 30 June 1955
SECTION C, FIELD SERVICE			Total Amount -	$ 704,586.95

SECTION D, SUMMARY OF COST

Through 30 June 1955, the total dollar value of contracts executed was $199,423,694.88. The breakdown of this cost is as follows:

1.	Research and Development Contracts	39,470,388.73
2.	Industrial Contracts	159,248,719.20
3.	Field Service Contracts	704,586.95
		$199,423,694.88

TABLE V

INDUSTRIAL FUNDS -- ACTUAL MONEY SPENT FY 1951-FY 1961

The following information was furnished by Mr. Paul R. Collier, Missile System Industrial Management Officer, ABMA, and gives the actual Industrial expenditures for the years listed -- FY 1951 through FY 1961. Amounts are not broken down to show sums paid to individual minor contractors.

CORPORAL HISTORY

FY 51	$14,813,376	Type I 320 missiles and 11 sets ground equipment
FY 52	7,580,930	
FY 53	76,060,373	Type II 465 missiles and 19 sets ground equipment
FY 54	30,197,930	Modifications, repair parts and documentation
FY 55	87,505,244	Type IIA 157 missiles for Army (plus 113 missiles, 10 sets ground equipment and 3 sets Type IV test equipment for United Kingdom costing $27,500,000)
FY 56	12,764,631	6 sets Type IV test equipment
FY 57	10,418,450	47 missiles and 65 practice warheads
FY 58	7,199,000	22 missiles and 60 practice warheads
FY 59	14,660,000	90 milliles and 38 practice warheads
FY 60	1,660,000	40 practice warheads and system engineering
FY 61	1,680,000	53 practice warheads and system engineering

DISTRIBUTION TO CONTRACTORS

	Firestone	Gilfillan	Others	Total
FY 56	3,975,462	3,275,494	5,513,675	12,764,631
FY 57	7,302,000	1,263,000	1,853,450	10,418,450
FY 58	3,387,394	1,758,038	2,053,568	7,199,000
FY 59	12,888,524	500,000	1,271,476	14,660,000
FY 60	974,797	376,482	308,721	1,660,000
FY 61	600,000	600,000	480,000	1,680,000

[redacted]

TABLE VI

CONTRACT FACT SHEET

Missile System CORPORAL (Industrial)

Contractor	Date	Type	Initiated By Letter Contract?	Contract Objective	Fee (Avg %)	G&A (Avg %)	Total Value
Prime: Firestone Tire & Rubber Company							
DA-04-495-ORD-681	29 Jun 55	CPFF*	No	CPL Type IIA Missiles	5.56**	8.9	$19,894,829.43
DA-04-495-ORD-1430	15 Dec 58	Fixed Price W/Form IV Price Redetermination	Yes	CPL Type IIA Missiles	9.058/1	11.2/2	5,866,920.00
DA-04-495-ORD-1312	27 Jun 58	CPFF*	No	Engineering Services related to CORPORAL Missile System	6.3	8.9	838,312.95
Sub: Gilfillan Brothers, Inc.							
DA-04-495-ORD-1281	23 Jun 58	CPFF*	No	Engineering Services related to CORPORAL Missile System	7.0	8.9	349,781.00

* Cost-plus-fixed-fee.
** Initial fixed fee of 7% for prime cost-plus-fixed-fee contract has been reduced to approximately 5.56%
/1 Approximate profit
/2 Formal contract expected to be $11,733,840.00

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TABLE VII

CONTRACTOR FACILITIES
FUNDED BY GOVERNMENT

CORPORAL MISSILE SYSTEM

ACTUAL

Contractor	Production Equipment	Brick and Mortar	Total
Firestone Tire & Rubber Company	$2,340,779	-0-	$2,340,779
Clary Multiplier	447,000	-0-	447,000
Ryan Aeronautics	122,000	-0-	122,000
Total	$2,909,779	-0-	$2,909,779

ANTICIPATED

Contractor	Production Equipment	Brick and Mortar	Total
Firestone Tire & Rubber Company	-0-	-0-	-0-
Clary Multiplier	-0-	-0-	-0-
Ryan Aeronautics	-0-	-0-	-0-
Total	-0-	-0-	-0-

[redacted]

[redacted]

TABLE VIII

RCS XMC-5

ARGMA

CORPORAL

FUNDS, PROCUREMENT AND DELIVERY (U)

FY	PROGRAM FUND REQUIREMENTS (IN MILLIONS OF DOLLARS)							PROCUREMENT AND DELIVERIES											
								MISSILE						GROUND EQUIPMENT					
	DEVELOPMENT			PEMA	MCA	OTHER	TOTAL	R&D		PRODUCTION				NON TACT **		TACT **			
	R&D	PEMA IN SPT	R D T&E					PROC	DEL	ARMY PROC	OTHER PROC*	ARMY DEL	OTHER DEL*	PROC	DEL	ARMY PROC	OTHER PROC*	ARMY DEL	OTHER DEL *
58 & PRIOR	35.2	4.1		210.3		27.5	277.1			1,011	113	851	113	7	7	12	5	12	5
59				13.7			13.7			90		108							
60				(1.0) 1.0			(1.0) 1.0					120							
61				(.8) 3.1			(.8) 3.1					22							
62				1.2			1.2												
63				.9			.9												
64																			
65																			
66																			
67																			
TOTAL	35.2	4.1		232.0		27.5	298.8			1,101	113	1,101	113	7	7	12	5	12	5

* MARINE CORPS AND MAP ** BATTALION (CARRY-OVER PROGRAM AUTHORITY) (PRIMARY PROGRAM)

DOES NOT INCLUDE REQUIREMENTS SUCH AS AK PROGRAMMED DIRECTLY FROM OCO TO OAC AND OTHERS IN FY 59 AND PRIOR YEARS.

ARMY ROCKET & GUIDED MISSILE AGENCY
ARMY ORDNANCE MISSILE COMMAND
NO MC-C-2-559 REV [illegible]
MICS NO. DATE 30 JUNE 60

[redacted]

TABLE IX

CORPORAL

FUNDS, PROC & DEL (U)

FY	PROGRAM FUND REQMTS (IN MILLIONS OF DOLLARS)					PROCUREMENT & DELIVERIES									
						MISSILE				GROUND EQUIPMENT					
	DEV					PRODUCTION				NON TACT		TACTICAL			
	RDT & E	PEMA/S	PEMA	OTHER	TOTAL	ARMY PROC	OTHER PROC	ARMY DEL	OTHER DEL	PROC	DEL	ARMY PROC	OTHER DEL	ARMY PROC	OTHER DEL
58 & PRIOR	35.2	4.1	210.3	27.5	277.1	1011	113	851	113	7	7	12	5	12	5
59			13.7		13.7	90		108							
60			2.0		2.0			131							
61			(.5) 1.7		(.5) 1.7			11							
62															
63															
64															
65															
66															
67															
TOTAL	35.2	4.1	228.2	27.5	295.0	1101	113	1101	113	7	7	12	5	12	5

(PRIMARY PROGRAM) DOES NOT INCLUDE REQMTS SUCH AS A.K. PROGRAMMED DIRECTLY FROM OCO TO OAC & OTHERS IN FY-59 & PRIOR YEARS.

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EXTRACTED FROM

Technical Report No. 39

FLIGHT ANALYSIS OF FIRST FOURTEEN ROUNDS OF CORPORAL TYPE 1 FIRED IN E-U PROGRAM

October, 1954

Technical Staff
WHITE SANDS PROVING GROUND
New Mexico

SUMMARIZATION OF ENGINEER-USER FIRINGS

CORPORAL SYSTEM MALFUNCTIONS

Rounds E-U 1 through 14

MALFUNCTIONS IN CORPORAL GROUND
GUIDANCE, HANDLING, AND ANCILLARY
EQUIPMENT
(During Period of Rounds E-U 1 to 14)

Missile Project: CORPORAL Type I, Fourteen-Round Engineer-User Program

Round Number	Date Fired	Flight Time	Range	Impact	Remarks
EU-1	30 Jan 53	165.8 Sec	Unknown	70.61m right 6,629 .6m short	Premature fuel shutoff, improper range correction, extra high trajectory.
EU-2	26 Feb 53	183.18 Sec	Unknown	6,936m right, 84,072.3m long	Missile failed to respond to fuel shut-off signal, burned until fuel exhausted.
EU-3	23 Mar 53	171.59 Sec	Unknown	3,606.94m right, 1,351.2m long	Missile responded satisfactorily to shut-off signal, flew satisfactory trajectory. Test successful.
EU-4	14 May 53	68 Sec	23.7 km	214m long, 22m left	Missile propellant shutoff by radio signal from Flight Safety at 68 sec due to heavy overcast and loss of missile by radar and optical trackers.
EU-5	8 Jun 53	183.5 Sec	45.22 mi	7,051.2m long, 70.9m right	Missile 54 sec late reaching range correction velocity.
EU-6	7 Jul 53	205 Sec	82.3 km	6,962m short, 18.5m left	Error in shutoff equation, "go short" command sent instead of "go long", resulting in large miss-distance.
EU-7	4 Aug 53	162 + Sec	42.5 km	25.6m right, 548.7m long	Missile performed as programmed - test successful.
EU-8	18 Aug 53	91.64 Sec (aft part)	7.029 mi (aft part) 2.34 mi (nose part)	N/A	Central power system failed; forward and aft sections broke apart at 30.5 sec terminating thrust.

Missile Project: CORPORAL Type I, Fourteen-Round Engineer-User Program (Cont)

Round Number	Date Fired	Flight Time	Range	Impact	Remarks
EU-9	1 Oct 53	124 + Sec	Unknown	308m right, 29,951m long	Shutoff failure; range correction velocity reached 24 sec late, resulting in large miss-distance.
EU-10	13 Oct 53	158.05 Sec	52.8 km	49.1m right, 1,445m long	Missile sent "down" command instead of "up". Range correction velocity reached at 148.01 sec instead of 116 sec, resulting in large miss-distance.
EU-11	27 Oct 53	175 Sec	52.5 km	40m left, 1,518m long	Malfunction in range correction system resulted in large miss-distance.
EU-12	15 Dec 53	170 + Sec	54.5 km	2.3m left, 2,544m long	Missile performed as programmed; test successful except for long miss-distance.
EU-13	12 Jan 54	175 Sec	Unknown	12,960.7m left, 7,799.8m short	Overcast conditions; high elevation angle, high acceleration; test successful except for very large miss-distance.
EU-14	22 Jan 54	14.24 Sec	3,070.21 ft	N/A	Dense smoke from side of missile just before takeoff, probably due to aniline leak. Missile yawed hard right at T-plus-1 sec, began to roll at T-plus-9 sec, continued northeast and impacted 3,070.21 ft from launcher, 14.24 sec after takeoff. Failure of north servo system, due to vibration, caused hard right yaw; action of south fin in response to yaw-right error signal caused roll.

INTRODUCTION

Contained in this report is the analysis of the first 14 Type I CORPORAL missiles fired in the Engineering-User Program of White Sands Proving Ground. These missiles were flown during a period when many production changes were being made and when certain units of tactical equipment were not yet available. For that reason this group cannot be considered a homogeneous sample of such equipments now in the field, and the results of these tests cannot be extrapolated to include all of these equipments. In general, the equipment tested falls into the following categories:

Equipment	Round Nos.	Produced By	Type
Missile	1-10	Firestone-JPL modif.	DA-04-495-ORD159
Missile	11-14	Firestone	DA-04-495-ORD430
Ground Guidance	1-8	JPL	Prototype
Ground Guidance	9-14	Gilfillan Bros.	Production Set #1

The procedures used to fire these 14 rounds were not the presently published tactical procedures as these were not then available. The procedures used were developed by WSPG as a result of information gathered from communication with the Jet Propulsion Laboratory.

Since the firing tables (FT CORPORAL A-1) were not available, the system settings were calculated at WSPG on the basis of trajectories calculated at JPL, at the Ballistic Research Laboratories, and at WSPG.

SYSTEM DESCRIPTION

The CORPORAL XSSM-A-17 is a guided missile fired from a mobile ground installation at medium-range surface targets. The system is designed to carry a 1500-pound warhead at ranges of 50,000 to 120,000 meters with a circular probable error of 300 meters. The missile is designed to fly a series of standard trajectories similar to that illustrated in Figure 1. The range of the missile is primarily controlled by terminating thrust at a velocity, as determined by the shutoff computer, that will minimize the range error at impact. So that the missile will be in a proper region of a position-velocity space at a shutoff, the elevation computer system guides the missile along a predetermined trajectory from 22 seconds to shutoff. Range error is further reduced by determining (on the basis of measured position and velocity) the predicted impact error, near the peak of the trajectory, and by programming a terminal maneuver to compensate for this error. The azimuth error is controlled by commands calculated to keep the missile heading on target from 22 seconds to impact minus 10 seconds. The missile is controlled to fly close to the standard trajectory by means of yaw and pitch programs, and by autopilot control. Deviations from this standard trajectory are determined by a combination of radar and Doppler data. These

[redacted]

data are transmitted to the missile as commands to help perform the functions described above.

METHOD OF ANALYSIS

In order to determine that the system was correctly performing its functions, the flight trajectory was measured by the DOVAP system, the function of the ground-based computers were recorded, and limited missile functions were measured with telemetry. To check the validity of the input information to the computers, the outputs of the radar and Doppler units of the system were compared with DOVAP data. These inputs were utilized to calculate the outputs of various sections of the ground computer by using the equations that it solves. By comparing these calculations to the measured outputs of the computers, it was determined that the computers either arrived at the results:

1. Correctly - on the basis of good input data, or
2. Incorrectly - but in a manner consistent with proper equipment and erroneous data, or
3. Completely incorrect.

The operation of any unit of the system was satisfactory if it performed its function in a manner consistent with the input data. The operation of the missile was checked by limited use of telemetry and by comparing the commands given to the missile by the ground equipment with the result obtained from DOVAP data.

The system was evaluated by using the following criteria to compare impact results with military characteristics:

a. If a component malfunctions during flight and thus prevents the missile from accomplishing its mission by an amount consistent with random errors alone, the flight is unsuccessful.

b. When autopilot and Doppler shutoff (SO) are used alone, no estimate of the standard deviation caused by random effects was made.

c. When the complete system less range correction unit (RCU) was used, a standard deviation in range of 610m and a standard deviation in azimuth of 99m were upper limits assignable to random errors. A minimum of over 1.96 standard deviations in either component was used to determine success or failure.

d. When a complete system is flown, random errors should not introduce more than a standard deviation equal to 420m in range and to 99m in azimuth. This is equivalent to a circular probable error (CPE) of 300m. A complete system flight is successful then if miss distance is less than 823m in range and less than 194m in azimuth. This definition assumes that a flight with a miss distance larger than 1.96 standard deviations is a failure because only 5% should normally fall outside this limit.

[redacted]

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In order to assess difficulties encountered in preparing for a mission, unsatisfactory condition reports (ORDBS Form 85, Revised) were obtained for the system. From these data, excessive part failures and preparation time were determined.

RESULTS OF TEST

I. In-Flight Results

By considering the system as a whole, it was found that 21% of the rounds (Rounds 3, 4, and 7) had range errors attributable to random errors consistent with the equipment flown. The causes of the large errors found in the other rounds were:

a. One or more component malfunctions that produced a gross error in range (54%).

b. One or more errors of personnel resulting from incomplete training (18%).

c. Errors in determining the systems settings without firing tables (7%).

Eight rounds were considered in determining the effectiveness of the azimuth guidance system. Rounds not considered were discarded, either because there was a definite malfunction of personnel error in some other part of the missile system which adversely affected the azimuth system or prevented it from operating, or because equipment necessary to the operation of the azimuth system was not flown in the missile.

Reasons for discarding each of these six rounds were:

Round 2	- No CU-54 flown.
Round 3	- No CU-54 flown.
Round 8	- Early impact resulting from central power failure.
Round 9	- Failure to shutoff, and switching to optical tracking just prior to termination of azimuth guidance.
Round 13	- Missile tracked on minor lobe of radar.
Round 14	- Early impact resulting from failure of north fin servo system.

The mean error and probable error in azimuth were calculated on the basis of the eight remaining rounds (95% confidence intervals are given for each).

Mean right 20 meters	left 21 m $\leq$ M $\leq$ right 61 m
Probable error 33 meters	21 m $\leq$ P.E. $\leq$ 67m

[redacted]

Because of the small sample no attempt was made to find the azimuth error as a function of range. Instead data for all ranges were combined and the above figures were calculated. It should be noted that 6 of these rounds were fired at 53,000m; one at 78,000m; and one at 111,000m.

II. Preflight Malfunction Results

Malfunctions found by CORPORAL Engineering-User Test personnel, Systems Test Division, WSPG, were reported on the system during the period of preparation for flight tests. Evaluation of failure of these 14 rounds and the associated equipment indicated a frequency of malfunctions of major components (including tube failures) as follows:

Table A

Missile Malfunctions

Major Item	Per Cent	Total Reports
Autopilot system	28	35
Programming	17	22
Radar command unit	9	11
Doppler	9	11
Telemetry	9	11
Range correction	8	10
Propulsion	6	7
Cabling	5	6
Missile power supply	4	5
Motor generator	2	3
Gyros	2	3
Bracketry	1	2
Totals:	100	126

Table B

Ground Guidance Malfunctions

Major Item	Per Cent	Total Reports
Radar (electronics)	53	64
Radar (structural)	2	2
Computer (electronic)	22	26
Doppler (electronic)	12	15
Doppler (structural)	1	1
Engine-generator (operational)	6	7
Tracker M-2	1	1
SET (electronic)	2	3
SET (structural)	1	1
Totals:	100	120

Table C

Ground Handling and Ancillary Equipment Malfunctions

Major Item	Per Cent	Total Reports
Erector	20	12
Air-supply truck	20	12
Launcher	16	10
Acid truck	13	8
Aniline truck	8	5
Servicer	8	5
Air-compressor truck	5	3
Service checkout truck (electronic)	5	3
Firing truck (electronic)	3	2
Firing truck (structural)	2	1
Totals:	100	61

These malfunctions data are summarized again in Table D in terms of type failure and the equipment in which these type failures were found. The column labeled GFE reported data on Government-furnished equipment (generators, etc.).

Table D

Malfunctions by General Type

Type	Gnd Guid Prototype	Set No. 1	Gnd Handlg	JPL Mod.	ORD 430	GFE	Pers Opns
Incorrect Mf.	1	1	8	5	1		
Poor connection	3	7		3			
Incorrect type	3	1	9	5		1	
Insecure mounting			5	7			
Incorrect opr.	1	2	2	4	3	1	
Improper assembly	1	2	7	16	4		
Miswiring	2	2		2	1		
Inadequate protection	2		2	3			
Foreign matter	4	1	1	2	2		
Corrosion	1						
Poor design	1				2		
Inadequate insulation				1			
Wear	17	9	9	5	2	6	
Tube or crystal failure	26	19		22	12		
Mistreatment	1	1	2	3	2		5
Maladjustment	2	1	3	9			4
Lubrication				2			
Unknown	3	1	2	8	1		
Totals:	68	47	50	97	30	8	9

[redacted]

See table of CORPORAL system malfunctions, round by round, for a complete tabulation of CORPORAL System malfunctions for the 14 Eneineering-User rounds fired.

Table E lists results in terms of the subsystem error and cause of this error. If the cause of error is known, a value of 1 is assigned to the error. If there are two possible causes with no positive means of determining the proper one, a value of ½ is assigned to the error.

Table E

	Rounds Evaluated	Malfunction Detected	Personnel Training	Computational* Errors
CG Equipment	14	2½	2½	2
Radar	10	0	2	0
Doppler	12	0	0	0
Sin B	8	½	½	
Elev. Comp.	8	0	0	0
Grnd SO System	11	0	0	1
Grnd RC System	5	2	0	1
Azimuth Comp. System	11	0	0	0
Missile	14	7	0	0
CU-54	10	2	0	0
Missile SO	12	2	0	0
Central Power	14	1	0	0
Propulsion	14	1	0	0
Fin Servo	14	1	0	0
Others	14	0	0	0

*These errors resulted from the lack of a firing table. They would probably not have occurred if the tables had been used.

The effect of these malfunctions was increased by the lack of spare parts. In order to render missiles flightworthy, it was necessary to cannibalize missiles allocated for future tests 10 times during tests on those 14 rounds. The above condition was further aggrevated in that certain ORD 7 and ORD 8 spares which had been returned to Firestone on 11 May 1953 for modification were not received in time for use in these first 14 rounds.

Since the equipment used in all flights was not a complete set of tactical equipment, no accurate measure of the preparation time was obtained. Locating and repairing the malfunctions, however, increased the checkout and preparation time before each flight. Data on each round is summarized in Table F. It should be noted that an average of 58 man-hours were added to the preparation time because of these malfunctions.

[redacted]

E-U Rd. No.	Man-Hours Missile Loc.	Man-Hours Missile Rpr	Consumed in Grnd. Guid. Loc.	Consumed in Grnd. Guid. Rpr	Locating and Handl/Ancil Loc.	Locating and Handl/Ancil Rpr	Repairing GFE Loc.	Repairing GFE Rpr	Malfunctions Total Rnd
1	2.0	57.0	37.2	6.1	5.0	0.2	1.0	0.5	109.0
2	2.8	111.0	8.1	6.6	0.3	0.0	2.1	0.1	131.0
3	3.6	14.2	0.8	0.1	1.0	0.5	0.1	0.2	20.5
4	9.5	11.4	10.3	34.3	0.1	1.5	0.0	0.0	67.1
5	11.6	22.1	5.4	30.7	7.0	0.0	0.0	0.0	69.8
6	5.2	11.8	13.0	7.0	0.0	0.0	0.0	0.0	37.0
7	28.2	14.3	1.3	0.4	4.6	4.4	0.8	1.0	55.0
8	4.6	5.5	21.4	2.7	0.0	0.0	0.0	0.0	34.2
9	1.1	0.7	3.4	4.3	0.0	0.0	0.0	0.0	9.5
10	6.5	6.6	1.4	0.5	8.9	10.5	0.0	0.0	34.4
11	0.5	0.2	0.3	0.2	1.2	7.3	0.0	0.0	9.7
12	14.3	4.6	1.0	4.7	30.1	76.6	0.0	0.0	131.3
13	1.6	1.6	7.4	0.9	4.2	40.0	0.5	0.1	56.3
14	8.1	8.8	24.3	1.5	0.3	6.0	0.0	0.0	49.0
TOT:	99.6	269.8	135.3	100.0	55.7	147.0	4.5	1.9	813.8

Table F

One incident that occurred on Rounds 2, 4, and 6 caused delay not reported in Table F. While these missiles were being emplaced on the launcher, rain caused many components to malfunction. The missile could not be flown until its interior had thoroughly dried.

CONCLUSIONS

The following conclusions were based on the results of these 14 rounds. In general, engineering changes from missile to missile, to effect improvements of different components, produced a highly exaggerated state of nonhomogeneity, thereby precluding any statistical confidence in the results obtained. However, since there were no known major changes in the azimuth guidance system during the firing of these rounds, the results given on the accuracy of the azimuth system are believed to be valid within the limits of this small sample.

1. Input Information from Radar System - In general, the input information from the radar was sufficiently accurate for the system to perform its mission. It should be noted that two of the rounds failed to accomplish the mission of the system because of component malfunctions in the CU-54, and that another two of the rounds failed because the radar system was not operated correctly because of inadequately trained personnel.

2. Input Information from the Doppler - The Doppler information furnished to the system was of sufficient accuracy and reliability for the system to accomplish its mission.

3. Sin β Computer - The Sin β computer circuits treated the information with reliability and with an accuracy consistent with good system performance. Extreme care must be taken in training personnel to make accurate potentimeter settings throughout the system.

4. Pitch and Yaw Programmer - The pitch and yaw programmer positioned the missile near the standard trajectory with accuracy consistent with satisfactory elevation and azimuth control.

5. Elevation Control System - Although the operation of the elevation system was satisfactory in the first seven rounds, the Jet Propulsion Laboratory and this Proving Ground believed that the accuracy in positioning at shutoff could be improved by a change in the computer loop gain. This change was made in Round 8, but since Rounds 9 and 12 were the only rounds which showed the effects of the change, conclusive evidence is not available to evaluate this change. However, the information from these two rounds and from the first seven indicates that the elevation control system operated successfully.

6. Shutoff System - The shutoff computer evaluated and transmitted shutoff with sufficient reliability and accuracy for the system to accomplish its mission. However, it is to be noted that two of the missiles failed to act on the shutoff signal and continued to burn until fuel was exhausted.

7. Range Correction System - Insufficient data forestalls any conclusion on the general operation of the range correction system. Data from performance of the range correction computer during flights of Rounds 7 and 11, however, and data obtained during normal maintenance and preflight checks of this computer, indicate that the reliability of relays in this computer should be improved.

8. Azimuth Guidance System - The azimuth guidance system was satisfactory.

9. The Missile - Of the seven or eight system malfunctions detected which definitely prevented the system from accomplishing its mission, seven were found in missile-borne components. Improvement of missile component reliability, particularly for those components listed in Table E, would afford a large gain in system performance.

10. Level of Personnel Training - Since approximately 20% of the system failures resulted from personnel errors, it is evident that the level of personnel training is critical to the success of the system.

11. The System - Examination of impact data on the system leads to the conclusion that military characteristics were met in azimuth, but were not met in range. The causes for the failure of the system are component malfunctions, mainly in the missile, which prevent the system from accomplishing its mission. The effectiveness of the system was shown to depend, to a large degree, on the level of training of the operating

personnel. It is further concluded that the effectiveness of the system is impaired by the large number of man-hours spent in correcting malfunctions during preparation of the system for its mission. The variation of the additional preparation times for locating and repairing these malfunctions will make it impossible to accurately predict when the missile can be fired.

CORPORAL SYSTEM MISSILE MALFUNCTIONS

(ROUNDS E-U-1 THROUGH E-U-14)

E-U Round 1 - Missile 1247 - 30 Jan 53

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Programmer							
Microswitches (switch S-10)	Function Omitted	Insecure Mntng.	R Oper	Repaired	1.5+ JPL Time	.2	.1
Change-over Ckt (motor clutch)	Loose	Adjustment	Prel Phase	Repaired	Unkn	.2	1.2
Autopilot Amp							
North Servo Amp (V-9N output Tube)	Fails to Position	Low Emission	Prel Phase	Repaired	.5+ JPL Time	.5	2.5
Pitch Gyro							
Gyro Container	Broken	Mistreatment	In Inspec	Sent to Lab (Ret'd to vendor)	None	.1	Unkn
Yaw & Roll Gyro							
Gyro Heater Thermo. (thermo. terminal	Burned	Short	Prel Phase	Sent to Lab (Ret'd to vendor)	None	.2	None

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E-U Round 1 - Missile 1247 - 30 Jan 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Gyro Container	Broken	Mistreatment	In Inspec	Sent to Lab (Ret'd to vendor)	None	.1	Unkn
West Servo Unit							
Auto Pilot Syst. (uni-ball joint)	Locked	Lubrication	Opt Test	Repaired	Unkn	.1	.2
Telemetry							
Blip Cable (cable)	Missing	Improper Assembly	In Inspec	Modification (repaired)	4.0	Unkn	15.0
Blip Channel					4.0	Unkn	2.0
(mixing resistor)	Missing	Improper Assembly	In Inspec	Modification (repaired)	8.0	.1	2.0
(cable to program)	Missing	Improper Assembly	In Inspec	Modification (repaired)	8.0	.1	8.0
Doppler Transponder							
Shutoff amp.	Fails to Close	Adjustment	Opt Test	Repaired	Unkn	Unkn	8.0
Central Power Supply							
Motor Generator (ball bearing)	Locked	Lubrication	R Oper	Replaced (scrapped)	75.0	.1	Unkn

[redacted]

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E-U Round 1 - Missile 1247 - 30 Jan 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Cabling and Junction Boxes							
(cannon plug)	Missing	Incorrect Mfg.	Prel Phase	Used w/o change	None	.2	None
Warhead Telemetry							
T25 Telemetry Package	Function Omitted	Unkn	Prel Phase	Used w/o change	2.5	.1	None
Doppler Transponder	Function Omitted	Inadequate Protection	Prel Phase	Repair	unkn	1.0	100.0
Switch Box (Warhead batteries discharged because of failure to react warhead arming switch box)							

E-U Round 2 - Missile 1251 - 26 Feb 53 11 Malfunctions

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Structure)							
Stowage Compartment	Leakage	Inadequate Protection	Prel Phase	Used w/o change	Unkn	None	None
Missile (Electronic)							
Telemetering Unit							
Cable-to-missile Programmer	Missing	Improper Assembly	In Inspec	Modified (repaired)	Unkn	.1	8.0
Autopilot System							
West Servo Pack	Faulty Control	Foreign Matter	Prel Phase	Replaced (repaired)	Unkn	.5	.5
Programmer (air safety and change-over lock switches)	Inoper	Miswiring	Opt Test	Used w/o change	Unkn	None	None
Motor Generator (bearings)	Noisy Oper	Wear	Opt Test	Used w/o change	Unkn	None	None
Doppler Transponder							
Receiver (timing ckts)	Faulty Control	Adjustment	Opt Test	Repaired	3.5	.2	.5

E-U Round 2 - Missile 1251 - 26 Feb 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Transmitter (timed ckts)	Faulty Control	Adjustment	Opt Test	Repaired	Unkn	.2	.5
Doubler (timed ckts)	Faulty Control	Adjustment	Opt Test	Repaired	Unkn	.2	.5
Shutoff Amp (wiring)	Shorted	Inad. Insul	Opt Test	Repaired	Unkn	.5	.5
Central Power Supply (cable plug)	Improper Phasing	Improper Assembly	Opt Test	Repaired	Unkn	Unkn	.5
Cabling and Junction Boxes							
Signal Cables (cannon plug)	Missing	Improper Assembly	Opt Test	Used w/o change	3.5	.1	None

E-U Round 3 - Missile 1261 - 23 Mar 53 — 7 Malfunctions

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Programmer							
Change-over Motor (terminal)	Thrown Solder	Improper Assembly	Opt Test	Repaired	Unkn	.5	1.0
Receptacle	Wrong Signal	Poor Connection	Opt Test	Used w/o change	Unkn	.5	None
Telemetry Unit							
Cable to Programmer	Missing	Improper Assembly	In Inspec	Modified (repaired)	Unkn	.1	8.0
Missile (Propulsion)							
Statham Gauge	Fails to Position	Incorrect Mfg	In Inspec	Replaced (repaired)	Unkn	.5	1.0
Accumulator (tubing)	Missing	Improper Assembly	Oper Inspec	Repaired	None	None	.2
Propellant Valve (check valve)	Leakage	Improper Assembly	Oper Inspec	Replaced (scrapped)	1.0	1.0	2.0
Shuttle Valve	Leakage	Unkn	Oper Inspec	Replaced (repaired)	1.0	1.0	2.0

E-U Round 4 - Missile 1263 - 14 May 53

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Programmer							
Master Timer Meter (clutch)	Loose	Admustment	Opt Test	Repaired	Unkn	.5	.5
Micro Switching System (microswitch)	Loose	Insecure Mounting	Opt Test	Repaired	Unkn	.5	5.0
Ring Modulator (beacon signal checking)	Drift	Unkn	Opt Test	Replaced (repaired)	Unkn	3.0	Unkn
Autopilot Amplifier							
North Servo Amp (feedback pot)	Loose	Insecure Mounting	In Inspec	Repaired	Unkn	Unkn	Unkn
East Servo Amp (feedback pot)	Loose	Insecure Mounting	In Inspec	Repaired	Unkn	Unkn	Unkn
West Servo Amp (feedback pot)	Intermit Oper	Open	Opt Test	Replaced (repaired)	Unkn	3.2	1.1
(potentiometer wire)	Burned	Mistreatment	In Inspec	Repaired	Unkn	Unkn	Unkn

E-U Round 4 - Missile 1263 - 14 May 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Integrators							
Cathode Follower (tube 5687)	Drift	Incorrect Type	Opt Test	Replaced (repaired)	1.1	.2	.2
Subcarrier oscil (terminal connect)	No Indication	Poor Connection	Prel Phase	Repaired	Unkn	1.0	.1
Missile (Propulsion)							
Main Air Regul Sys							
Statham Gauge	Incorrect Tolerance	Incorrect Mfg	Opt Test (Ret'd to vendor)	Sent to Lab	Unkn	1.0	.5
Propellant Valve							
Dash Pot (filstrictor)	Incorrect Tolerance	Improper Assembly	Opt Test	Modified Repaired	1.0	.1	4.0

E-U Round 5 - Missile 1265 - 8 Jun 53 5 Malfunctions

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Programmer							
Master Timer, 400 cycle synchronous motor	Noisy Oper	Incorrect Mfg	Opt Test	Replace (scrap)	2.0	.5	8.0
Gain Program Motor (micro-switch, for reset light)	Function Omitted	Insecure Mounting	Opt Test	Repaired	Unkn	.5	3.0
Gyro and Accel Change-over Motor (Microswitch, for reset light)	Function Omitted	Insecure Mounting	Opt Test	Repaired	Unkn	.5	4.0
Master Timer Cams (reset cam, top deck)	Function Omitted	Adjustment	Opt Test	Repaired	Unkn	.6	1.0
Microswitching sys. (beacon motor microswitch)	Intermit Oper	Poor Connection	Opt Test	Modified (repaired)	Unkn	.5	4.0
Central Power Supply							
Power junction box fuze	Function Omitted	Unknown	Opt Test	Replaced	Unkn	8.0	0.1
Autopilot System							
South Servo Pkg. Fin position pt.	Locked or tight	Wear	Opt Test	Replaced	Unkn	1.0	2.0

E-U Round 6 - Missile 1267 - 7 Jul 53 — 9 Malfunctions

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Programmer Master Timer Cams							
(lock cam)	Faulty Control	Incorrect Mfg	Opt Test	Used w/o change	Unkn	.5	None
Programmer Pot Sys (pitch command unit potentiometer)	Intermit Oper	Unknown	Opt Test	Replace (scrapped)	Unkn	.25	2.0
Forward Yaw Accel.							
Yaw Accelerometer (heater element)	Function Omitted	Open	Opt Test	Replace (scrap)	Unkn	.5	1.0
North Servo Package							
Fin Position Pot.	Burned	Inadequate Protection	Opt Test	Replace (scrap)	Unkn	.1	1.0
East Servo Package							
Fin Position Pot.	Intermit Oper	Incorrect Type	Opt Test	Replace (scrap)	Unkn	.5	.5
Memory Device & Timer							
Timer Magnetic Clutch (timer lead screw)	Intermit Oper	Adjustment	Opt Test	Repaired	Unkn	2.0	1.0

E-U Round 6 - Missile 1267 - 7 Jul 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Telemetry System							
(plug DPD 32C2-335)	No Indication	Foreign Matter	Prel Phase	Replaced (repaired)	Unkn	.5	1.5
Cathode Follower (tube 5977)	No Indication	Dead	In Inspec	Replaced (repaired)	Unkn	.5	2.0
Temperature Oscillator (tube 6AK6)	Intermit Oper	Low Emission	Prel Phase	Replace (scrap)	Unkn	.1	.2
Autopilot System							
Gain Programmer Motor Reset Light Microswitch	Function Omitted	Insecure Mounting	Opt Test	Repaired	Unkn	0.25	2.6

E-U Round 7 - Missile 1269 - 4 Aug 53 <u>16 Malfunctions</u>

Missile (Electronic)							
Programmer							
Master Timer	Intermit Oper	Unknown	Opt Test	Replace (scrap)	Unkn	1.0	2.0
RF Head Assembly							
Crystal Mixer (crystal)	Burned	Overloading	Opt Test	Replaced (scrapped)	Unkn	1.0	1.0

E-U Round 7 - Missile 1269 - 4 Aug 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
T-R Box (T-R tube)	Function Omitted	Incorrect Type	Opt Test	Replaced (Ret'd to vendor)	Unkn	2.1	2.1
Local Oscillator (tube 2C40)	Weak Electrical Toler.	Unknown	Opt Test	Replaced (scrap)	Unkn	1.0	1.0
Integrators							
Balancing System (tube V-1)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
(tube V-2)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
(tube V-3)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
(tube V-4)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
(tube V-102)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
(tube V-103)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
(tube V-104)	Oscil.	Unknown	Opt Test	Replaced	Unkn	3.0	1.0
Pitch Accelerometer System							
Forward Pitch Accel. (heater input circuitry)	Shorting	Miswired	Opt Test	Repaired	Unkn	2.0	1.0
Central Power Supply							
Power Distrb Box (plug 157)	No Indication	Improper Assembly	Opt Test	Repaired	Unkn	.1	.1

E-U Round 7 - Missile 1269 - 4 Aug 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
(plug 201)	No Indi-cation	Improper Assembly	Opt Test				
Missile (Structure)							
Stowage Compartment							
Forward Yaw Accel Mntng. Bracket (dowel pin)	Missing	Improper Assembly	In Inspec	Replaced	Unkn		
Electronic Installa-tion							
Programmer Ring Modulator No. 231 (Tubes (4)	Wrong tubes	Incorrect Type	In Inspec	Replaced	Unkn	0.1	0.1

E-U Round 8 - Missile 1297 - 13 Aug 53 2 Malfunctions

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
North Servo Package							
Fin Position Pot	Locked	Overheated	Opt Test	Replace (scrap)	Unkn	0.5	1.5
Transition Oscillator (tube 6AK6)	Faulty Control	Low Gain	Prel Phase	Replace (scrap)	Unkn	.1	.1

E-U Round 8 - Missile 1297 - 13 Aug 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
West Servo Pkg. Fin position potentiometer	No Indication	Incorrect Type	Opt Test	Replaced	Unkn	0.1	0.5

E-U Round 9 - Missile 1299 - 1 Oct 53 <u>7 Malfunctions</u>

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Integrator							
(V-10, Tube 5687)	Function Omitted	Dead	Opt Test	Replace (scrap)	Unkn	.2	.5
Pitch Accelerometer System							
Regulated Power Supply (V-101 tube 5687)	Oscil.	Intermit Short	Opt Test	Replace (scrap)	Unkn	1.0	.1
Programmer							
Command Unit Prog. Motor (cam)	Intermit Oper	Adjustment	Opt Test	Repaired	Unkn	.1	.7
Power Supply							
(V-103 tube 5651)	Faulty Control	Tube Failure	Opt Test	Replace	Unkn	1.0	.5

E-U Round 9 - Missile 1299 - 1 Oct 53

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
(V-104 tube 5651)	Faulty Control	Tube Failure	Opt Test	Replace (scrap)	Unkn	1.0	.5
RF Assembly							
Crystal Mixer (crystal IN21-B)	Weak	Low Sensit	Prel Phase	Replace (scrap)	Unkn	.1	.5
Doppler Transponder MK-1							
Detector & AGC Ckt (tube 6AL5)	Intermit Oper	Shorted	Opt Test	Replace (scrap)	Unkn	.5	.5
Autopilot System							
Yaw Accelerometer Sys Forward Yaw Accelerometer mtg. brkt. Dowel pins	Missing	Incomplete Assembly	Initial Inspection	Repaired	Unkn	0.5	1.1
Electronic Installation							
Range Corr. Sys. Integration Boland Amplifier & Feedback Network Tube V-4 4814	Function Omitted	Mistreatment	Opt Test	Replaced	Unkn	0.5	0.1

E-U Round 9 - Missile 1299 - 1 Oct 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Autopilot Amplifier							
South Servo-package No. 836 "O" ring	Intermit Oper	Unknown	Opt Test	Replaced	Unkn	0.1	0.5

E-U Round 10 - Missile 1351 - 13 Oct 53

Missile (Electronic)							
Central Power Supply							
Motor Generator Set Bearings	Noisy Oper	Unknown	Opt Test	Replaced	Unkn	0.1	1.0
Autopilot Amplifier							
East Servo amp Twin tee network	No Indication	Shorted Intermit	Opt Test	Repaired	Unkn	3.5	4.0
Doppler Transponder MK-1							
(condenser 1000 uhf	Burned	Shorted	Opt Test	Replace (scrap)	Unkn	1.0	0.1
10-k-c amplifier (tube 12 AU7)	Intermit Oper	Shorted	Opt Test	Replace (scrap)	Unkn	1.5	0.5

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E-U Round 10 - Missile 1351 - 13 Oct 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
RF Assembly							
Crystal Mixer (crystal IN21-B)	Weak	Poor Sensit	Opt Test	Replace (scrap)	Unkn	.1	.5
Central Power Supply							
Motor Generator (radio noise filter TB453B)	Burned	Shorted	Opt Test	Replace (scrap)	Unkn	.1	.5

E-U Round 11 - Missile 1305 - 27 Oct 53

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Telemetry System							
Transmitter	Weak	Unknown	Prel Phase	Replace (Ret'd to vendor)	Unkn	.2	None
Autopilot System							
Programmer Telemetry Blip Channel Wiring to Plug 158	Function Omitted	Opern	Opt Test	Repaired	Unkn	0.3	0.2

E-U Round 12 - Missile 1304 - 15 Dec 53

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Programmer							
Ledex Selector Switch (fastening screw)	Missing	Improper Assembly	Opt Test	Replace (repaired)	Unkn	.2	.3
Master Timer & Gear Train from Master Timer Motor to Cam Shaft	Worn	Improper Assembly	Opt Test	Replace (scrapped)	Unkn	.5	.5
East Servo Package							
Fin Position Pot	Function Omitted	Shorted	Opt Test	Replace (scrap)	Unkn	.5	.5
Memory Device & Timer							
Timer Motor (lead screw mech)	Inoper	Foreign Matter	Opt Test	Retained (repaired)	Unkn	.3	.2
Operating Cylinder							
Dash Potentiometer (floating piston)	Quick Operating	Unknown	Opt Test	Replaced (Ret'd to vendor)	Unkn	.1	None

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E-U Round 12 - Missile 1304 - 15 Dec 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION)	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Autopilot Amp Sys South Servo Amp	Intermit Oper	Tube Failure	Opt Test	Replaced	3.0	1.0	0.5
Command Unit							
RF Assembly Crystal Mixer Crystal 1N2113	Improper Instrument Reading	Tube Failure	Opt Test	Replaced	1.5	0.2	2.0
Doppler Transponder							
Transmitter Tube V-8 5763	Inoper	Tube Failure	Opt Test	Replaced	2.0	0.5	0.5
Range Correction System							
Power Supply Yaw Accelerometer Balance	Improper Instru-ment Reading	Miswired	Opt Test	Repaired	1.0	0.5	0.5
Range Correction System							
Timer Lead screw mech-anism	Improper Instru-ment Reading	Foreign	Opt Test	Cleared	2.0	1.0	0.5

E-U Round 12 - Missile 1304 - 15 Dec 53 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Range Correction System							
Integrator Ser No. 43 Filter Network Tube V-6 V-7 5814	Improper Instrument Reading	Tube Failure	Opt Test	Replaced	3.0	1.0	0.5

E-U Round 13 - Missile 1306 - 12 Jan 54 1 Malfunction

Missile (Electronic)							
Programmer							
Master Timer Cam (reset cam)	Function Omitted	Improper Assembly	Opt Test	Repaired (used w/o change)	Unkn	.2	.1
Autopilot Sys Yaw Signal Ampl	Improper Balance	Tube Failure	Opt Test	Replaced	19	.2	.1
Tubes V-5 V-6 5726	Improper Balance	Tube Failure	Opt Test	Replaced	19	.2	.1
Roll Signal Ampl Tubes V-5 V-6 5726	Improper Balance	Tube Failure	Opt Test	Replaced	Unkn	.1	.1

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E-U Round 13 - Missile 1306 - 12 Jan 54 (Cont)

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DISPOSITION	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Range Corr. Sys.							
Integrated d-c Amplifier Tube V-1 6072	Improper Balance	Tube Failure	Opt Test	Replaced	Unkn	.1	.3
Integrator							
Cathode follower Tube V-4 V-5 5814	Improper Balance	Tube Failure	Opt Test	Replaced	Unkn	.1	.5
Auto Pilot System							
South Servo Pkg. Fin Position Pot.	Fails to Position	Improper Des	Opt Test	Replaced	Unkn	.1	.5
Programmer Yaw Programmer helipot	Faulty Cont	Incorrect Mfg.	Modification	Use w/o change	Unkn	.5	.0
Power and cabling Signal cable Signal valve	Improper Instrument Reading	Poor Connection	Opt Test	Repaired	0	.5	.1

E-U Round 14 - Missile 1312 - 22 Jan 54

No Malfunctions

NOMENCLATURE M I U C/P	SYMPTOM	CAUSE	PLACE OF FAILURE	DISPOSITION (FINAL DIS-POSITION	OPER TIME HRS	TIME TO LOCATE HRS	TIME TO REPAIR HRS
Missile (Electronic)							
Cabling & Junction Box							
Signal Cable	Improper Reading	Open	Opt Test	Repaired	Unkn	1	.1
Doppler Transponder							
Doppler Switch-box Plug J-568	Intermit	Poor Connection	Opt Test	Repaired	4.5	6	.1
Power and Cabling							
Pull-away cable	Damaged	Improper Design	Rt Oper	Repaired	0	.1	.5
Cabling & Junction Box							
Propulsion Cable Plug 610	Inoper	Oper Technique	Opt Test	Repaired	0	0	.1
Range Correction Disconnector							
Integrator Relay 3	Inoper	Opn	Opt Test	Replaced	Unkn	1	8

ROUND 1

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Radar (Structure) Lock (Screw	Fails to Close	Stripped Threads	Routine Operation	Used w/o Change	4.0	0.1	Unkn
Radar Trailer (Electronic) Sync. Dist. Unit (V-1 isolation amp. to beacon)	No Indication	Wear	Routine Operation	Replaced	97.0	2.0	2.0
Control Osc. & Indic. #17 Pitch Channel (V-2 tube 12AT7	Faulty Control	Low Emission	Operational Test	Replaced	100.0	2.0	0.3
Frequency Changer Drive Unit (oil bath pan)	Leakage	Incorrect Type	Routine Operation	Repaired	100.0	0.3	Unkn
Switching Panel (terminating resistor)	Oscillation	Wear	Operational Test	Replaced	110	32.0	0.3

ROUND 1 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Coder Pulse Fourth Pulse Strip (V-11 tube 12AT7)	Unstable	Incorrect Mfg.	Opt. Test	Replaced	130	0.5	0.3
Doppler Doppler Unit MK-1 Range Correct. Dis. (decade contact #1)	Improper Perform.	Foreign Matter	Routine Operation	Repaired	997.0	.1	3.0
Computer Elevation Assembly Amplifier (wiring)	Oscillation	Miswired	Operational Test	Repaired	249	0.2	0.2
Generator Engine Distributor (rotor)	Intermittent Operation	Wear	Routine Operation	Replaced	840	1.0	0.5
Warhead Trailer (structure) Cradle Assem.	Inoperative	Incorrect Type	Operational Test	Not Used	Unkn	None	None

ROUND 1 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Firing Set Power Supply Firing panel external switch leads from firing truck	Missing	Incorrect Manufacture	Prelaunch Phase	Used w/o Change	5.0	0.2	----

ROUND 2

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Radar Trailer (Electronic) Phase Shifter -Amp (vacuum tube V618)	Faulty Control	Wear	Preliminary Phase	Replaced	170.0	0.5	0.3
(tube 12AU7)	Faulty Control	Wear	Preliminary Phase	Replaced	170.0	0.5	0.3
Driver Filament Transformer (transformer)	Inoperative	Wear	Preliminary Phase	Replaced	178.0	0.5	2.0
Voltage Calibrator Pushbutton Switch	Inoperative	Shorted	Operational Test	Repaired	113	2.0	2.0

ROUND 2 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Computer (Electronic) Pulse Coder (relay 11)	Intermittent Operation	Contacts Stuck	Operational Test	Repaired	273	1.0	0.2
Computer Cable Arrangement (cable)	Worn	Improper Assembly	Operational Test	Used w/o Change	300	Unkn	None
Power Supply Rectifier (tube 5Y3)	Intermittent Operation	Overloading	Operational Test	Replaced	285	0.5	0.2
Elevation Computer Amplifier (cathode resistor R-3)	Inoperative	Wear	Operational Test	Replaced	286	2.0	0.6
(cathode resistor R03)	Incorrect Tolerance	Wear	Operational Test	Replaced	286	-.2	0.6
Doppler Trailer Hewlett-Pack. Meter Amplifier (vacuum tube 6AK5)	Intermittent Operation	Wear	Preliminary Phase	Replaced	30	0.1	0.1

ROUND 2 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
AGC Amplifier Bandpass Filt. Amplifier (vacuum tube 6AB6)	Noisy Operation	Microphonic	Preliminary Phase	Replaced	2.0	0.1	0.1
Shutoff Discriminator Keying Switch Circuit (relay)	Fails to Open	Wear	Preliminary Phase	Replaced	1113.4	0.1	0.1
Generator Trailer Generator Voltage Reg. (auto. contr.)	Faulty Cont.	Wear	Prel. Phase	Repaired	1000	1.0	1.0
(auto. contr.)	Faulty Cont.	Wear	Routine Op.	Used w/o Change	1030	1.0	
(auto. contr.)	Faulty Cont.	Improper Assembly	Routine Op.	Used w/o Change	1038	0.1	None
Set Command Trailer (Structure) Air Conditioner Heater	Faulty Control	Unknown	Routine Operation	Used w/o Change	Unkn	0.1	None

ROUND 2 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Audio OSC Automative Amp. Cont. (110-v bulb)	Intermittent Operation	Vibration	Operational Test	Repaired	Unkn	0.5	0.1
Firing Truck Missile Cont. Panel Fin Position Meter	Faulty Control	Unknown	Preliminary Phase	Used w/o Change	Unkn	0.3	None

ROUND 3

Radar Trailer (Electronic) Master Range Unit PRF Driver (rotary switch SW2)	Overheating	Foreign Matter	Routine Operation	Repaired	132	0.3	0.2
Pulse Coder 4th Pulse Channel (V16-tube 12AT7)	No Indication	Dead	Operational Test	Replaced	Unkn	0.3	0.6
Cathode Follower (V28 tube 12AT7)	No Indication	Wear	Operational Test	Replaced	100	[illegible]	[illegible]

ROUND 3 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Antenna Assem. (Structure) Azimuth Amplidyne Azimuth Wheel (shear pin)	Fails to Position	Incorrect Type	Operational Test	Replaced	1.0	0.1	0.2
Erector Boom Assem. Forward Handl. Ring (cushion)	Loose	Adjustment	Operational Test	Modified	Unkn	0.5	----
Firing Truck (Structure) Firing Panel Communication System (telephone handle)	Broken	Incorrect Type	Routine Operation	Repaired	Unkn	0.5	0.5

ROUND 4

Radar (Electronic) Driver Pulse Width Switch (switch connection)	Function Omitted	Open	Routine Operation	Repaired	138	0.5	0.1

ROUND 4 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Pulse Coder Cathode Fol-lower (V2 tube 12AT7)	No Indication	Wear	Operational Test	Replaced	Unkn	0.1	0.1
Amplifier (tube 12AT7)	No Indication	Wear	Operational Test	Replaced	206	0.5	0.4
Voltage Calibrator Regulator Tube (tube 6AQ5)	Faulty Control	Wear	Routine Operation	Replaced	138	0.5	0.1
Receiver IF Video Amplifier (tube 6AC7)	Noisy Operation	Wear	Routine Operation	Replaced	Unkn	0.1	0.1
Power Supply (tube 5U4G)	Weak	Foreign Matter (tube)	Operational Test	Replaced	210	0.5	0.1
(fuse holder)	Function Omitted	Poor Connec-tion	Operational Inspection	Repaired	210	0.1	0.2
Mixer Assem. Crystal Mixer (crystal IN21B)	Noisy Operation	Overloading	Operational Test	Replaced	210	0.8	0.2

ROUND 4 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Auto Tracking Unit Balance Amplif. (tube 6SL7)	Noisy Operation	Wear	Routine Operation	Replaced	136	0.3	0.4
Master Range Unit PRF Driver (switch - K2)	Fails to Position	Foreign Matter	Operational Test	Repaired	206	0.5	0.1
Frequency Changer Drive Unit (seals)	Leakage	Incorrect Manufacture	Routine Operation	Modified	40	Unkn	28
Rollins 80 Sig. gen.	Weak	Unknown	Operational Test	Sent to Lab.	210	0.7	None
Salvo Range Unit Power Supply (tube 2x2)	No sweep	Foreign Matter (tube)	Operational Test	Replaced	200	2.0	1.5
(Transformer V810)	Burned	Overheating	Operational Test	Replaced	Unkn	2.0	1.5
Range Select. Switch (relay K1)	Noisy Operation	Miswired	Operational Test	Repaired	205	0.5	0.2

ROUND 4 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Control Oscillator DC amplifier (V2 tube 12AT7)	No Indication	Wear	Operational Test	Replaced	206	0.5	0.6
Doppler (Electronic) Range Correc. Discrim. Step Counter (tube 6AL5)	No Indication	Wear	Routine Operation	Replaced	1192.3	0.2	0.2
Computer (Electrical) Range Correc. Discrim. Step Counter (tube 6AL5)	No Indication	Wear	Routine Operation	Replaced	1192.3	0.2	0.2
Computer (Electrical) Control Panel Timers (Wiring)	Broken	Inadequate Protection	Operational Inspection	Repaired	Unkn	0.3	1.0

ROUND 4 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Air Supply Truck (Structure) Tank Assem. Air Valve	Leakage	Overloading	Routine Operation	Repaired	Unkn	0.1	1.5
Air Compressor (Structure) Air Drying Towers Air Drying Valve	Leakage	Wear	Routine Operation	Used w/o Change	Unkn	Unkn	None
Launcher (Structure) Guide Pin Assembly Emergency Air Connect. Line	Incorrect Tolerance	Incorrect Type	Preliminary Phase	Modified	Unkn	0.5	2.0
ROUND 5							
Radar (Electronic) Rollins 80 Sig. Gen.	Function Omitted	Foreign Matter	Operational Test	Repaired	400	0.5	15.0

ROUND 5 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Rollins 80 Sig. Gen.	Function Omitted	Adjustment	Operational Test	Repaired	400	0.3	15.0
Monitor Synchroscope Sweep Multi-vibrator (tube 8057-6)	Weak	Wear	Operational Test	Replaced	406	0.5	0.1
Video Amplif. (resistor R77)	Inoperative	Poor Connection	Operational Test	Repaired	406	1.0	0.2
(coil L-2)	Inoperative	Poor Connection	Operational Test	Repaired	406	2.0	0.2
Base (tube 2A86)	Broken						
Driver High-voltage Rectifier (tube V305)	Shorting	Wear	Operational Test	Replaced	172	0.1	0.1
Master Range Unit (crystal)	Chipped	Mistreatment	Operational Test	Replaced	405.4	1.0	0.1

ROUND 6

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Radar (Electronic) Range Indic. System							
Intensity Potentiometer (resistor)	Faulty Control	Wear	Routine Operation	Replaced	478	1.0	2.0
Cabling	Shorting	Inadequate Protection	Routine Operation	Repaired	478	0.5	0.3
32,000-yd TDV scope (lucite Marker disk)	Locked	Adjustment	Operational Test	Repaired	420	0.1	0.2
Range Power Supply Filter Capacitor (filter)	Function Omitted	Shorted	Routine Operation	Replaced	478	1.0	1.0
Automatic Tracking Power Supply (rectifier tube V501)	Function Omitted	Open	Operational Test	Replaced	428	0.1	0.1

ROUND 6 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Tracking Unit Coupling Transformer (rectifier V-501)	Overheated	Shorted	Routine Operation	Replaced	431	0.1	0.5
Monitor Synchroscope Socket Wiring (ground lead from pen #1)	Intermittent Operation	Open	Routine Operation	Repaired	Unkn	0.5	0.5
Antenna Assem. Trailer (Electronic) Reference Generator (field magnet)	Sluggish	Wear	Operational Test	Repaired	Unkn	0.2	1.3
Telemetry Trailer (Electronic) Subcarrier Oscillators Voltage Cont. Bias Circuit (divider dropp. resist)	Improper Decoup.	Improper Design	Routine Operation	Modified	305	6.5	1.0

ROUND 6 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Calibration Oscillator (tube 6AG7)	Intermittent Operation	Dead	Preliminary Phase	Replaced	Unkn	3.0	0.1

ROUND 7

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Ground Computer DC Chopper Amplifier AC Section (d-c chopper)	Noisy Operation	Wear	Routine Operation	Replaced	556	0.3	0.1
Differentiator Sec. (input condenser C2)	Function Omitted	Shorted	Maintenance	Repaired	553.5	0.5	0.3
Frequency Standard Output Contr. (potentiometer R119)	Intermittent Operation	Corrosion	Routine Operation	Repaired	553.5	0.5	0.3
Generating Trailer Unit, M-7 (Elect.) Engine	Overheating	Wear	Routine Operation	Replaced	Unkn	0.2	None
(spark plug)	Faulty Control	Wear	Routine Operation	Repaired	Unkn	0.2	1.0

ROUND 7 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOUTS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Generating Trailer Unit, M-18 Engine	Low Output	Unknown	Routine Operation	Replaced	Unkn	0.2	None
Generator Circuit Breaker	Load not taken	Wear	Routine Operation	Replaced	Unkn	0.2	None
Service Check-out Truck (Electronic) Clarke Receiv. RF Section (tube socket, 6J6-V103)	Intermittent Operation	Poor Connection	Preliminary Phase	Repaired	Unkn	1.0	0.4
Service Check-out Truck Power Supply Voltage Reg. (fize)	Runction Omitted	Open	Operational Test	Replaced	Unkn	0.5	1.0
Aniline Truck (Structure) Transfer Hose Missile End of Nozzle (spring nut)	Locked	Stripped Threads	Routine Operation	Replaced	Unkn	0.1	Unkn

ROUND 7 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	Time to Repair Trouble
Air Compressor (Structure) Air Blower Impeller (blade)	Inoperative	Wear	Routine Operation	Replaced	Unkn	3.0	3.0
Winch Gear Shift Lever	Faulty Control	Incorrect Manufacture	Routine Operation	Retained	----	----	----
Air Supply Truck (Structure) No. 1 Air Bottle Air Hose to Gauge	Leakage	Incorrect Type	Routine Operation	Used w/o Change	----	----	----

ROUND 8

Radar Trailer (Electronic) RO Range Unit Sawtooth Gen. (potentiometer R-27)	Faulty Control	Poor Connection	Operational Test	Repaired	Unkn	1.0	0.3

ROUND 8 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILUTE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Range Power Supply (tube)	Faulty Control	Wear	Routine Operation	Replaced	Unkn	0.3	0.3
Auto Track Unit Amplifier (tube V-3104)	Faulty Control	Wear	Routine Operation	Replaced	Unkn	1.0	0.1
Blower Motor Wiring (lead BL-203)	Overheating	Poor Connection	Operational Test	Repaired	Unkn	0.5	1.0
Crystal Mixer (crystal IN21B)	Weak	Wear	Preliminary Phase	Replaced	Unkn	0.3	0.1
Control Oscillator (tube V-2)	Electrical Tolerance	Low Gain	Operational Test	Replaced	Unkn	0.1	0.2
Terminal Board 2B (screw)	Overheating	Poor Connection	Routine Operation	Repaired	Unkn	0.2	0.2
Receiver (cable connection J705)	Intermittent Operation	Poor Connection	Operational Test	Repaired	Unkn	18.0	0.5

ROUND 9

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Radar Trailer (Electronic) Modulator (magnetron 2J-27)	Incorrect Tolerance	Incorrect Inst.	Operational Test	Replaced	Unkn	1.0	0.5
Bullet Connector (duplexer)	Shorting	Unkn	Operational Test	Replaced	Unkn	0.1	2.0
Power Meter (TS 125 A/P) (thermistor lead)	Function Omitted	Overloading	Operational Test	Replaced	Unkn	0.3	0.7
Computer Trailer (Electronic) Nobotron Reg. (6-volt DC) Filter Netw. (capacitor)	Overheating	Miswired	Operational Test	Replaced	528.6	0.5	0.1
Range Correction #3 Relay System (socket for relay 9)	Broken	Mistreatment	Operational Test	Replaced	529.4	1.0	0.3

ROUND 9 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAULURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Doppler Trailer (Electronic) Shutoff Dis-criminator Electronic Switch	Shorting	Improper Assembly	Maintenance	Repaired	521.6	0.2	0.2
Transmitter Assembly Interlock	Tight	Wear	Maintenance	Repaired	537.6	0.3	0.5

ROUND 10

Radar Trailer (Electronic) AGC Circuit (tube V702)	Function Omitted	Low Emission	Operational Test	Replaced	Unkn	0.8	0.1
Power Supply (tube V709)	Electrical Tolerance	Low Emission	Maintenance	Replaced	Unkn	0.1	0.1
Crystal Mixer (crystal)	Function Omitted	Overloading	Operational Test	Replaced	2.5	0.2	0.1
TR Box (crystal IN21B)	Function Omitted	Overloading	Operational Test	Replaced	2.5	0.2	0.1

ROUND 10 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Doppler Trailer (Electronic) Berkly Freq. Meter	Intermittent Operation	Adjustment	Operational Test	Replaced	574.4	0.1	0.1
Doppler Trailer (Structure) Transmitter Cabinet Inner Door (hinge)	Bent	Incorrect Type	Maintenance	Retained	543.9	0.1	None
Launcher (Structure) Gear Box Cover	Broken	Mistreatment	Operational Test	Repaired	Unkn	0.5	2.0
Erector #7 (Structure) Wheel Drive Assembly (inner oil seal)	Leakage	Foreign Matter	Operational Test	Replaced	215.0	0.3	None
Erector #7 (Structure) Carrier Unit Coolant Hose (air hose)	Broken	Incorrect Type	Operational Inspect.	Replaced	Unkn	Unkn	Unkn

ROUND 10 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Erector #7 (Electronic) Main d-c switch	Shorting	Overloading	Routine Operation	Repaired	200.0	0.1	0.5
Erector #2 Forward Left Drive Motor Field Winding	Overheating	Shorted	Routine Operation	Replaced	Unkn	8.0	8.0

ROUND 11

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Computer (Electronic) (AG fuze holder)	Intermittent Operation	Incorrect Manufacture	Operational Test	Replaced	641.6	0.3	0.2
Service Checkout Truck 642 (Electronic) Servo J-Box Test Cable (cable)	Function Omitted	Assembly Technique	Operational Test	Repaired	Unkn	0.2	0.3
Air Supply Truck 630 & 628 (Structure) High-Press. Valves	Leakage	Wear	Routine Operation	Repaired	135.8	1.0	7.0

ROUND 12

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Computer Trailer (Electronic) Amplifier A-20 Potentiometer	Intermittent Operation	Wear	Operational Test	Replaced	701.7	0.1	0.5
Relay Amplifier	Inoperative	Poor Connection	Operational Test	Repaired	747	0.5	0.1
Arming Elector (Wiring)	Inoperative	Miswired	Operational Test	Repaired	761.1	0.2	0.1
Doppler Trailer (Electronic) Shutoff Amplif. & Servo Helipots	Noisy Operation	Wear	Operational Test	Replaced	Unkn	0.1	2.0
Berkeley Freq. Meter	Intermittent Operation	Unknown	Operational Test	Replaced	Unkn	0.1	2.0
Service Check-out Truck (Electronics) Servo J-Box Test Cables	Function Omitted	Open	Operational Test	Repaired	Unkn	0.2	4.0

ROUND 12 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Aniline Truck (Structure)							
Hose	Leakage	Incorrect Type	Operational Test	Repaired	30.0	0.5	None
Right Rear Torque Bar	Broken	Insecure Mounting	Operational Test	Repaired	29.4	0.3	6.0
Acid Truck (Structure)							
Hose	Leakage	Improper Assembly	Operational Test	Adjusted	15.4	0.3	----
Hose	Leakage	Improper Assembly	Assembly	Adjusted	15.4	0.3	----
Acid Truck (Structure)							
Hose	Leakage	Incorrect Manufacture	Initial Inspection	Replaced	17.2	0.2	----
Hose	Leakage	Incorrect Type	Operational Test	Replaced	35.5	0.2	----
Hose	Bent	Inadequate Protection	Transportation	Used w/o Change	15.4	0.3	----
Retainer Plate Swivel	Leakage	Incorrect Manufacture	Operational Test	Replaced	17.2	0.1	----
Left Door	Tight	Adjustment	Initial Inspection	Adjusted	15.4	0.5	0.2
Spare-Tire Bracket (bolt)	Broken	Insecure Mounting	Operational Test	Repaired	30.0	0.3	4.0

ROUND 12 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Air Supply Truck (Structure) Brakes Air Line	Loose	Wear	Routine Operation	Repaired	25.0	0.2	Unkn
Transfer Hose Shutoff Valve (wing nut)	Fails to Position	Incorrect Manufacture	Operational Test	Modified	25.0	0.3	1.0
Bottle #2 Burst Diaphragm	Leakage	Improper Assembly	Storage	Replaced	22.3	0.5	1.0
Air Manifold Shutoff Valve (packing)	Leakage	Wear	Operational Test	Repaired	25.0	0.1	2.0
(stem seat)	Fails to Position	Incorrect Manufacture	Assembly	Replaced	25.8	1.0	5.0
Air Supply Truck (Structure) Upper Right Tank Diaphragm Holder (burst diaphragm)	Leakage	Incorrect Type	Preliminary Phase	Replaced	25.0	1.0	0.5
Lower Left Tank Tire (scrapping)	Weak Springs	Incorrect Type	Operational Test	Used w/o Change	25.0	0.5	None

ROUND 12 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Axle Torque Bar (grommet)	Loose	Adjustment	Routine Operation	Replaced	25.0	0.2	6.0
Elector (Structure) Rear-Right Drive-Wheel Motor Armature (commutator)	Worn	Incorrect Manufacture	Operational Test	Replaced	125	0.5	14.0
(commutator)	Damaged	Overheated	Operational Test	Repaired	142	0.2	8.0
Wheel Drive Assembly Wheel (tire)	Leakage	Incorrect Type	Modification	Modify	145	0.5	8.0
Erector (Electronic) Constant Voltage Rectifier	Overheated	Shorted	Routine Operation	Replaced	1240	4.0	No parts
Servicer (Structure) Hydraulic Cyl. Ram & Piston	Damaged	Mistreatment	Operational Test	Replaced	39.5	2.0	12.0

ROUND 12 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Vickers Vane Pump	Vibration	Improper Assembly	Operational Test	Replaced	13.2	2.0	None
Upper and Lower Mast	Loose	Improper Assembly	Operational Test	Used w/o Change	16.6	0.5	None
Rear Wheel Back Plate	Bent	Mistreatment	Transportation	Repaired	13.2	0.3	2.0
Left Outrigger Turn Backer	Bent	Insecure Mounting	Transportation	Used w/o Change	16.6	0.5	0.5
Launcher (Structure) Turntable (locking pin chain)	Broken	Unknown	Operational Inspection	Used w/o Change	Unkn	0.5	0.1
(locking pin)	Locked	Incorrect Manufacture	Operational Inspection	Used w/o Change	Unkn	0.1	0.2
Chair (crank handle)	Missing	Insecure Mounting	Transportation	Used w/o Change	450	0.5	0.1
East Arm Support End Bell (crank lug)	Broken	Inadequate Protection	Operational Test	Used w/o Change	450	0.2	None
Carriage Axle (axle stop)	Broken	Incorrect Type	Operational Test	Repaired	450	0.3	2.0

ROUND 12 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Main Air Line Cap (safety chain)	Broken	Unknown	Operational Test	Used w/o Change	Unkn	Unkn	Unkn

ROUND 13

Radar Trailer (Electronic)							
N^2 Gate Unit Poppet Selector	Inoperative	Wear	Routine Operation	Replaced	500	0.1	0.1
Timing Generator 5KC Driver (tube V3)	Overheating	Tube Failure	Routine Operation	Replaced	500	0.5	0.1
Automatic Tracking Safety Relay (contact K502)	Inoperative	Foreign Matter	Maintenance	Repaired	450	2.5	0.1
Data Panel Terminal #8 (ring connector)	Missing	Open	Routine Operation	Repaired	425	1.0	0.3
Cabling (connector)	Impr. Instr. Reading	Improper Assembly	Initial Flight	Repaired	----	----	----

ROUND 13 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Tracker M-2 C A2 Drive Motor Gear Box	Leakage	Wear	Routine Operation	Repaired	500	0.5	0.1
Computer Trailer (Electronic) Range Correction Impact Time Part III (relay K-7)	Inoperative	Wear	Routine Operation	Replaced	815	0.3	0.1
Computer Trailer (Electronic) Meter Switch Amplifier 41	Inoperative	Poor Connection	Operational Test	Repaired	788.7	3.0	0.2
Aniline Truck (Structure) Boom Assembly Hook Assembly (cable carriage wheel)	Broken	Mistreatment	Routine Operation	Replaced	22.5	0.2	----
(pulley)	Broken	Worn	Routine Operation	Replaced	22.5	0.2	----
Air Supply Truck (Structure) Frame L Bracket	Broken	Insecure Mounting	Operational Test	Replaced	26.0	0.2	6.0

ROUND 13 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Erector (Structure) Forward Left Drive DC, Motor Armature (commutor)	Worn	Incorrect Manufacture	Operational Test	Replaced	125	1.5	8.0
Front Drive Assembly Right Drive Wheel Assem. (tire)	Leakage	Wear	Operational Test	Replaced	165	0.1	16.0
Rear Drive Assembly Left Drive Wheel Assem. (ring, O ring)	Leakage	Improper Assembly	Operational Test	Repaired	148	4.0	8.0
Launcher (Structure) Tail Assembly (light bracket)	Damaged	Mistreatment	Initial Inspection	Replaced	Unkn	0.2	2.0

ROUND 14

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Radar Trailer (Electronic) Cabling (connector)	Impr. Instr. Reading	Poor Connection	Operational Test	Repaired	500	0.3	0.1
PRF Driver (capacitor 28)	Inoperative	Wear	Routine Operation	Replaced	500	16.0	0.1
Control Oscillator and Indicator Multivibrator (tube V-3)	Impr. Instr. Reading	Tube Failure	Operational Test	Replaced	475	0.2	0.1
Rollins Signal Generator (tube 12AT7)	Inoperative	Tube Failure	Operational Test	Replaced	2.0	2.0	0.5
(tube 6AH6)	Inoperative	Tube Fail Tube Failure	Operational Test	Replaced			
Computer Trailer (Electronic) DC Amplifier, Panel I (tube 6AU6)	Noisy Operation	Microphonic	Routine Operation	Replaced	815	0.1	0.1

ROUND 14 (Cont)

ITEM	SYMPTOM	CAUSE	OPERATION WHERE FAILURE OCCURRED	ACTION	HOURS Total Time Used	HOURS Time to Locate Trouble	HOURS Time to Repair Trouble
Computer Trailer (Electronic)							
DC Amplifier, Panel II Tube 12AX7	Noisy Operation	Microphonic	Routine Operation	Replaced	815	0.1	0.1
Tube 6AU6	Noisy Operation	Microphonic	Routine Operation	Replaced	815	0.1	0.1
DC Amplifier Panel III Tube 12AX7	Noisy Operation	Microphonic	Routine Operation	Replaced	815	0.2	0.1
Tube 6AU6	Noisy Operation	Mincophonic	Routine Operation	Replaced	815	0.2	0.1
Tube 6AQ5	Noisy Operation	Microphonic	Routine Operation	Replaced	815	0.1	0.1
Doppler Trailer (Electronic) Shutoff Discriminator Carrier Channel (relay K101)	Inoperative	Shorted	Operational Test	Replaced	801.1	0.5	0.1
Launcher (Structure) Turntable Assembly Arm Support (jack arm gimbal)	Inoperative	Improper Assembly	Assembly	Repaired	Unkn	0.3	6.0

NONTACTICAL ITEMS OR PROCEDURES

Primarily as a result of unavailabiaity, inadequacy, or malfunctioning of the tactical equipment, a total of 58 nonstandard procedures were utilized during the firing of these 14 rounds. Abridged extracts from the Operational Summaries are tabulated below to summarize the nontactical procedures used. It should be noted that the frequency of these procedures decreased during the latter rounds of this series.

OPERATIONAL SUMMARY

This portion of the summary presents (in convenient tabular form) abridged extracts from the Operational Section of the flight appendices of those engineering-user rounds wherein nontactical or nonstandard procedures were used.

Where particular nontactical or nonstandard procedures are of interest to the reader, a more detailed description can be obtained from the appendices.

Item No.	Nontactical Items or Procedures Used	E/U Round Number
1	JPL prototype equipment used to check missile in gantry (JPL test equipment used).	1
2	Shop crane and JPL cradle used to mate warhead to missile.	
3	Navy VIKING Gantry was used.	
4	R & D fueling equipment was used.	
5	350-foot air supply lines used instead of tactical 100-foot length.	
6	No servicer used.	
1	JPL prototype equipment used to check missile in gantry (JPL test equipment used).	2
2	Navy VIKING Gantry was used.	
3	R & D fueling equipment was used.	
4	Missile air topping (nontactical procedure).	
5	Doppler and skin-tracking used during flight; no radar used.	
6	No servicer used.	
1	JPL prototype equipment used to check missile in gantry (JPL test equipment used).	3
2	Navy VIKING Gantry was used.	
3	R & D fueling equipment was used.	
4	Missile air topping (nontactical procedure).	
5	Doppler and skin-tracking used during flight; no radar used.	
6	No servicer used.	

Item No.	Nontactical Items or Procedures Used	E/U Round Number
1	JPL prototype equipment used to check missile in gantry (JPL test equipment used).	4
2	R & D fueling equipment used.	
3	JPL pole beacon used.	
4	No servicer used.	
5	Engineering-user gantry used.	
1	JPL prototype equipment used to check missile in gantry (JPL test equipment used).	5
2	R & D fueling equipment used.	
3	Missile air topping.	
4	Tektronix 514-D synchroscope used as a coincidence standard.	
5	No servicer used.	
6	Engineering-user gantry used.	
1	Missile checked in horizontal position and then rechecked vertically.	6
2	JPL pole beacon used.	
3	Warhead arming signal was manually transmitted.	
4	No servicer used.	
5	Engineering-user gantry used.	
6	JPL prototype equipment used to check missile in gantry.	
1	Missile checked in horizontal position and then rechecked vertically.	7
2	Missile air topping (nontactical procedure).	
3	No servicer used.	
4	Engineering-user gantry used.	
5	JPL prototype equipment used to check missile in gantry.	
1	Missile checked in horizontal position and then rechecked vertically.	8
2	West fin launcher flame shield filed down ¼ inch.	
3	Warhead mating.	
1	Missile was checked in horizontal position and vertically.	9
2	JPL prototype equipment used to check missile.	
1	Nonstandard coding adjustment procedure.	10
2	JPL prototype equipment used to check missile.	
3	Warhead arming signal manually (not automatically) sent.	

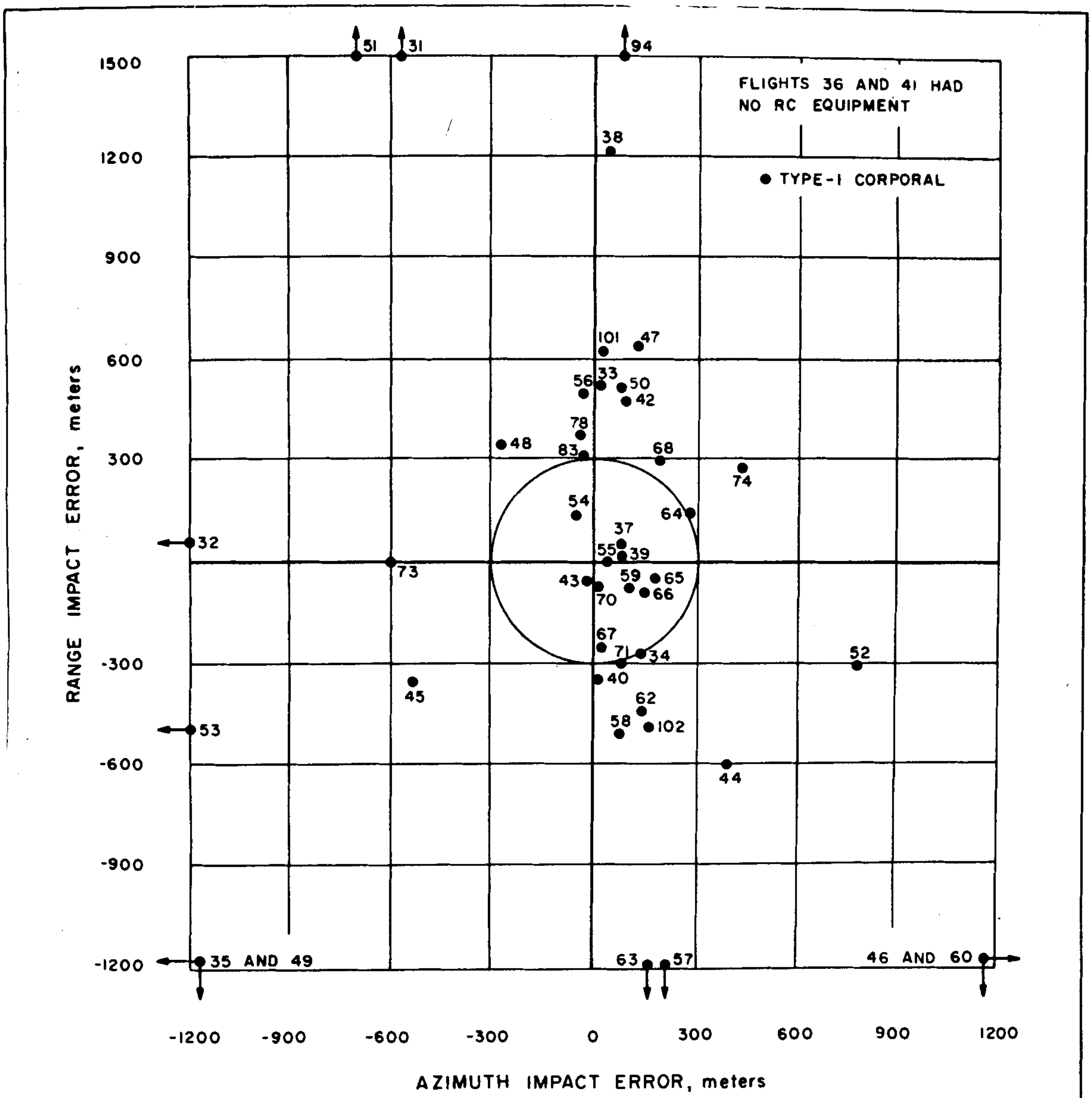
Item No	Nontactical Items or Procedures Used	E/U Round Number
1	Nonstandard coding adjustment procedure.	11
2	Warhead arming signal manually (not automatically) sent.	
3	JPL prototype equipment used to check missile (test equipment).	
1	Nonstandard coding adjustment procedure.	17
2	Warhead arming signal manually transmitted.	
3	JPL prototype equipment used to check missile (test equipment).	
1	Nonstandard coding adjustment procedure.	13
2	JPL prototype equipment used to check missile (test equipment).	
3	Warhead arming signal manually transmitted	
1	JPL prototype equipment used to check missile.	14

CHARTS OF CORPORAL FIRINGS

The charts included herein were extracted from JPL Report No. 20-100, THE CORPORAL, A Surface-to-Surface Guided Ballistic Missile, Jet Propulsion Laboratory, California Institute of Technology, March 17, 1958.

1. Plot of Impact Points of All JPL Type I CORPORAL Firings
2. Plot of Impact Points of All JPL Type II CORPORAL Production Rounds
3. Plot of Impact Points of All JPL Type II CORPORAL Rounds, Except Aborts
4. Plot of Impact Points of JPL CORPORAL Flights Nos. 32 Through 105, Except Five Special Experiments
5. Plot of Impact Points of JPL CORPORAL Flights Nos. 32 Through 105, Except Aborts and Special Experiments
6. Plot of Impact Points of All CORPORAL Firings of 46th Group, Army Field Forces
7. System Reliability
    a. Over-all CORPORAL System Reliability
    b. System Failures
    c. Enlargement: Over-all CORPORAL System Reliability
    d. Enlargement: System Failures
8. Data Summary for Flights 32 Through 105

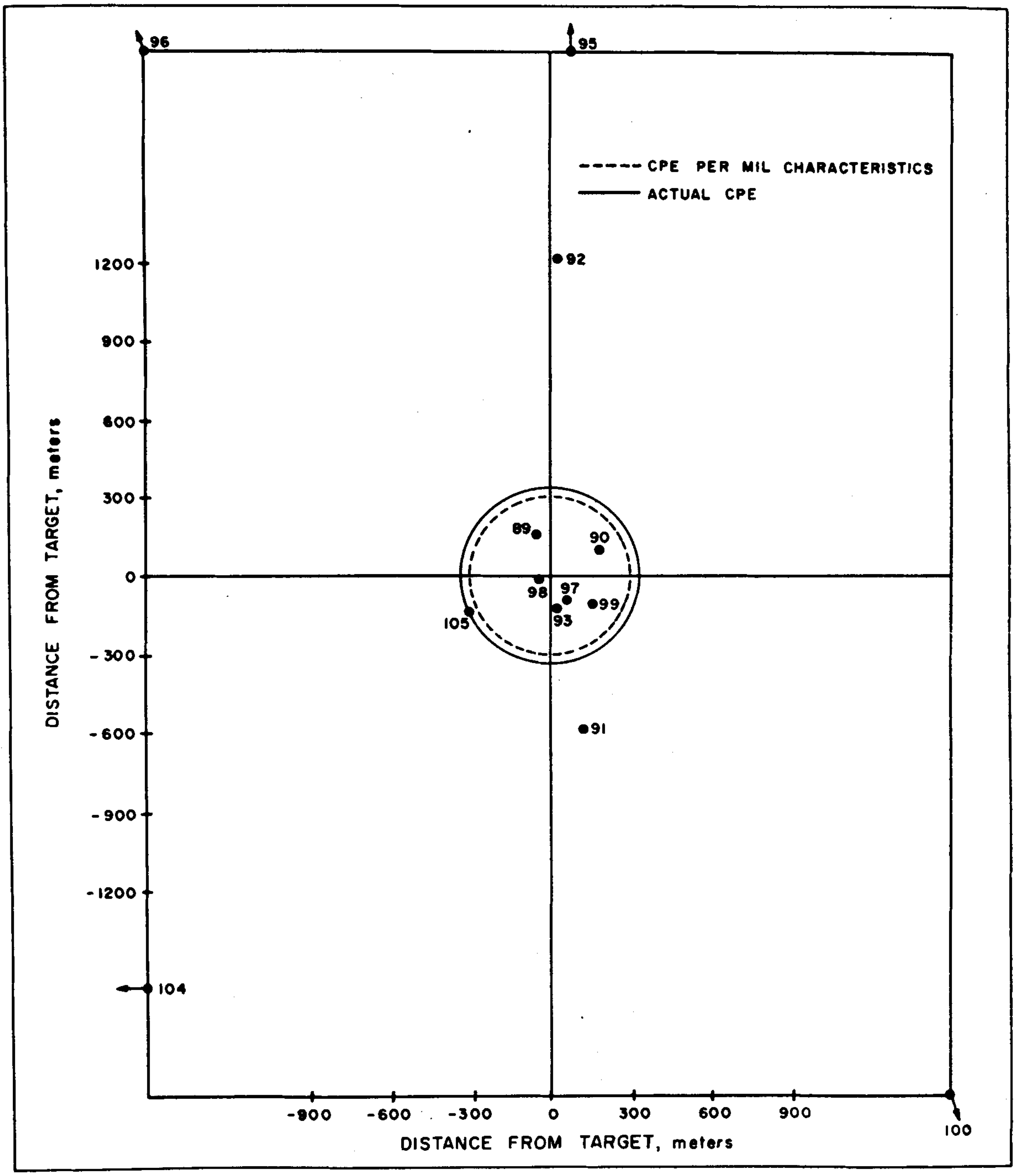
[redacted]



Plot of Impact Points of all JPL Type-I *Corporal* Firings

[redacted]

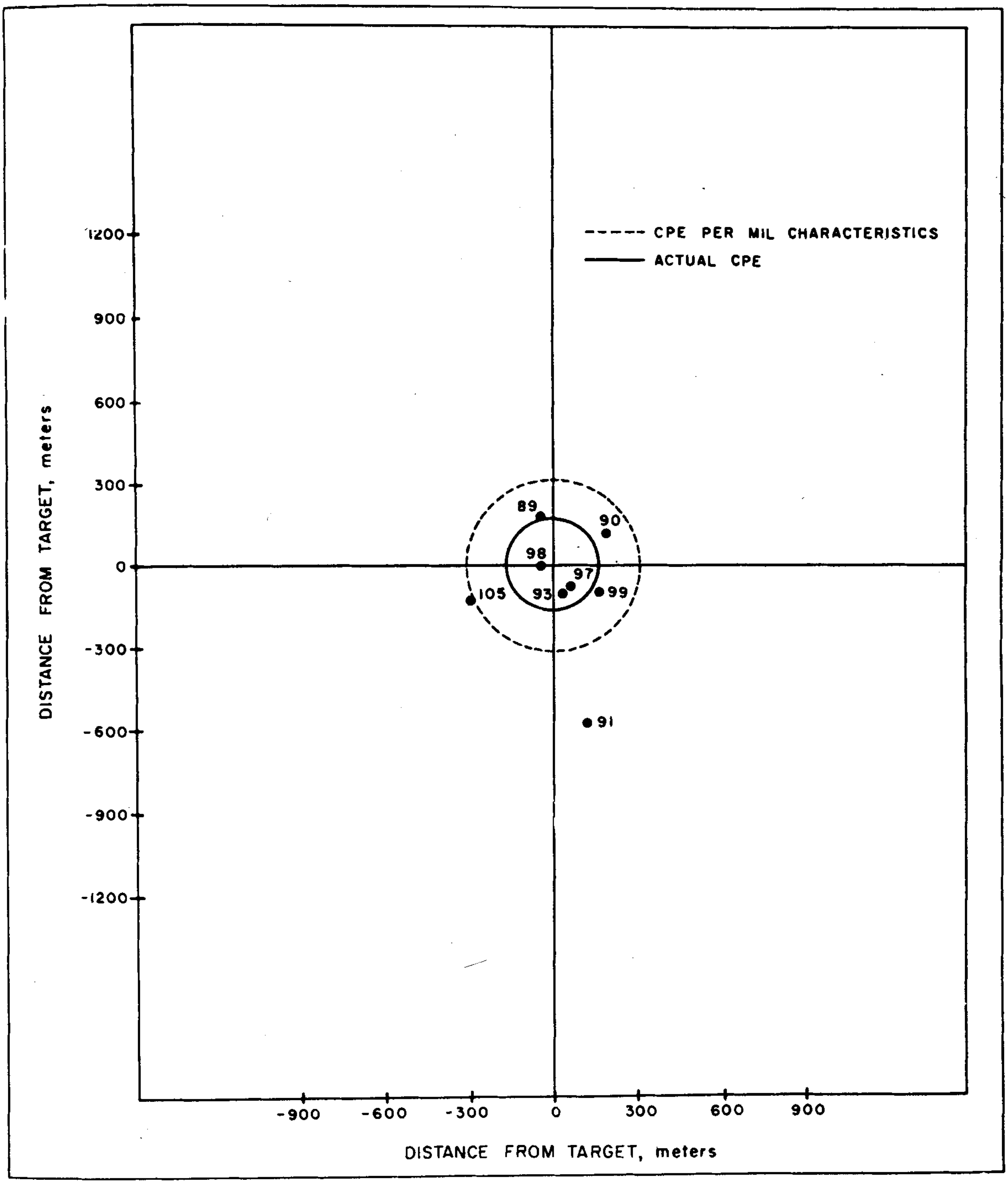
[redacted]



Plot of Impact Points of all JPL Type-II *Corporal* Production Rounds

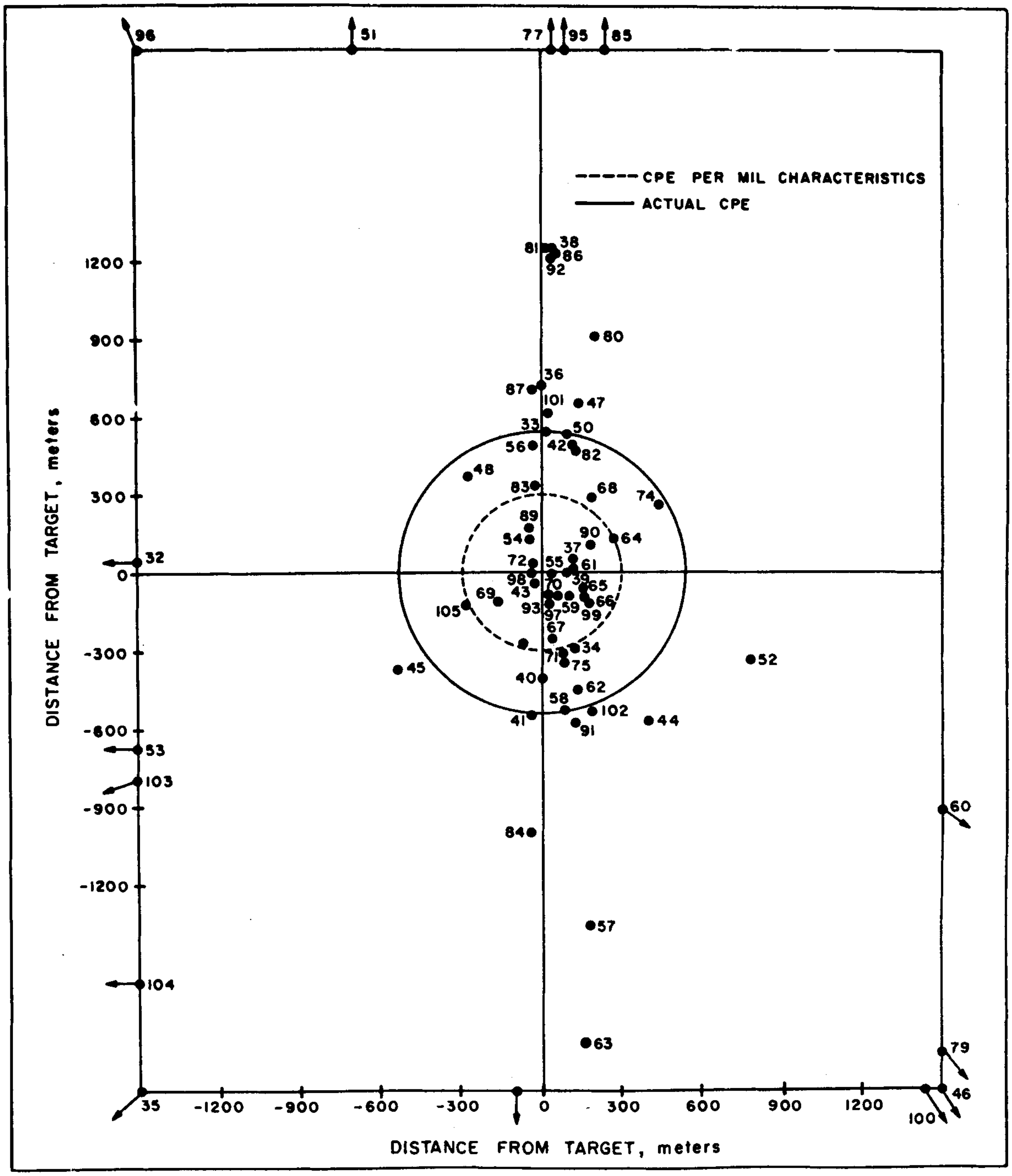
[redacted]

[redacted]



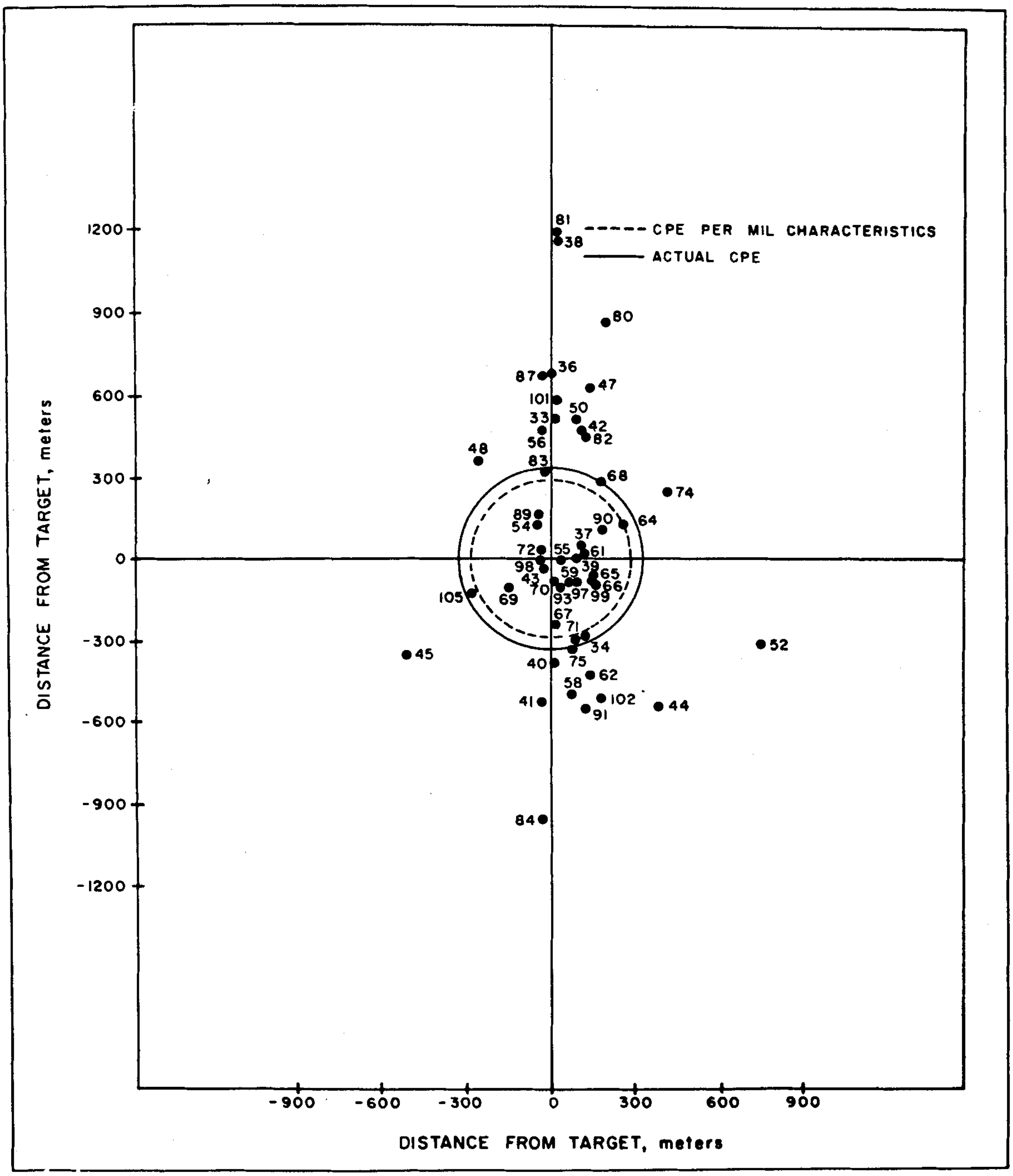
Plot of Impact Points of all JPL Type-II *Corporal* Rounds, Except Aborts

[redacted]



Plot of Impact Points of JPL *Corporal* Flights Nos. 32 Through 105, Except Five Special Experiments

[redacted]



Plot of Impact Points of JPL *Corporal* Flights Nos. 32 Through 105, Except Aborts and Special Experiments

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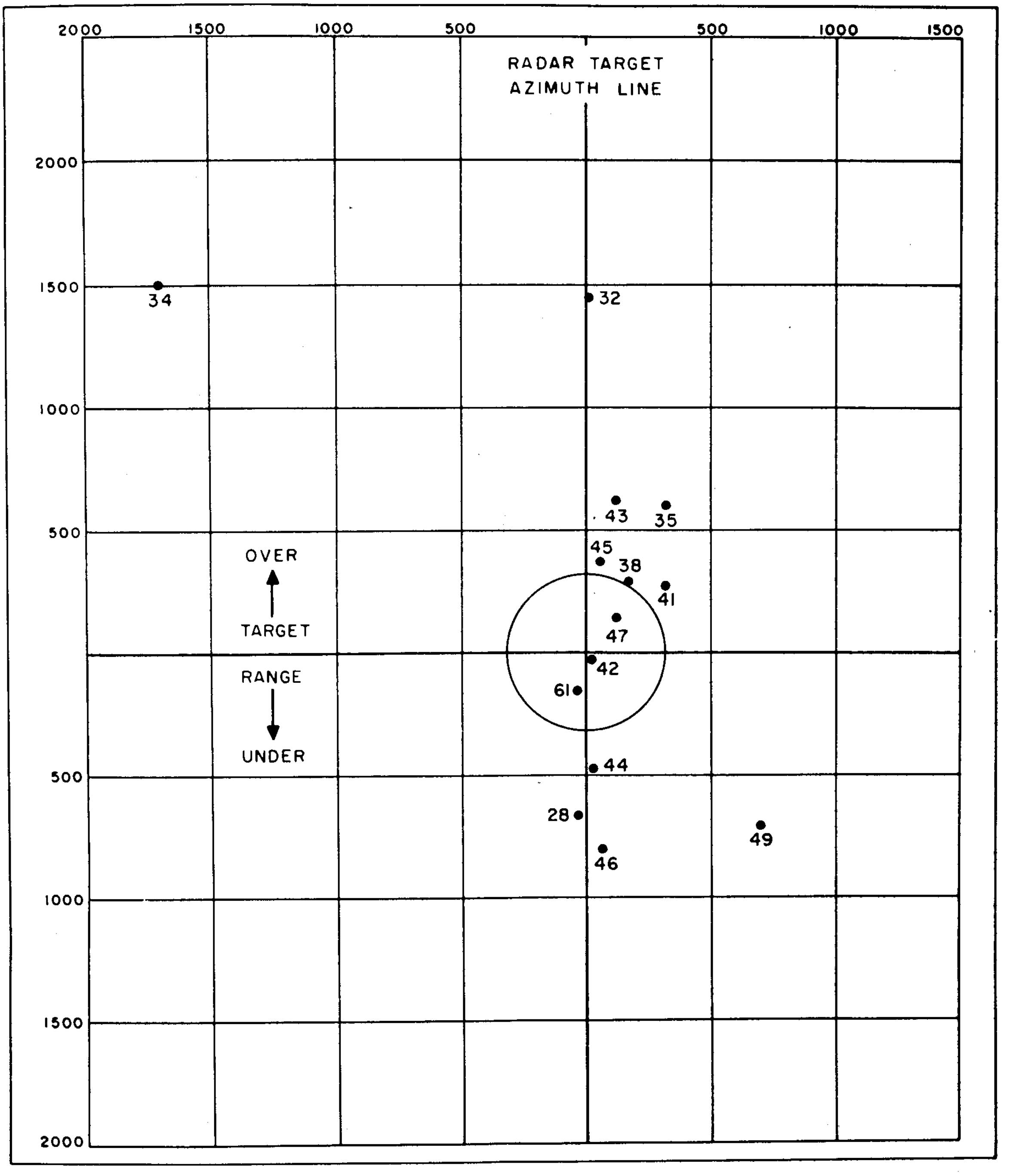

Plot of Impact Points of all Corporal Firings by 46th Group, Army Field Forces

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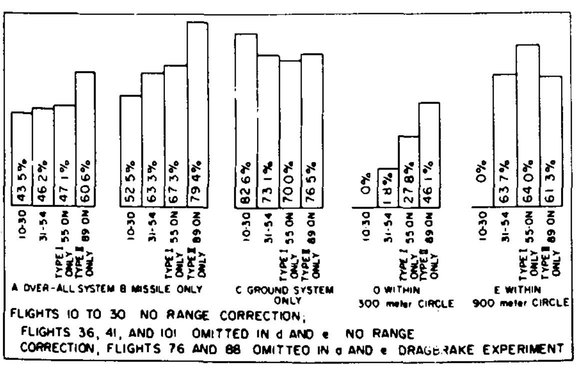
SYSTEM RELIABILITY

The evolution of *Corporal* system reliability and accuracy is graphically demonstrated by Fig. 511, which shows the steady climb of over-all reliability. It can be seen that the improvement is concentrated in the missile itself, whereas the ground system reliability shows no significant changes.

Accuracy has steadily improved to the point where 46.1% of the last group of missiles have impacted within a 300-meter circle; however, the percentage falling within a 900-meter circle is substantially unchanged, indicating no reduction in the average number of aborts.

A breakdown of the failures encountered in the *Corporal* system is shown in Table 18. These results should be accepted in a qualitative sense because the accuracy is degraded both by the difficulty of assigning failures to systems and by the fewer samples obtained per group after subdividing the original data. The numbers in the chart are the probability of success based on an assumed Poisson distribution, after calculating the probability of zero failures with a failure rate determined by the actual record of past flights.



Over-all *Corporal* System Reliability

System Failures

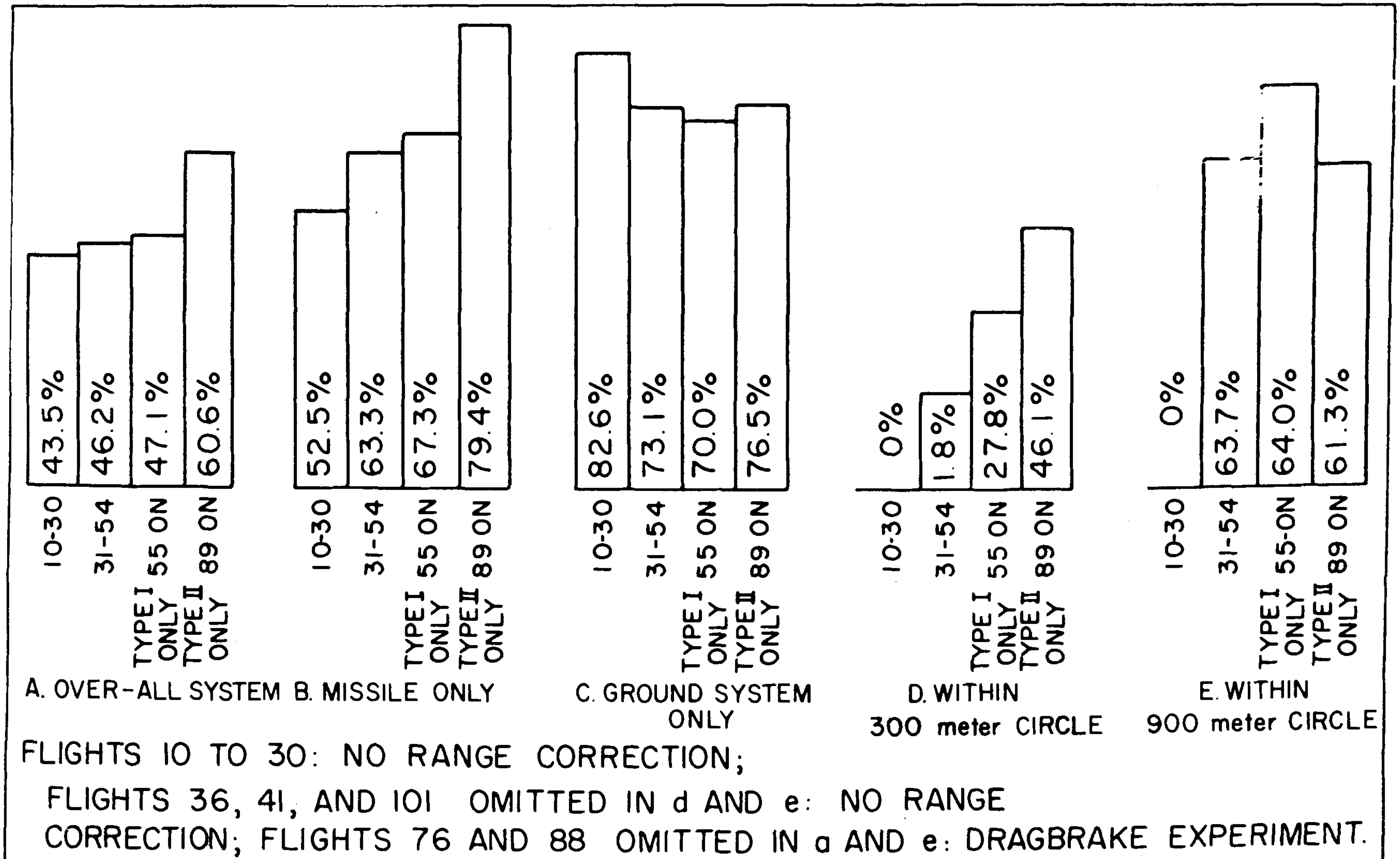
Item	Probability of Success %				
	Flight Nos. 10 to 30 (21 flights)	Flight Nos. 31 to 54 (24 flights)	Flight Nos. 55 to 92 Type I (38 flights)	Flight Nos. 93 to 105 Type II (13 flights)	Flight Nos. 10 to 105 all (96 flights)
Missile equipment:					
airframe	100	100	98.7	100	99.5
propulsion	86.7	92.0	90.0	92.6	90.2
control power	78.8	92.0	97.4	100	92.0
radar	84.8	92.0	93.6	100	92.0
Doppler	100	95.9	100	100	99.0
autopilot and controller	90.9	86.4	93.6	85.8	90.2
Combined probability of success for missile equipment	52.5	63.2	67.4	79.4	64.2
Ground equipment:					
radar	100	76.2	87.7	100	88.7
computer	90.0	95.9	88.8	82.5	90.2
Doppler	100	100	90.0	92.6	94.9
field power	90.9	100	100	100	97.9
Combined probability of success for ground equipment	82.7	73.1	70.0	76.5	74.3
Combined probability of success for complete system	43.5	46.2	47.1	60.6	47.7

Data Analysis

Data analysis has been an important function in design evaluation of the *Corporal* missile program. Only the period extending from September 1952 to July 1955 is discussed here. Both type-I and type-II missile and ground equipment were involved in these tests.

General information as to firing range, standard trajectory flown, target error, equipment used, and applicable comments may be found in Table 19. Although an effort was made to include data for all flights from 32 through 105, in some instances (as shown in the Table) necessary information was not available.

[redacted]



Over-all *Corporal* System Reliability

System Failures

Item	Probability of Success %				
	Flight Nos. 10 to 30 (21 flights)	Flight Nos. 31 to 54 (24 flights)	Flight Nos. 55 to 92 Type I (38 flights)	Flight Nos. 93 to 105 Type II (13 flights)	Flight Nos. 10 to 105 all (96 flights)
Missile equipment:					
airframe	100	100	98.7	100	99.5
propulsion	86.7	92.0	90.0	92.6	90.2
central power	78.8	92.0	97.4	100	92.0
radar	84.8	92.0	93.6	100	92.0
Doppler	100	95.9	100	100	99.0
autopilot and controller	90.9	86.4	93.6	85.8	90.2
Combined probability of success for missile equipment	52.5	63.2	67.4	79.4	64.2
Ground equipment:					
radar	100	76.2	87.7	100	88.7
computer	90.0	95.9	88.8	82.5	90.2
Doppler	100	100	90.0	92.6	94.9
field power	90.9	100	100	100	97.9
Combined probability of success for ground equipment	82.7	73.1	70.0	76.5	74.3
Combined probability of success for complete system	43.5	46.2	47.1	60.6	47.7

Data Analysis

[redacted]

Data Summary for Flights 32 through 105

EXTRACTED FROM

Report No. 20-100

THE CORPORAL

A Surface-to-Surface
Guided Ballistic Missile

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

March 17, 1958

27-10

[redacted]

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105

Flt No.	Firing Range km (approx)	Standard Trajectory Flown	Unbiased Target Error Right Meters	Unbiased Target Error Left Meters	Biased Range Error Long Meters	Accelerometers Yaw	Accelerometers Pitch	RCE	Antenna Mark I (std)	Antenna Mark II (std)	Antenna Mark I & II (with slot antenna
32	52.6	JPL	−2823	−105	45	—	—	—	—	—	—
33			14	387	537	X	X	Mk I	X	—	—
34			127	−442	−292	no	X	Mk I	—	X	—
35			—	—	—	no	X	Mk I	—	X	—
36			−2	562	712	none		none	X	—	—
37			117	−108	42	no	X	Mk I	X	—	—
38			31	1089	1239	no	X	Mk I	—	X	—
39			98	−143	7	X	X	Mk I	X	—	—
40			12	−551	−401	no	X	Mk I	X	—	—
41			−33	−701	−551	none		none	—	X	—
42			112	346	496	no	X	Mk I	X	—	—
43	↓		−29	−191	−41	no	X	Mk I	—	X	—
44	111.6		398	−819	−569	no	X	Mk I	X	—	—
45			−538	−622	−372	X	X	Mk I	X	—	—
46			—	—	—	X	X	Mk I	X	—	—
47			137	404	654	X	X	Mk I	X	—	—
48			−273	121	371	X	X	Mk I	X	—	—
49			—	—	—	X	X	Mk I	X	—	—
50			94	281	531	X	X	Mk I	X	—	—
51	↓		−702	2787	3037	no	X	Mk I	—	X	—
52	84.		782	−525	−325	X	X	Mk I	X	—	—
53			—	—	—	X	X	Mk I	X	—	—
54	↓		−45	−70	130	X	X	Mk I	X	—	—
55	52.6		42	−154	−4	X	—	Mk I	—	X	—
56	52.6		−38	338	488	X	—	Mk I	X	—	—
57	111.6		180	−1603	−1353	X	—	Mk I	—	X	—
58	52.6		83	−671	−521	X	—	Mk I	—	X	—
59	52.6		98	−243	−93	X	—	Mk I	X	—	—
60	111.6		—	—	—	X	—	Mk I	X	—	—
61	111.6		116	−236	14	X	X	Mk I	X	—	—

[redacted]

[redacted]

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105 (Cont)

Flt No.	Firing Range km (approx)	Standard Trajectory Flown	Unbiased Target Error Right Meters	Unbiased Target Error Left Meters	Biased Range Error Long Meters	Accelerometers Yaw	Accelerometers Pitch	RCE	Antenna Mark I (std)	Antenna Mark II (std)	Antenna Mark I & II (with slot antenna
62	84.	↓	135	−647	−447	X	—	Mk I	—	X	—
63	111.6	↓	159	−2050	−1800	X	—	Mk I	X	—	—
64	111.6	JPL	268	−121	129	X	—	Mk I	—	X	—
65	129	BRL	156	−367	−67	X	—	Mk I	—	X	—
66	111.6	JPL	152	−335	−85	X	—	Mk I	X	—	—
67	↓	JPL	21	−508	−258	X	—	Mk I	—	X	—
68	↓	JPL	186	45	295	X	—	Mk I	X	—	—
69	↓	JPL	−163	−364	−114	X	X	Mk II	—	X	—
70	52.6	JPL	15	−237	−87	X	—	Mk I	X	—	—
71	111.6	JPL	90	−554	−304	X	—	Mk I	—	X	—
72	↓	JPL	−36	220	30	X	—	Mk II	X	—	—
73	↓	JPL	−456	−73	−177	—	—	Mk I	X	—	—
74	129	BRL	436	−41	259	—	—	Mk I	—	X	—
75	129	BRL	83	−644	−344	X	X	Mk II	—	X	—
76	37	JPL	54	—	—	none		none	X	—	—
77	52.6	BRL	44	—	9853	X	—	Mk II	X	—	—
78	52.6	F.T.I	−50±30	—	366±40	—	—	none	—	X	—
79	117	F.T.I	7042	—	−5561	X	X	Mk II	—	X	—
80	117	F.T.I	202	—	906	X	X	Mk II	X	—	—
81	52.6	BRL	15	—	1245	X	X	Mk II	X	—	—
82	111.6	BRL	129	—	468	X	—	Mk II	X	—	—
83	111.6	BRL	−16	—	335	X	—	Mk I	X	—	—
84	52.6	BRL	−37	—	−996	X	X	Mk II	—	X	—
85	62.6	BRL	233	—	86,021	X	X	Mk II	X	—	—
86	117	F.T.I	49	—	1231	X	X	Mk II	—	X	—
87	117	F.T.I	−32	—	701	X	X	Mk II	X	—	—
88	122	BRL	102	—	—	X	no	none	X	—	—
89	117	F.T.I	−43	—	169	X	X	Mk II	—	X	—
90	125.5	F.T.II	189	109	—	X	X	Mk II	—	X	—
91	125.5	F.T.II	126	−577	—	X	X	Mk II	—	X	—

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105 (Cont)

Flt No.	Firing Range km (approx)	Standard Trajectory Flown	Unbiased Target Error Right Meters	Unbiased Target Error Left Meters	Biased Range Error Long Meters	Accelerometers Yaw	Accelerometers Pitch	RCE	Antenna Mark I (std)	Antenna Mark II (std)	Antenna Mark I & II (with slot antenna
92	50.5	F.T.II	35	1217	—	X	X	Mk II	–	–	X
93	50.5	F.T.II	33	−111	—	X	X	Mk II	–	–	X
94	52.6	F.T.I	57	1572	1722	–	–	none	X	–	–
95	125.5	F.T.II	88	24,060	—	X	X	Mk II	–	–	X
96	125.5	F.T.II	−1690	4541	—	X	X	Mk II	–	–	X
97	50.5	F.T.II	62	−89	—	X	X	Mk II	–	–	X
98	50.5	↓	−37	−4	—	X	X	Mk II	–	–	X
99	50.5	↓	164	−100	—	X	X	Mk II	–	–	X
100	125.5	↓	6150	−123,007	—	X	X	Mk II	–	–	X
101	125.5	↓	21	612	—	none		none	X	–	–
102	50.5	↓	0±30	−523	—	X	X	Mk I	X	–	–
103	50.5	↓	—	—	—	X	X	Mk I	X	–	–
104	125.5	↓	−2097	−1572	—	X	X	Mk II	–	–	X
105	125.5	↓	−293	−134	—	X	X	Mk II	–	–	X

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105 (Cont)

Flt No.	Telemetering Stowage Compartment	Warhead	Ground Equipment Computer	Doppler	Radar	Special Requirements	Comments
32	—	———	Mk I	Mk I	Mk I		beacon interference
33	—	———		Mk I			
34	—	———		Mk II			
35	—	———		Mk II			autopilot power failure at takeoff
36	—	———		Mk I			no RCE because of chemical war-head detonation did not occur
37	—	———		Mk I			
38	—	———		Mk II			
39	—	———		Mk I			
40	—	———		Mk I			6- ft dish
41	—	———		Mk II			
42	—	———		Mk I			10-ft R&D dish, tactical proto-type computer
43	—	———		Mk II			
44	—	———		Mk I			jamming after shutoff
45	—	———		Mk I			missile power troubles
46	—	———		Mk I			minor lobe, destroyed, 10-ft dish
47	—	———		Mk I			6-ft dish (special feed)
48	—	———		Mk I			6-ft dish
49	—	———		Mk I			programmer failed, straight up
50	—	———		Mk I			
51	—	———		Mk II			radar operator tracking troubles
52	—	———		Mk I			
53	—	SANDIA		Mk I			minor lobe, bad azimuth
54	—	———		Mk I			
55	—	———		Mk II			
56	—	———		Mk I			
57	X	———		Mk II			radar tracking troubles

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105 (Cont)

Flt No.	Telemetering Stowage Compartment	Warhead	Ground Equipment Computer	Doppler	Radar	Special Requirements	Comments
58	X	———		Mk II			
59	no	JPL		Mk I & II			new propellant
60	X	SANDIA		Mk I			old propellant, shutoff failure and explosion
61	no	JPL		Mk I & II			1st ORD 437 prototype missile, new propellant
62	X	SANDIA		Mk II			
63	X	———		Mk I			missile RCE failure, old propellant
64	—	SANDIA	Mk I	Mk II	Mk I		
65	—	———		Mk II			
66	—	———		Mk I & II			new prop. std
67	—	———		Mk II			
68	—	———		Mk I & II			
69	no	JPL-SANDIA		Mk II			
70	no	SANDIA		Mk I			"Bondoque"
71	—	DOFL		Mk I			
72	X	JPL		Mk I & II			ORD 437 prototype
73	X	chemical		Mk I & II		chemical warhead	target and range errors given are at burst point
74	—	DOFL		Mk II			
75	no	JPL-SANDIA		Mk II			tactical ORD 437
76	no	JPL		Mk I		fixed drag brakes	
77	no	JPL-SANDIA		Mk I & II			incorrect shutoff computer setting
78	X	chemical		Mk II		chemical warhead	target and range errors given are at burst point
79	no	JPL-SANDIA		Mk II			tactical ORD 437, ground operator troubles, missile pitch channel failure
80	no	JPL		Mk I & II			ORD 437 GB

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105 (Cont)

Flt No.	Telemetering Stowage Compartment	Warhead	Ground Equipment Computer	Ground Equipment Doppler	Ground Equipment Radar	Special Requirements	Comments
81	X	DOFL		Mk I & II			
82	X	SANDIA		Mk I & II			
83	X	chemical		Mk I			expected warhead detonation did not occur
84	X	OST		Mk II			
85	X	DOFL		Mk I & II			no shutoff, propulsion failure
86	X	OST		Mk II			
87	X	DOFL		Mk I & II			
88	no	JPL		Mk I		retractable drag brakes	
89	no	OST		Mk II			1st 85 msec Doppler compensation, 1st production type-II missile
90	no	———		Mk II			"Sandspit," very little data
91	X	DOFL	Mk II	Mk II			
92	X	OST		Mk I & II			AVD computer saturated (modified after flight)
93	X	DOFL-SANDIA		Mk I & II			
94	X	T-35 JACKSTRAW	Mk I	Mk I	Mk I		target and range errors given are at burst point
95	X	OST		Mk I & II			ground Doppler L.O. misturned
96	X	SANDIA	Mk II	Mk I & II	Mk II		controller malfunction, propulsion malfunction, wrong launcher offset
97	X	DOFL		Mk I & II			
98	X	T-35		Mk I & II		T-35 warhead	target and range errors given are at burst point
99	X	JPL		Mk I & II			
100	X	DOFL		Mk I & II			autopilot failure
101	X	JPL	Mk I	Mk I	Mk I	X-band lock-loop	
102	no	chemical		Mk I		chemical warhead	

DATA SUMMARY FOR FLIGHTS 32 THROUGH 105 (Cont)

Flt No.	Telemetering Stowage Compartment	Warhead	Ground Equipment Computer	Doppler	Radar	Special Requirements	Comments
103	no	T-35		Mk I			missile pitch gyro failure
104	X	T-35	Mk II	Mk I & II	Mk II		M-2 tracking troubles, bias in missile azimuth channel
105	X	T-35	Mk II	Mk I & II	Mk II	Doppler tracking filter test	target and range errors given are at burst point

GLOSSARY FOR FIRING TABLES

BRL - Ballistic Research Laboratories, (Aberdeen Proving Ground)

DOFL - Diamond Ordnance Fuze Laboratory

F.T.I - (CORPORAL) Type I Firing Tables

F.T.II - (CORPORAL) Type II Firing Tables

OST - Operational Suitability Test -- as near tactical warhead as possible in testing--nonatomic components--carried small amount of telemetering

RCE - Range-Correction Equipment

T-35 - Fragmentation Warhead -- a "cluster" type

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UNCLASSIFIED

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CORPORAL PROPULSION SYSTEM

EXTRACTED FROM

REPORT NO. 20-100

THE CORPORAL

A Surface-to-Surface
Guided Ballistic Missile

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

March 17, 1958

UNCLASSIFIED

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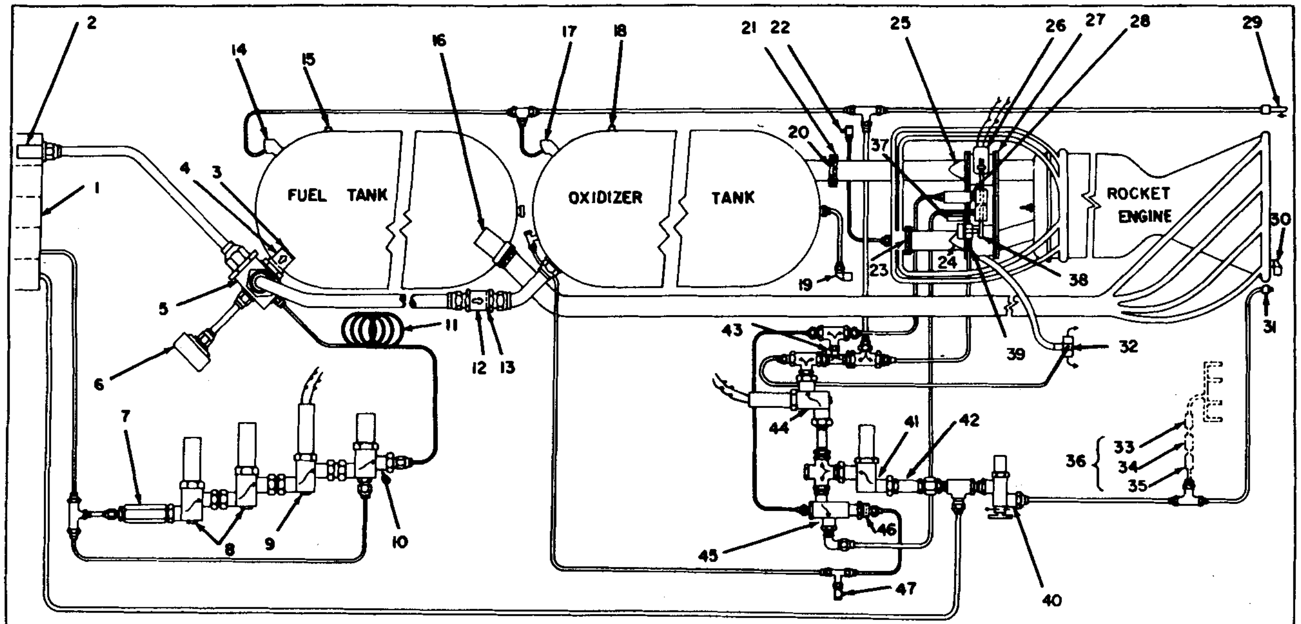

1. AIR TANK (19 cells)
2. AIR-TANK FILTER
3. 115-psi BURST
4. CHECK VALVE
5. PNEUMATIC MAIN AIR PRESSURE REGULATOR
6. VENT AND SIGNAL VALVE
7. AIR-LINE FILTER
8. PILOT AIR-PRESSURE REGULATOR ASSEMBLY
9. FIRING SOLENOID VALVE
10. PNEUMATIC AIR-CUTOFF VALVE
11. CAPILLARY AIR LINE
12. CHECK VALVE
13. 115-psi BURST
14. PNEUMATIC AIR-VENTING VALVE
15. FILL PLUG
16. FUEL STRAINER
17. PNEUMATIC AIR-VENTING VALVE
18. FILL PLUG
19. OXIDIZER DIAPHRAGM DRAINAGE VALVE
20. OXIDIZER ORIFICE
21. 60-psi BURST
22. FUEL-LINE BLEEDER VALVE
23. 60-psi BURST
24. FUEL STRAINER
25. OXIDIZER STRAINER
26. PROPELLANT VALVE ELECTRIC-TIMING MOTOR
27. PROPELLANT VALVE
28. PROPELLANT VALVE CLOSING AIR ACCUMULATOR
29. EMERGENCY SHUTOFF AIR COUPLING
30. FUEL DIAPHRAGM DRAINAGE VALVE
31. AIR TANK CHARGING VALVE
32. FUEL DISCHARGE VALVE
33. ACCUMULATOR
34. PRESSURE REGULATOR
35. FILTER
36. AIR SERVO SYSTEM FOR FINS
37. BLASTING CAP
38. LATCH
39. CHECK VALVE
40. AIR STOP VALVE
41. AUXILIARY AIR PRESSURE REGULATOR
42. AIR-LINE FILTER
43. AIR SHUTTLE VALVE
44. SHUTOFF-ARMING SOLENOID VALVE
45. START-DELAY VALVE
46. 375-psi BURST
47. OXIDIZER-LINE BLEEDER VALVE

Diagram of Propulsion System

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PROPULSION

The basic specification for the CORPORAL propulsion unit required that the rocket motor be capable of delivering a 20,000-pound thrust for approximately 60 seconds. A liquid regeneratively cooled motor was selected for development. The present CORPORAL fuel-cooled motor develops 20,000 pounds of thrust for durations up to 64 seconds and utilizes compressed air to pump a propellant combination of stabilized fuming nitric acid (SFNA: 14% NO_2, 2.5% H_2O, and 0.6% HF) as the oxidizer and aniline-furfuryl alcohol-hydrazine (46.5%-46.5%-7%) as the fuel.

FUNCTIONAL DESCRIPTION OF PROPULSION SYSTEM

Air stored at an initial pressure of 2350 lbs per sq inch - absolute - in a 25.7 cubic foot tank, consisting of a bundle of nineteen aluminum tubes, enters a pressure regulator from which it simultaneously flows aft into the two separate stainless-steel propellant tanks at approximately 450 lbs per sq inch - gauge. Upon the opening of the two-port propellant valve, the two propellants flow through their respective circuits into the combustion chamber of the rocket engine, where they react spontaneously to produce and maintain a combustion pressure of 300 lbs per square inch - absolute. The resulting hot gases exhaust from the nozzle at a velocity of 6000 ft/sec.

The oxidizer flows directly through a single short pipeline into the oxidizer injector manifold from which it is ejected into the combustion chamber. However, the fuel flows through a single pipeline along the entire length of the oxidizer tank, at which point it branches into four flexible lines which carry it to a manifold at the aft end of the rocket engine. From this point the fuel flows forward through forty-four axial passages, in which the fuel absorbs heat from the walls of the nozzle and combustion chamber, and after which it enters another manifold. From there it travels through four short, flexible lines into a single pipeline, reversing direction a second time. Finally, the fuel enters the fuel injector manifold whence it is ejected into the combustion chamber.

Energizing the firing solenoid valve initiates the propulsion starting sequence. This valve admits regulated pilot air pressure to the dome of the main air-pressure regulator via a capillary surge-damping tube. Acting upon a piston within the dome, the pilot air pressure opens the pintle of the main air-pressure regulator. This allows air from the high-pressure air tank to be delivered at a reduced pressure to the two propellant tanks simultaneously. When a pressure level of 100 lbs per square inch (formerly 60 lbs per sq inch) has been reached, the two propellants rupture burst-diaphragms in their respective outlet lines, at which time the propellants flow forward a few inches to the closed ports of the propellant valve. As the oxidizer tank pressure reaches 375 lbs per square inch, a diaphragm is ruptured which then admits this air pressure to open the delayed-opening valve. As a result, air at 600 lbs per sq inch pressure enters the opening side of the pneumatic operating cylinder of the propellant valve. The propellant valve then opens during a 4-second

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period, being retarded by an electric braking-motor and gear train. During this period, propellant-tank pressures have reached approximately 450 lbs per square inch; the flow rates of the two propellants into the combustion chamber have reached their normal values; the missile has left the launcher; and full thrust of 20,000 pounds has been attained.

At approximately 43 seconds after takeoff, a cam on the program timer causes completion of the arming of the propulsion-system shutoff circuits, the first arming already having been accomplished by the opening action of the propellant valve. This is a duel action consisting of the final arming of the electrical blasting-cap circuit and the opening of a solenoid valve. This latter action simultaneously causes the pressurization of the closing side and depressurization of the opening of the fuel-by-pass-blocking valve. At any time after this, when the missile velocity reaches the predetermined value required for the target range, a radio signal from the ground computer causes detonation of a blasting cap located within the release cylinder. The resulting high-pressure gases act upon a small spring-loaded piston, withdrawing the propellant-valve latch. The propellant valve then slams closed in approximately 0.008 second and stops the flow of propellants into the combustion chamber, which terminates the thrust. Approximately 25 pounds of fuel continue to flow through the rocket-engine cooling passages, the fuel-bypass port of the propellant valve, and the opened blocking valve, dumping overboard on two opposite sides of the aft end of the missile. The remaining propellants surge forward in their tanks, prevented by check valves from entering the main air-pressure regulator. Air continues to flow into the fuel tank and out through the fuel-bypass circuit until the air-tank pressure drops to 520 lbs per sq inch. At this pressure, a spring-balanced valve closes, stopping the flow of pilot-pressure air into the dome of the main air regulator, which causes the main air regulator to close. The remaining tank air continues to feed the control servos for the remainder of the flight.

Until the missile leaves the launcher, the propulsion system may be shut off in the event of an emergency by opening a solenoid in the emergency-shutoff air line at the launcher. This admits air at 1200 lbs per sq inch to the missile-emergency-air circuit, where it simultaneously closes the propellant valve and opens the vent valves on the two propellant tanks.

Prior to initiation of the firing sequence and in the event of slight leakage of air through the closed main air regulator, the vent-signal valve will actuate a warning light at the firing panel. Also, by venting to the outside, this valve will tend to prevent the propellant tanks from being pressurized. If the air pressure at this valve reaches 135 lbs per sq inch, as it does during the firing sequence, the valve ceases to vent.

ROCKET-MOTOR DEVELOPMENT

At the time the CORPORAL program was initiated (in 1944), no rocket motor of the required size was available in the United States. During

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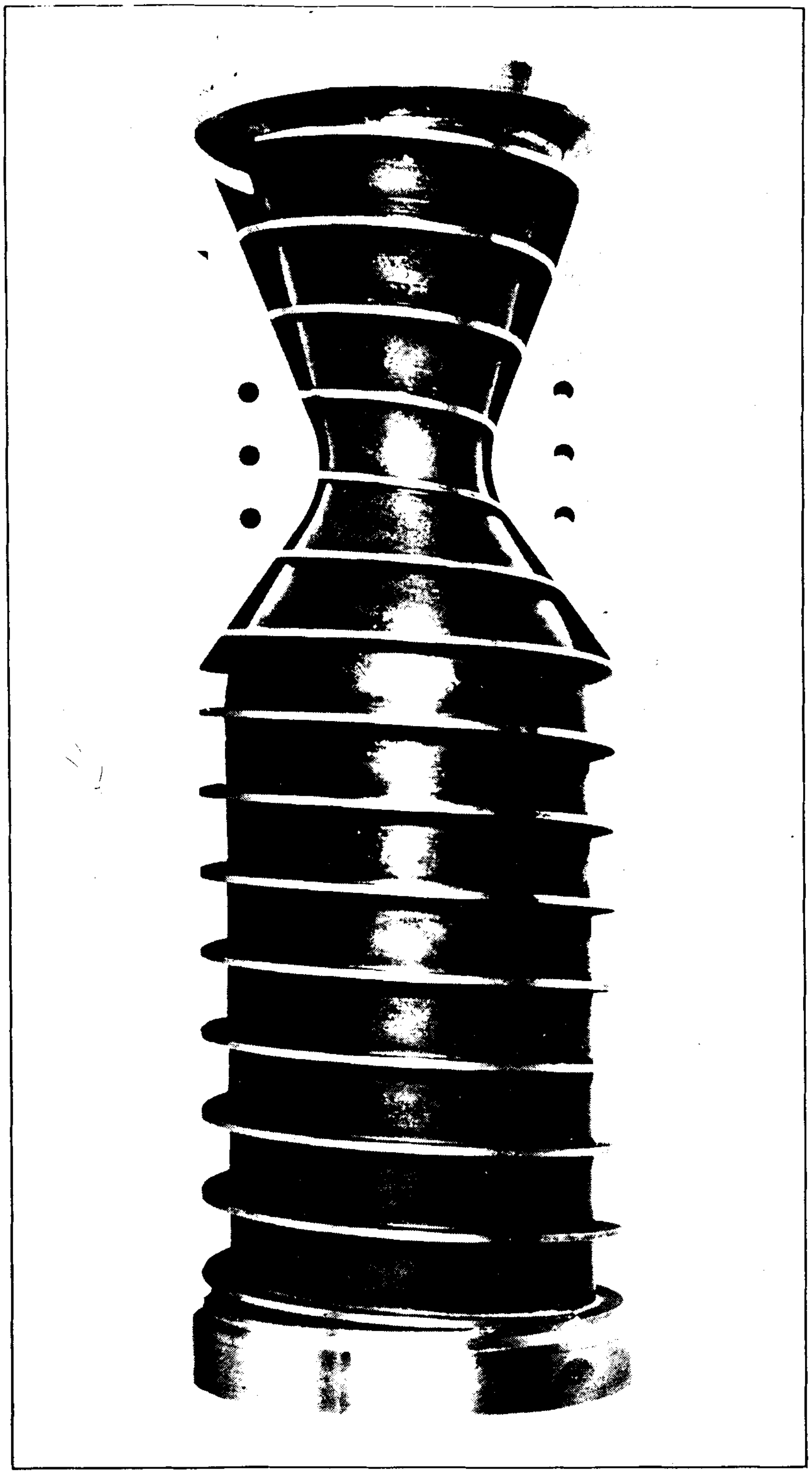
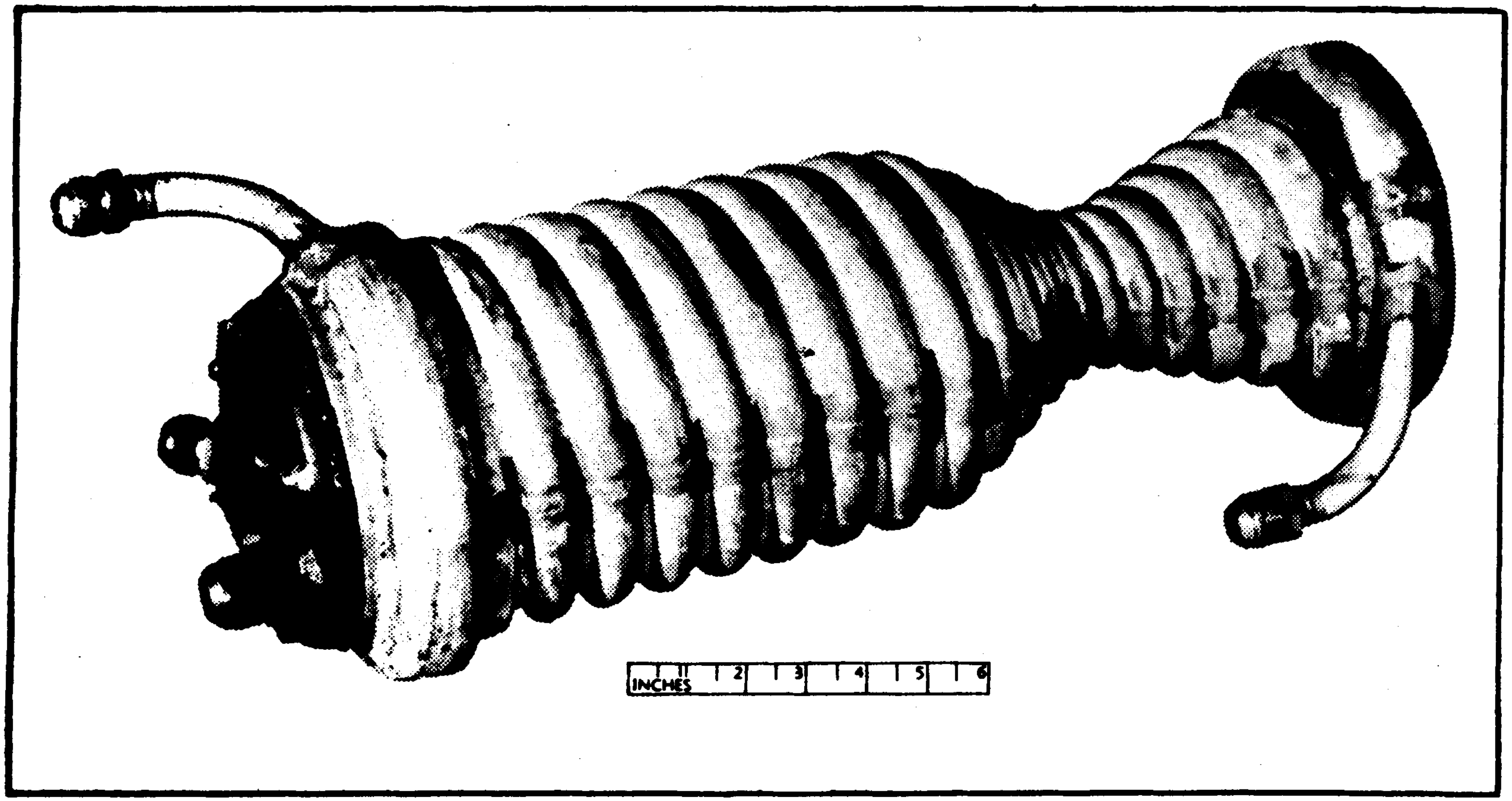
Wac Corporal A Motor



View of *Wac Corporal A* Motor Showing Thin Inner Steel Shell and Helical Ribs



Wac Corporal B Motor

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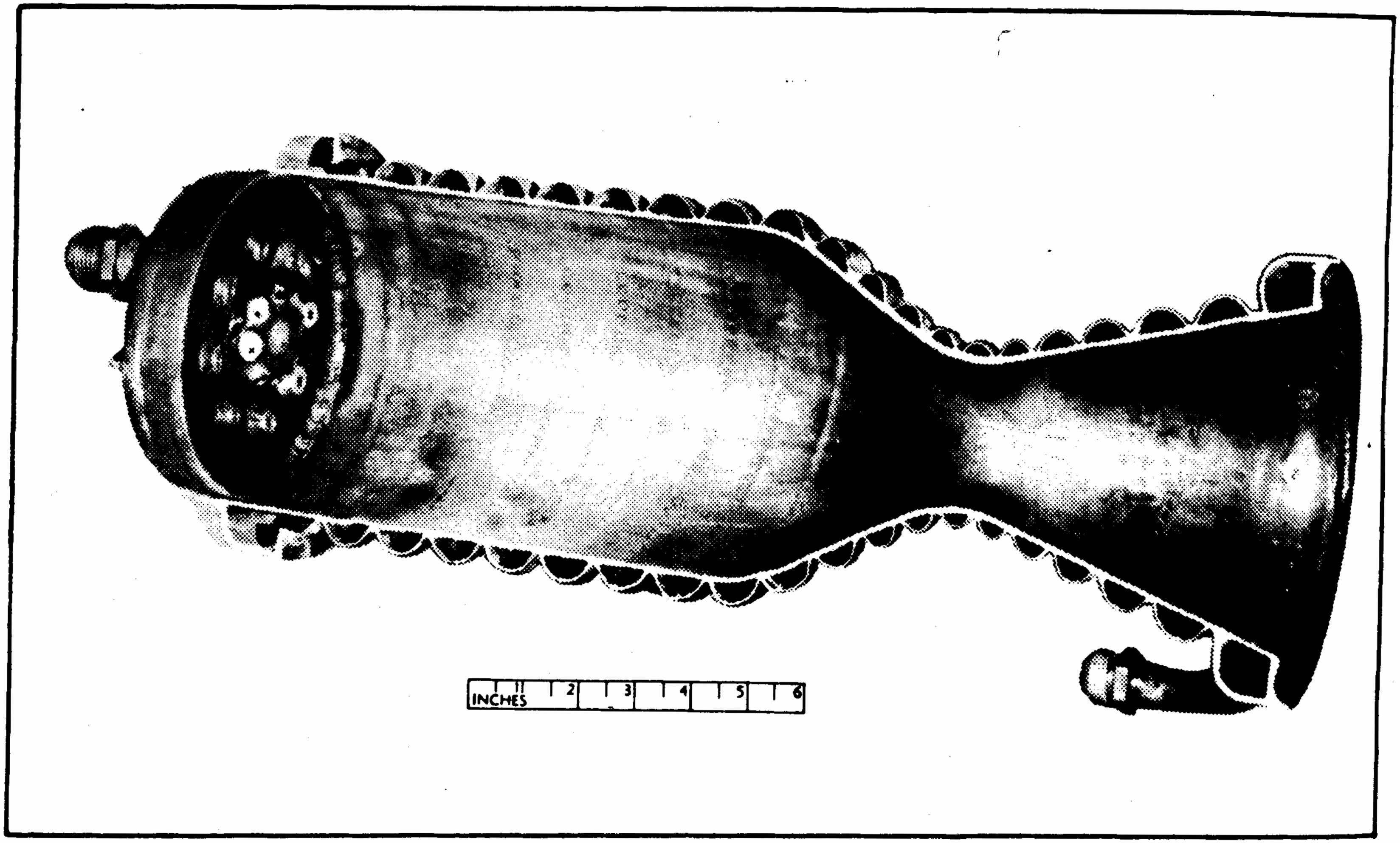

Construction of *Wac Corporal B* Motor

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the latter part of that year, while the CORPORAL system was being designed, the Ordnance Corps (then the Ordnance Department) asked the Jet Propulsion Laboratory to study the feasibility of developing a high-altitude sounding rocket capable of carrying 25 pounds of meteorological instruments to an altitude of at least 100,000 feet, in order to fulfill a Signal Corps requirement. The outcome of this study was the WAC CORPORAL rocket which, in addition to meeting the original requirement, also served as a scaled-down model of the CORPORAL flight vehicle and provided experience which proved valuable in development of the CORPORAL missile system.

The WAC CORPORAL Rocket Motor

Two sounding rockets were developed in response to the initial Signal Corps request: the WAC CORPORAL A and, subsequently, the more refined WAC CORPORAL B. Also, a modified WAC CORPORAL rocket was used as the second stage in the Bumper vehicles, one of which, when launched from a German V-2 first-stage vehicle, set an altitude record of 242 miles and a velocity record of 5150 mph.

The design of the WAC CORPORAL A motor was based on that of a 1500-pound-thrust fuel-cooled motor which had been developed by the Aerojet-General Corporation for operation with mixed acid (80% nitric acid and 20% sulfuric acid) and monoethylaniline. The design was modified to suit the requirements of the WAC CORPORAL. In order to obtain higher exhaust velocities, a propellant combination was selected which used 6.5% FNA (fuming nitric acid containing 6.5% NO_2) as the oxidizer and 80% aniline--20% furfuryl alcohol as the fuel. Prior to the development of the WAC CORPORAL, considerable experience had been acquired with small motors using the nitric acid--aniline propellants with gas-pressurized feed systems.

The WAC CORPORAL A motor had a relatively thin inner shell of steel with a helical rib mechined in the outside surface. A cylindrical outer shell fit snugly around the inner shell, and an aluminum filler block followed the contour of the inner shell. An expansion joint was provided in the outer shell to allow the inner shell to expand. The injector was of the impinging-jet type, with eight oxidizer streams impinging on eight fuel streams in the combustion chamber.

The second phase of the WAC CORPORAL program had as one of its goals the attainment of higher altitudes by increasing the propellant--to--gross-weight ratio of the rocket. The program led to the development of the WAC CORPORAL B rocket, with a lightweight motor of 1500-lb thrust, operating at a chamber pressure of 300 lbs per sq inch - absolute - and a mixture ratio of 2.75. The characteristic velocity c* of the WAC CORPORAL B motor, which weighed less than 12 pounds compared with 50 pounds for the WAC CORPORAL A motor, was about 4400 ft/sec, a decrease in c* of about 200 ft/sec from the WAC CORPORAL A motor. This decrease was attributed possibly to the reduced characteristic chamber length L* of the WAC CORPORAL B motor (61 in., compared with 73 in. for the WAC CORPORAL A motor), or to minor modifications of the injector. The WAC CORPORAL B

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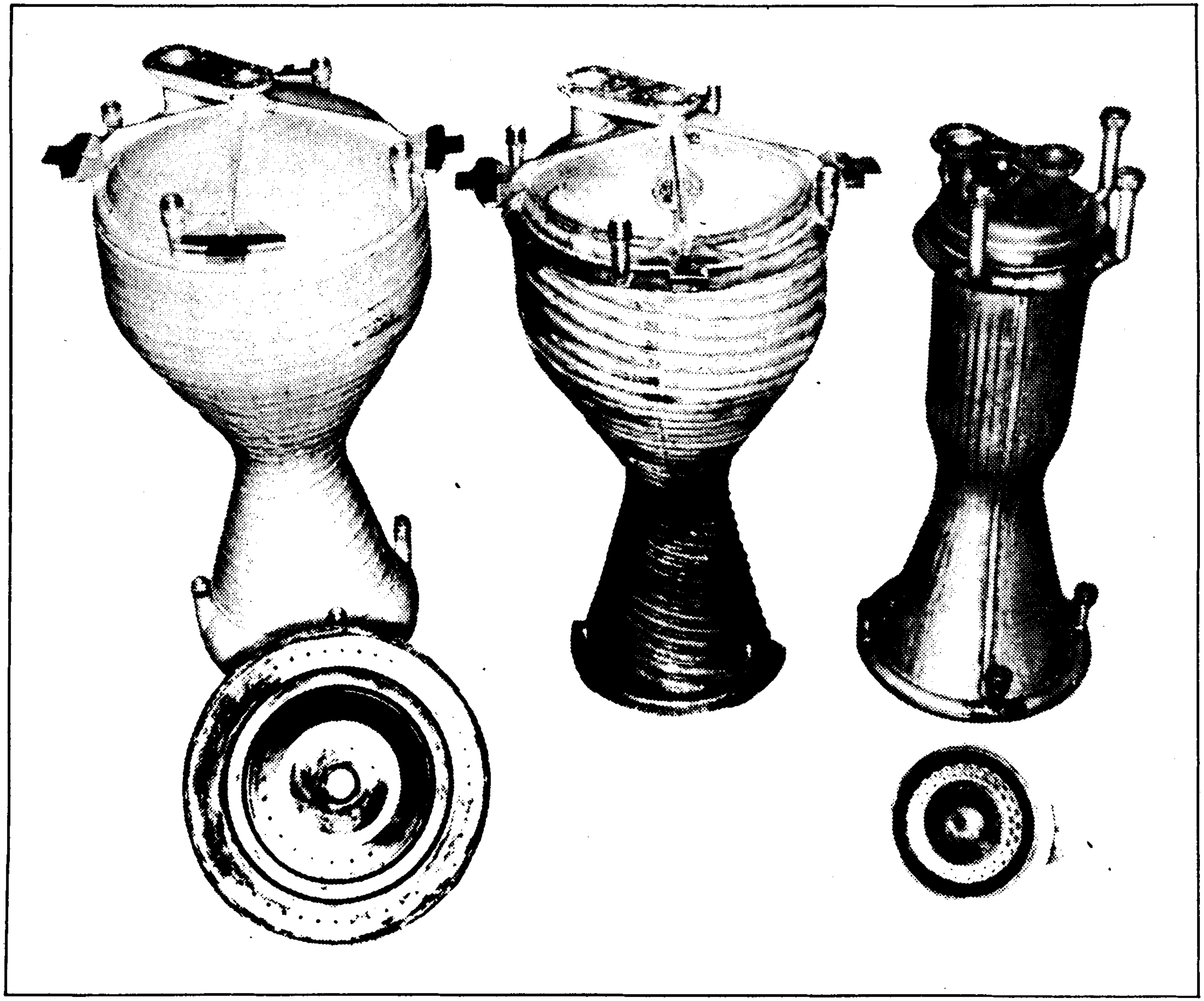

Development of *Corporal* Motor Design

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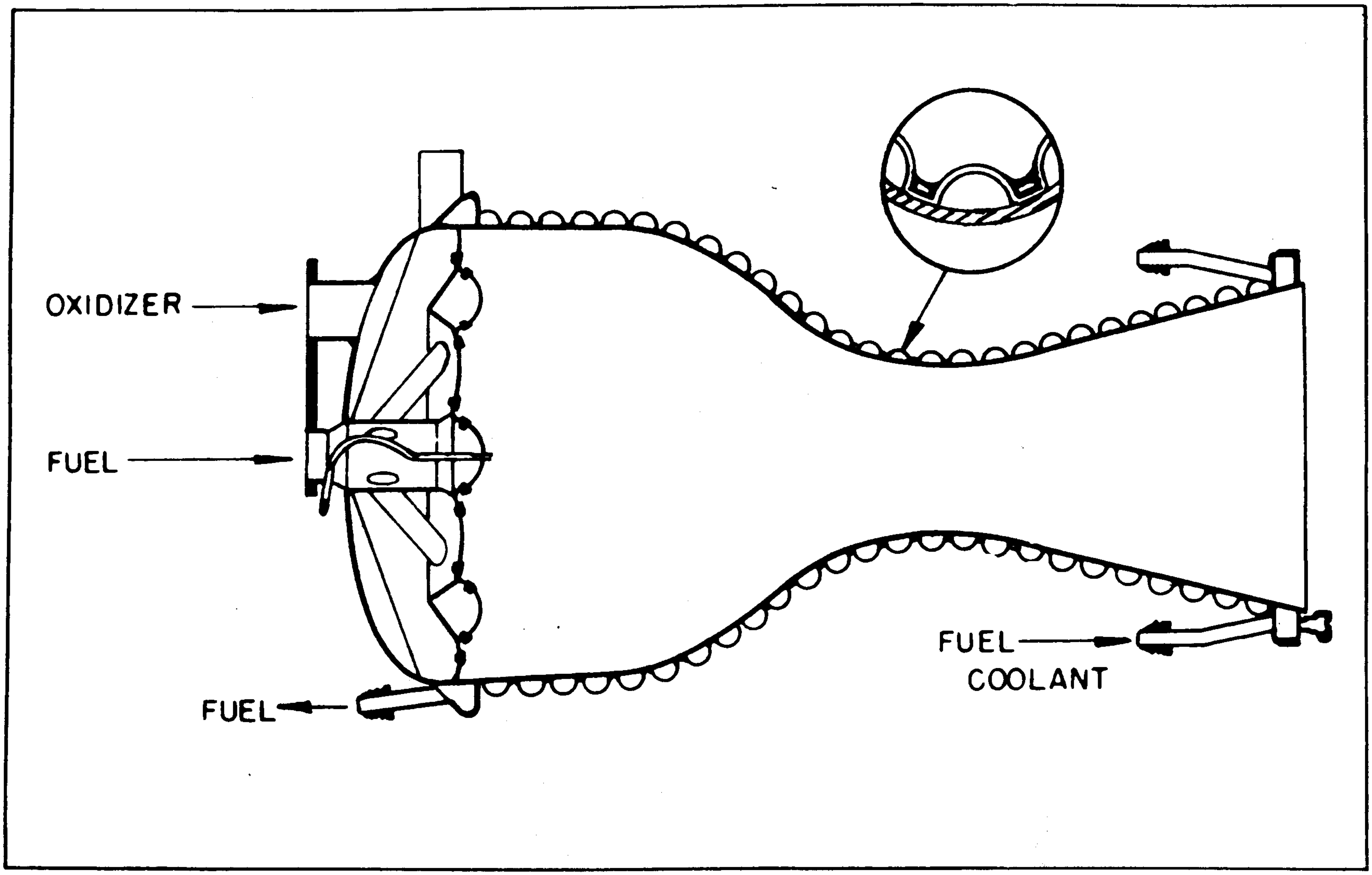

Early *Corporal* Lightweight Motor

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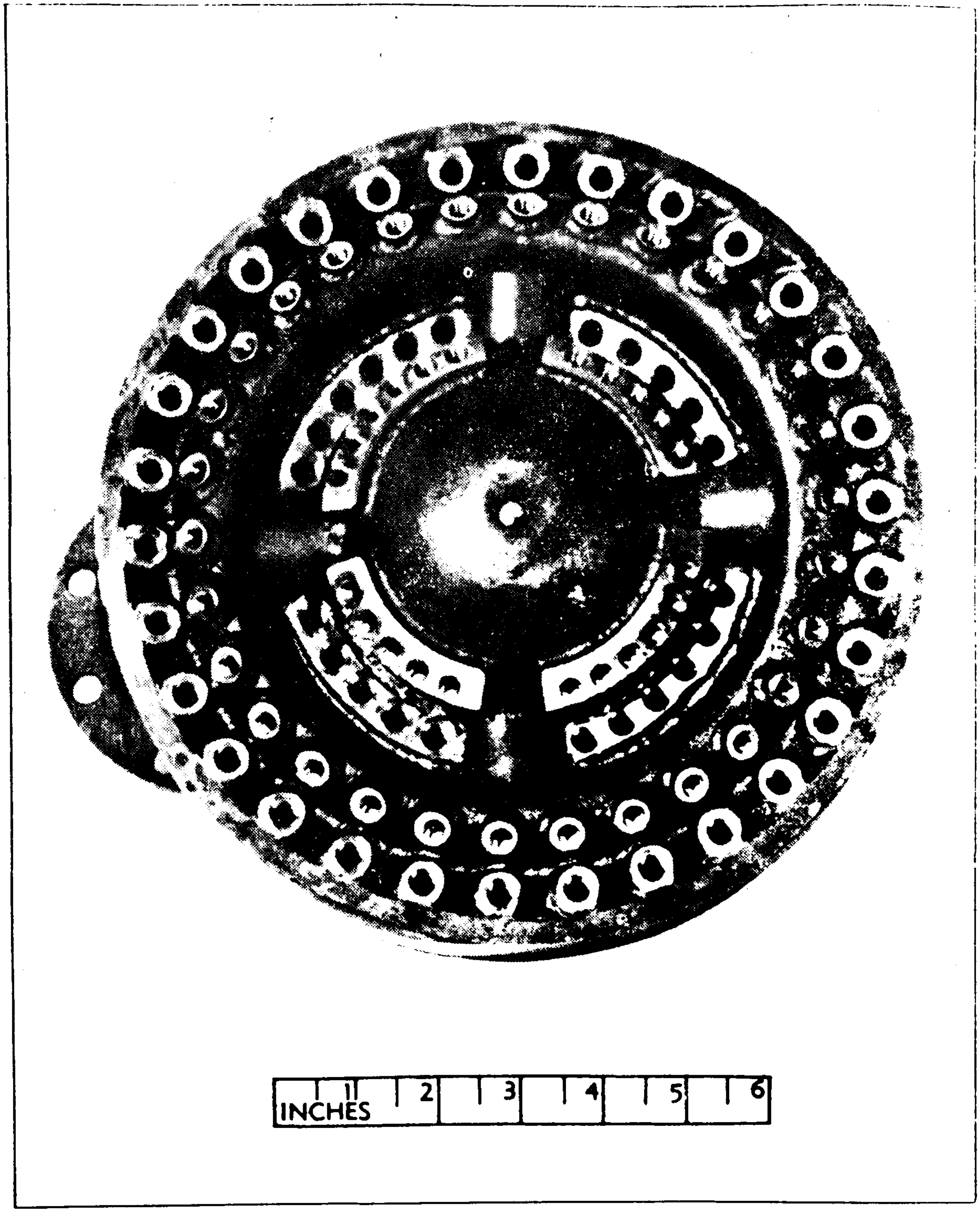

First Injector for *Corporal* Axially Cooled Moto

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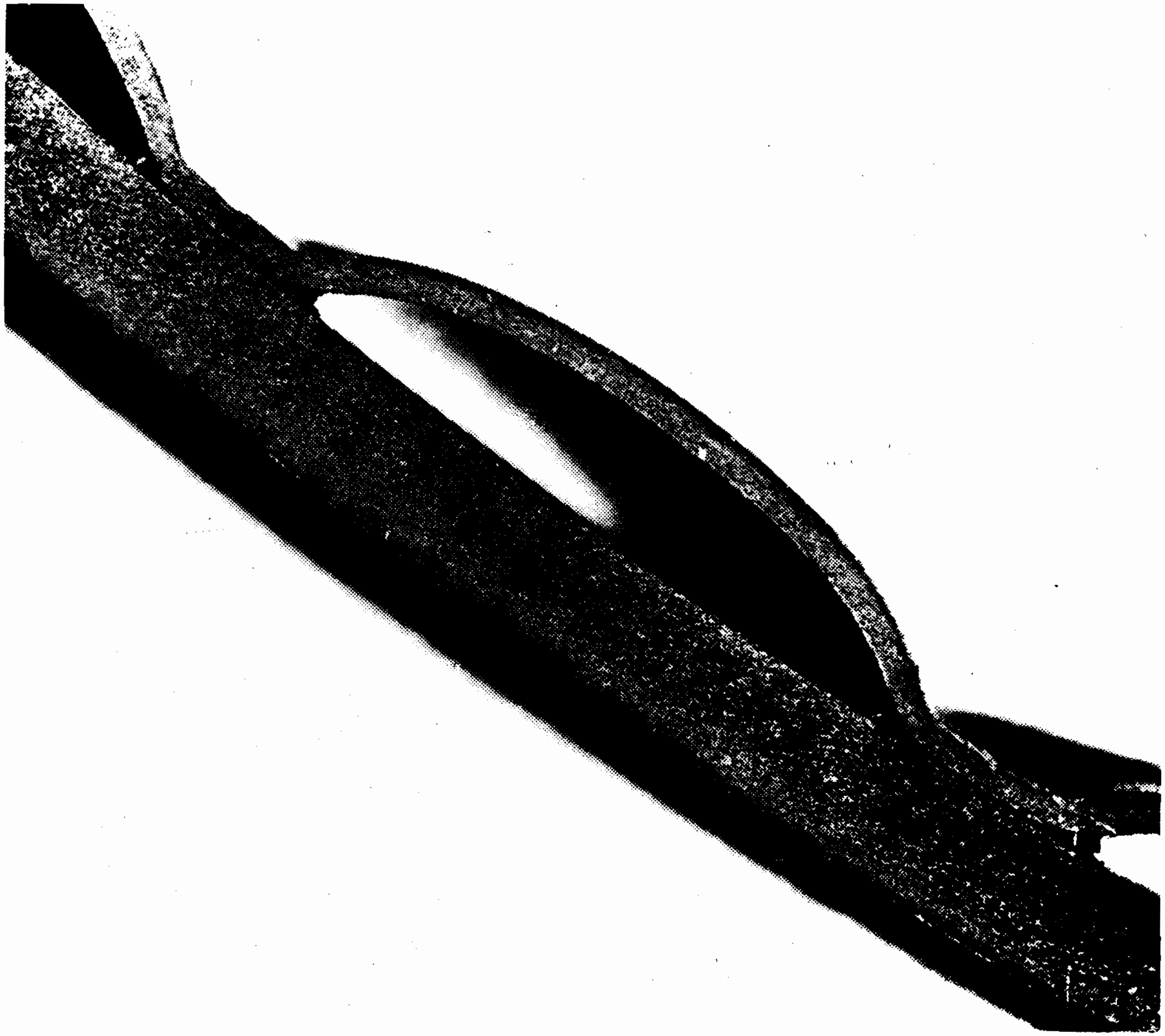

Construction of Cooling Passages, *Corporal* Axially Cooled Motor

motor had a smoothly contoured inner shell that was spot-welded to the thin outer-shell stampings which formed the helical cooling passages. The injector was an eight-pair impinging-jet type, similar to that of the WAC CORPORAL A motor.

The CORPORAL Rocket Motor

One of the major achievements of the CORPORAL program was the development of the axially cooled rocket motor, operating on FNA and aniline--furfuryl alcohol mixtures. This propellant system was selected for the CORPORAL for a number of reasons: (1) considerable experience and performance data had been obtained with these propellants at the Jet Propulsion Laboratory; (2) the system was hypergolic, thereby simplifying ignition; (3) the cost was low; and (4) the system was capable of providing moderately high performance. Fuel was chosen as the coolant because considerable experience was available with this type of cooling, and mild steel could be used to fabricate the motor. The development of a suitable 20,000-pound-thrust motor became an urgent problem when earlier designs proved incapable of consistently passing a 60-second firing test which simulated flight operation.

a. Early designs. The first design was a heavyweight motor weighing 650 lb and was made of mild steel. In this motor, multiple, helical cooling passages were formed by machining closely spaced ribs continuously to the relatively heavy outer shell. The injector was an eighty-pair impinging-jet type, oxidizer on fuel. The diameter, velocity, and direction of the individual streams were comparable with those in the WAC CORPORAL A and other motors tested at the Jet Propulsion Laboratory. The eighty pairs of orifices were distributed in a relatively uniform manner over the injector face. The nominal operating conditions for this motor were as follows:

Thrust $F = 20{,}000$ lb at 15,000-ft altitude.

Chamber pressure $P_c = 300$ per square inch - absolute.

Mixture ratio $r = 2.65$.

Characteristic velocity $c^* = 4500$ ft/sec.

A number of heavyweight motors having the inner and outer shells attached by silver solder failed in proof test by cracking and eroding in the throat region. However, three heavyweight motors having the inner and outer shells attached by welding proved to be suitable for vehicle use after the preliminary proof firing, and these motors were used in the first three CORPORAL flight rounds.

As the fabrication and testing of the heavyweight rocket motor were being conducted, the design of the WAC CORPORAL B rocket motor was developed. The success of this motor led to an attempt to scale the design to 20,000-pound thrust, resulting in the so-called lightweight CORPORAL motor, which weighed 200 pounds. This motor had the same internal geometrical chamber configuration and the same injector pattern as the heavyweight motor, but it employed the lightweight construction of the WAC CORPORAL B motor. The inner shell, a smoothly contoured part that carried the internal chamber pressure loads, was joined by spot-welding to the thin outer shell stampings, which formed the helical cooling passages. Four lightweight motors were built, using various materials for the inner shells: one of 18-8 stainless steel, one of 19-9DL stainless steel, and two of mild steel. None of these motors was satisfactory for vehicle use after proof firing. The region where the inner and outer shells were joined was poorly cooled, and burnouts resulted. Since the internal pressure loads were carried by the inner shell, this shell had to be relatively thick, resulting in high wall temperature and loss in strength. Several other rocket motors of a modified heavyweight design, weighing 450 pounds and combining features of the two basic designs, also failed in proof test.

b. Axially cooled mild-steel motor. Failure of the earlier designs led to the development of the axially cooled motor which is presently used in the CORPORAL missile. The axially cooled motor, weighing only about 125 pounds, has given very reliable operation. Its success results largely from its unique configuration, wherein the cool, uncorrugated outer shell carries the chamber pressure loads, and the thin inner shell, corrugated to form forty-four axial cooling passages, is copper-brazed to the outer shell. Both shells are made of type-1020 mild steel. The gas side of the inner shell is chrome-plated for resistance to corrosion. The fuel pressure drop across the cooling jacket is about 75 lbs per sq inch.

The first injector designed for the axially cooled motor failed in its first firing test, the face being badly burned. The redesigned injector for the CORPORAL motor, has fifty-two pairs of impinging jets and gives a resultant momentum angle of the propellants of about 2.5 deg toward the chamber wall. The pressure drops across the injector are about 85 per square inch across the oxidizer side, and about 60 lbs per sq inch across the fuel side.

Originally, the over-all design specifications for the axially cooled motor were the same as those for the earlier designs of the motor, namely:

F = 20,000 lb at 15,00-ft altitude.

p_c = 300 lbs per sq inch - absolute.

r = 2.65.

For Rounds 1 through 10, the propellant tanks were designed to give a mixture ratio of 2.65. The first three flight rounds, which used heavyweight motors, were operated at or near this design mixture ratio. All subsequent rounds used the axially cooled motor. Early tests of the motor showed that lower mixture ratios produced higher characteristic velocities and also produced smoother operation. The curve of c* versus r peaked near a mixture ratio of 2.2 for the original propellant system, consisting of FNA (6½%) and aniline (80%)--furfuryl alcohol (20%). In

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order to take advantage of these improved characteristics of motor operation at lower mixture ratio, the operating mixture ratio was subsequently changed first to 2.45 and then to 2.2. After Round 11, the propellant tanks were designed for an operating mixture ratio of 2.2 for the propellant system FNA (6½%) and aniline (80%)--furfuryl alcohol (20%). When the propellants were changed to their present compositions, SFNA (nominally containing 14% NO_2, 2.5% H_2O, and 0.6% HF) as the oxidizer and aniline (46.5%)--furfuryl alcohol (46.5%)--hydrazine (7%) as the fuel, the operating mixture ratio of the missile became 2.13, due to changes in density of the propellants. For mixture ratios ranging from about 2.05 to 2.30, the performance of the CORPORAL motor using the final propellant system SFNA and aniline (46.5%)--furfuryl alcohol (46.5%)--hydrazine fuel (7%) is given by the equation

$$c^* - 4492 - 302 (r - 2.13) + 2p_c - 306)$$

where

c^* = characteristic velocity in ft/sec,

r = mixture ratio,

= oxidizer flow rate/fuel flow rate, and

p_c = effective chamber pressure in lbs per sq inch - absolute.

Since the ratio of chamber cross-sectional area to throat area is small (2.04), the combustion gases attain a relatively high velocity in the chamber. Consequently, the measured head-end chamber pressure must be divided by an appropriate factor (1.055) to obtain a value of effective chamber pressure for calculating c^*.

The axially cooled motors used in early flight rounds and most of those used in developmental testing programs were fabricated at the Jet Propulsion Laboratory. The motors employed in the Douglas and Firestone flight rounds were manufactured by the Ryan Aeronautical Company. In order to provide a second source, Firestone established the necessary tooling and other facilities for making CORPORAL motors.

The motors used in the Douglas flight rounds were proof-fired by the Aerojet-General Corporation, and those used in the Firestone flight rounds were tested at White Sands Proving Ground, New Mexico.

c. Axially cooled stainless-steel motor. A single axially cooled motor having the same basic configuration as the mild-steel CORPORAL motor, but made entirely of stainless steel, was constructed. The purpose was two-fold: to obtain a lighter motor and to improve markedly the corrosion resistance, particularly of the cooling circuit. The motor chamber was built of 18-8 type-347 stainless steel, the outer shell being 0.062 inch thick and the inner shell 0.020 inch thick. The total motor weight was only 69 pounds, including a special lightweight high-performance injector. The motor failed during its first static firing, after 12 seconds of smooth operation. The failure was attributed to partial

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blocking of one of the cooling passages by a foreign object which was subsequently found lodged in the passage. Examination of the rest of the motor showed no signs of failure, indicating that the design was satisfactory. The performance obtained prior to the failure was excellent, the average c* being about 4730 ft/sec at r = 2.30 and p_c = 312 lbs per square inch - absolute. However, there was insufficient time available for proving out this high-performance motor for use in the CORPORAL.

PERFORMANCE

The sizes of the propellant tanks are such that when the nominal quantities of propellants (4423 lb of oxidizer and 2143 lb of fuel, respectively) are contained in the tanks and piping, there is at a temperature of 60^{o} F. expansion space equivalent to 8.1% and 7.1% of the volumes of the propellants. This space is required for thermal expansion. Upon the opening of the main air regulator, the propellant tank pressures build up quickly from atmospheric pressure toward nominal values of approximately 450 lbs per sq inch - absolute.

The propellant valve begins to open just prior to the occurrence of overshoot peaks in the tank pressures, permitting first the oxidizer and then the fuel to start entering into the combustion chamber. The combination of valve timing and ignition lag is such that the propellants accelerate quickly to peak flow rates substantially higher than nominal. By the time the propellant valve is approximately 60% open, the chamber pressure has built up, the flow rates and tank pressures have levelled off to normal values, the missile has left the launcher, and the air-tank pressure has dropped from 2350 to 2100 lbs per sq inch - gauge.

Throughout the remaining burning period, the air-tank pressure decreases at the rate of approximately 27 lbs per sq inch per second. As a result of this and of the operating characteristics of the main air regulator, the propellant-tank pressures rise by a few per square inch. The increasing propellant-tank pressures, together with the increasing axial acceleration of the missile and the decreasing distances from the propellant-air interfaces to the rocket motor, result in an increase in flow rates, a decrease in propellant mixture ratio, and an increase of a few lbs per sq inch in chamber pressure.

The main air regulator and the oxidizer-line mixture-ratio restrictor orifice are adjusted at the factory for optimum performance of the propulsion system at 30 seconds of burning time.

LOW-TEMPERATURE TESTS

Investigation of limitations on low-temperature operation of the CORPORAL propulsion system was undertaken by the Jet Propulsion Laboratory during 1954 and was extended into early 1956. The purpose of this program was to determine what components, if any, would prevent reliable operation at ambient temperatures down to −25^{o} F.

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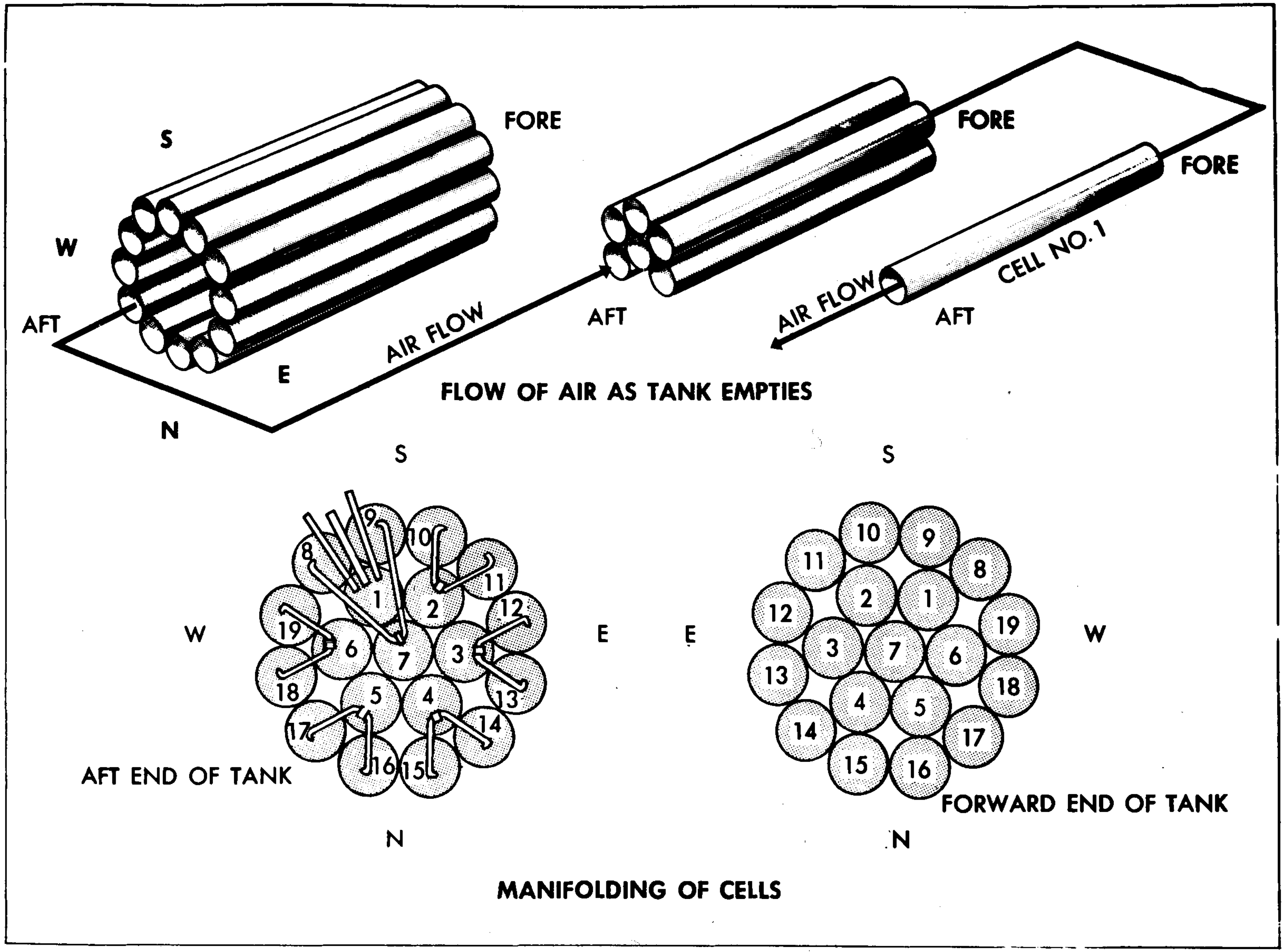

Air-Tank Construction for *Corporal* Production Rounds

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program was started in 1952 to investigate materials which might be used as substitutes for the 19-9 DX in both propellant tanks. On the ORD-437 contract, drawings were issued allowing an alternate tank design using AISI 410 stainless steel, which contains 12% chromium and no other critical elements. Tanks made of this material should be very satisfactory, provided that the CORPORAL oxidizer will not remain in the oxidizer tank for more than 7 days at 130° F. Various coatings tried on 4130 steel all failed to show sufficient corrosion-resistance to the oxidizer. Stabilized stainless-clad steels held promise, providing that corrosion-resistant welds of sufficient strength could be produced. Heat-treatable aluminum tanks were also promising, but further development in producing high-efficiency welds on high-strength aluminum alloys was required.

Air Tank

In the production missile, the air tank consists of a bundle of nineteen aluminum tubes of $6\frac{1}{4}$-inch OD, 0.153-inch wall, and 90-inch length. The total internal volume of the tank is 25.7 cubic feet, and the weight is 604 pounds. This tank, containing domed heads attached to the individual tubes by snap rings, is proof-tested to 2750 per square inch and is operated at 2350 lbs per sq inch air pressure in the missile. Its use dates back to Flight E-7 in January 1951.

Prior to Flight E-7, single-cell tanks, each consisting of a 30-inch OD cylinder with hemispherical heads, were used. Flights E-4 through E-6 utilized forged cylinders of SAE 4140, machined to 0.25-inch wall thickness with machined skirts. The heads were 3/16 inch thick. The internal volume was 25.9 cubic feet; the weight was 529 pounds; and the operating pressure was 2,000 per square inch. Flight E-2 utilized the same air-tank construction as E-4 through E-6, except that all wall thicknesses were 0.375 inch, and the internal volume was 32.5 cubic feet. As a result, the tank weighed 1139 pounds. It was pressure-tested to 2520 lbs per sq inch and operated at 2100 lbs per sq inch. After the unsuccessful firing of E-2, this air tank was salvaged. A single small crack was discovered and repaired, and the tank was flown in E-3. The cylindrical portion of the air tank in E-1 was welded of SAE 4130 steel plates 0.50 inch thick. The heads were 0.375 inch thick, whereas the internal volume was 32.5 cubic feet, and the weight was 1259 pounds. Proof-test pressure was 1900 lbs per sq inch, and operating pressure was 1600 lbs per sq inch.

No active program has been instituted to replace this air-tank design. In order to maintain the current air-tank weight with a single-cell welded steel construction similar to that of the propellant tanks, it would be necessary to achieve weld strengths greater than 180,000 lbs per sq inch. Up to the present time, attempts to accomplish this objective have not succeeded except on small-scale tests.

It was concluded from this test program that the CORPORAL Type-II propulsion system is reliably operable at -25^{o} F, provided that certain component modifications involving O-ring seals are incorporated and that suitable oxidizer restrictors are employed to prevent excessively high mixture ratios.

COMPONENT DEVELOPMENT

During the evolution of the CORPORAL propulsion system, it was necessary for this Laboratory to develop many of the components whose design criteria had been established as the result of JPL investigation of optimum propulsion-system design.

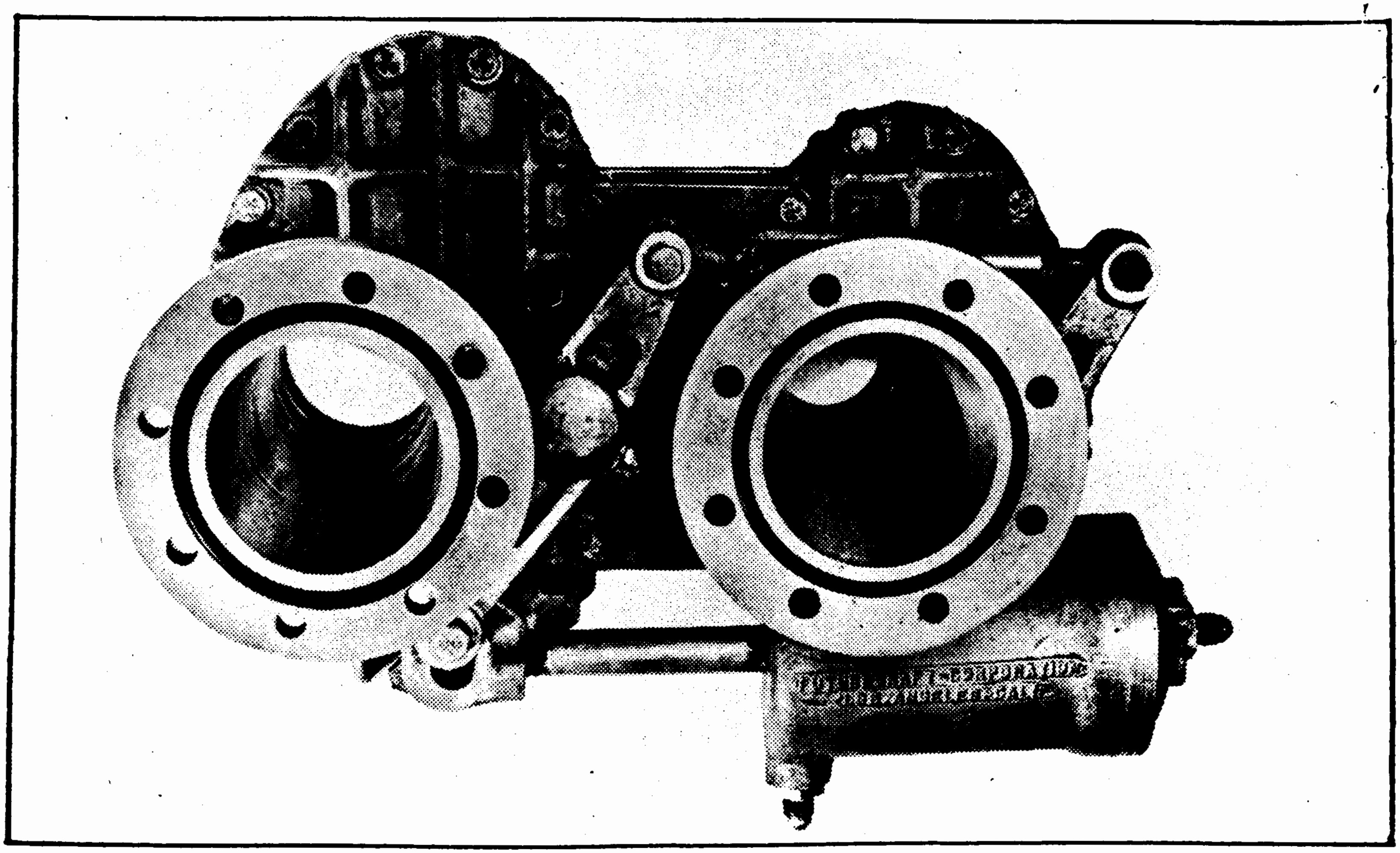
Propellant Tank

In the final version, both the oxidizer tank and the fuel tank of the CORPORAL were fabricated of 19-9 DX stainless steel in the form of 30-in.OD cylinders welded to hemispherical heads. All walls were 0.125 inch thick. The cylinders were diagonally rolled from large sheets made up of welded plates, with the result that they contained neither longitudinal nor girth welds. The oxidizer tank had an internal volume of 49.0 cubic feet and weighed 541 pounds. The fuel tank, with an internal volume of 33.4 cubic feet, weighed 319 pounds. The tanks were hydrostatically tested at 600 lbs per sq inch and were operated at approximately 450 lbs per sq inch air pressure in the missile. The corrosion-resistance of the tanks to the CORPORAL oxidizer (red fuming nitric acid with 0.5% hydrofluoric acid as corrosion inhibitor) was excellent, and the tanks were unaffected by the CORPORAL fuel.

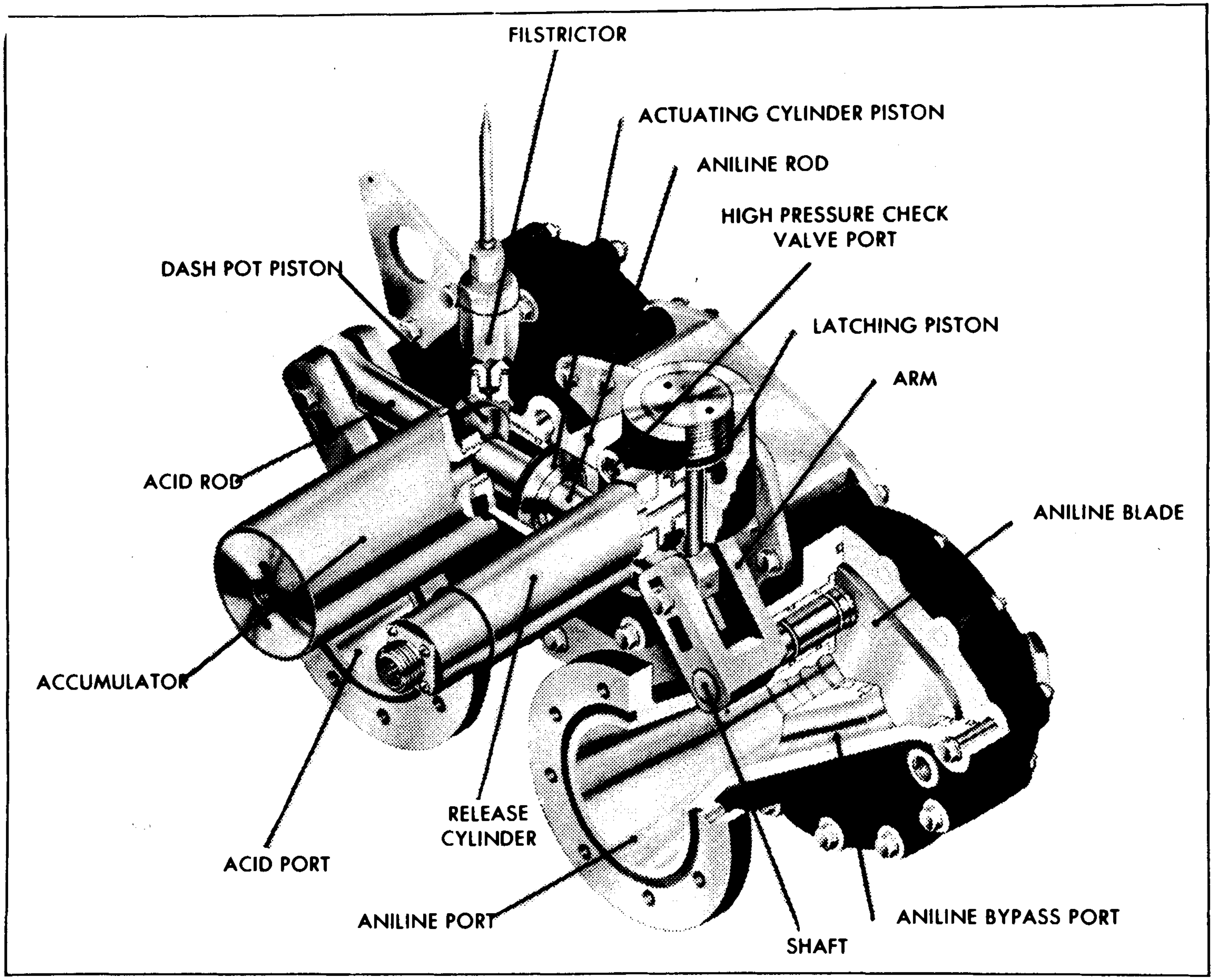
The current tank design dates back to CORPORAL Flight No. 11 (December 1951) with the exception that, prior to the beginning of the ORD-437 contract in mid-1954, 19-9 DL stainless steel was used. The change from 19-9 DL to 19-9 DX was made to conserve columbium, a trace element, by the substitution of titanium, a less critical strategic metal. The first ten CORPORAL flights were made with larger oxidizer tanks (51.7 cu ft) and smaller fuel tanks (28.8 cu ft). Flights Nos. 4 through 10 utilized a tank with a wall thickness of 0.125 inch, weighing 553 and 329 pounds, respectively. Flights Nos. 1 through 3 utilized tanks with wall thickness of 0.188 inch and weights of 796 and 485 pounds, respectively.

Prior to the fabrication of the first 19-9 DL propellant tanks, a program had been investigated to use AISI 501, a 5% chromium steel modified by the addition of molybdenum. The first attempts were with an integral-head combination of air, fuel, and oxidizer tanks. Fabrication difficulties both in the handling of such a large structure and in obtaining adequate weld strength led to the abandonment both of this method of fabrication and of the material.

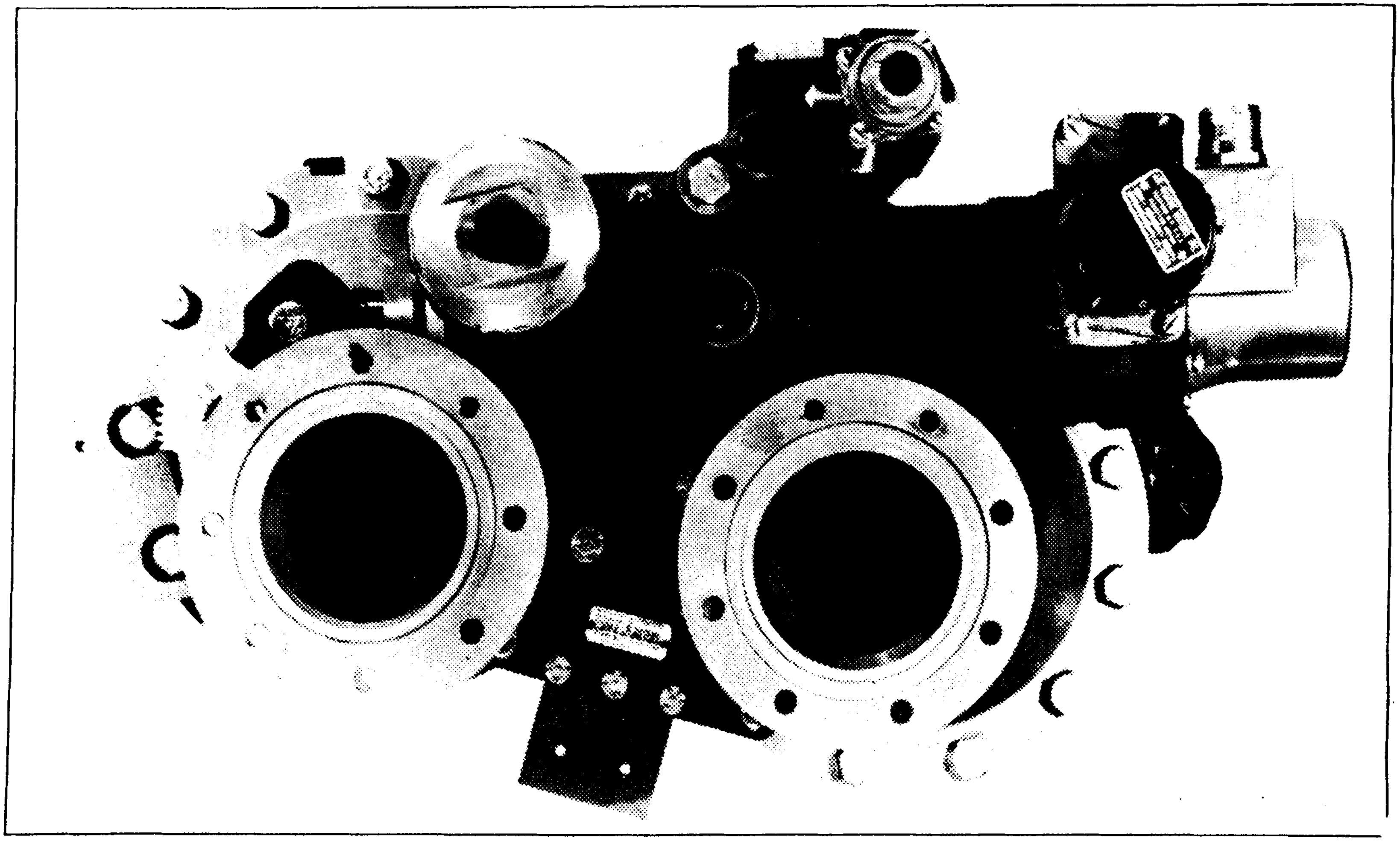
Recognizing the critical nature of chromium and nickel contained in the 19-9 DX stainless steel in the event of a national emergency, a



View of Early Propellant Valve Showing Hydraulic Operating Cylinder



Propellant Valve for Type-I *Corporal*



Propellant Valve for Type-II *Corporal*

[redacted]

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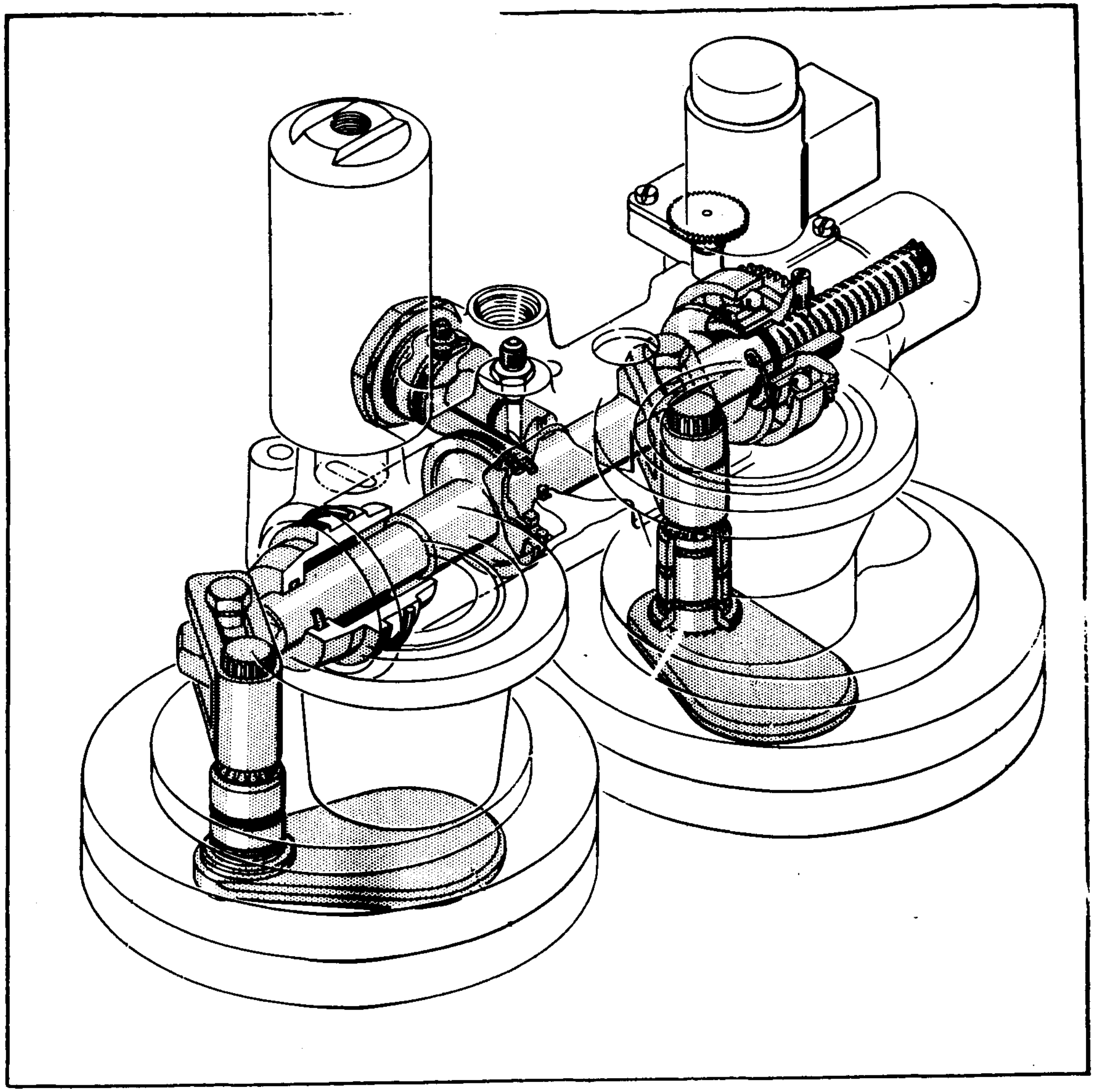


Cutaway View of Propellant Valve

Propellant Valve

The CORPORAL propellant valve is the largest and most intricate valve in the propulsion system. This valve might be regarded as two blade valves, one controlling the acid flow and the other controlling the propellant flow, held together by tie plates and operated by a common pneumatic operating cylinder. This valve is designed to provide a slow, controlled opening, a low pressure drop in the open position, and quick close. The slow opening, required for smooth starting of the CORPORAL motor, is obtained by means of an electromechanical timer attached to the operating cylinder shaft. To open the propellant valve, air at 600 lbs per sq inch is supplied to the opening side of the operating cylinder. One end of the operating shaft is threaded. A timer nut driven by a synchronous motor through a reduction gear train travels down the threaded shaft at a rate which produces a complete valve opening in 4.2 ± 0.3 seconds, an opening time found by experience to provide satisfactory starting of the CORPORAL motor.

To prevent an accumulation of unburned fuel in the motor during starting (which might cause an explosion upon the introduction of oxidizer blade lead. The oxidizer port is partially opened first while the fuel port remains closed to insure the arrival of oxidizer in the motor chamber before the arrival of fuel. Adjustments are provided in the valve linkage for the control of the oxidizer blade lead.

A bypass port is provided in the fuel side of the propellant valve. This port is open when the valve is in the closed position, but the port is closed by the fuel blade when the propellant valve is opened. During quick close, the fuel is diverted from the injector to the bypass port and is dumped overboard. This avoids a sudden stoppage of the fuel flow and the resultant water hammer effect in the fuel circuit. No bypass is provided in the acid circuit as the water hammer effect on quick closure is negligible.

Range control of the CORPORAL is accomplished by shutting off the motor at a predetermined missile velocity, through quick closing of the propellant valve. The propellant valve is latched in the fully open position by means of a latching piston which engages the operating cylinder shaft. Air pressure is applied to the closing side of the oper operating cylinder piston 43 seconds after takeoff. Simultaneously, pressure is removed from the opening side of the piston, but valve movement in the closing direction is prevented by the latching piston, which remains engaged with the operating cylinder shaft. Lifting of the latching piston is accomplished by pressure generated in the release cylinder. An electrical blasting cap carried in the release cylinder is detonated through an electrical circuit in the missile upon reception of the ground cutoff signal. Pressure generated by the blasting cap acts on the opening side of the latching piston, lifting the piston and permitting the operating cylinder shaft to move to the closed position. Complete leak-tight closure is obtained in 6 to 8 milliseconds.

Several safety features for the protection of the missile and personnel have been incorporated in the propellant valve. Should power to the synchronous motor be lost during starting, the electromechanical timer will continue to open, although at a somewhat faster rate. This reduces the possibility of the valve stopping when partially open due to electrical failure and thus preventing attainment of full propellant flow. A port is provided in the latching cylinder through which high-pressure air from the emergency shutoff circuit may be introduced to raise the latch piston and close the propellant valve without the necessity of first firing the blasting cap. This allows the propellant valve to be closed from the firing panel in an emergency as long as the missile remains on the launcher.

The propellant valve has undergone a series of evolutionary changes over a period of approximately 8 years. The valve used in the type-I missile differed in two major respects from the valve used in the type-II CORPORAL. The type-I propellant valve had a cast valve body, as contrasted with the present bar stock body. In addition, a hydraulic dashpot arrangement was used to control the opening rate of the valve. This device consisted of a dashpot connected to the end of the operating cylinder shaft. Upon pressurization of the opening side of the operating cylinder, a fluid was forced from the dashpot through a small capillary restrictor at a predetermined rate. The opening rate was controlled by changing the amount of restriction in the capillery. This hydraulic dashpot system possessed several disadvantages. The viscosity of the hydraulic fluid used, Dow Corning Silicone Oil No. 200, varied with temperature, resulting in changes in flow rate in the restrictor with changing temperature. To compensate for this effect, it was necessary to add additional restriction by crimping the capillary or to remove restriction by shortening the capillary as the ambient temperature increased or decreased. Adjusting the capillary restriction to compensate for ambient-temperature change proved to be very troublesome in the field. Proper filling of the dashpot and capillary required special field equipment which proved to be difficult to maintain and use. To overcome these and other disadvantages, an electromechanical timer was substituted.

A predecessor of the type-I valve used a hydraulic operating cylinder in place of the later pneumatic cylinder. In this valve, fuel under pressure was bled from the fuel circuit through a restrictor to the opening side of the operating cylinder. During tank pressurization, fuel passed through the restrictor into the operating cylinder at a controlled rate and opened the valve. This early valve was designed to close during flight in the event of a missile system malfunction, but was not designed to provide range control. Consequently, the valve did not include a quick-close feature.

Other Components

Refinement of the CORPORAL propulsion system also required the development of many smaller components.

a. <u>Air Regulators</u>. Two types of regulators are used in the CORPORAL missile. The main air regulator is a dome-loading type in which a reference pressure provided by another regulator is balanced on one side of a piston by the regulated pressure acting on the other side of the piston. Any unbalance between the reference pressure and the regulated pressure results in movement of the piston to correct the unbalance. The dual-dome regulator and the auxiliary regulator are of the spring-loaded type. A piston is balanced on one side by a spring set at a given compression; outlet (regulated) pressure opposes the spring force on the opposite side of the piston.

b. <u>Air-cutoff Valve</u>. The air-cutoff valve closes the main air regulator when the air-tank pressure has decreased to approximately 540 lbs per sq inch. This closure conserves air for missile guidance requirements during the remainder of the flight.

c. <u>Start-delay Valve</u>. The function of the start-delay valve is to delay the opening of the propellant valve until the propellant tank pressures have reached a predetermined minimum. This is accomplished by means of a burst deaphragm in the start-delay valve. The start-delay valve is normally held closed by a spring. An air line from the oxidizer tank is attached to the opening side of the start-delay valve. A burst diaphragm on the opening side of the valve is fractured at about 375 lbs per sq inch by pressure from the oxidizer tank, which then shifts the valve to the open position. Opening the start-delay valve admits air to the opening side of the propellant valve.

The closing side of the start-delay valve is pressurized 43 seconds after takeoff, thereby closing the valve. With this valve in the closed position, the downstream air circuitry, including the opening side of the propellant-valve operating cylinder, is vented to atmosphere in preparation for quick closing of the propellant valve at cutoff.

d. <u>Shuttle Valve</u>. The type-II shuttle valve consists of a valve body having three openings and a movable piston. This valve, located in the propellant-valve air circuit, admits air to the closing side of the propellant valve from either the missile cutoff-air circuit or from the ground-controlled emergency shutoff circuit. The shuttle valve shifts in the direction of the least pressure and passes air from the higher pressure source. In normal missile operation, the emergency shutoff circuit is not pressurized. The shuttle valve therefore shifts to admit air from the internal missile supply for normal operation. In case of emergency shutoff on the launcher, however, emergency air at a higher pressure is used to shift the shuttle and to close the propellant valve and other valves which must be closed at this time.

e. <u>Vent and Signal Valve</u>. The vent and signal valve is installed downstream of the main air regulator. This valve vents slight leakage through the main air regulator to atmosphere. If the leakage becomes great enough to raise the inlet pressure at 15 lbs per sq inch, the piston moves and closes the microswitch. A warning light on the firing panel then indicates that excessive leakage exists through the main air regulator. If the inlet pressure rises above approximately 125 lbs per square inch, as during a normal start, the piston shifts further to close the vent and signal valve and to prevent continued venting. Thus, during flight no air is lost through this valve.

f. Bypass-blocking Valve. To prevent dumping of fuel through the fuel-discharge circuit prior to propellant-valve opening, a bypass-blocking valve is installed in the fuel-bypass circuit downstream of the propellant valve. This valve is a poppet-type, normally closed valve with a spring return on the poppet. In flight this valve remains closed, blocking the fuel bypass circuit until 43 seconds after takeoff. At this time, the opening side of the bypass-blocking valve is pressurized. The bypass circuit is thus opened to discharge fuel overboard upon closure of the propellant valve.

g. Pneumatic Vent Valves. One pneumatic vent valve is attached to the forward end of each propellant tank. Upon pressurization of the emergency circuit the vent valves open, releasing the pressure in the propellant tanks and venting the air tanks to atmosphere through the main air regulator.

h. Check Valves. One air check valve is located in the air line between the main air regulator and the oxidizer tank; a second air check valve is located downstream of the main air regulator at the entrance to the fuel tank. The primary purpose of these check valves is to prevent possible mixing of gases or liquids from the propellant tanks in the propellant-tank air-supply piping from the main air regulator.

Check valves were added to the air circuit following Round 3, when an explosion apparently occurred in the propellant tanks or air-supply piping as a result of propellant mixing in the air circuit after cutoff.

i. Filters. Filters are placed in the air circuitry upstream of each of the small regulators in the missile to prevent the introduction of foreign material into the regulators. These filters consist of a small aluminum case containing a felt filter. A wire screen near the filter outlet retains the filter medium.

j. Solenoid Valves. Two solenoid valves are used in the CORPORAL propulsion system. The firing solenoid valve is located in the dome circuit; the auxiliary solenoid is located in the air circuitry for closing the propellant valve. To commence a missile firing, the firing solenoid valve is opened, permitting air from the dual dome loaders to pressurize the dome of the main air regulator. The auxiliary solenoid valve is opened 43 seconds after takeoff. Actuation of this solenoid valve closes the start-delay valve and pressurizes the closing side of the propellant-valve operating cylinder preparatory to closing the propellant valve at cutoff.

k. Rupture Diaphragms. Five rupture diaphragms are used in the CORPORAL missile. Two diaphragms which burst at about 100 lbs per sq inch (formerly 60 lbs per sq inch) are located immediately upstream of the propellant valve to keep the propellants out of the propellant valve until the propellant tanks are pressurized. A 115 lbs per sq inch burst diaphragm is located downstream of each air-line check valve to protect the check valves from exposure to propellants during filling and handling operations. A fifth burst diaphragm which bursts at approximately 375 inch is located on the opening side of the start-delay valve to delay opening of this valve until the tank pressure has reached a predetermined minimum.

l. Air-tank Charging Valve. The air-tank charging valve consists of two parts, a body assembly and connector. The connector is attached to the launcher, whereas the body assembly is located in the aft casting surrounding the motor exit on the missile. With the missile on the launcher the connector is inserted in the body assembly. The connector lifts the poppet and permits air from the ground supply to pass through the coupling to the air-tank charging line. The connector remains in place until takeoff, at which time the missile lifts from the launcher and the connector is pulled from the body assembly. The poppet then closes by a combination of spring force and missile air pressure, preventing loss of air through the valve during flight.

m. Air-stop Valve. The air-stop valve is located in the air charging line to the missile air tank. Closing the air-stop valve prevents changing of the missile air tank but allows air from an external source to flow to the servo system in the missile. The servo system can thus be operated for checkout without filling the missile air tank.

The air-stop valve is manually operated by means of a tee handle. Closing the valve vents the downstream port through the screened vent in the valve. The valve may be locked in either the closed or open position by means of a spring clip.

n. Emergency Air Coupling. The emergency air coupling and slip tube from a connection for the passage of emergency high-pressure air from the launcher into the missile. This coupling consists of a small fitting having two internal O-rings into which a slip tube attached to the launcher is fitted.

o. Release Cylinder. The release cylinder is a small chamber in which the detonation of an electric blasting cap provides pressure for the lifting of the propellant-valve latch. The cylinder is screwed into the latch port on the propellant valve. A heavy wall chamber, fitted with a liner, contains the pressure generated by the detonation of the blast cap. A gland is provided at one end of the cylinder through which the blasting-cap wires pass to an electrical receptacle. A baffle to prevent the discharge of shrapnel is placed over the gas outlet port at the other end of the cylinder.

CORPORAL TRAINING -- INDIVIDUAL AND UNIT

CORPORAL TRAINING

1. INDIVIDUAL

2. UNIT

The materials comprised under the general heading were compiled from the following sources:

DOCUMENTS

Ordnance Technical Report, ORDNANCE GUIDED MISSILE & ROCKET PROGRAMS, Vol. III, CORPORAL FIELD ARTILLERY GUIDED MISSILE SYSTEM, INCEPTION THROUGH 30 JUNE 1955.

USA OGMS, PROGRAM OF INSTRUCTION FOR 9-R-F19 (renumbered 9-R-245.1): CORPORAL GROUND GUIDANCE REPAIR, RSA, Alabama, July 1959.

USA OGMS, PROGRAM OF INSTRUCTION FOR 9-R-F21 (renumbered 9-R-249.1): CORPORAL MISSILE REPAIR, RSA, Alabama, July 1959.

USA OGMS, PROGRAM OF INSTRUCTION FOR 9-R-F22 (renumbered 9-R-437.1): CORPORAL GROUND HANDLING EQUIPMENT REPAIR, RSA, Alabama, July 1959.

USA OGMS, PROGRAM OF INSTRUCTION FOR 9-N-4812: CORPORAL MAINTENANCE SUPERVISION, RSA, Alabama, July 1959.

USA OGMS, DETAILED SCHEDULE OF CLASSES, 1st, 2nd, 3rd, and 4th QUARTERS, FISCAL YEAR 1961, RSA, Alabama, 22 July 1960.

USA OGMS, UNNUMBERED MEMORANDUM: <u>COURSE REDESIGNATION</u>, dated 8 October 1957.

USA OGMS, UNIT TRAINING CENTER FUNCTION MANUAL, RSA, Alabama, 1 March 1959.

INTERVIEWS WITH

CROPP, Mr. N. L., Publications Officer, Reports Branch, ABMA Control Office.

CUMMINGHAM, Captain Daniel L., USA, Deputy Commander, Unit Training Command, USA OGMS, RSA, Alabama, Building 3200, 14 February 1961.

FREDERICKS, Sergeant First Class Russell M., USA, Administrative Specialist, Programming Branch, Office of Operations, USA OGMS, RSA, Alabama, Building 3300, 1 March 1961.

GUILLORY, First Lieutenant R. W., USA, Chief, CORPORAL Branch, FAM Division, Department of Individual Training, USA OGMS, RSA, Alabama, Building 3305, 14 February and 1 March 1961.

GULLICK, Mr. John M., Assistant Chief, CORPORAL Branch, FAM Division, Department of Individual Training, USA OGMS, RSA, Alabama, Building 3305, 14 February and 1 March 1961.

MANCINI, Master Sergeant James D., USA, Noncommissioned Officer in Charge of Office of Operations, USA OGMS, RSA, Alabama, Building 3300, 14 February and 1 March 1961.

TABLE I

INDIVIDUAL TRAINING

CORPORAL BRANCH, FAM DIVISION,
INDIVIDUAL TRAINING DEPARTMENT,
USA ORDNANCE GUIDED MISSILE SCHOOL,
REDSTONE ARSENAL, ALABAMA

INTRODUCTION

The first Ordnance Guided Missile Training Program at Redstone Arsenal began on 10 March 1952 with seven officers enrolled in the "Guided Missile Officers Course." Since that date, additional courses have been provided for both officers and enlisted men. Those courses have undergone several modifications, coinciding with improvements in the missile system itself, the acquisition of training equipment and facilities, and the development of more efficient teaching methods and more capable instructors. Course numbers have changed; descriptive nomenclature of courses have been reworded; course content has been modified; military occupational specialist (MOS) requirements have been defined and redefined. Table B lists MOS, course numbers, course titles of courses for FY 1956, and inputs programmed for FY 1956. The succeeding tables list changes in course number, MOS, and nomenclature of courses offered as changes occurred. Table E lists courses as of 1 March 1961. Only those officers courses conceivably leading toward service with CORPORAL in some capacity are listed.

TABLE B

OGMS TRAINING REQUIREMENTS FOR FY 1956

Officers and Warrant Officers

MOS	COURSE NUMBER	TITLE	TOTAL INPUTS
4810	9-0-68	Guided Missile Unit Commander Course	48
None	9-0-21	Ordnance Guided Missile Maintenance and Supply Management - CORPORAL Phase	290
4812	9-0E-70	Guided Missile System Maintenance "SSM" (Warrant Officers Course)	71
		TOTAL	409

Enlisted Men

NEW MOS	OLD MOS	COURSE NUMBER	TITLE	TOTAL INPUTS
241	1360	9-E-58	Doppler Repair Course "SSM"	47
242	1361	9-E-59	Computer Repair Course "SSM"	28
243	1362	9-E-60	Radar Repair Course "SSM"	44
244	1363	9-E-61	Internal Repair Course "SSM"	96
432	1338	9-E-66	Mechanical System Repair Course "SSM"	136
			TOTAL	351

TABLE C

CHANGE IN MOS AND COURSE NUMBERS

Officers and Warrant Officers

MOS	COURSE NUMBER	TITLE
	9-0-18	Ordnance Guided Missile and Special Weapons Staff Officer
None	9-0-21	Ordnance Guided Missile Management Orientation
	9-0-68B	Ordnance Associate Guided Missile Company Grade Officers Course (FAGM)
4812	9-OE-70	Guided Missile Systems Maintenance Supervisor, SSM (Warrant Officers Course)

Enlisted Men

MOS	COURSE NUMBER	TITLE
241	9-E-58	Guided Missile Doppler Systems Repair, CORPORAL
242	9-E-59	Guided Missile Computer Systems Repair, CORPORAL
243	9-E-60	Guided Missile Radar Systems Repair, CORPORAL
244	9-E-61	Guided Missile Internal Guidance Systems Repair, CORPORAL
432	9-E-66	Guided Missile Mechanical Systems Repair, CORPORAL

[redacted]

TABLE D

SUBSEQUENT CHANGE IN MOS AND COURSE NUMBER

Officers and Warrant Officers

MOS	COURSE NUMBER	TITLE
	9-A-F7	Ordnance Staff Officer Guided Missile and Special Weapons
None	9-G-F1	Ordnance Guided Missile Management Orientation
	9-0-68B	Ordnance Guided Missile Officers Course (FAGM)
4812	9-N-4812	Guided Missile Maintenance Supervision (CORPORAL) (Warrant Officers Course)

Enlisted Men

MOS	COURSE NUMBER	TITLE
241.1	9-R-241.1	Surface-to-Surface Missile Doppler Repair
242.1	9-R-242.1	Surface-to-Surface Missile Computer Repair
243.1	9-R-243.1	Surface-to-Surface Missile Radar System Repair
244.1	9-R-244.1	Surface-to-Surface Missile Internal Guidance System Repair
432.1	9-R-432.1	Surface-to-Surface Missile Mechanical Systems Repair

[redacted]

TABLE E

COURSE NUMBERS FOR FY 1961

Officers and Warrant Officers

For FY 1961, the course numbers and titles were as follows:

MOS	COURSE NUMBER	TITLE
None	9-G-F1	Ordnance Guided Missile Management Orientation (2 weeks)
4801	9-A-4801 (9-A-F9)	Ordnance Guided Missile Officer, FAGM (19 weeks, 4 days)
4513	9-A-4513	Ordnance Staff Officer Guided Missile and Nuclear Weapons (18 weeks)
4812	9-N-4812	CORPORAL Maintenance Supervision - Warrant Officers Course (43 weeks)

Enlisted Men

MOS	COURSE NUMBER	TITLE
	9-R-F19	CORPORAL Ground Guidance Repair (23 weeks)
	9-R-F21	CORPORAL Missile Repair (17 weeks)
	9-R-F22	CORPORAL Ground Handling Equipment Repair (9 weeks)

The three enlisted men's courses listed immediately above had interim course numbers, waiting for assignment of MOS's.

TABLE F

REVISION OF ENLISTED MOS's AND REPAIRMAN COURSES CORPORAL WEAPON SYSTEM

1. The enlisted repairman courses for the CORPORAL Weapon System were officially revised and approved by CONARC on 25 April 1960 as follows:

a. Former Courses 9-R-241.1, CORPORAL Doppler Repair, 9-R-242.1 CORPORAL Computer Repair, and 9-R-243.1 CORPORAL Radar Repair were combined to form course 9-R-F19, CORPORAL Ground Guidance Repair. The designation 9-R-F19 was an interim course number awaiting assignment of an MOS.

b. Former Course 9-R-244.1 CORPORAL Internal Guidance Repair and the missile propulsion and missile mechanical portion of former course 9-R-432.1 CORPORAL Mechanical Repair were combined to form course 9-R-F21 CORPORAL Missile Repair. The designation 9-R-F21 was an interim course number awaiting assignment of an MOS.

c. Former Course 9-R-432.1 CORPORAL Mechanical Repair was revised to exclude missile propulsion and missile mechanical subject matter. This course was designated 9-R-F22, CORPORAL Ground Handling Equipment Repair as an interim course number awaiting assignment of an MOS.

2. References: Letter, ORDAB-MT-C, dated 19 October 1960, subject: Changes to CORPORAL Course Numbers.

a. Course number of Course 9-R-F19, CORPORAL Ground Guidance Repair is changed to read: 9-R-245.1. MOS trained in this course is Ground Guidance Repairman (CORPORAL), 245.1.

b. Course number of Course 9-R-F21, CORPORAL Missile Repair is changed to read: 9-R-249.1. MOS trained in this course is Missile Repairman (CORPORAL), 249.1.

c. Course number of Course 9-R-F22, CORPORAL Ground Handling Equipment Repair is changed to read: 9-R-437.1. MOS trained in this course is Ground Handling Equipment Repairman (CORPORAL), 437.1.

[redacted]

TABLE G

REVISED COURSE NUMBERS AND TITLES

Officers and Warrant Officers

MOS	COURSE NUMBER	TITLE
None	9-G-F1 (2 weeks)	Ordnance Guided Missile Management Orientation
4801	9-A-4801 (19 weeks, 4 days)	Ordnance Guided Missile Officer, FAM
4513	9-A-4513 (18 weeks)	Ordnance Staff Officer, Guided Missile and Nuclear Weapons
4812	9-N-4812 (43 weeks)	CORPORAL Maintenance Supervision

Enlisted Men

MOS	COURSE NUMBER	TITLE
245.1	9-R-245.1 (23 weeks)	CORPORAL Ground Guidance Repair
249.1	9-R-249.1 (17 weeks)	CORPORAL Missile Repair
437.1	9-R-437.1 (9 weeks)	CORPORAL Ground Handling Equipment Repair

Descriptions of MOS's 4812, 245.1, 249.1, and 437.1 follow.

[redacted]

A. Course: 9-N-4812 CORPORAL Maintenance Supervision

B. Purpose: To train Warrant Officers, and to technically qualify selected enlisted personnel as Warrant Officers, to supervise the maintenance of CORPORAL guided missile systems and associated equipment. MOS for which trained: Warrant Officer, Guided Missile Systems Maintenance Officer, CORPORAL (4812).

C. Prerequisites: Warrant Officers: Credit for courses in algebra and trigonometry and have some background in general science, or have a standard score of 45 of higher on GED tests 3 and 5, high school level. Must have a knowledge of basic electricity and electronics equivalent to scope of instruction contained in Course 9-R-240.0. Normal color perception. Must sign 2 year commitment statement as prescribed in paragraph 7a (2), section I, DA Pam 20-21. Security clearance required: SECRET (Interim).

<u>Enlisted</u>: Grade E-6 or above. Qualified as Doppler Repairman (CORPORAL) (241.1), Computer Repairman (CORPORAL) (242.1), Radar Repairman (CORPORAL) (243.1), Internal Guidance Repairman (CORPORAL) (244.1), or Mechanical Repairman (CORPORAL) (432.1) who has a knowledge of basic electricity and electronics equivalent to the scope of instruction contained in Course 9-R-240.0. Must have maintained CORPORAL equipment in the field for at least 6 months. Credit for courses in algebra and trigonometry and have some background in general science, or have a standard score of 45 or higher on GED tests 3 and 5, high school level. Qualified for appointment as Warrant Officer in accordance with provisions of SR-140-106-1, except for the lack of proper military school training. Twenty-four months or more of active duty service remaining after completion of the course. Standard score of 100 or higher on aptitude area EL. Security clearance required: SECRET (Interim).

<u>Special Information</u>: The selection of commissioned officers to attend this course will be made by Headquarters, Department of the Army.

	Peacetime	Mobilization
D. <u>Length</u>:	42 weeks	37 weeks
E. Training Locations:	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama

F. Percentage of Training Requirement to School Trained: 100% 100%

G. MOS Feeder Patterns:

Prerequisites MOS's	MOS Trained in this Course	Feeds Following MOS's
Officer - None →	4812 →	None
Enlisted: 241.1, 242.1, 243.1, 244.1, 432.1 →	4812 →	None

H. Ammunition Requirements: No ammunition required.

I. Common Subjects Recapitulation: Not Applicable.

A. Course: 9-R-437.1, CORPORAL Ground Handling Equipment Repair.

B. Purpose: To train enlisted personnel to inspect, test and perform field maintenance and repair of CORPORAL ground handling, launching, servicing and associated test equipment. MOS for which trained: Ground Handling Equipment Repairman, CORPORAL (437.1).

C. Prerequisites: Grade E-6 or below and qualified as an Automotive Repair Helper (630.0). High school graduate with credit for courses in algebra and trigonometry or have a standard score of 45 or higher on GED tests 3 and 5, high school level. Standard score of 100 or higher on aptitude area GM. Normal color preception and full use of both hands and legs. Nine months or more of service remaining after completion of course. Security clearance required: SECRET (Interim).

	Peacetime	Mobilization
D. Length:	9 weeks	7 weeks
E. Training Locations:	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama
F. Percentage of Training Requirement to be School Trained:	100%	100%

G. MOS Feeder Patterns:

Prerequisite MOS	MOS Trained in this Course	Feeds Following MOS
630.0	(To be announced)	(To be announced)

H. Ammunition Requirements: No ammunition required.

I. Common Subjects Recapitulation: Not applicable.

[redacted]

A. Course: 9-R-249.1, CORPORAL Missile Repair.

B. Purpose: To train enlisted personnel to inspect, test, perform field maintenance and repair on internal electronic and mechanical components of the CORPORAL missile system and associated test equipment including the AN/MSM-12 van. MOS for which trained: Missile Repairman, CORPORAL (249.1).

C. Prerequisites: Qualified as Surface-to-Surface Missile Electronic Helper (240.0). Credit for courses in algebra and trigonometry and have some background in general science or have a standard score of 45 or higher on GED tests 3 and 5, high school level. Fifteen months or more of service remaining after completion of the course. Standard score of 100 or higher on aptitude area EL. Normal color perception and full use of both hands. Security clearance required: SECRET (Interim).

	Peacetime	Mobilization
D. Length:	17 weeks	14 weeks
E. Training Location:	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama
F. Percentage of Training Requirement to be School Trained	100%	100%

G. MOS Feeder Patterns:

Prerequisite MOS	MOS Trained in this Course	Feeds Following MOS
240.0	To be announced	To be announced

H. Ammunition Requirements: No ammunition required.

I. Common Subjects Recapitulation: Not applicable.

[redacted]

[redacted]

A. Course: 9-R-245.1, CORPORAL Ground Guidance Repair

B. Purpose: To train enlisted personnel to inspect, test and perform field maintenance and repair of the CORPORAL ground guidance system and associated test equipment including the AN/MPM-38 Van. MOS for which trained: Ground Guidance Repairman, CORPORAL (245.1).

C. Prerequisites: Qualified as Surface-to-Surface Missile Electronic Helper (240.0). Credit for courses in algebra and trigonometry and have some background in general science or have standard score of 45 of higher on GED tests 3 and 5, high school level. Nineteen months or more of service remaining after completion of the course. Standard score of 100 or higher on aptitude area EL. Normal color perception and full use of both hands. Security clearance required: SECRET (Interim).

	Peacetime	Mobilization
D. Length:	23 weeks	20 weeks
E. Training Locations:	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama	US Army Ordnance Guided Missile School Redstone Arsenal, Alabama
F. Percentage of Training Requirement to be School Trained:	100%	100%

G. MOS Feeder Patterns:

Prerequisite MOS	MOS Trained in this Course	Feeds Following MOS's
240.0	To be announced	To be announced

H. Ammunition Requirements: No ammunition required.

I. Common Subjects Recapitulation: Not applicable.

[redacted]

TABLE H

STUDENTS ENROLLED, DROPPED, AND GRADUATED
FY 59, CORPORAL BRANCH, SSM DIVISION

ORDHB-GMS-T   Corporal Students - FY 59
Ch, P & S Br, FAM Div   Ch, Cpl Br   30 June 1959
Mr. Gullick/jw/3181

1. Information on students enrolled, dropped, and graduated during FY 59, inclosure 1, is forwarded for your information.

2. The information inclosed in accurate and is backed up by student rosters for each class on file in this office.

3. This information may be of the type desired by DIT for management improvement. A similar report could have been submitted each month as information from student rosters was tabulated monthly in this office.

1 Inclosure

PAUL C. WARD, Capt, Ord Corps
Chief, Corporal Branch

STUDENTS ENROLLED, DROPPED & GRADUATED
FY 59
CORPORAL BRANCH, SSM DIVISION

Course	1	2	3	4	5	6	7	8	9	10
9-R-241.1	6	0	0	6	48	3	0	43	0	49
9-R-242.1	9	1	0	8	58	4	1	41	12	49
9-R-243.1	34	0	1	33	70	0	0	58	12	91
9-R-244.1	27	0	0	27	127	4	5	77	42	104
9-R-432.1	15	0	0	15	108	1	4	69	34	84
9-N-4812	7	0	0	7	17	0	0	0	17	7
TOTAL	98	1	1	96	426	12	10	288	116	384

1. Student carryover from FY 58.
2. Students carried over from FY 58 dropped for academic reasons.
3. Students carried over from FY 58 dropped for non-academic reasons.
4. Students starting in FY 58 and graduating in FY 59.
5. Students enrolled FY 59.
6. Students dropped FY 59 for academic reasons.
7. Students dropped FY 59 for non-academic reasons.
8. Students starting and graduating FY 59.
9. Student carryover to FY 60.
10. Total graduated FY 59.

Incl 1

TABLE I

STUDENTS ENROLLED, DROPPED, AND GRADUATED
FY 60, CORPORAL BRANCH, SSM DIVISION

ORDHB-GMS-TF
Ch, P&S Office — Corporal Students - FY 60
FAM Division — Ch, Cpl Br — 27 Jul 60
Mr. Gullick/jw/3-1803

1. Information on students enrolled, dropped, and graduated during FY 60, inclosure 1, is forwarded for your information.

2. The information inclosed is accurate and is backed up by student rosters for each class on file in this office.

3. This information may be of the type desired by Department of Individual Training for management improvement. A similar report could have been submitted each month as information from student rosters was tabulated monthly in this office.

1 Inclosure
Students Enrolled, Dropped, and Graduated

PAUL C. WARD
Capt, Ord Corps
Chief, Corporal Branch

STUDENTS ENROLLED, DROPPED & GRADUATED
FY 60
CORPORAL BRANCH, FAM DIVISION

COURSE	1	2	3	4	5	6	7	8	9	10
9-R-241.1	0	0	0	0	14	2	0	12	0	12
9-R-242.1	12	0	0	12	34	1	2	31	0	43
9-R-243.1	12	0	0	12	5	0	0	5	0	17
9-R-244.1	42	0	0	42	101	2	2	83	14	125
9-R-432.1	48	1	2	45	102	1	3	75	23	120
9-N-4812	17	0	0	17	0	0	0	0	0	17
TOTAL	131	1	2	128	256	6	7	206	37	334

1. Student carryover from FY 59.
2. Students carried over from FY 59 dropped for academic reasons.
3. Students carried over from FY 59 dropped for non-academic reasons.
4. Students starting in FY 59 and graduating in FY 60.
5. Students enrolled FY 60.
6. Students dropped FY 60 for academic reasons.
7. Students dropped FY 60 for non-academic reasons.
8. Students starting and graduating FY 60.
9. Student carryover to FY 61.
10. Total graduated FY 59.

[redacted]

TABLE J

STUDENTS PROGRAMMED VS ACTUAL INPUTS, FY 60

ORDHB-GMS-TFC Students Programmed vs Actual Inputs - FY 60
Ch, P&S Br,
FAM Division

27 Jul 60
Mr. Gullick/jw/3-1803

Listed below is a comparison of students programmed versus actual input to courses conducted by this branch during FY 60.

COURSE	PROGRAMMED INPUT	ACTUAL INPUT
9-R-241.1	21	14
9-R-242.1	42	34
9-R-243.1	7	5
9-R-244.1	118	101
9-R-432.1	150	102
9-N-4812	8	0
TOTAL	346	256

PAUL C. WARD
Capt, Ord Corps
Chief, Corporal Branch

[redacted]

TABLE K

INPUTS SCHEDULED FOR FY 61

For FY 1961, the following inputs were scheduled for the respective officer courses:

9-G-F1	ORD GM Mgt Orien (2 wks)	287
9-A-4801	ORD GM Officer, FAM (19 wks, 4 dys)	35
9-A-4513	ORD Stf Off, GM & Nuclear Wpn (18 wks)	9
9-N-4812	CORPORAL Maintenance Supervision (43 wks)	None

Enlisted Men's Courses for FY 1961 as of 1 March 1961

NEW COURSE NUMBERS	TITLE	GRADUATED	PROGRAMMED INPUT	ACTUAL INPUT
245.1	CPL Grd Guid Repair	17	99	65
249.1	CPL Msle Repair	None	None	None
437.1	CPL Gnd Hand Equip Repair	7	16	13
	Carryovers in Old Course Numbers			
9-R-244.1	SSM Internal Guid System Repair	14		14
9-R-432.1	SSM Mechanical Systems Repair	23		23

TABLE L

CUMULATIVE GRADUATES OF OGMS TO 15 FEBRUARY 1961

CUMULATIVE GRADUATES TO 15 FEBRUARY 1961, OFFICER AND WARRANT OFFICER COURSES

Course Numbers	ORD	Other	WO	EM	CIV	Allied	Total
9-N-4812	35	0	22	89	2	12*	160
9-G-F1	451	120	25	67	699	19	1381
9-A-4801	226	12	0	0	0	3	241
9-A-4513	133	1	0	0	0	10	144

ENLISTED MEN - NEW MOS**

9-R-437.1	7
9-R-245.1	17

ENLISTED MEN - OLD COURSES - ALLIED, AS OF 28 FEBRUARY 1961

241.1	SSM Doppler Repair	1
242.1	SSM Computer Repair	1
243.1	SSM Radar System Repair	1
244.1	SSM Internal Guidance System Repair	1
432.1	SSM Mechanical Systems Repair	4

* A class of 12 British officers and warrant officers enrolled in Course Nr 9-N-4812 in 1955 and graduated in 1956. These graduates were trained on Type II CORPORAL equipment and were to serve as a cadre to initiate CORPORAL Weapon System Training in the Royal Electrical and Mechanical Engineer Corps, United Kingdom Army.

** A breakdown of old EM MOS's was not available as listed above (1 March 1961). All discontinued courses and MOS's were lumped together.

TABLE M

COURSES PROGRAMMED FOR FY 62, AS OF 6 FEBRUARY 1961

PROGRAMMED OFFICERS' COURSES FOR FY 1962, AS OF 6 FEBRUARY 1961

Course Numbers	Title	Programmed Input
9-G-F1	ORD GM Mgmt Orientation (including 20 English-speaking foreign nationals)	360
9-A-4801	ORD GM Officers, FAM	40
9-A-4513	ORD Staff Off GM & Nuclear Weapons	40
9-N-4812	Warrant Officers Course	None

PROPOSED DETAILED SCHEDULE OF EM CLASSES FY 62 CORPORAL WEAPON SYSTEM

COURSE	CLASS	STUDENTS REPORT	START	CLOSE	INPUT
9-R-245.1	1	30 Jun 61	3 Jul 61	8 Dec 61	12
CORPORAL Ground	2	11 Aug 61	14 Aug 61	2 Feb 62	12
Guidance Repair	3	22 Sep 61	25 Sep 61	16 Mar 62	12
(23 Weeks)	4	3 Nov 61	6 Nov 61	27 Apr 62	12
	5	5 Jan 62	8 Jan 62	15 Jun 62	12
	6	16 Feb 62	19 Feb 62	27 Jul 62	12
	7	30 Mar 62	2 Apr 62	7 Sep 62	12
	8	11 May 62	14 May 62	19 Oct 62	12
	9	22 Jun 62	25 Jun 62	30 Nov 62	5
TOTAL					101
9-R-249.1	1	30 Jun 61	3 Jul 61	27 Oct 61	9
CORPORAL Missile	2	4 Aug 61	7 Aug 61	1 Dec 61	9
Repair	3	6 Oct 61	9 Oct 61	16 Feb 62	9
(17 Weeks)	4	10 Nov 61	13 Nov 61	23 Mar 62	9
	5	26 Feb 62	29 Feb 62	25 May 62	9
	6	2 Mar 62	5 Mar 62	29 Jun 62	9
	7	4 May 62	7 May 62	31 Aug 62	9
	8	8 Jul 62	11 Jun 62	5 Oct 62	4
TOTAL					67

PROPOSED DETAILED SCHEDULE OF EM CLASSES (Cont)
FY 62
CORPORAL WEAPON SYSTEM

COURSE	CLASS	STUDENTS REPORT	START	CLOSE	INPUT
9-R-437.1	1	30 Jun 61	3 Jul 61	1 Sep 61	12
CORPORAL Ground	2	1 Sep 61	4 Sep 61	3 Nov 61	12
Handling Equip-	3	3 Nov 61	6 Nov 61	19 Jan 62	12
ment Repair	4	18 Jan 62	22 Jan 62	23 Mar 62	12
(9 Weeks)	5	23 Mar 62	26 Mar 62	25 May 62	8
	6	25 May 62	28 May 62	27 Jul 62	5
TOTAL					61

TABLE II - UNIT TRAINING

UNIT TRAINING COMMAND, USA OGMS, REDSTONE ARSENAL, ALABAMA

Unit	Type	Date Activated	General Order	Date Departed	Destination	Commanding Officer
26th Ord Co	GMDS* CPL	15 Feb 55	21, Redstone Arsenal, 11 Feb 55	15 Sep 55	Fort Bliss, Texas	Capt Kenneth C. Johnson
543rd Ord Co	GMDS CPL	15 May 55	44, Redstone Arsenal, 1 Apr 55	18 Nov 55	Fort Bliss, Texas	Capt John R. Harris
515th Ord Co	GMDS CPL	15 Aug 55	139, Ord Tng Command, 12 Aug 55	27 Feb 56	Fort Sill, Oklahoma	Capt Robert Duval
7th Ord Co	GMDS CPL	14 Nov 55	56, Ord Tng Command, 8 Nov 55	15 May 56	Fort Bliss, Texas	Capt Thomas N. Gaiser
205th Ord Plat	GMDS CPL	15 Nov 57	48, Ord Tng Command, 8 Nov 57	25 Jun 58	Leghorn, Italy	Lt Stanley N. Walters
228th Ord Detachment**	GMHM*** SSM	25 Sep 58	33, USAOTC, 4 Sep 58	As of 15 Feb 61, still at OGMS, Redstone Arsenal, Ala.		Capt William H. Lentz

* GMDS = Guided Missile Direct Support.

** Organized as a platoon, the 228th Ordnance Detachment had one officer, one warrant officer, and thirty-one enlisted men as of 15 Feb 61.

*** GMHM = Guided Missile Heavy Maintenance.

Late in 1953 or early in 1954, the 96th Ordnance Direct Support Company was formed at WSPG, transferred to Fort Bliss, and deployed overseas, the first Ordnance support unit to be so deployed.

The 137th was formed at Fort Bliss but did not deploy. This company served more or less as a trouble-shooting unit and supported firings. Mr. N. S. Cropp, Publications Officer, Reports Branch, ABMA Control Office.

CORPORAL PRESENTATION

Presented by

Messrs. J. R. Hall and J. W. Tyndall

at

White Sands Proving Ground
(Renamed White Sands Missile Range)

22 March 1956

CORPORAL PROJECT

INTRODUCTION

Gentlement, the presentation to be given today is <u>SECRET</u>.

The CORPORAL was one of the first missiles to be fired on this proving ground with flight testing starting in 1947.

In retrospect, we may find that one of the real values of the CORPORAL, as an Army weapon system, was that it was our first surface-to-surface missile and much was learned, and is to be learned, from the solutions developed to the problems confronted during the conduct of the Engineer-User operation here at White Sands Proving Ground.

This afternoon we will review the history, briefly outline the system operation, describe analysis procedures, outline test results, and discuss problem areas with the hope that it will benefit the planning and conduct of other projects on the proving ground, as well as informing cognizant divisions of future CORPORAL operations.

HISTORY

In January 1944, the Ordnance Corps of the Department of the Army requested Jet Propulsion Laboratory to undertaka a research program for the development of a moderately long range surface-to-surface missile to be used as the test vehicle for propulsion and guidance components. — This program was initiated as a direct result of the introduction of the German V-2.

The first product of this program, in December 1944, was the PRIVATE A, which resembled the present CORPORAL only in ratio of caliber to length. It was eight feet long and was powered by a 1000-pound thrust, solid-type propellant motor of thirty seconds burning duration. The data gathered through these flights was mainly for aerodynamic stability studies.

The second test vehicle was the now famous WAC CORPORAL which, as you might remember, was used as the second stage of the V-2 BUMPER, two-stage rocket. The WAC CORPORAL contained a liquid-propellant motor of 1500-pound thrust and was about sixteen feet long. One of these vehicles is on display in the Rocket Garden in front of Headquarters Building.

The ORDCIT test vehicle was the culmination of the over-all project and was a scaled-up version of the WAC CORPORAL. The ORDCIT test vehicle was essentially the shape of the present CORPORAL with a motor of 20,000 pounds thrust. The first test flight was in 1947.

The first test flights were sufficiently promising to develop and enthusiastic response in Washington, and in 1949 the CORPORAL Type I program was initiated.

[redacted]

The Type I missile system utilized some HERMES components and a DOVAP-type doppler transponder, and, with the exception of the propulsion system, it left much to be desired in the way of a tactical missile system.

Besides reliability aspects, it was found that a 1000-watt transmitter, operating anywhere in Europe on the well-known DOVAP frequency, could jam the shutoff system.

The Type I CORPORAL was turned over to Field Force units in early 1953, and one Battalion was sent to Europe in late 1954.

Continued problems concerning missile reliability forced a redesign and in early 1955 the Type II CORPORAL was in production.

The Type II CORPORAL was essentially a repackaging of certain components; it also involved shifting the doppler shutoff system frequency to a UHF band and coding the frequency.

The R&D phase has been completed on Type II and Engineer-User operation has been supplanted, in part, by a product improvement program funded through the Industrial Division, Redstone Arsenal.

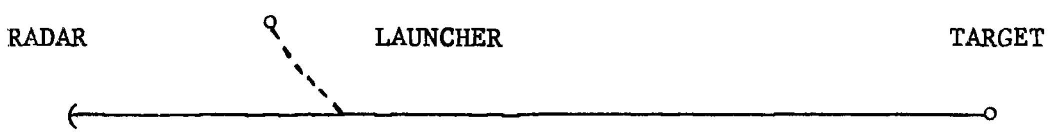
SYSTEM OPERATION

A. General

Basically, the CORPORAL Missile flies a zero-lift trajectory. It has a minimum range of 50 Km and a maximum range of 130 Km. Without external guidance, it has approximately a 10-mile CPE, and with external guidance, this is theoretically reduced to ± 300 m in range and ± 30 m in azimuth. The main control in range is by variation of the shutoff velocity. A final control in range is through a range correction system which initiates a correction just prior to impact. Azimuth guidance is in effect throughout most of the flight.

B. Trajectories

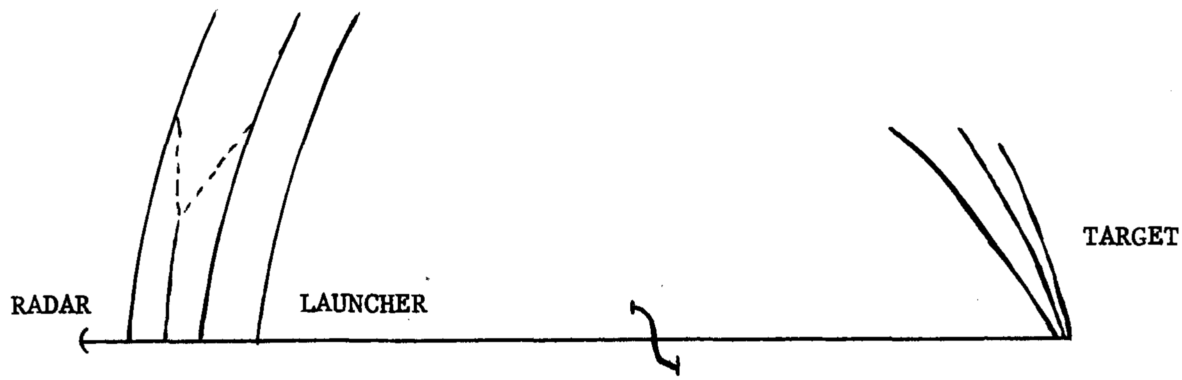
The system was designed so that with a given Radar-Target azimuth, all launchers within ± 600 m from the target line and from -200 m to + 2800 m from the radar can be brought to bear on the target. A typical plan view of an azimuth entry might be as follows:



For a given target range, there are three trajectories that can be flown, integrated respectively, from + 300 m, + 1300 m, and + 2800 m in front of the radar and on the Radar-Target line. The missile is programmed to enter the trajectory which is closest to its launcher, but

[redacted]

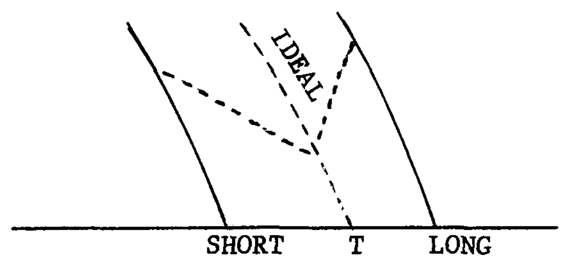
in no case can it be further than 500 m. A typical side view of range, or elevation entry, might be as follows:



For the first four (4) seconds, the missile altitude is vertical. Between four (4) and thirty (30) seconds, depending on the range and azimuth launcher offset, the missile is programmed to the target line and simulatneously starts a normal elevation program. After the ground station is turned on, the missile is guided in elevation to the desired trajectory and is established on the proper azimuth.

Shutoff generally occurs in the 50 to 65 second interval, and the range correction computation and transmission in the 95 to 130 second interval, with the correction applied at Impact —20 seconds.

The range correction maneuver is executed as follows:



C. Internal Guidance

Internal aerodynamic stability is realized through an autopilot system whose sensing elements are attitude and roll gyros during the burning phase, and pitch and yaw accelerometers plus roll gyros during the coast and re-entry phase. Accelerometer control is desirable, because it tends to keep the missile headed into the apparent wind and, thus, minimize lateral and normal trajectory drift. However, because of initial trajectory entry requirements and because of the adverse effect of vibration on accelerometers during the burning phase, gyros have to be used. The missile control surfaces cannot exert aerodynamic forces in excess of that required for a one "g" maneuver, and once shutoff is attained the impact can be changed only slightly.

D. External Guidance

For measurement of position and velocity, and for generation of commands, the raw data supplied to the system are Radar slant range, elevation angle, azimuth angle, and doppler velocity.

1. Shutoff

As mentioned previously, the shutoff system has the greatest influence in range. Approximately one meter per second variation of velocity in the shutoff region will change the impact point by 200 m. In the shutoff region, the missile is accelerating at approximately 30m/sec^2, and while shutoff is not a timed event, an error of .005 second late should result in a shutoff velocity .15m/sec too large and, in turn, a range error of 30 m.

For a given flight, an ideal shutoff velocity is set into the system, and if the missile flies the ideal trajectory, it will shut off at the present velocity (as measured by doppler tons). To account for any perturbations that may occur, such as thrust or density changes, a shutoff computer predicts the range error at shutoff and varies the shutoff velocity by an amount necessary to reduce the predicted range error to zero.

2. Elevation

To allow the shutoff computer to operate properly, the missile velocity vector at shutoff has to be fairly close to standard, and to achieve this an elevation positioning system is utilized. During the burning phase the missile position is continuously compared with a standard trajectory, and correcting commands are generated by an Elevation computer.

3. Range Correction and Impact Time

To correct for perturbations between shutoff and the trajectory peak that would effect the desired impact range, the position and velocity of the missile are measured at approximately the trajectory peak and a range miss-distance is predicted by the Range Correction computer. The predicted miss-distance is calculated and sent to the missile where it is stored until 20 seconds before impact, at which time the missile executes a maneuver (as previously explained) to correct the range error. The maximum possible correction is $\pm$ 1200 m.

Closely allied with the Range Correction computer is a Time-to-Impact prediction computer. Depending on the desired range, a timer is set in the missile to allow the maneuver to start at a given time after receipt of the Range Correction command transmitted over the Radar. Ideally, this is at I − 20 seconds. To prevent the command from being executed either sooner or later than that desired, the time of transmission of the Range Correction signal is controlled by the Time-to-

[redacted]

Impact computer which predicts the approximate time of impact and, thus, allows the Range Correction maneuver to be initiated at I — 20 seconds.

The predicted range error is stored in the form of a voltage. When applied, the doubly integrated output of an accelerometer is compared with this value and the missile flies a cosine curve and intersects the earth at maximum amplitude.

4. Azimuth

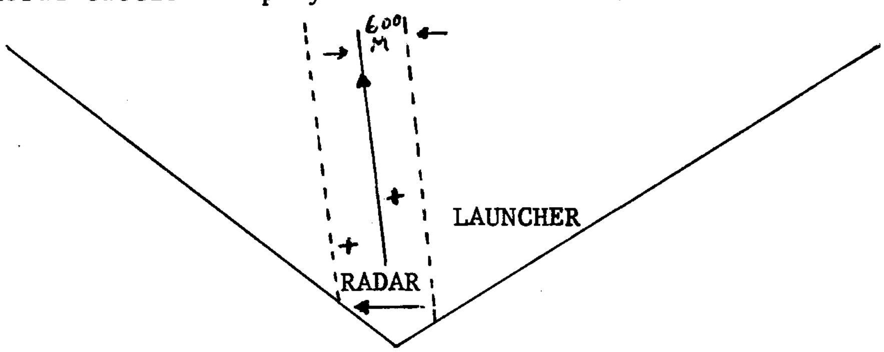
To control the flight of the missile in azimuth, an azimuth computer is utilized. Variations in lateral distance from the Radar-Target line are computed and the missile is continuously directed to the target.

5. Arming Elector

To allow or disallow warhead arming, an Arming Elector is incorporated which utilizes as input data the predicted range and azimuth error. Arm limits can be set to any reasonable value. Arming is sent to the missile via both the doppler and radar command loops and a no-arm decision prevents the transmission of the arming signal.

E. Tactical Deployment

The general tactical deployment is as follows:



A battalion is composed of one (1) firing battery; each battery has three (3) launchers. A battery is supposed to control a 120° sector, and it is seen that only a few launchers can bear on a target if the sector is to be suitably covered.

*   *   *   *   *

* Calculations omitted.

RESULTS OF TESTING

Before discussing any particular test results, it might be well to maintain that we think that the most formidable testing problem was not the testing itself, but the generation of timely test results.

[redacted]

[redacted]

CORPORAL testing has been divided into four general groups as follows:

II-A Series	-	Flight Tests
II-B Series	-	Lab Tests
II-C Series	-	Field Tests
II-D Series	-	Proof Tests

Flight Tests:

The flight testing program, to date, has included both Type I and Type II. Type I testing commenced in January 1953 and continued through September 1954. Twenty rounds were flown under various range and azimuth offsets in an attempt to find impact bias due to the various offsets. However, the reliability, which amounted to a figure round 10%, precluded attempts to find a bias of any type. Other objectives included an evaluation of firing tables, compilation of Field Service date, a compilation of reliability data, and provision for a warhead test vehicle. Technical Memorandum number 39 contains the results of the above testing.

Type II Engineering flight testing under Test Plan II-A-1, which is now being completed, commenced in March 1955 and to this date nineteen (19) missiles have been flown. The flight test objectives on Type II have, primarily, been the same as in Type I. Considerable improvement in system reliability has been evidenced with latest figures indicating that about 50% of all Type II rounds fired by White Sands Proving Ground landed within three CPE of the desired impact point. The present plans call for the completion of round analysis in June 1956. A Tech Memo, indicating the methods of analysis and various definitions to be used in subsequent reports, will be published and Tech Memos for each round fired will be added when completed.

Lab Testing

Laboratory testing on the Type I CORPORAL was relatively limited in its scope, and results to date have shown that modified objectives in future laboratory tests would be desirable. Components have been tested and re-tested and, circuit-wise, much has been investigated. But we believe that the real objective should be to find the effect of component operation or malfunction on system performance or impact accuracy. Further laboratory tests will be directed to this end.

A rather comprehensive Laboratory Testing program for Type II was planned with the above in mind, but insufficient funds precluded the tests. At the present time, however, we are using the computer facilities here to aid in flight analysis and to determine trajectory perturbation effects. Also, Test Plan II-B-3, an investigation of the environmental effects on the ground guidance equipment, has been partially completed. About 15 to 20 Tech Memos in all have been published on Type I and Type II Lab Tests.

[redacted]

Field Testing

Field testing concerns, mainly, the heavy equipment used for launching and handling. All testing under this phase has been completed except for special investigations of malfunctions.

Proof Testing

Approximately four sets of Type I and three sets of Type II ground equipment have been tested; however, no missiles have been flight-tested specifically for proof purposes. All major proof testing has been completed.

PROBLEM AREAS

A. Specifications

The CORPORAL system was contracted for without any detailed specifications being supplied by the Ordnance Corps other than the broad military characteristics, and sometimes these were modified to fit the manufactured component specification. This led to much confusion and delay in the testing operation here at WSPG because laboratory and flight-test personnel did not know precisely what an assembly was supposed to do. Even at the present time, many procedures and tolerances have yet to be firmed-up regarding the ability of field-type testing to minimize the rejection of satisfactory components and to maximize the rejection of unsatisfactory components. Gilfillan Brothers, Inc., and Firestone Tire and Rubber Company have been given contracts to determine and publish a complete set of tolerances and procedures.

B. Data

In conducting our flight analysis, we constantly were faced with the problem of data reliability, and it was only during the testing of Type II that we acquired data approaching the accuracy of the system. The accuracy of DOVAP and camera theodolite data, which we use as the reference trajectory, was not known. Our ground guidance instrumentation put more error into the recordings than we were trying to find in the system. In fact, some of our flight analysis was a matter of conjecture, as far as quantitative results were concerned. For Type II, data probable errors were determined on all raw data, and in some cases equipment was improved so that accuracy was increased by a factor of ten.

At the present time, data accuracy is such that we can determine system performance to above $\pm$ 200 m in range.

C. Timeliness of Data

One of the problems, political in nature but important in the stature of the proving ground, was the usurping by the contractor of WSPG test

[redacted]

data (usually through verbal channels) concerning important design limitations.

In three cases, we have had the contractor perform modifications to our equipment correcting just those design limitations which were subsequently published (reported) in a White Sands Proving Ground document. This, in itself, is not bad, but for the proving ground to receive its proper recognition, it does show that there is an urgent requirement to produce more timely data.

FUNDING

Up to the beginning of Fiscal Year 1946, all of the CORPORAL operations at WSPG, with the exception of Proof Test, were funded from R&D. However, Industrial Division has taken over the majority of funding for their product improvement program. At the present time, a series of test plans to be outlined later are in the process of review at Redstone Arsenal to determine if a need exists for the objectives stated in each. A decision is expected shortly.

THE FUTURE

A. Type IIa

The component reliability problem still exists on Type II and to increase missile reliability, the five major missile electronic components are being ruggedized; missiles using these components will be classified Type IIa.

B. Product Improvement Tests

Flight objectives have been shifted to evaluation of product improvements. Contracts have been let to Firestone Tire and Rubber Company and Gilfillan Brothers to improve certain assemblies; it is the mission of White Sands Proving Ground to flight-test these and provide the raw data directly to the contractor. WSPG is also required to provide an independent evaluation of these assemblies to Redstone Arsenal.

WSPG telemetering channel assignments for the product improvement tests have presented a problem. The original telemetering equipment was designed for a specific set of measurements, and modifications for each flight are now required. We have acquainted the contractors with our equipment, and if end gages, other than those supplied, are required, the contractor has agreed to supply them. We hope that this procedure will work out.

Both laboratory and flight testing will continue for about another two and one-half years.

[redacted]

[redacted]

The Industrial Division of Redstone Arsenal is in the process of preparing a WSPG Industrial Test Program which should clarify our responsibility concerning the tests that they desire.

It has been pointed out to the various contractors that WSPG will not just supply a manpower pool for contractor use. WSPG will perform the tests and act in an engineering capacity in the conduct of all tests.

Recently, contractors have been made aware of the environmental and computer facilities available at this proving ground, and it is expected that these facilities will be utilized from time to time by contractor personnel. In most cases the contractor was aware only of the flight test facility, and was very gratified to see our laboratories.

C. Type III

Still another redesign of rather major proportion is in process; it is designated Type III. It is not planned to produce this system at the present time, and it is intended that this be a shelf-item if an emergency arises.

This system will incorporate "X" band radar with a single trailer for all ground guidance equipment, with the exception of the radar antenna. This will be separately mounted along with its RF equipment on a 40 mm gun carriage.

Full use of printed circuit cards will be made to ease testing and replacement of parts.

The missile will remain essentially as is, with the exception of the Radar Transponder and Autopilot Controller and further reggedization of components.

Personnel requirements in the ground guidance station are reduced to about one-fourth (¼).

The R&D testing and development will begin in October 1956. One missile per month will be fired through December 1956. Thereafter, two per month will be fired until twenty are expended. The expected completion date of this contractor program is October 1957.

WSPG laboratory support will be required for the contractor's program. It is expected that environmental facilities will be of major importance to the contractors. Ground guidance instrumentation will be handled by the contractor.

It is planned that Engineer-User tests will commence in January 1958. Approximately forty (40) rounds will be fired at WSPG under the E-U Program.

[redacted]

D. Special Tests

Many times, a series of flight malfunctions may occur, any of which may necessitate a special component test to be performed. Usually these tests are of the "do-it'yesterday" variety and are initiated by a DF from OM to the cognizant agency. These test requirements may occur three of four times a year, and it is expected that the operating divisions should be geared to handle them.

STATISTICAL INFORMATION CONCERNING CORPORAL DEVELOPMENT

tabulated from

Report No. 20-100
THE CORPORAL,
A SURFACE-TO-SURFACE GUIDED BALLISTIC MISSILE

published by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
March 17, 1958

and

VOLUME III, CORPORAL
of "Ordnance Guided Missile & Rocket Programs"
dated from inception through 30 June 1955
(on file in the Technical Library,
ABMA, Redstone Arsenal, Alabama)

HISTORY OF CORPORAL

PART I.

1. System: WAC CORPORAL.

2. Dated from November 1944 through September 1946.

3. Type: Unguided, high-altitude sounding rocket.

4. Description:

   a. Length: 16 feet.

   b. Diameter: 12 inches.

   c. Weight: 700 lbs gross weight, 300 lbs empty. (Weights varied somewhat from round to round.)

   d. Thrust: 1500 lbs.

   e. Burning Time: 45 seconds.

   f. Maximum Design Altitude: 100,000 feet.

   g. Payload: 25 lbs of instruments.

5. Purpose: Meteorological Studies and Rocket Design Research.

6. Fuel: Oxidizer: Nitric Acid

   Fuel: Aniline

7. Firing Data: (Ref firing tests above, Doc 10.) WAC CORPORAL proved to be a very successful research vehicle. Its success influenced initiating a further development such as the CORPORAL E development.

8. Difficulties and Failures as well as Progressions: Data not available.

9. Problems: Data not available.

10. What is being done - or was done - how and why: Reference firing tests above, Doc 10.

11. Discontinued in June 1947 when purpose was fulfilled.

12. Contractors: Jet Propulsion Laboratory.

PART II.

1. (U) System: CORPORAL E.

2. (U) Dated: From January 1945 to December 1951.

3. (U) Type: Surface to surface research missile using autopilot guidance.

4. (C) Description:

a. Length: 45 feet.

b. Diameter: 30 inches.

c. Weight: 10,000 plus lbs.

d. Thrust: 20,000 lbs.

e. Burning Time: 60 seconds.

f. Maximum Range: 75 statute miles.

g. Payload: 500 lbs.

5. (U) Purpose: Experimental rocket to facilitate design of a tactical missile.

6. (U) Fuel: Oxidizer: Nitric Acid.

Fuel: Aniline.

7. (C) Firing Data:

Round	Date	Result
1	22 May 47	Impacted two miles from target.
2	17 Jul 47	Motor developed insufficient thrust and missile impacted close to the launcher.
3	4 Nov 47	Motor burned out at 43 seconds and reduced range from 60 miles to 14 miles.
4	7 Jun 49	Missile cut down by range safety.
5	11 Jul 50	Impacted 3.4 miles short of target at 51.2 mile range.
6	2 Nov 50	Impacted 34 miles short of target which was at 70 mile range.

Round	Date	Result
7	Jan 51	Impacted 5 miles short of target which was at a range of 63.85 miles.
8	22 Mar 51	Impacted 4 miles short.
9	12 Jul 51	Impacted 20 miles long. No shutoff occurred.
10		No round 10 was flown.
11	10 Oct 51	Cut down by range safety.

8. (C) Difficulties and Failures:

a. Failure of Main Air Regulator.

b. Failure of engine and propulsion system.

c. Air coupling failure.

d. Dome air regulator failure.

e. Electronic failures.

Progressions: The above components were redesigned to gain improved reliability in violent environments.

9. (C) Problems: The structural and electronic difficulties listed in paragraph 8 - eliminated by redesign of components.

10. (U) What is being done - or was done - how and why: See paragraph 9.

11. (C) Firings under the provisions of the CORPORAL E Program were discontinued near the end of 1951. Missiles with the basic configurations of the CORPORAL E were fired under the Type I CORPORAL Program. The CORPORAL E was basically a research vehicle used for the development of guidance and control mechanisms and a reliable propulsion system. As such, by the end of 1951, the vehicle had fulfilled its purpose.

12. (U) Contractor and Sub-Contractors:

a. Design: Jet Propulsion Laboratory
b. Propulsion System Fabrication: Jet Propulsion Laboratory
c. Airframe Fabrication: Douglas Aircraft Corporation
d. Guidance: Sperry Gyroscope Company

PART III.

1. (U) System: CORPORAL Type I, XSSM-G-17.

2. (U) Dated: From January 1951 to December 1954.

3. (C) Type: Surface to surface missile using variable in-flight shutoff, range correction and over-riding command guidance in azimuth.

4. (C) Description:

a. Length: 45 feet.

b. Diameter: 30 inches.

c. Weight: 11,400 lbs.

d. Thrust: 20,000 lbs.

e. Burning Time: 63 seconds.

f. Range: 25-75 nautical miles.

g. Payload: 1,500 lbs.

5. (U) Purpose: Tactical support artillery - large area surface destruction.

6. (U) Fuel: Oxidizer: IRFNA (Inhibited Red Fuming Nitric Acid).

Fuel: Aniline.

7. (C) Firing Data: A total of 64 Type I rounds were fired (20 were fired in the Engineer-User operation and 44 were fired by Jet Propulsion Laboratory) in the years 1951 through 1954. A breakdown of firings by month is not available.

8. (C) Difficulties and Failures as well as Progressions:

a. Propellant shutoff malfunctions.

b. Right azimuth bias observed in impacts.

c. A reliable propulsion system was developed.

9. (C) Problems: The problems listed in paragraph 8a were solved by redesign of components. The right azimuth bias in paragraph 8b was effectively removed by incorporating accelerometer control in azimuth.

10. (U) What is being done - or was done - how and why: See paragraph 9.

11. (U) Type I firings for flight evaluation ceased approximately December 1954.

12. (U) Contractors and Sub-Contractors:

a. Airframe and Propulsion: Firestone Tire and Rubber Company.

b. Guidance and Control: Gilfillan Bros., Incorporated.

PART IV.

1. (U) System: CORPORAL Type II, Guided Missile, Artillery M-2 (SM2E-1).

2. (U) Dated: From January 1953 through December 1955.

3. (C) Type: Surface to surface missile using variable in-flight shutoff, range correction, and over-riding command guidance in azimuth.

4. (C) Description:

a. Length: 45 feet.

b. Diameter: 30 inches.

c. Weight: 11,400 lbs.

d. Thrust: 20,000 lbs.

e. Burning Time (Max): 63 seconds.

f. Range: 25-75 nautical miles.

g. Payload: 1,500 lbs.

5. (U) Purpose: Tactical Support artillery - large area surface destruction.

6. (U) Fuel Type:

a. Oxidizer: Inhibited Red Fuming Nitric Acid (IRFNA).

b. Fuel: Aniline.

7. (C) Firing Data:

a. Jet Propulsion Laboratory fired 61 Type II rounds between the first firing on 28 October 1953 and the final JPL R&D firing in July 1956. No "firings-per-month" breakdown is available on JPL rounds.

b. Engineer-User flights have been accomplished under the following time schedule. The tests are presently scheduled to continue through the present date (January 22, 1959).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1955	0	0	1	2	0	0	3	3	3	0	2	0

8. (C) Difficulties and Failures as well as Progressions: Type I CORPORAL performance indicated that improvement of components was necessary to provide greater reliability. Thus, the Type II CORPORAL missile evolved. As more was learned about flight environments, through actual flight tests and environmental testing on the ground, components became more reliable. Most improvements were made in the electronic components of the missile.

9. (C) Problems: The biggest problem in the development of the CORPORAL missile has been component reliability. The improvement of component reliability has thus become the major objective of the flight test program. The program has been successful as is shown by the increasing overall missile reliability.

10. (U) What is being done - or was done - how and why: See paragraph 9.

11. (U) The project is still current.

12. (U) Contractors and Sub-Contractors:

a. Airframe and propulsion system: Firestone Tire and Rubber Company.

b. Guidance and Control: Gilfillan Bros., Incorporated.

CORPORAL CONTRACTS, INCEPTION THROUGH 30 JUNE 1955

I. RESEARCH AND DEVELOPMENT:

A. The principal CORPORAL research and development contractors were the Jet Propulsion Laboratory of the California Institute of Technology, Pasadena, California; the Douglas Aircraft Company, Santa Monica, California; and Gilfillan Brothers, Los Angeles, California.

1. The Jet Propulsion Laboratory contract, ORD-18, totaled $28,296,868 by 30 June 1955.

2. The Douglas Aircraft Company contract, ORD-21, totaled $1,414,645 by 30 June 1955.

3. The Gilfillan Brothers contract, ORD-468, totaled $6,063,618 by 30 June 1955.

B. An additional $3,695,257 had been obligated for CORPORAL research and development by 30 June 1955. Scores of contractors and/or sub-contractors were carrying out various phases of this additional program. A representative list included:

Rheem Manufacturing Company, Catalyst Research Corporation, Emerson Electric Company, General Electric Company, Engineering Research Corporation, Hazeltine Electronics Corporation, Bendix Aviation Corporation, American Machine and Foundry Company, the Physical Science Laboratory of New Mexico College of Agriculture and Mechanic Arts.

C. Grand total for CORPORAL research and development, inception through 30 June 1955: $39,470,388.

II. INDUSTRIAL PROGRAM:

A. The principal CORPORAL industrial contractors were the Firestone Tire and Rubber Company, Los Angeles, California, for the Type I and Type II missiles; and Gilfillan Brothers, Los Angeles, California, for the ground guidance and control systems.

1. The major Firestone contracts, with supplemental agreements, totaled $85,375,266 by 30 June 1955. These contracts were:

a. ORD-159, totaling $26,348,037 with supplements.

b. ORD-355, totaling $19,402,128 with supplements.

c. ORD-437, totaling $39,625,101 with supplements.

2. The major Gilfillan Brothers (Industrial Program) contract, ORD-350, totaled $30,154,987 with supplements and modifications as of 30 June 1955.

B. An additional $43,718,466 had been obligated for CORPORAL production by 30 June 1955. Scores of contractors and sub-contractors were participating in this Industrial Program. A representative list included:

American Pipe and Steel Company, Clary Corporation, Texas Metal and Manufacturing Company, Dow Chemical Company, Toledo Scale Company.

C. Grand total for CORPORAL production, inception through 30 June 1955: $159,248,719.

III. <u>FIELD SERVICE PROGRAM</u>:

A. The CORPORAL field service contractors were the Firestone Tire and Rubber Company, Gilfillan Brothers and Hewlett Packard Company.

1. The Firestone field service contracts, ORD-531 and ORD-607, totaled $356,935 as of 30 June 1955.

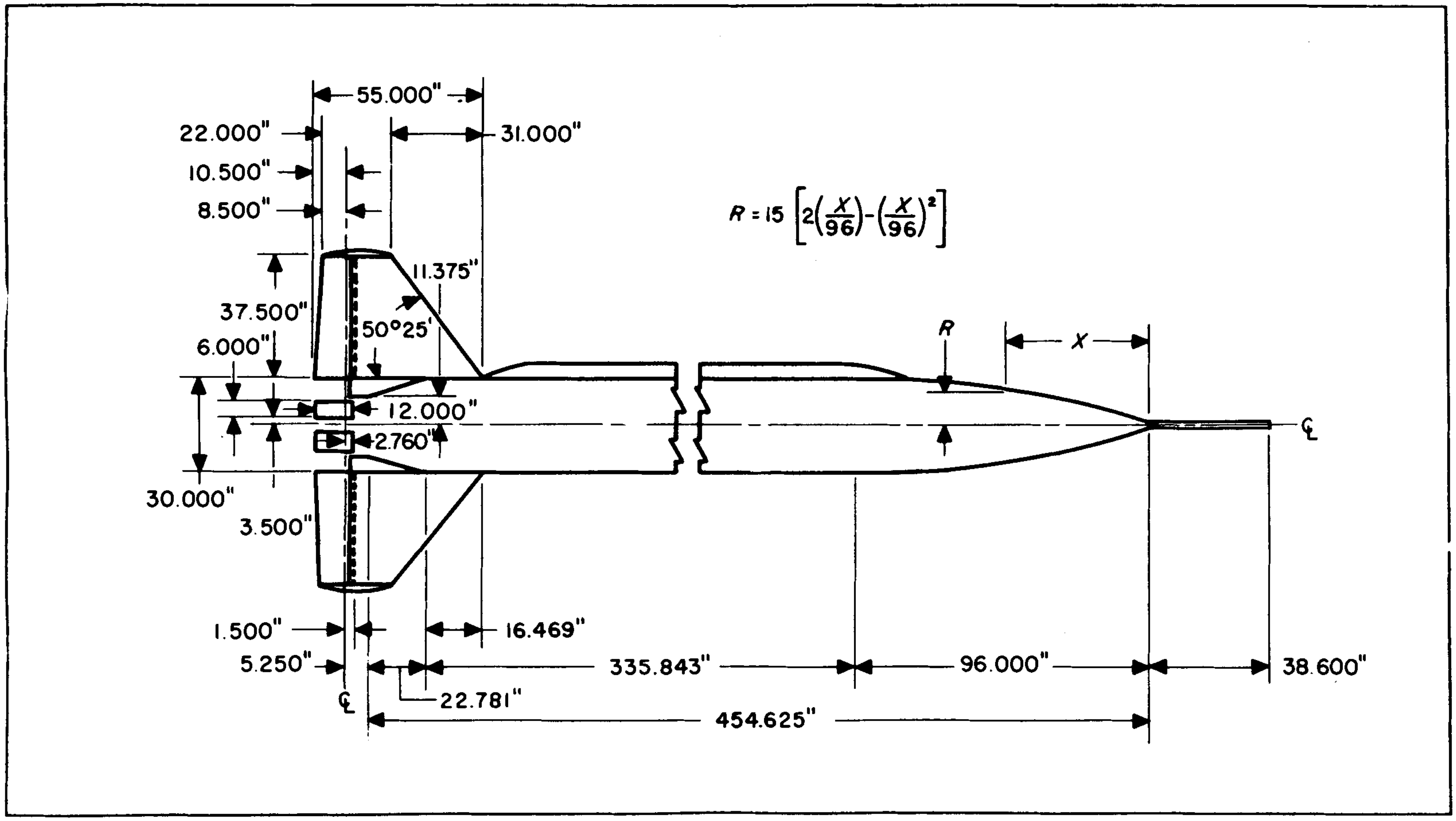
2. The Gilfillan field service contracts, ORD-530 and ORD-608, totaled $34,572 as of 30 June 1955.

3. The Hewlett Packard Company field service contract, ORD-4843, totaled $7,080 as of 30 June 1955.

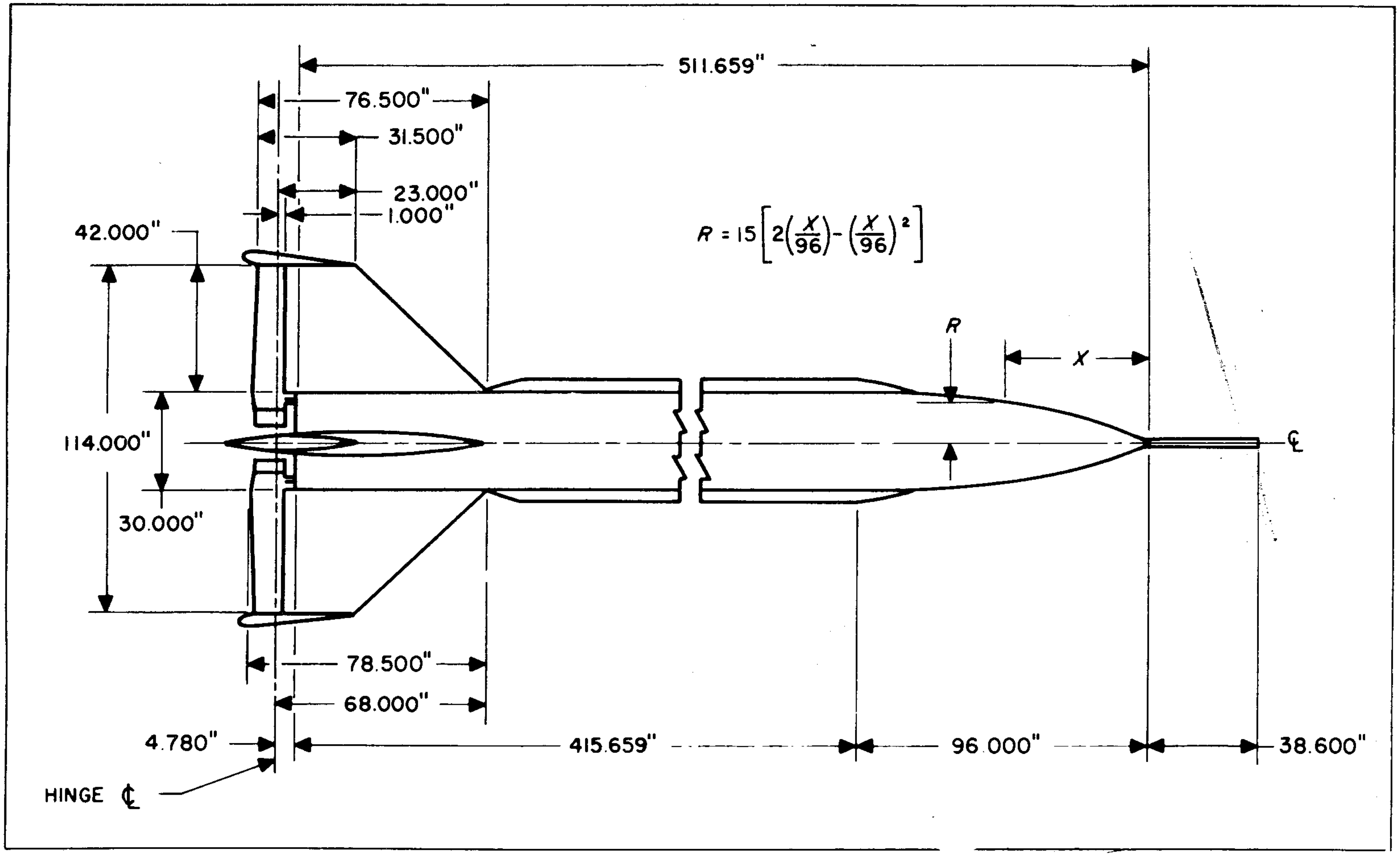
B. Grand total for CORPORAL field service, inception through 30 June 1955: $704,587.

IV. <u>SUMMARY OF PROGRAM AS OF 30 JUNE 1955</u>:

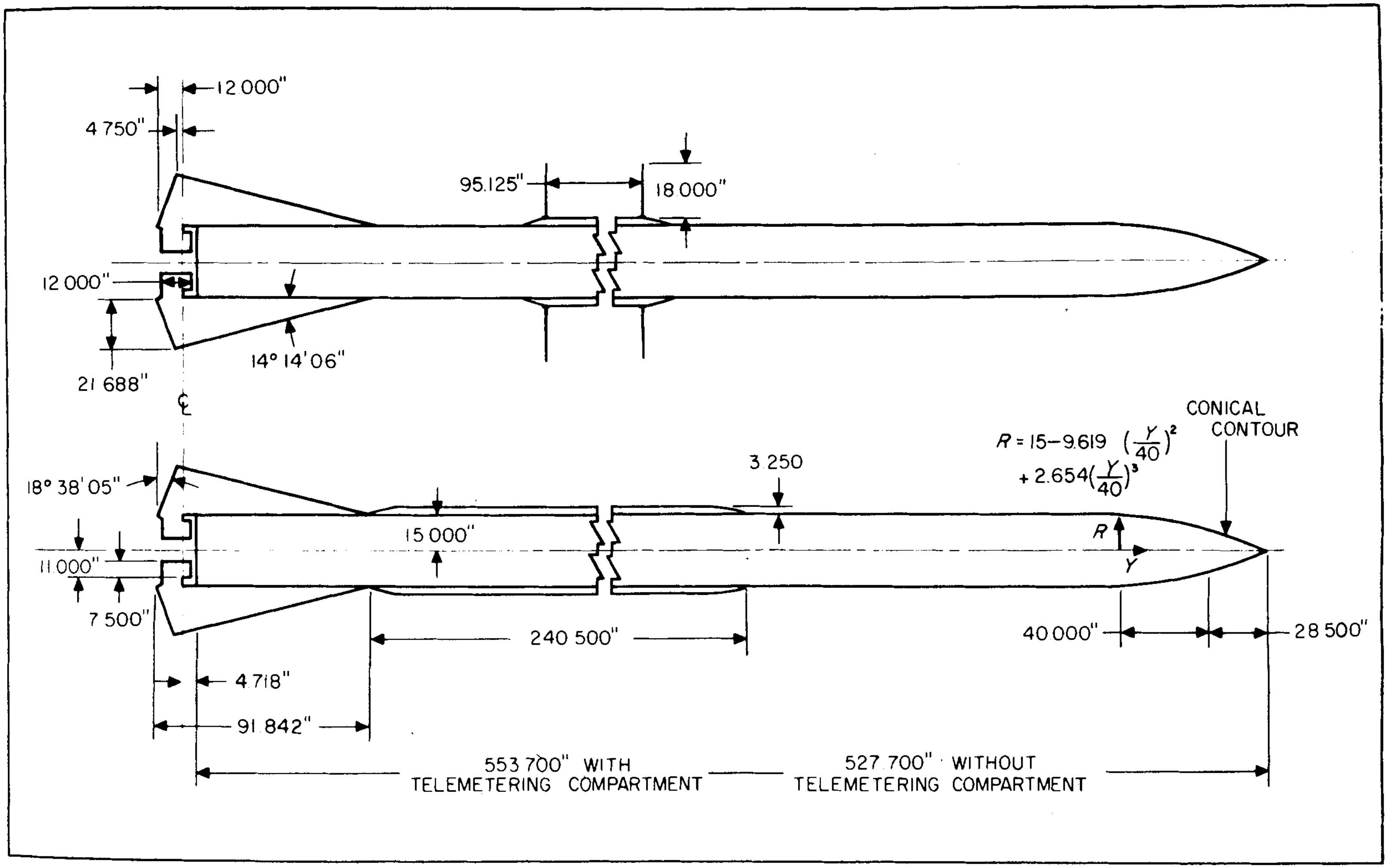
Research and Development	$ 39,470,388
Industrial	159,248,719
Field Service	704,587
TOTAL	$199,423,694



Configuration of *Corporal* Round 1



Configuration of Corporal Round 4



Configurations of Type-I (Rd 11) and Type-II *Corporal* Missiles