TIME BETWEEN AIRCRAFT OVERHAULS OPTIMIZATION BY MAXIMIZING FLEET TOTAL FLYING HOURS

Ivan Djokic
State University of Novi Pazar, idjokic@np.ac.rs
Ljubomir Lazic
State University of Novi Pazar, llazic@np.ac.rs
Aldina Pljaskovic*
State University of Novi Pazar, apljaskovic@np.ac.rs
Aleksandra Pavlovic
State University of Novi Pazar, apavlovic@np.ac.rs

Abstract: *The purpose of the work was to investigate the feasibility of determining when an aircraft should be overhauled in order to maximize the total flying hours of a fleet. It was assumed that the aircraft reliability parameters are known. Also, it was assumed that maintenance capacity is limited and constant. Analysis was based on a discrete-event simulation model using General Purpose Simulation System (GPSS), which estimates available and achieved flight hours of a military aircraft G-4 fleet throughout complete life cycle, under a certain maintenance scenario. The model also gives all necessary parameters to compute the total aircraft maintenance cost, linking reliability, operational tempo and maintenance scenario.*

Keywords: *aircraft, overhaul, simulation, optimization.*

* Corresponding author

1. INTRODUCTION

The Integrated Logistic Support (ILS) is the process that facilitates development and integration of all of the logistics support elements to acquire, test, field, and support military systems. The ILS elements are: maintenance, manpower and personnel, supply support, support equipment, technical data, training and training support, computer resources support, facilities, packaging, handling, storage, and transportation, and participation in complete engineering process of a system [1]. Objective of the maintenance planning is to identify, plan, provide resources, implement maintenance concepts and requirements, and to ensure the best possible equipment/capability available, when a military unit needs it at the lowest possible cost.

Aircraft, as a military system, need to be maintained for many different reasons. To have a high safety and reduced costs, are two reasons. Both corrective and preventive maintenance are carried out on aircrafts. The preventive maintenance cost a lot of money and during the maintenance time, the aircraft is not available for flying. One major part of the aircraft preventive maintenance is to undertake overhauls. The overhauls are flight time dependent and need to be carried out before the aircraft are allowed to fly again. During the overhaul, there are often a lot of other maintenance tasks carried out like repairs and modifications. A good plan for the required maintenance capacity in the workshops is essential to reduce the total maintenance cost. There is also another reason to have the right maintenance capacity and schedule, that is - the availability of the fleet needs to be high enough. If the workshop capacity is too low, it will lead to a low availability of the aircrafts and that can lead to problems of achieving the targeted flight time production. One part in determining the total maintenance needs is to determine the optimal overhaul capacity.

However, there are situations in practice with a developed and fixed maintenance capacity, limited available flight hours, and an increased operational tempo needs. In this work the optimization model has been formulated as flight hours maximization under limited overhaul capacity, changing aircraft maintenance scheduling, the overhaul extent and available flight hours after the overhaul. To be able to construct the model, the maintenance work at the Serbian Air Force has been studied. The parameters that are needed for the model have been described.

Verification of the model has been carried out through G-4 fleet (30 aircraft) example.

2. RELATED WORK

The development of life-cycle models is necessary to identify key factors that affect operational readiness and cost of required readiness. Modeling needs complex and time consuming research to examine many input parameters and possible scenarios, and models usually cover specific system or only a part of a life-cycle.

One approach uses optimizations maximizing availability and profitability of the production system by varying both maintenance strategies and logistics factors. The obtained results indicate that a joint optimization of logistics and maintenance strategies provides better results than optimizing those elements independently and highlights the need for a comprehensive sophisticated model [2]. Another approach combines knowledge from government and industry space operation and design experts, with system analysis methodologies to predict operational characteristics of a future space transportation system. The model proposed under this approach utilizes expert knowledge to predict the operational requirements of a system, incorporates simulation in order to include alternatives, processing variability, and other random events [3]. Some researches combine several models that can be used in identifying critical logistics factors that have an impact on the system readiness and life cycle cost. Typical concept uses two models: the first one, a discrete-event simulation model, estimates the operational availability of a system given input parameters under a certain scenario. The second one, a spreadsheet model, computes the life cycle cost using the same input parameters for the simulation model [4]. One method provides a complete formulation for maintenance scheduling and a heuristic approach to solve the problem. The heuristic procedure provides good solutions in reasonable computation time [5]. Some works deal with specific maintenance facilities. One paper presents an approach to determine the optimal aircraft overhaul capacity in the workshops for JAS 39 aircraft fleet. The aircraft fleet contains one aircraft type with different models of that type. A mathematical model has been constructed to calculate the lowest cost alternative. The mathematical model uses various types of data to calculate the optimal workshop overhaul capacity like costs, times, numbers of workers, aircrafts used flight time etc. [6].

In this work an integration of available flight hours and maintenance optimization is done, based on vehicle life cycle simulation. The simulation model is a very flexible one and gives the opportunity to change a variety of parameters: fleet size, aircraft reliability, operational tempo, work allocation between maintenance levels, time-to-repair distribution, preventive maintenance strategy, etc. The model is also applicable to other maintenance systems [7]. The simulation results give a detailed insight into fleet life cycle: obtained flight hours of the fleet and every aircraft, maintenance facilities utilization, queues, logistics administrative time, maintenance labor, maintenance cost (minimal, maximal, mean, standard deviation).

3. AIRCRAFT MAINTENANCE SIMULATION MODEL

The simulation model was built using GPSS in such a way that software not only provides tools for modeling and simulation of a wide variety to maintenance services, but also has possibility to shape input data and carry out output statistics [8]. Simulation model describes a traditional three-level maintenance concept, consisting of Organisational level (OLM), Intermediate level (ILM) and Depot level (DLM) maintenance adopted for aircraft G-4.

The OLM is performed by operational squadron and consists of the preparation of aircraft for flight and elementary aircraft servicing, including these activities: pre-flight inspection, thru-flight inspection, post-flight inspection, aircraft servicing and operation, aircraft ground handling, ammunition loading, and remove/replace of failed line replacement units (LRUs).

The ILM is performed by maintenance squadron and consists of work on the aircraft as well as on individual disassembled components. During the ILM, activities defined within both, the scheduled and unscheduled maintenance, are carried out. Scheduled Maintenance consists of periodic and phase inspection activities carried out on mechanical systems such as: airframe systems servicing, clearance check and adjustment, cleaning or replacement of the filter elements, lubricating according to lubrication plan. In the course of aircraft operation, unscheduled maintenance activities occur, too. These are especially: special inspection after a specific occurrence, upgrades or maintenance activities performed on aircraft systems in compliance with bulletins, remove/replace of systems components due to failure, troubleshooting and isolation. The OLM and ILM are performed within squadrons at one Air Force Base.

Detailed specification of the Depot level maintenance performed on each system, aggregate and module are based on the logistic support analysis. The period of Depot level scheduled maintenance depends of aircraft design and technology and for G-4 aircraft is designed to every 1,000 flight hours.

Scheduled maintenance mostly covers airframe and mechanical systems and consists of: (1) phase inspections after 50, 100, 200 flight hours, (2) periodic inspections based on calendar time, cycles, starts, and landings.

Output parameters of the model are: fleet availability, aircraft availability, fleet flight hours, aircraft flight hours, aircraft usage histogram, number of preventive maintenance actions, aircraft preventive maintenance histogram, number of corrective actions, maintenance capacity utilization, queues, total preventive maintenance working hours, total corrective maintenance working hours, aircraft failure histogram, ect.

4. EXAMPLE

The importance of simulation and its use in optimization lies in the fact that many problems are too complex to be described in mathematical formulations. Nonlinearities, combinatorial relationships or uncertainties often give rise to simulation as the only possible approach to solution. Our simulation model is tested through relatively complex example: find the most effective (maximum flight hours) overhaul concept under financial and maintenance capacity constraints, for a fleet of 30 aircrafts. The optimization process consists of four steps: (1) Requirements establishment, (2) Definition of maintenance alternatives, (3) Fleet life cycle simulation for every maintenance alternative, and (4) Selection of the optimal solution.

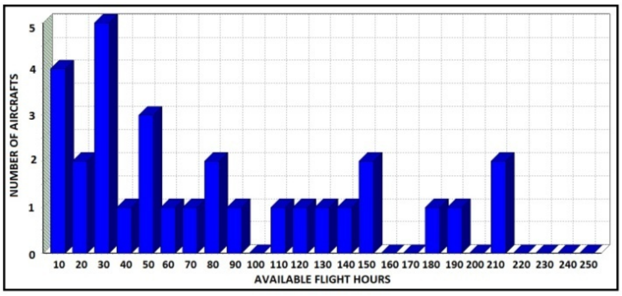

Figure 1. Aircraft available flight hours histogram

Requirements – Optimize aircraft maintenance system for G-4 fleet (30 aircrafts), adjusting time between overhaul. The optimization aim is maximization of available flight hours for 5 operational years. The maintenance capacity consists of 20 OIL teams, 5 working places and teams for ILM, and 4 working places and teams for DLM. Average operational tempo needs 300 flight hours per aircraft per year. Starting available flight hours are 5780 (173 hours per aircraft), and their distribution per aircrafts is shown in Figure 1. G-4 service life is 5000 flight hours.

Maintenance alternatives – For the illustrative purpose two DLM alternatives are simulated. Alternative 1 is the basic, shown in Table1. Every time the G-4 aircraft reaches 1000 flight hours, the aircraft is taken out of service for overhaul. Meaning that, it will undergo overhaul after 1000, 2000, 3000 flight hours, and so on. The first overhaul is called TO1 and the second overhaul is called TO2 and so on.

Table 1. G-4 basic overhaul schedule

G-4 Overhaul Alternative 1

Name	Flight Hours
TO1	1000
TO2	1000
TO3	1000
TO4	1000
TO5	1000

Alternative 2 is called short overhaul, because time between overhauls is shortened, overhaul activities are reduced, and aircraft gets less available flight hours after every implemented overhaul. This alternative is the most cost effective among a set of short overhauls, and it is shown in Table 2.

Table 2. G-4 short overhaul schedule

G-4 Overhaul Alternative 2

Name	Flight Hours									
SO1	500									
SO2	500	1000								
SO3	500		1500							
SO4	500	1000		2000						
SO5	500		1500		2500					
SO6	500	1000		2000		3000				
SO7	500		1500		2500		3500			
SO8	500	1000		2000		3000		4000		
SO9	500		1500		2500		3500		4500	
SO10	500	1000		2000		3000		4000		5000

In this alternative aircraft will undergo overhaul after 500 FH, 1000, 1500 flight hours and so on. The first overhaul is called SO1 and the second overhaul is called SO2 and so on. There are different maintenance tasks to be done depending on how much the aircraft have flown. The first time an aircraft come for overhaul the maintenance tasks are carried out every 500 flight hours that means in other words that this maintenance tasks will be carried out every time the aircraft undergo overhaul. The second time the aircraft come in for overhaul, besides the maintenance tasks of every 500 flight hours, the maintenance tasks for every 1000 flight hours are also carried out. The third time the aircraft is undergoing overhaul, the maintenance tasks at every 500 and 1500 flight hours are carried out. Between overhauls, flight time dependent services are carried out. The services are done at the flying units on their maintenance department, can be also carried out at workshops, if necessary. There are also services that are not flight time dependent and that is the service that are done before and after every flight.

Simulation - Objective functions are the target functions in focus on which the optimization criteria are deployed, either minimizing or maximizing the objective function by varying the decision variables. The objective in our example is the maximization of the fleet flight hours with fixed maintenance capacity. Optimization process consists of repetitive simulation runs with different values of the influence variables. Those variables are varied from simulation to simulation to find optimal combination of parameter values to solve the problem with respect to the objective function and constraints. Influence variable are aircraft operational tempo and maintenance alternatives. Results for one operational tempo and two overhaul alternatives are shown in Figure 2 and Figure 3.

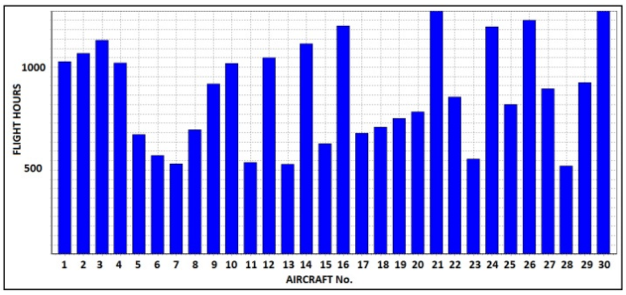

Figure 2. G-4 fleet flight hours during 5 years of service, overhaul alternative 1

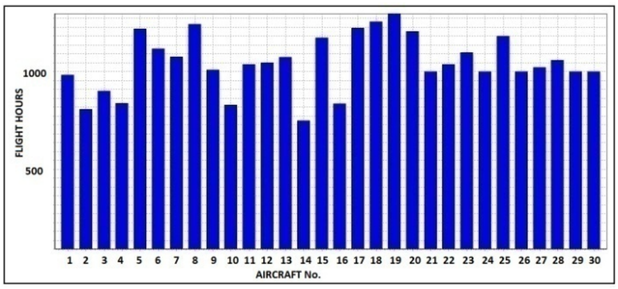

Figure 3. G-4 fleet flight hours during 5 years of service, overhaul alternative 2

Results show that for the simulated operational tempo overhaul alternative 2 gives more flight hours (average 1051 flight hour per aircraft, standard deviation 157 flight hours), then overhaul alternative 1 (average 859 flight hour per aircraft, standard deviation 275 flight hours).

Optimal solution – Simulation runs for all operational tempos have shown that overhaul alternative 2 provides more G-4 fleet flight hours then alternative 1. The simulation results are reasonable, because short overhauls allows better aircraft availability. But, there are many parameters that affect the overhauls. The values of the parameters are important to be reliable so the result from the model also can be reliable.

5. CONCLUSION

Results of the simulation runs confirmed the assumption that aircraft availability can be improved by optimizing a maintenance strategy, with fixed maintenance capacity. Our simulation model is flexible enough to cover variety of scenarios: different requirements, different fleet size, different aircrafts, different operational tempos, different maintenance strategies and infrastructure, etc. The model functionality was demonstrated through an illustrative example of 30 F-4 aircraft fleet.

ACKNOWLEDGMENT

This research was partially supported by Ministry of Education, Science and Technological Development of Serbia, under the grants TR32023 and TR35026.

REFERENCES

[1] *Integrated Logistics Support*, 2008. Headquarters Department of the Army, Washington DC, USA

[2] Achermann, D., 2008. *Modelling, Simulation and Optimization of Maintenance Strategies under Consideration of Logistic Processes*, A dissertation submitted to the SWISS Federal Institute of Technology Zurich for the degree of Doctor of Technical Sciences.

[3] Ruiz-Torres, A. J. and Zapata, E., 2000. *Simulation Based Operational Analysis of Future Space Transportation System*, Proceedings of the 2000 Winter Simulation Conference, 1123-1131, Orlando, FL, USA.

[4] Kang, K. and McDonald, M., 2000. *Impact of Logistics on Readiness and Life Cycle Cost: a Design of Experiments Approach, Space Transportation System*, Proceedings of the 2000 Winter Simulation Conference, 1336-1346, Orlando, FL, USA.

[5] Sriram, C. and Haghani, A. 2003. *An optimization model for aircraft maintenance scheduling and re-assignment,* Transportation Research Part A 37, 29–48.

[6] Larsson, M., 2010, *Development of a decision support tool for capacity optimization of an aviation workshop,* master thesis, Lulea University of Technology.

[7] Djokic, I., Lazic, L., Pljaskovic, A. and Pavlovic, A., 2013. *Optimization of Vehicle Maintenance Concept Using Simulation*, ICEST, 9-12, Ohrid.

[8] Schriber, T. J., 1974. *Simulation Using GPSS*, John Wiley & Sons.