COMPARING ALTERNATIVE STRATEGIES OF AIRCRAFT MAINTENANCE

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Abstract—The global economic downturn has significantly affected many industries, and the airline industry has not been left out. This has resulted in airlines looking for ways to reduce their cost of operation in order to make profits. The industry requires significant capital investment, but the returns do not match up in most cases.

Optimization of maintenance provides an airline with a good opportunity to reduce on costs, and especially direct maintenance costs, since these normally account for 11% of the total operating cost.

Most airlines utilize the preventive maintenance strategy, with different airlines having different approaches to the same. Very few airlines venture into the condition monitoring strategy. Most research work on maintenance optimization also centers around preventive maintenance. Further, very few attempts have been made to combine multiple maintenance strategies.

This paper makes an attempt to combine two strategies, Preventive maintenance and condition monitoring. A simulation model has been developed to predict the maintenance requirement of aircraft in an airline operating under known conditions. This demand has then been subjected to both maintenance strategies, and the cost of applying each strategy has been determined.

It can be concluded that by selectively applying and optimizing a combination of maintenance strategies, significant reductions in the cost of direct maintenance can be achieved.

Keywords—Aircraft, maintenance planning, maintenance strategies

I. INTRODUCTION

AIRCRAFT operators worldwide can attest to the fact that despite the high status that comes along with operating an airline, it is a business that has a high risk, yet the returns are not as significant. For an airline to make any profit, its costs must be kept at a minimum and its output maximized. This means that the aircraft Availability must be high, and this should be accompanied by high passenger and cargo turnovers. Aircraft costs normally fall under direct and indirect cost, where direct cost relate to the actual operation, such as fuel, cockpit crew and maintenance of the aircraft, and indirect costs relate to all other costs that enable the aircraft to operated, such as landing and navigation fees. This paper focuses on maintenance cost.

Maintenance costs can also be subdivided into direct and indirect maintenance costs. Direct maintenance cost describe all costs associated with the actual maintenance work, such as man-hour costs, component costs and repair costs. Indirect maintenance costs include component storage costs, equipment costs, hangar expenses, (lost) opportunity costs amongst others. Direct maintenance costs consist of 11% of the total costs for an airline [1]. The cost of maintenance may be given per

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aircraft, aircraft flight hour, or aircraft flight cycle. Such costs are heavily dependent on the type of aircraft flown, its age and utilization pattern. Airlines with a uniform fleet of one type aircraft will have it easier with maintenance than those with a mixed fleet, especially when the diversity of the fleet is at manufacturer level.

Over the years, the cost of direct and indirect maintenance has been increasing, owing to increased labor and fuel costs which in turn affect all other maintenance costs. On the other hand, competition in the global market has made it nearly impossible for airlines to increase their fares or freight charges. In extreme cases, such as with escalating fuel prices, airlines have had to introduce surcharges. But in general, airlines have had to continuously optimize maintenance, with the aim of reducing the cost while increasing its effectiveness.

II. PROBLEM DEFINITION

A. Background

Airlines are constantly seeking new ways to reduce their operating costs in order to make profits for their shareholders. Maintenance cost, direct or indirect, offer a good opportunity for such reductions. However, cost reduction should in no way imply compromising on the quality of maintenance.

Maintenance is normally categorized as *Line* or *Base maintenance*, where line maintenance refers to all work performed on a regular basis demanding less than 72 hours downtime. Base maintenance includes all work that may require significant downtime (exceeding 72 hours) [2]. Both line and base maintenance can be done in-house or by an MRO, depending on the airline's capability.

The effects of aircraft maintenance and adjustments thereof have a direct effect on (1) the aircraft, (2) the maintenance facility and (3) the rest of the airline.

Changes affecting the aircraft relate to those directly operating the aircraft, i.e. the crew. Changes to the maintenance facility affect the maintenance equipment, maintenance personnel and parts procurement and storage. Finally, change effects to the rest of the airline have a direct impact on the operations department and the owner of the aircraft.

Optimizing maintenance is therefore quite challenging if one is to consider all the above parameters. Existing models will normally address just one of the above areas, owing to the complexity of the problem.

B. Statement of the problem

There is a serious need to reduce the cost of direct maintenance per flight hour if airlines are to reign in on the escalating cost of maintenance.

C. Proposed solutions

Considering the different situations sketched above, the maintenance needs per airline will differ. There is, therefore a need for different approaches to maintenance to be considered and analyzed, whereafter the most effective approach will be selected, preferably for a given situation [3].

The solutions will be simulated and will consider that scheduled maintenance visits (routine maintenance) generate predictable non-routine maintenance activities [2], and the parts required are readily available within the facility. This is what will consist of direct maintenance costs. Indirect maintenance costs are a function of direct maintenance, hence easy to determine.

The solution will also consider and incorporate two maintenance strategies, namely Preventive Maintenance and Condition Based Maintenance (CBM).

Preventive maintenance will follow a sequence that is determined by the aircraft age - calender time (CT), flight hours (FH), flight cycles (FC) or a combination of any two (CT/FH, FC/FC, FH/FC).

Condition monitoring (CBM) requires action once a system or component falls outside its set limits of operation. In a simulation, such an observation can be modeled as an event, either discrete or stochastic, depending on the importance and performance of the part or component.

D. Limitations

The proposed analysis will concentrate on maintenance performed by an airline, and will not consider work contracted out. For purposes of simplifying the model, it will be assumed that the aircraft are not grounded due to maintenance faults or other external factors such as Airworthiness Directives (AD). However, it is important to note that modeling such events brings an analysis closer to the reality.

The analysis will use maintenance man hours as a measure of the cost of maintenance.

E. Assumptions

The following assumptions are made in the model used:

1) The airline operates one type of aircraft (in this case a Boeing 737)
2) All maintenance work under consideration is performed in-house.
3) There is a general relationship between man-hours and total maintenance cost, where man-hours normally account for 21% of the total cost [4].

III. ANALYSIS AND SIMULATION

The model applied utilizes the MIAM (see Figure 1 model developed by the author in a related research [2]. The MIAM model has been modified in order to incorporate the element on Condition monitoring. MIAM combines maintenance item intervals with simulated aircraft utilization scenarios (high, average and low utilization) and maintenance scenarios (such as low maintenance frequencies). From these, the Maintenance Demand (in number of visits and maintenance man-hours) is
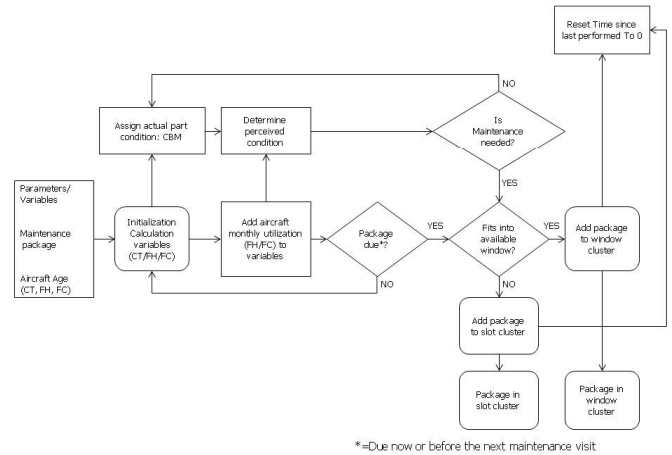

Fig. 1.   MIAM model: Line Maintenance

calculated [5]. The simulation period is set to five years so as to allow the outputs to stabilize. It is also repeated for a given set of parameters, wherefrom average values of the aircraft utilization and maintenance demands can be calculated. Finally, the outputs are validated using data provided by IATA, 2011 [4] on maintenance costs.

In order to incorporate failures of parts or systems as observed under condition monitoring, the Weibull distribution is applied. This distribution utilizes two parameters, namely the shape parameter β, and the scale parameter θ.

For $\beta < 1$, the probability density function (PDF) will resemble an exponential distribution. For large values of $\beta \geq 3$, the appears symmetrical, approximating a normal distribution. Where $1 < \beta < 3$ the PDF is skewed. Finally, if $\beta = 1$, the failure rate is constant.

θ is a scale parameter that influences both the mean and the spread of the distribution. It is also referred to as the *characteristic life*. [6]

For purposes of this simulation, the utilization of this distribution is sufficient, where β values of $0.5, 1$, and 2 were utilized, together with θ values of $1,000, 10,000$ and $20,000$. A combination of these values have been used in previous research work for aircraft systems and components maintained during line maintenance [2], [5].

A. Model validation

Model Validation is done in order to ascertain that the model is a reasonable representation of the real life process: that it reproduces system behavior with enough fidelity to satisfy analysis objectives [7].

(i) Assumptions made:
- The aircraft considered makes flights on a daily basis, throughout the entire period considered
- The aircraft performs flights solely for the airline, hence sticking to the airline's utilization pattern
- Maintenance clusters (work packages) are performed as scheduled. No escalations and extensions are considered

(ii) Inputs and Distributions:
- Maintenance dates (Due dates, Time Since Last Performed) have a MM/YY format.
- Maintenance is always performed at intervals larger than 28 days(4 weeks)

(iii) Outputs:Maintenance man-hour demand as a function of preventive maintenance and condition based maintenance.

IV. RESULTS AND DISCUSSION

It can be observed from figure 2, normal preventive maintenance (PM) will lead to a higher maintenance demand, owing to the fact that maintenance repair and replacement work will be carried out even when it is not necessary. However as the age of the aircraft increases, the difference becomes smaller. This is expected, since PM work on older aircraft tends to be derived from CM principles.
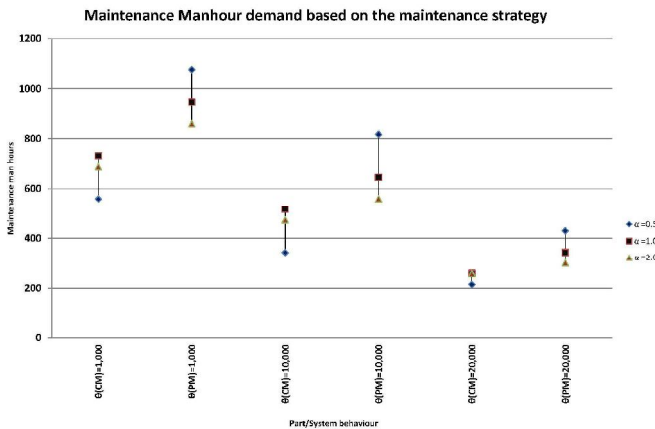

Fig. 2. Comparative Simulation Results

However, it must be noted that the performance of most maintenance tasks is regulated, and must be performed at specified intervals, regardless of whether the component or system is about to fail or not.
The comparative cost of performing maintenance using the two approaches is illustrated on figure 3.

	Maintenance cost($) / FH	Maintenance cost ($) / FC
Condition Monitoring	636.19	1601.96
Preventive Maintenance	941.89	2371.73

For a FH/FC ratio of: 2.5

Fig. 3. Comparative costs per flight hour and flight cycle

The amounts have been calculated using a man-hour rate of US$ 38. The amounts compare well with the actual market scenario, based on the IATA (2011) analysis. [4], where the average direct maintenance cost per flight hour was US$1,040, and per flight cycle US$ 2,577. The simulated output gives a significantly lower cost of maintenance per flight cycle in the case of condition monitoring. The overal improvement in cost is 38% utilizing condition monitoring, and 9% utilizing preventive maintenance.

V. CONCLUSION

By actively utilizing the Condition monitoring strategy, airlines can effectively reduce the direct maintenance costs. Optimization of maintenance intervals and maintenance windows can also help improve on the same. However, such optimization strategies can only operate within the regulated limits of maintenance tasks.
Further, condition monitoring is applicable to a some parts or systems in an aircraft. Electronic systems and components will normally have a constant failure rate, hence condition monitoring cannot be applied. This simulation has, however, tried to incorporate this factor by working with the shape parameter $\alpha = 1.0$.
This comparative analysis has attempted to combine and optimize two maintenance strategies. Most other work limits itself to one strategy owing to the complexity of maintenance in the airline industry.
As demonstrated, by optimizing the application of preventive maintenance and condition monitoring, airlines can establish new opportunities to reduce the cost of maintenance, and hence remain competitive in this high (investment) risk industry.

VI. FUTURE WORK

This research work provides a basis for further work, especially in the optimization of maintenance using multiple maintenance strategies. Most research work in this area focuses only on one strategy at a time. A number of assumptions have been made in this work. More research work can be done by eliminating some of these assumptions, and comparing the results with actual data from the industry.

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