Optimizing aircraft maintenance outsourcing decisions: a cost-benefit analysis

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***Abstract* – The decision to internalize or outsource maintenance services for a fleet of aircraft is a dilemma that has a direct impact on costs, aircraft availability and the capability to perform the missions that they are assigned. The absence of a model capable of simulating real scenarios lead fleet managers to not accurately assess the impact of different maintenance options on the total life cycle cost of aircraft, as well as their operational availability or the administrative and logistical implications of the different options. This research proposes a model that simulates various maintenance configurations, from totally in-house maintenance to totally outsourced. The model takes into account information about the fleet, the components on board the aircraft, current maintenance contracts, in-house maintenance structure required and aircraft availability data. By simulating different scenarios and analyzing the impact of fleet size and investments required, the model makes it possible to identify the most efficient maintenance option in terms of cost-effectiveness, maximizing the operational availability x life cycle cost ratio.**

***Keywords* – Aircraft maintenance; Cost-benefit analysis; Outsourcing.**

I. INTRODUCTION

This study is guided by a central research question: considering real fleet scenario, what is the most cost-effective balance between in-house and outsourced maintenance, and how do fleet size and resource costs influence this decision? This question frames the subsequent analyses and ensures that the study contributes directly to the decision-making needs of fleet managers.

Related to an aircraft fleet supportability, according to [1], there are some gaps in the supportability of the current system, as he states that experience in recent years has indicated that the complexity and the costs of systems, in general, have been increasing. Additionally, a combination of introducing new technologies in response to a constantly changing set of performance requirements, the increased external social and political pressures associated with environmental issues, many of the system currently in use today are not adequately responding to the needs of the user, and he also states that there is a lack of total cost visibility, mainly related to the costs related to operating and supporting phases.

Although the aircraft have a considerably high acquisition cost, it still represents a small fraction of the total cost, where the operation and supportability (O&S) represents a large part of the whole costs. According to [2], the General Accounting Office (GAO) of United States consider the 70:30 ratio, where 70% of the total cost is for Operation and Supportability, and 30% is for the acquisition cost.

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Although the acquisition cost is the most publicized and is the easiest to obtain, there is a lack of total cost visibility on the other costs involved in the life cycle of an aircraft, and the costs associated with the fleet supportability are somewhat hidden.

Considering the Operating and Support phase, one of the important decisions to be made is about the support structure to be used to perform the required maintenance services. In this way, the decision to outsource or internalize the maintenance is a critical strategic choice, since it will drive several investments and processes that must be defined in the early stages of the project. Considering outsourcing or internalizing maintenance, there are pros and cons to each option. Some pros considering the outsourcing options are: reduction of fixed costs; expenses on demand; focus on core business; access to expertise and technology; and flexibility and scalability. On the other hand, some cons of outsourcing are: loss of control; dependence on third parties; potential conflict of interest; risk of discontinuity; hidden and/or unpredictable costs.

Given that, this research performed a quantitative analysis where it was built a model that simulates several maintenance configurations, from totally in-house, passing though the current support structure used, until a totally outsourced structure. The model takes into account information about the fleet, the components on board the aircraft, current maintenance contracts, the in-house maintenance structure and aircraft availability data. In addition, the model makes it possible to analyze the impact of different scenarios, such as the impact of fleet size on decisions, resource costs, the size of the maintenance structure.

II. PROPOSED SOLUTION

In order to propose a relevant approach to the theme, it is necessary that the model covers the main aspects of the supportability in analysis, which increases model's robustness and validity. Given that, a first factor is that the model computes the operational availability, one of the main supportability metrics, since it covers the reliability of system components, the weight of preventive maintenance and also the support structure adopted [1]. Additionally, the model applies a cost-effective approach, computing the operational availability versus its cost for each scenario analyzed and for each level of investment desirable. Moreover, the model uses as input the insertion of real data, including aircraft components, usage profile data, maintenance data and considers the current supportability of the system, increasing the significance level of its results.

Additionally, the model proposed a system approach. One of the advantages of the system approach, instead of item approach, is that just the first one is able to identify the best support solutions and can estimate the system availability and its related impact on cost. The system approach can answer questions like: How much money should we spend to achieve a 90% availability? How much money would we save if the availability requirements was reduced from 90% to 80%? Is it economic to have more repair capability at the operating sites or they should be kept at the central maintenance base? And what does the optimal system cost-effectiveness curve look like? In that way, the fleet manager can have a holistic view of his assets [3].

Also, the system approach presents to the inventory manager an availability-cost efficiency curve of inventory alternatives, according to the available amount of money for investment in the acquisition of rotable items [4], as can be seem in Fig. 1.

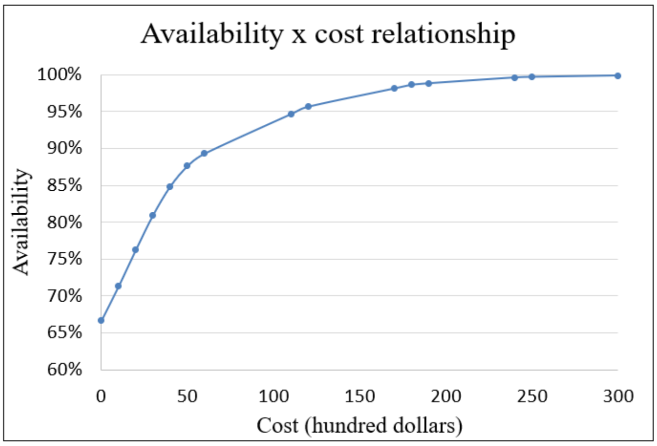

Fig. 1: Availability x inventory levels

Fig. 1 was a simplified illustration, as it only considered 2 components, it considered 1 single echelon (so there were no transportation stages), and did not consider scheduled maintenance tasks. On the other hand, the model developed considered 52 items, multiple echelons and also considered several preventive maintenance tasks. However, like any other model, it is necessary to make certain assumptions and consider some simplifying hypotheses in order to enable model convergence and focus on the most important aspects that are being analyzed. Given that, the model simulated has the simplifying hypotheses and assumptions listed below:

a) Spare parts are a closed cycle. Also, the spare parts can always be repaired (There is no item condemnation).
b) It is applied FIFO (fist in first out) rule.
c) The repair time does not depend on the number of items already being repaired.
d) Demand is a Poisson distribution with a constant average, regardless of the number of parts being repaired.
e) There is no lateral supply.
f) There is no cannibalization.

For this model, the variables of interest are the demand for items over time "m" and the repair time "t". The average demand of an item is proportional to failure rate (FRT), utilization rate (UTIL), quantity of items per aircraft (QPA) and the quantity of aircraft being operated (QTYACFT). The item demand can be expressed by (1).

$$m = FRT \times UTIL \times QPA \times QTYACFT \qquad (1)$$

Considering the demand for an item as a Poisson process, the probability distribution for the number of items under repair "λ" has the form of a Poisson distribution, no matter the repair time distribution, according to Palm's Theorem [3], with mean:

$$\lambda = m \times t \qquad (2)$$

Considering X as the number of items under repair that are not in stock and S as the number of stock items, its defined expected backorders (EBO) as an estimate of the number of missing items in a fleet [3], by (3):

$$EBO(s) = \sum_{x=s+1}^{\infty} (x - s).\Pr\{DI = x\} \qquad (3)$$

In order to avoid summation to infinity, equation (3) can be rewrite according to (4).

$$EBO(m.t, S) = \lambda - S + \sum_{x=0}^{S} (S - x).\Pr\{X = x\} \qquad (4)$$

In addition, the relationship between EBO and availability can be expressed according to (5).

$$A = \frac{MTBM}{MTBM + MMT + \frac{EBO}{m} \times UTIL} \qquad (5)$$

Where MMT = mean maintenance time

As can be seem, the number of backorder and availability has an inverse relation, and minimizing the expected backorder (EBO) increases availability. Due to that, given that "i" is a specific item and "c" its cost, with the aim of increasing fleet availability, the objective function is to minimize the total number of expected backorder in the system (EBO), as stated in (6).

$$\min \sum_{i=1}^{I} EBO(S_i) \qquad (6)$$

With budget constrains:

$$\sum_{i=1}^{I} c_i \times S_i \leq Budget\ (\$) \qquad (7)$$

To solve the optimization problem it was used the marginal analysis, that considered the benefit cost ratio (BCR) to buy one more item to the inventory, according to (8):

$$BCR = \frac{[\, EBO(S-1) - EBO(S) \,]}{c} \quad (8)$$

This analysis are computed for all the items, to choose the best one to be acquired. After this acquisition, the calculus is remade for all the items to find the next one to be acquired, and so on.

III. CASE STUDY

Before presenting the case study, it is important to situate this research within the state of the art. Several works have analyzed outsourcing in aircraft maintenance. Bazargan (2016) proposed an optimization approach to compare in-house versus outsourced strategies, highlighting cost minimization. Hsu and Liou (2013) developed a multi-criteria decision model including risk and flexibility aspects, while McFadden and Worrells (2013) provided a qualitative list of influencing factors. More recent contributions, such as Liu and Tyagi (2017), emphasized the financial impact of outsourcing by converting fixed into variable costs, and Commine (2023) studied the implications on flight safety. However, most of these studies remain qualitative or limited in scope. The main differential of the present work is the use of a quantitative model applied to real operational data, enabling direct simulation of fleet behavior under different supportability strategies. This covers an important gap in the literature and provides practical, evidence-based insights for decision-makers.

For the case study it was used the OPUS Suite software package, from Systecon Group, to perform the simulations. In this way, it was used OPUS, SIMLOX and CATLOC softwares.

For the supportability model, it was used real data from a aircraft fleet in operation. It was chosen a fleet of 15 aircraft, divided into 2 operating bases, the main base has 10 aircraft, while the remote base has 5 aircraft. It was assumed an average operation of 150 flight hours / year / aircraft.

For the support structure, it was considered that both operational bases make contact with a central base, and the central base has a contract with the aircraft manufacturer. Due to that, the support structure has a 3 echelon scheme. Additionally, according to field observations, the preventive maintenance is performed in-house, while corrective maintenance is outsourced via contract with original equipment manufacturer (OEM). In addition, spare parts are stored with the manufacturer too.

In relation to the aircraft data, 52 components were modeled, divided into 4 sub-systems: propulsion, landing gear, avionics, and others. With regard to preventive maintenance tasks, 8 maintenance intervals were modeled, covering 78% of the total maintenance tasks planned for the aircraft model. The Table 1 shows the respective intervals.

TABLE 1: SCHEDULED MAINTENANCE DATA

Maint. Interval	Nº of tasks	Elapsed time	Cost (US$)
1.200 FH	140	1.164	32.524,80
4A and hybrid	134	1.252	32.722,80
100 FH	121	291	5.622,15
1A and hybrid	81	810	24.673,85
2A and hybrid	56	475	12.566,40
8A and hybrid	56	1.252	41.666,23
600 FH	50	302	6.749,59
3A and hybrid	49	842	20.585,48
20 days	1	4	---

In Table 1, the task cost includes labor and material. The last task (20 days interval) refers to a task that, due to a design mistake, it must be performed every 20 days. Due to that, the manufacturer assumes its execution, spending its on consumables and labors, so there is no cost for the operator. Despite there is no cost it was modeled since its high frequency intervention could significantly affect the fleet performance.

After entering the data, the result of the availability x life support cost for a simulation period of 10 years is shown in Fig. 2.

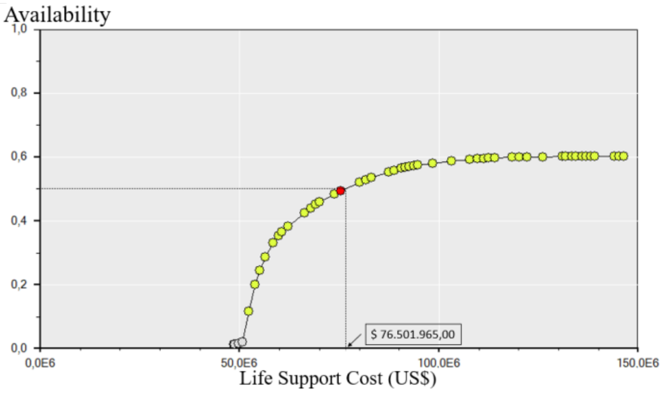

Fig. 2: Availability x life support cost of Default Model

From Fig. 2, each circle represents a different inventory level, and the more is spent (“x” axis) the greater the availability (“y” axis). The 50% availability as chosen in this research since it is the availability target by contract between the manufacturer and the operator.

Next, a simulation was carried out considering that all maintenance would be outsourced. Since in the current structure the preventive maintenance is performed internally, it is necessary to model that these tasks will also be outsourced. To do this, it was used data from the current contract with the manufacturer, and the result can be seen in Fig. 3.

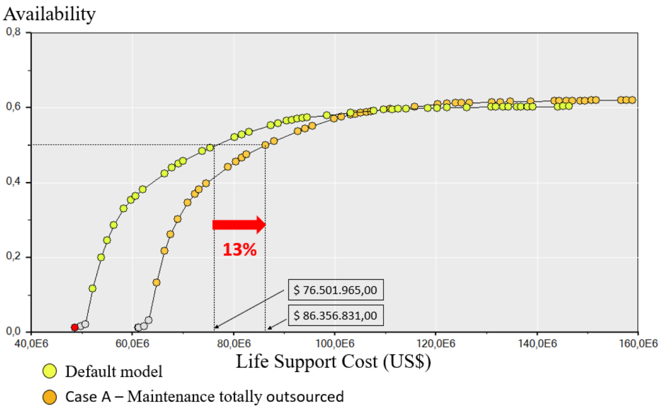

Fig. 3: Default Model x Totally outsourced maintenance

As can be seem, the maintenance totally outsourced had a 13% higher cost to keep the same availability.

The next step was to simulate maintenance totally in-house. For that, the corrective maintenance needs to be internalized, which requires several investments such as facilities, training, ground support equipment (GSE), bench tests and technical publications. Thus, considering a total investment of US$ 100 million over 10 years, the result of the availability x life support cost ratio can be seen in Fig. 4.

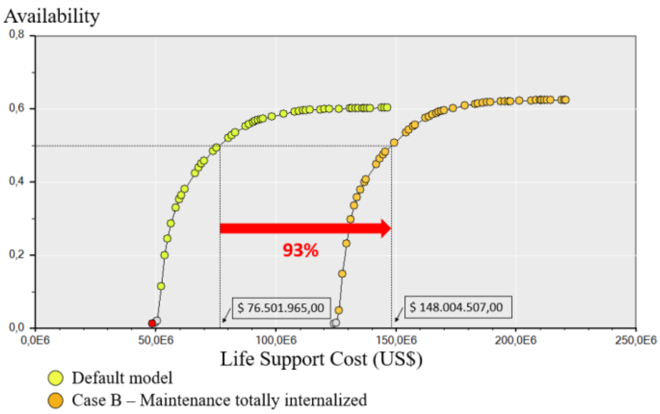

Fig. 4: Default Model x Totally in-house maintenance

As can be seen, the option to fully internalize repairs was highly unfavorable, with a 93% cost increase to keep the same availability. In this simulation the main drivers for this result were the high investments required and the small fleet size (only 15 units). For this investment, it was seem that as the fleet size increase the discrepancy is reduced. Due to that, the simulation was performed several times and it was found that the breakeven fleet size of 54 aircraft or more would make the totally internalized option advantageous. The Fig 5 shows the availability x cost relation for a fleet of 15, 54 and 90 aircraft.

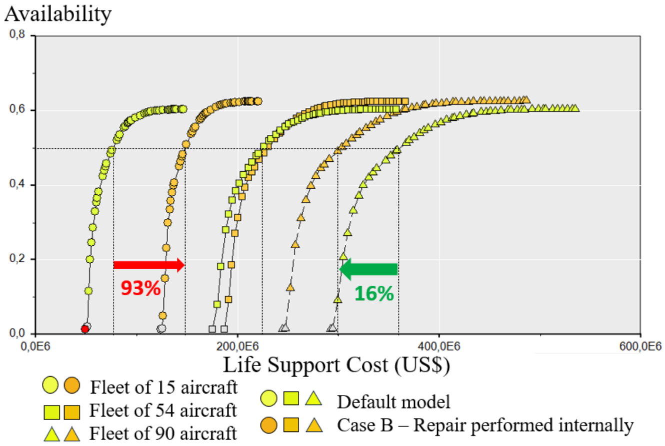

Fig. 5: Default Model x Totally in-house with different fleet size

Additionally, in order to find the relationship between the initial investment required and the breakeven aircraft fleet, the simulation was repeated considering investments of 50 and 150 million dollars, and the relationship between the level of investment and the breakeven fleet size can be seen in Table 2.

TABLE 2: RELATION BETWEEN INITIAL INVESTMENT AND BREAKEVEN FLEET SIZE

Total resource cost	Breakeven fleet size (units)
US$ 50 million	27
US$ 100 million	54
US$ 150 million	85

From the previous analysis its clear that the option to internalize or not the maintenance tasks are highly affected by the initial investments required and also the fleet size.

As could be seem, the Default Model (the support structure currently used in the real case) was the best choice, since it had the smallest life support cost for a 50% availability. Due to that, a hybrid support structure, with partial of the maintenances services being outsourced and partial being internalized was the best support solution. Additionally, in order to compare the results obtained in this research with previous works in the literature, Fig. 6 shows a comparison between the results obtained by [5] and the results of this research.

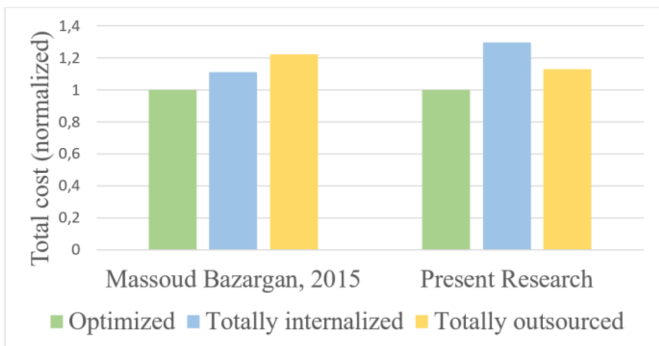

Fig. 6: Support structure comparison for different researches

Although there are differences between the methods, the main results were compared for illustrative purposes. As can be seen, in both cases the optimum result was a hybrid maintenance option with part being outsourced and part internalized, with the difference being that results from [5] showed the highest cost for the outsourced option, while the present work showed the highest cost for the fully internal option.

Finally, it was analyzed how the size of the support structure can impact fleet indicators. This was modeled through the number of repairs that can be carried out simultaneously. While a large support structure, capable of carrying out a large number of simultaneous repairs, will be able to immediately meet the demand for repairs, a small support structure, with less capacity to carry out simultaneous repairs, can generate delays in meeting the demand for repairs, which can negatively affect the fleet's main indicators. The fleet indicators considered were: availability; unavailability due to waiting for components; and mission completion rate. Given that, the simulation was performed several times changing the maximum nº of repair that can be performed simultaneously, and the result can be seen in Fig. 7.

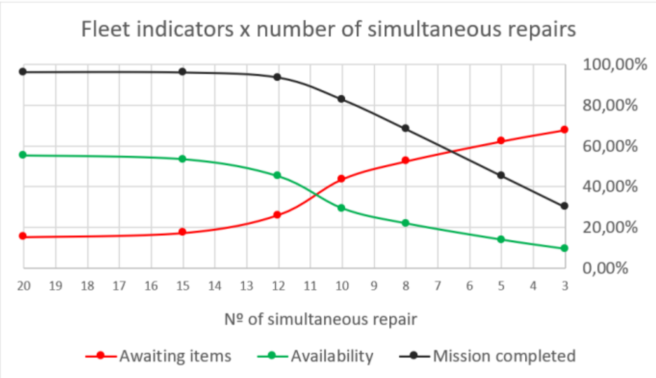

Fig. 7: Impact of simultaneous repair in fleet indicators

As can be seen, for the fleet modeled, the indicators have practically a constant value when considered 15 or more maximum simultaneous repair. On the other hand, the indicators are negatively impacted when the number of simultaneous repair was below 15. Therefore, the appropriate support structure for this fleet should be designed to have the capacity to perform up to 15 repairs simultaneously. A structure larger than this implies an increase in costs with no return in terms of fleet improvement, while a structure smaller than this would be cheaper but would cause a deterioration in fleet indicators.

IV. CONCLUSION

During the research problem, different methods for managing aircraft maintenance services were discussed, ranging from one extreme (fully in-house) to the other (fully outsourced). It was noted that the Default Model (the strategy used to support the fleet currently) was the best alternative. But, it was noted also that there are possible inefficiencies that could be addressed in order to improve the fleet indicators. One clue of this inefficiencies is that the current fleet availability is below the expected value. As an example of possible improvement could be if the manufacturer would be able to deal directly with the operational bases, thus eliminating intermediaries between the operator and the maintainer. Another possibility could be to allocate the inventory closer to the operating sites, which tends to reduce the latency to a fault occurrence. One last possibility could be the alteration in maintenance plan, since the fleet is highly impacted by the downtime due to scheduled maintenance. But this solution is not easy to implement, as it depends on several studies by the manufacturer, as well as approval from regulatory agencies.

Moreover, despite the scope of this work focused on the economic aspects of a support structure analysis, there are non-economic aspects that should also be taken into account in real cases. For example, considering a fleet of national defense aircraft, efficiency in the use of resources is not the only determining criteria. Sometimes, the need to maintain a greater degree of control over operations, as well as to respond quickly to specific demands, the loss of internal expertise (when services are frequently outsourced), or even the risk of political influences forcing a discontinuation of services at times of political instability can override the economic aspects.

Despite the robustness of the proposed model, some limitations must be acknowledged. First, the assumptions adopted (e.g., absence of lateral supply, constant failure/repair rates, only one failure mode for each component and no correlation between failure modes) may oversimplify the variability observed in real-world operations. Second, the study is based on a single fleet case, which may reduce variability compared to a real case with a fleet composed with more than one aircraft type and with different sizes, with different support structures and with different operational profiles. Third, some intangible aspects such as contractual flexibility, political influences, sudden technological changes or manufacturer product and service discontinuation were not quantified. These limitations suggest caution in directly extrapolating the results.

V. FUTURE WORK

Future research could extend this work in several directions. One possibility is to integrate risk analysis, considering stochastic variations in repair success rates or sudden supply chain disruptions. Another idea regarding the option of a fully in-house structure, analyzing the use of special tools/structures, where there is a limited quantity to serve the entire fleet, with the possibility of generating a waiting list and its impact on the indicators. Another variation can analyze the impact of keeping repairs at a central base compared to another condition in which operators have the capability to carry out the repairs themselves. In this situation, analyzing the optimal stock location also becomes relevant. Another possibility for future work would be to take into account the ageing of the fleet and its impact on decisions to internalize or outsource repair tasks. Another analysis could be made in relation to scheduled maintenance, in which the size of the hangar would be taken into account, in order to observe the number of aircraft that would be undergoing scheduled maintenance simultaneously, as well as the impact on the indicators if there is a limit on the size of the hangar available.

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