Techno Economic Analysis Of Remanufacturing For Low Ceiling Cabin Fan

Tanay Parekh, Divyam Joshi, Niket Vasavada, Vishal Fegade

Abstract: Product design for remanufacturing is a combination of designing processes whereby an item is designed to facilitate remanufacture. Design for remanufacturing is guided by an assessment of product or component value over time. This value may vary depending on the market and market demand and supply, legislation and technological improvements. Obviously the goal of design for remanufacturing is to improve manufacturability. Through this paper we aim to study the various key parameters which need to be considered for optimum designing of a new product or an existing product from the view of remanufacturing. Technology and Economic model will are developed using these key parameters for the selective components and they are employed for coordination and testing via simulation, finally with the solution of the updated parameters design of upadation can be accomplished.

Index Terms: Analysis, Case Study, Economic, Index Calculation, Product, Remanufacturing, Technical.

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1 INTRODUCTION

This paper is in continuation of a Review Paper titled “Techno Economic Analysis of Product Design and Development”. Product design can be defined as the idea generation, concept development, testing and manufacturing or implementation of a physical object or service [1]. Product designer encompasses many characteristics of marketing manager, product management, industrial designer and design Engineer [2]. While designing and developing the new product designer should keep in mind not only the objectives related to the product functionality but the environmental legislation. At present all world is facing the serious threat of the shortage of resources and environmental pollution. Now a day industry is looking for the product recovery including recycling, reconditioning and remanufacturing. Material recycling is one of the most popular traditional ways to deal with the used products, which means to return the used products into new raw materials again by smashing or melting them. Comparing with material recycling, product remanufacturing is a more profitable product disposition means ecologically and economically, as the reprocessing and manufacturing expenditure (Time, energy and cost etc.) are avoided.

Remanufacturing is defined as the practice of disassembling, cleaning, refurbishing, replacing parts (as necessary) & reassembling a product, the product may be returned to service with reasonably high degree of confidence that will endure (at least) another full life cycle (Bras, B. and Hammond R., 1996). Beside the reduction of cost in remanufacturing, knowledge of part failure gained through the remanufacturing process can result less expensive part design, fewer failure modes can be analyzed in early new product design phase. Improved quality product can be designed with decreased repair cost. Remanufacturing is a profitable business venture as material & energy saving is directly translated into cost when compared to newly manufactured equivalents. Furthermore, extending the life cycle of a product through remanufacturing will create additional profit when that remanufactured product is subsequently sold. To access full benefits of the remanufacturing in terms of reduced energy, material consumption and reduced waste design for remanufacture must be the integral part of the product design and development process. Product design for remanufacturing is a combination of designing processes whereby an item is designed to facilitate remanufacture. Design for remanufacturing is guided by an assessment of product or component value over time. This value may vary depending on the market and market demand and supply, legislation and technological improvements. Obviously the goal of design for remanufacturing is to improve manufacturability. This is totally distinct design task but it is often viewed as a part of concurrent engineering concept of Design of X, in this case X appears as remanufacture. But looking deeper Design for remanufacture is not simply design for X but in fact number of different factors to be considered simultaneously.

Design Strategies of Design for remanufacture:-

(1) Design for core collection
(2) Eco-design
(3) Design for disassembly
(4) Design for multiple life cycle
(5) Design for upgrade
(6) Design for evaluation.

The research work consist of industry suitable product design and development with focus on life cycle

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enhancement, remanufacturing consideration and environment sustainability Life cycle thinking: - The traditional paradigm focuses on obtaining profit by selling as many products to customer. The current paradigm change implies in considering lifecycle aspects of products and optimizing their value and benefits through engineering, assembly, service, maintenance and disassembly. Enhancement of the product life cycle can be done by redesigning product with Rationality of material and alternative manufacturing process. Component redesign may enhance a life of some component's life cycle which we can directly use in remanufactured product by reprocessing over it. However design for multiple lifecycle is not necessarily required for all products or components. Some components may be designated by design for single use or multiple reuses or multiple remanufacturing or for disposal. Improvement in all product life cycle phases can have positive impact upon the greening of supply chain.

2 LITERATURE REVIEW

Various authors and their papers have been appraised for the proper understanding of the copious factors and processes convoluted in the design for remanufacturing. The literature review comprehends technical, economic and other parameters desired for forming of required model. The literature survey details for this paper has already been carried out and is published in the IJSRP Volume 4, Issue 5, May 2014 Edition. This paper consists of the actual Technical and Economic Analysis of Remanufacturing using a case study.

3 METHODOLOGY

3.1 Overview

This project is founded upon the concept of remanufacturing, which is included in the 4 R technique based on the end of product life cycle. Using the techniques of Bras and Hammond [3] metric are developed for the various categories involved in the process of remanufacturing i.e. Disassembly, Cleaning, Inspection, Refurbishment, Assembly and Testing, to evaluate the remanufacturability of a product by bearing in mind its design features. A case study of a Low Ceiling Cabin Fans, designed and manufactured by Aco Fan Works, Mumbai, all the essential details required and used in this project has been provided and used by the company's consent. The Technical and Economic analysis has been performed on this case study using techniques derived from Bras and Hammond [3] and Product Development book by Anil Mital et al,.[4] As shown in Fig 3.1 a structured methodology has been followed for the development of product in this project, starting with the basic i.e. defining what is Remanufacturing, then proceeding with the major components of this study like

1) Influencing Factors,
2) Analysis of the Components,
3) Tabularization of Results,
4) Calculation of Metrics,
5) Calculating the Remanufacturing Index,
6) Calculation of percentage Recycled, Remanufactured and Reduced Components
7) Economic Analysis of Product.

The steps for remanufacturing process are varying according to the type of product being remanufactured but few steps always remain constant in all the processes like [5];

- Cleaning, Inspection and Sorting: The cores collected after their end of life are checked by first undergoing the process of cleaning, inspection and sorting. These products are the segregated into two type's i.e. Good condition and severely damaged; the good condition products are subjected to disassembly while the severely damaged products are either recycled or reduced.
- Disassembly: The good condition products procured from the above step are subjected to component decomposition. The disassembled parts and the sub assembled parts are inspected, if the part is not in a good condition then the part is subjected to recycle or is given for reducing facility else the good condition part is reconditioned with other favorable processes and are again used in reassembles.
- Reassembly: Once all the parts are segregated according to their functional roles, the parts of the assembly which are reconditioned are assembled along with the fresh parts to complete the assembly of the product and ready for market use.

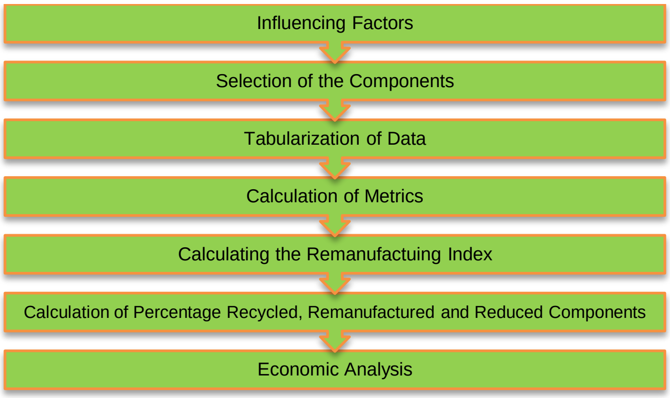


Fig. 3.1 Structure of Methodology Followed

3.2Influencing Factors

The foremost step employed for the decision making process to determine the influencing factors was to accumulate the data of the product under consideration. The details of the product have been collected by close visual inspection of the products; Manufacturing, Assembly and Disassembly processes. The product under consideration being Low Ceiling Cabin Fan the components include;

1) Front Grill
2) Front Body
3) Back Body
4) Blade
5) Mounting Plate
6) Aluminum Cover
7) Stator
8) Copper Wire
9) Sintered Bushing
10) M.S Rod
11) Hub

12) Tape
13) Screw
14) Nut
15) Motor
16) Synchronous Motor

The details of the material for each component produced have been tabularized along with their machining details and other features (refer table 4.1). To find out the influencing factors for each component, the criteria's as shows in Fig. 3.2 were considered. The figures of the components used in the product have been designed on Pro-E software using the dimensional details provided to us by Aco Fan Works, Mumbai. Various manufacturing processes used for the production of the components have been observed and their operation timings along with material required for making have the product has been noted down. The restrictions employed during the manufacturing of the components like the pitch angle for blade or the internal diameter of the front body so that it does not interfere with the span of the blade has been considered for individual component with the contemplation of all the relevant restrictions in which it has to operate. Last of all the defects or the failures which are convoluted during the operation of each component have been prudently perceived and have been listed.

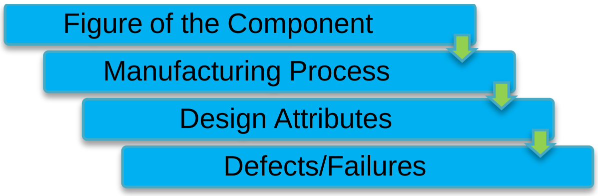


Fig. 3.2 Criteria's for considering Influencing Factors

3.3 Selection of Components

The components of the product can be divided into 3 categories once end-of-life is met with i.e. Reduce, Recycle and Remanufacture as showed in table 3.1. The components selected for these processes are put through various considerations like Material Selection, Manufacturing Processes, Design Considerations, Design of Assembly and Disassembly and Design of Maintenance. The plastic components used in the product like Front Grill, Front Body, Back Body, Blade and Mounting Plate are manufactured by Injection Molding process using plastic granules as the raw material. These components are thermosetting in nature and can be grinded into smaller granules and reused again in case of defects. The defects in these plastic components include marginal dis-colorization due to use over the period of time, no other defects of any sort are observed in them, hence these components become the most favored constituents which can be subjected to Recycling process. The smaller components like screw, nut, tap and sintered bushing are the modules which are subjected to severe wear and tear during the period of operation. Hence at the end-of-life these components have succumbed till their end and they need to be replaced there by becoming components which needs to be completely reduced or disposed of. Finally the components like Aluminum Cover, Stator, Copper Wire, Hub and M.S. Rod have a life cycle of more than 15 years, so these products can be reused in the process of remanufacturing as the life cycle of the product as a whole is just 5 years. These components are the key components in our project which is subjected and are considered for the analysis and calculation of remanufacturing index. If these components are found to be damaged during the inspection process then reconditioning processes applied on them accordingly. The finished good condition products are then assembled and used again in the production of the remanufactured product having a life span of 7 years.

Table 3.1 Selection of Components

Recycle	Reduce	Remanufacture
Front Grill	Sintered Bushing	Aluminum Cover
Front Body	Screw	Stator
Back Body	Nut	Copper Wire
Blade	Tape	M.S. Rod
Mounting Plate	Synchronous Motor	Hub

3.4. Tabularization of Data

For the purpose of generation of Metrics for the various categories like; Disassembly, Cleaning, Inspection, Reconditioning, Reassembly, Testing and Recycle, the data has been collected and from the various observations and calculations the data has been tabularized to be used in determining the metrics. The collection of data for these categories has been based on the various designing procedures (refer tables 4.2 to 4.5). These tables are prepared by taking reference from Ilgin, M. and Gupta, S, Remanufacturing Modeling and Analysis [5]

3.5 Calculating the Metrics

We have used the concept of Metrics developed by Bras and Hammond [3] to evaluate the remanufacturability of a product by considering its design features. A total of seven metrics have been developed under four categories which are seen in fig 3.5.

3.5.1 Cleaning Metric

Many processes can be employed for the cleaning process of a part depending upon the condition of the part (viz., loose debris, dry adhered debris, oily debris (baked) and oily debris (washed and dried). For the development of this metric the investment required in the cleaning process of each type is considered for scoring. The investment amount required in each method is compared with that of the other to generate a relative importance by developing a prioritization matrix (refer table 4.6). For giving the relative importance inside the matrix a key is generated which depicts the definitions of the value used in it. The score is calculated by the addition of all the values assigned to them. The relative important is calculated by dividing the score of one process to the total score of all the processes employed. The approximate cleaning score is calculated by dividing the lowest relative importance value with the value of the process, these values are rounded off and Usable cleaning score for each process is achieved. Using the data from the tabular format we can calculate αcleaning by the formula

$$\alpha_{cleaning} = \frac{IP.1}{CS} \qquad (1)$$

Where,

IP: Number of Ideal Parts

CS: Cleaning Score

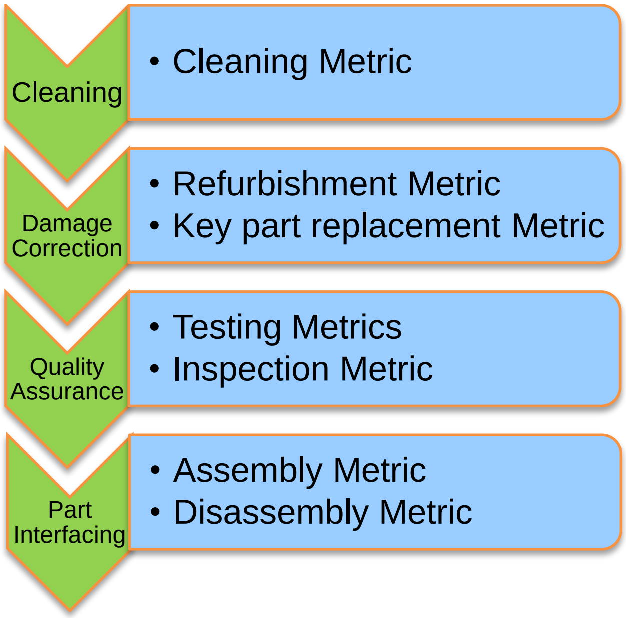


Fig. 3.5 the Four Categories of Metrics

Five types of cleaning processes are used in our product according to its need in individual products i.e. Air-Blow cleaning, Thermal Cleaning, Solvent-Based Cleaning, Biological Cleaning and Abrasive Cleaning [5]

1) Air-Blow Cleaning: This is a process which is used for the cleaning purpose of loose debris and dust accumulated on the surface of the product.
2) Thermal Cleaning: In thermal cleaning oil, grease, dirt, paint, adhesives, rust and other contaminants are cleaned from metal surfaces using heat. Blasting must be subsequently used to remove the leftover ashes and surface oxides. Thermal cleaning cannot be used for plastic components, lighter metal components, or heat-treated components.
3) Solvent-Based Cleaning: This process uses various solvents in the cleaning process. This cleaning technology can be detrimental to the environment, especially if the solvents cataloged by the Environmental Protection Agency (EPA) such as air, water, or land-hazardous contaminants are used in the process. Aqueous cleaning is an environmentally friendly process since it does not use any substance hazardous to the environment. However, more water and more energy may be required.
4) Biological Cleaning: Oils and Greases removed by the aqueous emulsions are consumed by bacteria in a bath. A sludge consisting of dead organisms is the only waste. Minimal downtime, and relatively small water, energy, and cleaning agent consumption are among the other benefits.
5) Abrasive Cleaning: Following the thermal and chemical cleaning processes abrasive cleaning is done to remove rust and scale and also to improve the surface finish and appearance of the component. Mechanical Automotive parts (viz., clutches, drive shafts, and engines) are usually cleaned using airless centrifugal steel-shot abrasion technologies. Some parts may be damaged due to the aggressive ways of cleaning and another problem is that amount investment in this process is very high.

3.5.2 Refurbishing Metric

Refurbishing refers to both the repair of damage to the part and the application of protective/aesthetic coatings. The damage maybe caused to the product itself during its life cycle or during the disassembly process, but the major concern is whether the damaged can be reconditioned or no, else the part will have to be replaced. Refurbishing process can be carried out by using various different processes, the loop hole is that different products will need different types of refurbishing processes hence generalizing them into categories like in case of cleaning is not possible. For the consideration an ideal case is a case in which no part would need any refurbishment of any sort. By using the data collected in the tabular form the metric value of refurbishing can be calculated by the following formula;

$$\alpha_{Refurbis\ h} = \left(1 - \frac{RFP}{TP}\right) \qquad (2)$$

Where,

RFP: Number of parts requiring Refurbishing

TP: Total number of parts

3.5.3 Key Part Replacement Metric

Replacing a part is the last resort for those parts which cannot be conventionally refurbished. Occasionally, several key parts in the product cannot be refurbished or reused and hence they must be replaced. If the number of replaced parts is more, then remanufacturing the product is impractical as the cost investment is too large. The ideal case in the key part replacement metric will also be when no part has to be replaced and using the data from the tabular form we can calculate the metric by using;

$$\alpha_{Key\ Replacement} = \left(1 - \frac{KPR}{KP}\right) \qquad (3)$$

Where,

KPR: Number of Key parts replaced

KP: Number of Key parts

3.5.4 Testing Metric

Testing process involved in the product is basically testing the performance of the product or the sub-assemblies against the predefined performance criteria to ensure that they function appropriately. The difference between testing and inspection is that in inspection the process is quick and is finished using the visual evaluations which is made by the inspector. Many products are subjected to different types of testing procedures. For example; Electrical Component will have to undergo a quick test to electric connection while, the mechanical component might be subjected to CFD or CFM which takes a longer time. Hence a common value has been fixed i.e. 10 seconds, for each test. This time is set as the ideal time which is required for a testing process. In-order to calculate the testing metric this ideal time is compared to the actual time by using the formula;

$$\alpha_{Testing} = \frac{NT.10s}{TT} \qquad (4)$$

Where,

NT: Total Number of Tests

TT: Total Testing Time

3.5.5Inspection Metric

Inspection is a process which is referred to as qualitatively examining the parts for damages. This inspection process is usually carried by visually checking the parts and is most often performed during disassembly or cleaning. This process is meant to look beyond the points of external wear and damage caused due to misuse by the user, abusive environments, corrosion, to focus on manufacturing defects which weren't identified by the manufacturer himself. The ideal number of inspections in this case would be represented by the theoretical minimum number of parts which do not need to be replaced during refurbishing. Therefore the inspection metric can be calculated by:

$$\alpha_{Inspection} = \frac{INS}{TP-RP} \qquad (5)$$

Where,

INS: Number of Ideal inspections

RP: Number of replaced parts

3.5.6 Assembly and Disassembly Metric

It is very evident that there are lot of similarities between the assembly and disassembly process. In manufacturing practice, the disassembly sequence is usually the opposite of its assembly or reassembly sequence. Many tools and equipment's are used in both processes but they both have different constrains, solving any constrains of Assembly or Disassembly alone won't necessarily improve the other process. Due to close relation between assembly and disassembly process their weights are calculated simultaneously. Following Boothroyd and Dewhurst, 25 seconds are allotted per ideal part for reassembly, where disassembly is often much faster than assembly, the DFA analysis can be modified to allocate only 15 Seconds per ideal part for disassembly. Using the timings calculated and tabularized the assembly and disassembly metrics can be calculated as follows;

$$\alpha_{Disassembly} = \left(\frac{(IP)(15)}{DT}\right) \qquad (6)$$

Where,

DT: Total Disassembly Time

$$\alpha_{Assembly} = \frac{IP.25}{AT} \qquad (7)$$

Where,

IP: Number of Ideal Parts

AT: Total Assembly time

3.6 Calculating Remanufacturing Index

The remanufacturing index is calculated by combining the preceding metrics into a single remanufacturability assessment index and can be accomplished in several ways [6] various criteria's as shown in fig 3.6 need to be satisfied to achieve the correct remanufacturing index. The weighted averaging is a common technique which is used as it satisfies all of these relevant criteria except for annihilation criterion. Due to the importance of the Key part replacement Metric as mentioned above, it will be considered a 'level one' metric and remaining metrics called 'level two' metrics, are combined using the weighted, inverted addition technique. And is calculated as

$$\alpha_{Remanufacturability} = \frac{\alpha_{Key\ Part}}{\sum_j^7\left(\frac{W_j}{\alpha_j}\right)} \qquad (8)$$

Where,

Wj is the weight associated with the ith 'level two' metric.

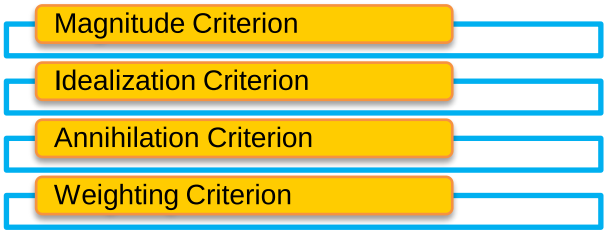


Fig. 3.6 Criterions required being satisfied

In-order to calculate the weights of the different categories in which the 'level two' metrics have been categorized (viz., Interfacing, Damage, Quality Assurance and Clean) their approximate importance is required i.e. their weights are required. These weights are obtained by comparing the investment in each category to another and scoring them (refer table 4.8). The process to be followed is as follows;

1) Acquire the standards for each of the eight metrics using equations as above.
2) Weighted Inverted Addition is used to evaluate the category indices by combining the appropriate metrics.
3) Using weighted inverted addition the category indices are combined to evaluate the second level index.
4) The first level (Key Part Replacement) and second level indices are combined by multiplying them to evaluate the Remanufacturing Index.

3.7 Calculation of Percentage of Recycled, Remanufactured and Reduced components.

A simple calculation of the percentage of recycled, remanufactured and reduced components in our product has been performed by segregating the components into their respective categories and then comparing the number of components in each category to the total number of components in the product. Table 4.9 shows the calculation of the same.

3.8 Economic Analysis

Estimating the cost of the product i.e. the profitability on which it operates, gives the company an economic advantage in the market and hence defining company's competitiveness. Cost estimating is an established fact and a routine activity. The returns pulled together after the sales of the product should not only be able to overcome the costs of production of the product but also be able to give an adequate amount of profit so as to put up with the direct costs of taxes, dividend to shareholders, interest on borrowed capital etc. The main goal in any product's development is to attain maximum design efficiency at the least cost. One of the ways to optimize the use of capital in hand is to increase the overall productivity of the product to stretch the limited resources. The Economics/Cost analysis of the product is done using various components involved in a company as showed in the fig 3.7.The basic cost analysis of the product has been done for a new product which is sold in market and then of the remanufactured product using refurbished components along with fresh components. For this rationale various costs are used for its calculation like; Direct costs, Indirect Costs, Direct Material cost. Direct labor cost is the cost which is incurred by the company for employing the workers and is determined by the time it takes to complete the task and the wage rate. All the details of wage rate and timings are provided by the company themselves. First step is determining the time required for all the processes to complete a given product, a wide range of readings are calculated and then the average of the timing is calculated.

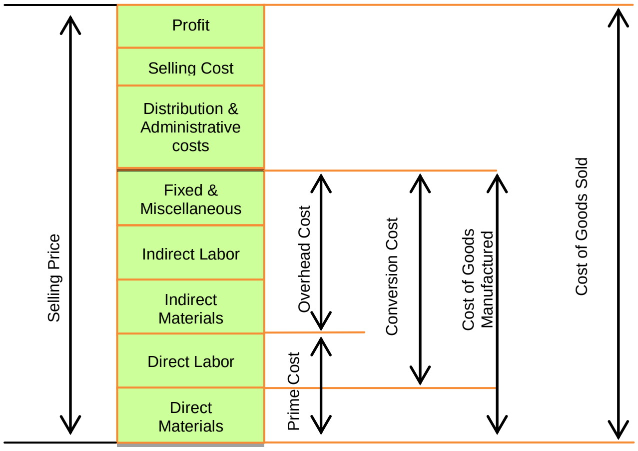


Fig 3.7 a typical cost and price structure

This timing is known as observed time. Normal time is the time which is required by a worker in reality, all workers are different and work at a different rating hence the rating determines the average rate at which the workers are going to work. An ideal case will be that workers are working at 100% rating and this time is calculated by multiplying the observed time with rating of the worker. This normal time can be modified by adding allowances for personnel time such as Lunch delays, emergency sick leaves etc. The formulae of these timings are given below;

$$Average\ Obeserved\ Time = \left(\frac{Total\ Time\ for\ X\ completed\ \ Cycles\ of\ the\ task}{X}\right) \quad (9)$$

$$Normal\ Time = Average\ Observed\ time \times Rating \quad (10)$$

$$Standard\ Time = {}^{Normal\ Time}/_{(1 - PDF\ allowance)} \quad (11)$$

This standard time achieved is then used to calculate the output per hour of each product as follows:

$$Pieces\ per\ hour = \frac{60}{Standard\ \ Time\ in\ Min} (12)$$

$$Standard\ Output/_{Day} = \left[\left({}^{Pieces}/_{Hour}\right) \times 8\ hours\right] pieces$$
$$(13)$$

The direct cost associated with the workers are calculated as

$$\frac{Direct\ Labor\ \ cost}{Piece} = Wage\ rate\ \left({}^{Rs}/_{Hr}\right) \times Standard\ Time\ \left({}^{Hr}/_{Piece}\right) \quad (14)$$

$$Direct\ Labor\ Cost/Day = (\#Pieces/Day) \times [Standard\ Time\ (Hr/Piece)] \times Wage\ Rate\ (Rs/Hr) \quad (15)$$

Direct Material Costs are the next category of costs which needs to be considered for procuring the details of the materials being used for the development of the product. This material cost is dependent upon various factors like the weight of the Kilograms for a product, the price at which the material is purchased and the cost of standard products. The following equations show how the material cost is calculated;

$$Material\ Cost\ for\ a\ Unit = (W \times P) + R \quad (16)$$

Where,

W = Weight in Kilograms of the product

P = Rate at which material is purchased

R = Cost of components which are standard parts and directly purchased

Indirect Cost or Overhead costs are the cost which cannot be clearly associated with a particular operation, product, project or system and must be prorated among all the costs units on some arbitrary basis. The Overhead cost according to the actual direct labor hours is given as follows:

$$Overhead\ Rate = (Actual\ Factory\ Overhead / Actual\ Direct\ Labor\ Cost) \times 100\% \quad (17)$$

Hence the total cost is calculated by adding all the costs above;

$$Total\ Cost = Direct\ Labor + Direct\ Material + Overhead \quad (18)$$

Using the same parameters of costs and overhead rate the cost of remanufactured product is calculated and compared with the original cost of the product and the saving in cost is highlighted. [4]

4. ANALYSIS OF PRODUCT

4.1 Technical Analysis

This section of the project consists of all the data and analysis performed on the difference components of the product. Table 4.1 shows the segregation of all the components used in the product into categories such as Material of Component, Manufacturing Process, Design Attributes and Defects/Failures. This table is used for determining the influencing factors on which the major key components are to be selected.

Table 4.1 Classification of Components for Influencing Factors

COMPONENT NAME	MOC	Manufacturing Process	Design Attributes	Defects/Failures
Front Grill	Recycled plastic	Injection molding	Angle of Grill, Distance Between Consecutive Grills	Discolourization, physical defects
Front Body	Recycled plastic	Injection molding	Internal Diameter	Discolourization, physical defects
Back Body	Recycled plastic	Injection molding		Discolourization, physical defects
Blade	Recycled plastic	Injection molding	Pitch, Weight distribution, Thickness of Blade, Internal Diameter.	Discolourization, physical defects
Mounting Plate	Recycled plastic	Injection molding		Discolourization, physical defects
Aluminum Cover	Aluminum	Shell mold Casting	avoiding contact	Gas porosity, Shrinkage
Stator	Steel	Die Casting	no loose connections, perfectly Varnishing	Unfilled Sections, Hot Tearing
Copper Wire	Copper	Drawing, Annealing	Diameter, Coating of wire	Internal cracking, Surface finishing
M.S. rod	M.S.	Cold Rolling	Diameter, Surface Finish	Flatness, Surface defects
Hub	Steel	Die Casting	Equidistance groove	Unfilled Sections, Hot Tearing
Motor			Perfectly Sealed, No Loose Connections	
Base	Recycled plastic	Injection molding	Diameter	Discolourization, physical defects
Circular Plate	Recycled plastic	Injection molding	Slot for motor	Discolourization, physical defects
Blower Shaft	M.S.	Cold Rolling	Diameter, Surface Finish	Flatness, Surface defects
Blower	Recycled plastic	Injection molding	Angle and equidistance	Discolourization, physical defects
Top cover	Recycled plastic	Injection molding		Discolourization, physical defects

The influencing factors determined after studying the various restrictions and constrains in which the components are manufactured helped us to narrow down the influencing factors. These factors are crossed referenced against the major key components which are to be remanufactured as shown in table 4.2

Table 4.2 Cross Referencing Influencing Factors to Components of Product

Component Name	Number Of Parts	Assembly Require Adjustme	Part Fatigue?	Coating be reapplied	Part is Refurbish ?	g	Electrical Insulation	
	A	B	C	D	E	F	G	H
Hub	1	N	N	N	Y	Y	N	Y
Stator	1	Y	Y	N	Y	Y	N	Y
Copper Wire	3	Y	Y	N	Y	N	N	Y
Aluminum Cover	1	Y	N	N	N	Y	Y	N
M.S. rod	1	N	N	Y	N	Y	Y	N
	Electrical Testing	Cleaning Of Varnish	Replaceable Parts?	Minimum Number Of	Number Of refurbished Parts?	Number Of replaced	Number Of key Parts	Key Parts
	I	J	K	L	M	N	O	P
Hub	N	Y	N	1	1	0	1	0
Stator	Y	Y	N	1	1	0	1	0
Copper Wire	Y	Y	Y	3	0	1	1	1
Aluminum Cover	N	N	Y	1	1	1	1	1
M.S. rod	N	N	N	1	1	0	1	0

Table 4.3 shows the timings for disassembly and assembly which were calculated by considering the actual manual removal time along with the handling time, multiplied by the number of components that need to be disassembled or assembled the addition of Removal and Handling time is multiplied, to obtain the Disassembly and Assembly time. Table 4.3 also features the time required for each component in the product to be manufactured. All the timings were observed and taken from Aco Fans Work, Mumbai, India. Table 4.4 highlights another important aspect required for the development of testing metric, it shows the number of components on which different types of tests are performed, their handling time and finally the total testing time required.

Table 4.3 Calculation of Disassembly and Assembly time

COMPONENT NAME	**Number Of Parts**	**Manual Removal Time per Part**	**Manual Handling time per part**	**Disassembly Time (sec) (A*(B+C))**	**Manual Insertion Time per Part**	**Assembly Time (sec) (A*(C+E))**	**Machining time(Sec)**
	A	**B**	**C**	**D**	**E**	**F**	**G**
Front Grill	1	5	5	10	5	10	90
Front Body	1	10	3	13	10	13	90
Back Body	1	5	3	8	5	8	90
Blade	1	5	3	8	5	8	90
Mounting Plate	1	5	3	8	5	8	90
Aluminum Cover	1	10	5	15	12	17	-
Stator	1	5	5	10	8	13	-
Copper Wire	3	25	3	84	30	99	9
M.S. rod	1	5	2	7	5	7	15
Hub	1	5	3	8	5	8	1200
Motor	1	10	5	15	10	15	-
TOTAL				**186**		**206**	**1674**

Table 4.4 Calculation of Testing Time

Tested Component	**Number Of components**	**Number of times test performed**	**Handling time required**	**Testing time required**	**Total testing time**
	A	B	C	D	E
Hub	1	1	10	30	40
Stator	1	2	25	30	110
Copper Wire	3	1	5	10	45
Aluminum Cover	1	1	10	30	40
M.S. rod	1	2	15	40	110
TOTAL					**345**

Table 4.5 Various Cleaning, Inspection, Refurbishment and Testing tests performed on Components

Component Name	**Cleaning**	**Inspection**	**Refurbishment**	**Testing**
Hub	Solvent Based Cleaning	Visual (Surface Defects)	Coating	NA
Stator	Thermal Cleaning	Visual (Burnout Check)	NA	Electric Circuit Technique
Copper Wire	Abrasive Cleaning	Visual (Conductivity Check, Breakage Check)	Coating	NA
Aluminum Cover	Aqueous Cleaning	Visual (Bending Check)	Filler paste, Coating	NA
M.S. rod	Abrasive Cleaning	Visual (Bending, Surface Damage Check)	Filler paste, Coating	NA

Table 4.6 Prioritization of Cleaning Processes

Cleaning Type	**Air Blow**	**Thermal**	**Solvent**	**Abrasive**
Air Blow	1.0	0.2	0.3	0.2
Thermal	5.0	1.0	1.7	1.0
Solvent	3.0	0.6	1.0	0.6
Abrasive	5.0	1.0	1.7	1.0
	Score	**Relative Importance**	**Approx C.S**	**Usable C.S**
Air Blow	1.70	0.07	1.00	1.00
Thermal	8.70	0.36	5.14	5.00
Solvent	5.20	0.21	3.00	3.00
Abrasive	8.70	0.36	5.14	5.00
Value		**Definition**		
5.0		(Row) Requires much more investment than (column)		
3.0		(Row) Requires little more investment than (column)		
1.7		(Row) Requires more investment than (column)		
1.0		(Row) Requires same investment than (column)		
0.6		(Row) Requires less investment than (column)		
0.3		(Row) Requires little less investment than (column)		
0.2		(Row) Requires much less investment than (column)		
C.S		Cleaning score		

As the data required for the creating of metrics is complete, the next step is the formation or creation of metrics. Table 4.5 and 4.6 shows the various cleaning processes which are used on components and the prioritization matrix is prepared by using the weighted addition method and the cleaning score is developed. The cleaning index is calculated as shown below

$$\alpha_{Cleaning} = \frac{5}{21}$$

$$\alpha_{Cleaning} = 0.238 \qquad (18)$$

Using the equations developed by Bras and Hammond [3] and the data collected from the above tables the indexes for Refurbishment, Key Part Replacement, Testing, Inspection, Assembly and Disassembly are called as follows;

$$\alpha_{Refurbis\ h} = (1 - 4/5)$$

$$\alpha_{Refurbis\ h} = 0.2 \qquad (19)$$

$$\alpha_{Key\ Replacement} = (1 - 2/5)$$

$$\alpha_{Key\ Replacement} = 0.6 \qquad (20)$$

$$\alpha_{Testing} = \frac{7.10s}{15}$$

$$\alpha_{Testing} = 0.667 \qquad (21)$$

$$\alpha_{Inspection} = \frac{1}{5-2}$$

$$\alpha_{Inspection} = 0.333 \qquad (22)$$

$$\alpha_{Disassembly} = \left(\frac{(5)(15)}{186}\right)$$

$$\alpha_{Disassembly} = 0.403 \qquad (23)$$

$$\alpha_{Assembly} = \frac{5.25}{206}$$

$$\alpha_{Assembly} = 0.606 \qquad (24)$$

Table 4.7 Values of the various metrics

Metric	**Index Value**
Key Part Replacement	1.000
Cleaning	0.238
Refurbishment	0.200
Testing	0.667
Inspection	0.333
Assembly	0.606
Disassembly	0.403

Table 4.8 Prioritization of Metric categories

	I	**D**	**Q**	**C**	**Score**	**E.I**	**A.I**
I	1	0.2	10	0.2	11.4	0.25	20%
D	5	1	0.2	5	11.2	0.25	30%
Q	0.1	5	1	0.1	6.2	0.14	20%
C	5	0.2	10	1	16.2	0.36	30%
Total					**45**		
Value				**Definition**			
10				(Row) Requires much more investment than (column)			
5				(Row) Requires more investment than (column)			
1				(Row) Requires same investment than (column)			
0.20				(Row) Requires less investment than (column)			
0.1				(Row) Requires much less investment than (column)			
E.I				Exact Importance			
A.I				Approximate Importance			
I				Interface			
D				Damage			
Q				Quality Assurance			
C				Cleaning			

According to the process described in the methodology section the Metrics of different categories are prioritized according to the weighted inverted addition. The approximate importance which is calculated from this table is used in the below formulae to calculate the Remanufacturing Index. The different formulae used are as follows;

$$I = \frac{1}{\left(\frac{45\%}{a}\right)+\left(\frac{55\%}{d}\right)} \quad (25)$$

$= 0.475$

$$Q = \frac{1}{\left(\frac{20\%}{t}\right)+\left(\frac{80\%}{i}\right)} \quad (26)$$

$= 0.370$

$$D = \frac{1}{\left(\frac{100\%}{r}\right)} \quad (27)$$

$= 0.2$

$$Remanufacturing = \frac{k}{\left(\frac{20\%}{I}\right)+\left(\frac{30\%}{D}\right)+\left(\frac{20\%}{Q}\right)+\left(\frac{30\%}{C}\right)} \quad (28)$$

$\boldsymbol{Remanufacturing\ Index = 0.357}$

By the use of these formulae the remanufacturing index of our product was calculated and was found out to be 0.357. The following table 4.9 shows the percentage of components which were recycled, reused and remanufactured in our product.

Table 4.9 Percentage of components Recycled, Reused and Remanufactured

COMPONENT NAME	Reduce	Recycle	Reuse	Remanufacturing
Front Grill	0	1	0	0
Front Body	0	1	0	0
Back Body	0	1	0	0
Blade	0	1	0	0
Mounting Plate	0	1	0	0
Aluminum Cover	0	0	0	1
Stator	0	0	0	1
Copper Wire	0	0	0	1
Sintered Bushing	1	0	0	0
M.S. rod	0	0	0	1
Hub	0	0	0	1
Tape	1	0	0	0
Screw	1	0	0	0
Nut	1	0	0	0
Syn. Motor	1	0	0	0
TOTAL	**5**	**5**	**0**	**5**
%	**0.33**	**0.33**	**0.00**	**0.33**

4.2 Economic Analysis

As mentioned in the earlier passage of Methodology, the economic analysis of the product is carried out by considering the factors like Direct Labor Cost, Indirect Cost and Direct Material Cost. All the data required for this analysis has been gathered from company resources. The following series of equations shows the methodology followed to calculate the cost of a new product and the cost of remanufactured product;

4.2.1For New Product

$$Average\ Observed\ Time = (Total\ Time\ for\ 'X'\ complete\ cycles\ of\ the\ task\ /\ 'X') = 1880\ Seconds \quad (29)$$

$$Normal\ Time = Average\ Observed\ time\ X\ rating = 1880\ X\ 0.6 = 1128\ seconds \quad (30)$$

$$Standard\ Time = (Normal\ Time)\ /\ (1 - PDF\ allowances) = 2256\ seconds \quad (31)$$

$$Pieces\ per\ hour = 60\ /\ Standard\ time\ in\ minutes = 1.6\ pieces \quad (32)$$

$$Standard\ Output/Day = [(Pieces/Hour)\ X\ 8\ hours]\ Pieces = 12.8\ pieces \quad (33)$$

$$Direct\ Labor\ Cost\ /\ Piece = Wage\ Rate\ (Rs/hr.)\ X\ Standard\ Time\ (hr.)/piece = 24.8 \quad (34)$$

$$Direct\ Labor\ Cost\ /\ Day = (\#\ Pieces\ /\ Day)\ X\ [Standard\ Time\ (Hour/Piece)]\ X\ Wage\ Rate\ (\$/Hour) = 317.44\ Rs \quad (35)$$

$$Material\ Cost = (W\ X\ P) + R = 465\ Rs \quad (36)$$

$$Overhead\ Rate = (Actual\ Factory\ Overhead\ /\ Actual\ Direct\ Labor\ Cost)\ X\ 100\% = (1280 * 100)\ /\ 317.44 = 4.03 \quad (37)$$

$$Overhead\ Cost = Direct\ Labor\ Cost\ /\ Piece\ *\ Overhead\ Rate = 24.8\ X\ 4.03 = 100\ Rs \quad (38)$$

$$Total\ Cost\ /\ Piece = Direct\ Labor + Direct\ material + Overhead = 317.44 + 465 + 100 \quad (39)$$

$$\boldsymbol{Total\ Cost\ /\ Piece = 880\ Rs} \quad (40)$$

4.2.2For Remanufactured Product

For a remanufactured product the cost of it depends upon the cost of procuring the product from the scarp dealer, cost of disassembly, cost of reassembly, cost of inspection, cost of testing, cost of reconditioning and cost of recycling. The direct labor cost remains the same in the facility as remanufacturing will also be performed in the same facility where the fresh product is produced. The overhead cost of the factory also remains constant. Table 4.10 shows the various processes performed under the categories mentioned above along with their costs for each product.

Table 4.10 Cost of processes for Remanufactured Product

Category	Process	Cost (Rs)
Disassembly		
Cleaning	Cleaning Agent	20
Inspection		
Reconditioning	Coating, Varnish	20
Reassembly	Screw Nut	20
Testing	Electric Testing, RPM	13
Recycle	Injection Molding	40
Total		113

Hence the total cost of the Remanufactured Product is calculated as follows;

$$Total\ Cost\ =\ Direct\ Labor\ Cost\ +\ Overhead\ Cost\ +\ Cost\ of\ Procuring\ +\ Cost\ of\ Processes \quad (41)$$

$$\boldsymbol{Total\ Cost\ =\ 630\ Rs} \quad (42)$$

On comparison of (40) and (42) it is clearly evident that the cost of remanufacturing product is lowered by 250 Rs and on that 20% profit can be added and the product can be sold. The life cycle of the product which originally was 5 years, is now halved and the product is sold for a life cycle of 3 years. The details of the product design has been attached in the appendix, the product was designed according to the dimensions provided by Aco Fans Work, Mumbai, India.

5. CONCLUSION

The aim and objective on which this study was based were brought to fruition and all the needed values were calculated up to the topmost paradigms. With the calculated Remanufacturing Index it is especially palpable that a minimal product like a Low Ceiling Cabin Fan could be remanufactured to its 33rd percent, using remanufacturing technique in all the equipment's used in our circadian life ranging from Refrigerators to Air Conditioners can wholly intensify the utilization of the resources to their optimal extent. Using the various analysis techniques the feasibility of components which are susceptible to remanufacturing technique can be found out and be employed to reduce the carbon foot print of each product significantly along with the reduction in the cost of the product itself. Hence to conclude, the agenda for future will be to select many such case studies for the study of remanufacturing for their positive effects in the field of resources utilization and reduction of carbon foot prints.

6. APPENDIX

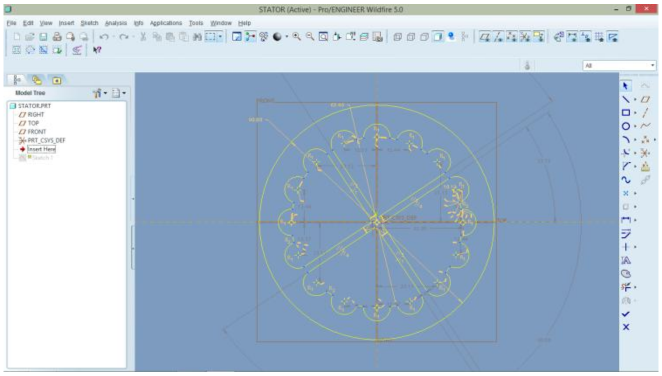


Fig. 1 2D sketch of Stator

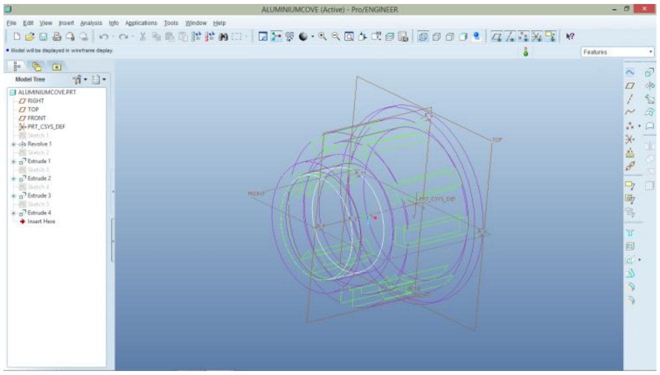


Fig. 2 2D Aluminum Cover

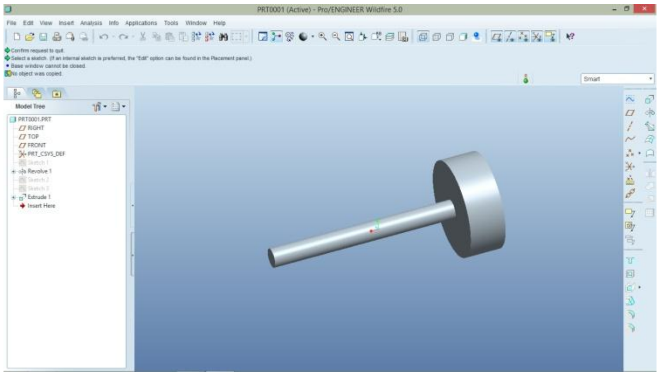


Fig. 3 3D model of Shaft and Motor

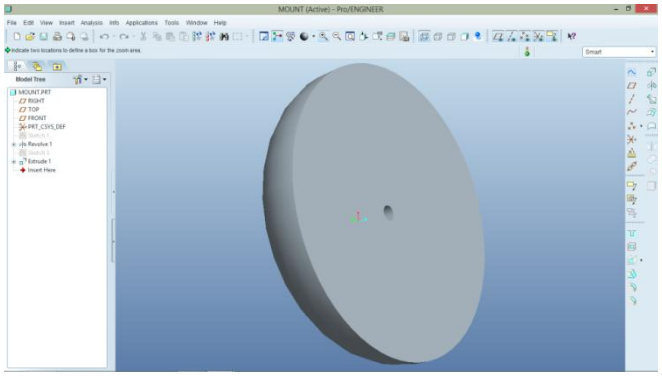


Fig. 4 3D model of Mounting Plate

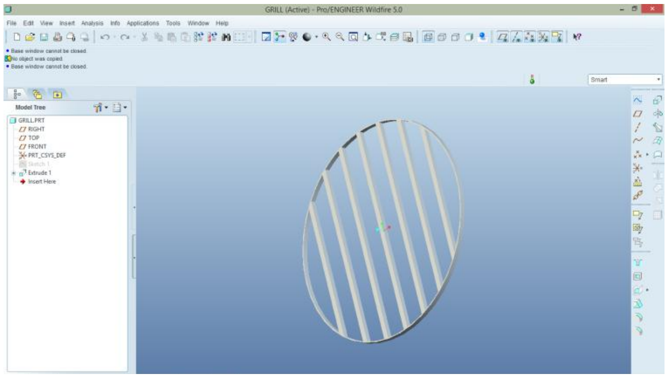


Fig. 5 3D model of Front Grill

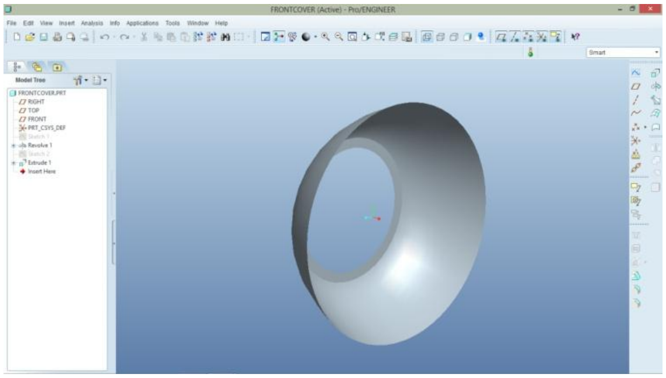


Fig. 6 3D model of Front Cover

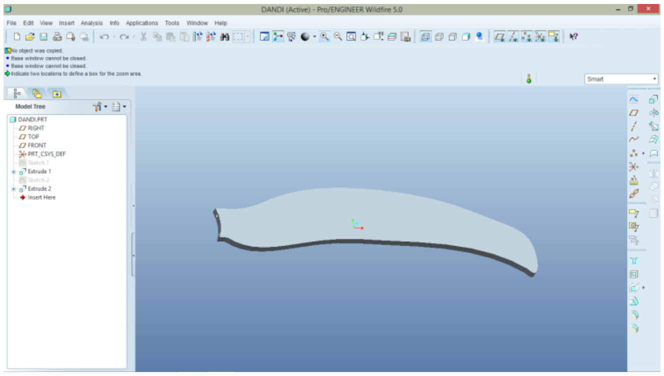


Fig. 7 3D model of Blade

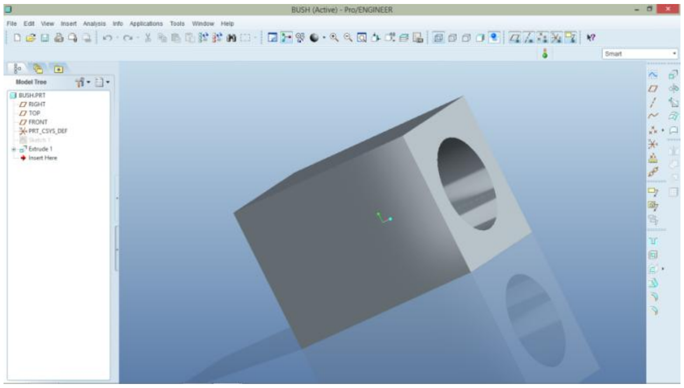


Fig. 8 3D model of Sintered Bushing

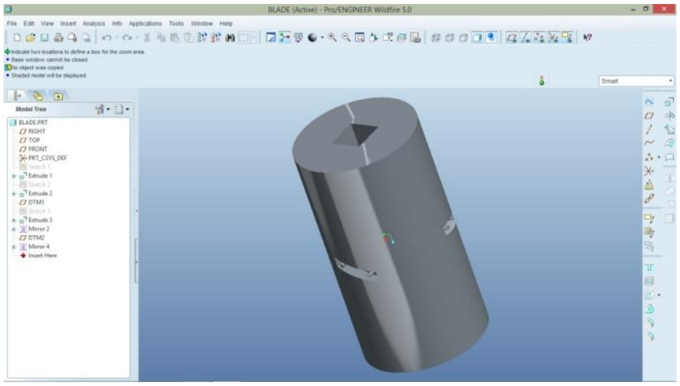


Fig. 9 3D model of Blade Bush Assembly

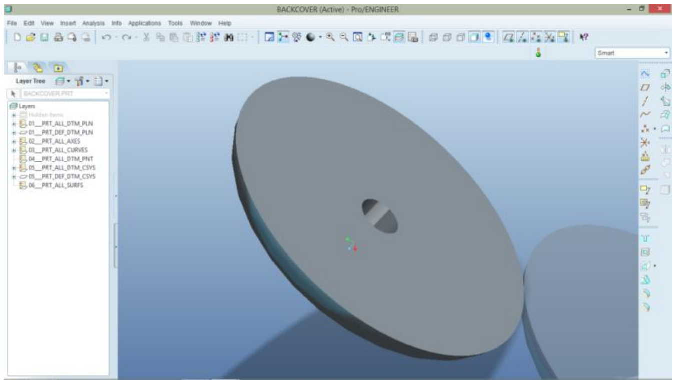


Fig. 10 3D model of Back Cover

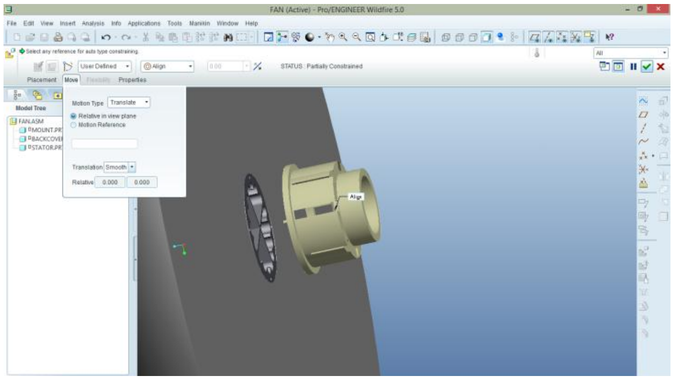


Fig. 11 Assembly of Aluminum Cover to Stator

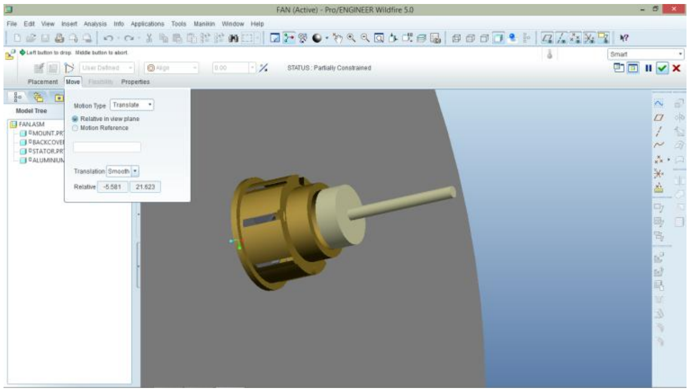
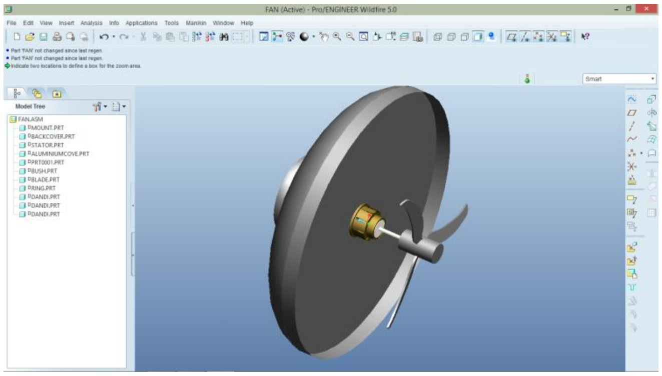
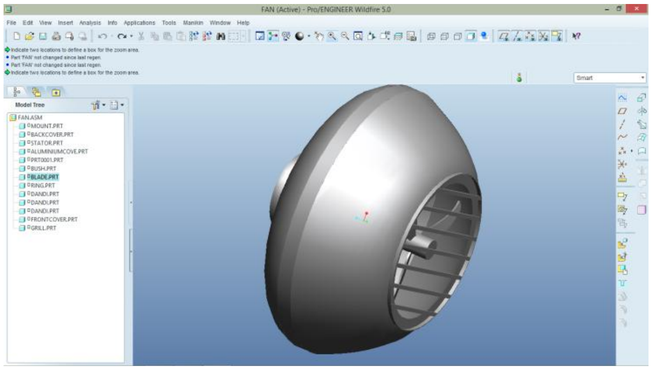


Fig. 12 Assembly of Motor to Aluminum Cover



- Part 'FAN' not changed since last regen.
- Part 'FAN' not changed since last regen.
- Indicate two locations to define a box for the zoom area.

Fig. 13 Assembly of Blades to Shaft



- Indicate two locations to define a box for the zoom area.
- Part 'FAN' not changed since last regen.
- Part 'FAN' not changed since last regen.
- Indicate two locations to define a box for the zoom area.

Fig. 14 Final Assembled Product

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