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INTELLIGENT SCHEDULED MAINTENANCE METHODOLOGY FOR GENERAL AVIATION STRUCTURES BASED ON MSG-3 AND MULTIPLE- CRITERIA DECISION MAKING ANALYSIS

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Abstract: *Aircraft scheduled maintenance requirements are rapidly extending and developing. Scheduled maintenance has to be effective, reliable and economically reasonable. In the field of general aviation and FAR 23/ EASA CS-23 especially, preventive maintenance based on part replacing or repairing is still dominant. DAMAGE TOLERANCE philosophy implementation into an aircraft design influences maintenance procedures, which are adjusted to older SAFE LIFE philosophy. Aircraft manufactures are developing new ways, how to integrate requirements of damage tolerance application into scheduled maintenance procedures. Huge airliners manufactures (FAR 25/ CS-25) are using the ATA MSG-3 intelligent maintenance approach based on inspection. This paper describes development of intelligent scheduled maintenance methodology, utilizing ATA MSG-3 procedures, expert knowledge and multiple criteria decision making.*

Keywords: MSG-3, Maintenance, Aircraft, Structures, Multiple-Criteria Decision Analysis.

1. Introduction

In nowadays FAR 23/ CS-23 aircraft structures design is still usually applied SAFE LIFE philosophy. It means, that structure is designed to survive specific design life with an appropriate reserve. Failure of this structure is than highly improbable. Main disadvantage of this philosophy is that each structure has specified life-time and due to safety reserves higher weight compared to the structure designed according to the DAMAGE TOLERANCE philosophy. Scheduled maintenance of these structures is based on their replacement after specific time interval. Therefore, specific structure life-time could be lower than aircraft life-time. It is not an exception, that structure is replaced, when it is still functional and reliable.

However, structures designed according to the DAMAGE TOLERANCE has ability to sustain occurring defect. It is possible to manage extension of defect due to maintenance based on inspection. Grow of defect (more precisely crack) must be slow, which makes possible to detect these defects. In the case of low severity defects, scheduled maintenance is created to monitor its spreading. Structures with high severity defects are restored or replaced. Therefore, the amount of replaced items is significantly reduced, for the price of increased maintenance requirements.

Application of MSG-3 is one of the solutions, how make maintenance more effective and adequate to the elevated complexity. It has been successfully used for decades in airliner aviation (FAR 25/ CS-25).

MSG-3 (ATA, 2011) is task oriented process of scheduled maintenance based on Reliability-Centered Maintenance (RCM) management adjusted for aviation industry application. Process of scheduled maintenance creation is designed to establish most effective method how to maintain particular items and systems. MSG-3 utilizes logic decision tress to determine relevant requirements for preventive maintenance according to identified item failure modes, degradation process and resulting consequences.

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MSG-3 consists of four categories: Aircraft Systems and Powerplant; Aircraft Structures; Zonal Inspections; Lightning/High Intensity Radio Frequency (L/HIRF).

For simplification, this paper illustrates purposed intelligent scheduled maintenance methodology only on Aircraft Structures.

In the case of aircraft structures, there are three basic failure causes: Fatigue Damage (FD); Accidental Damage; Environmental Damage (ED). For aircraft structures the most relevant type of failure cause is fatigue damage (FD) especially in the case of DAMAGE TOLERANCE philosophy application. MSG-3 contains Fatigue Damage Analysis Diagram as mean of maintenance task definition for structures with fatigue failures possibility. There are three resulting tasks: General Visual Inspection (GVI); Detailed Visual Inspection (DET); Special Detailed Inspection (SDI) including Nondestructive Testing (NDT). However, MSG-3 does not offer way, how to choose a proper task for particular item. Purposed methodology uses multiple-criteria decision analysis as a part of multiple criteria decision making to establish most effective tasks set based on various requirements.

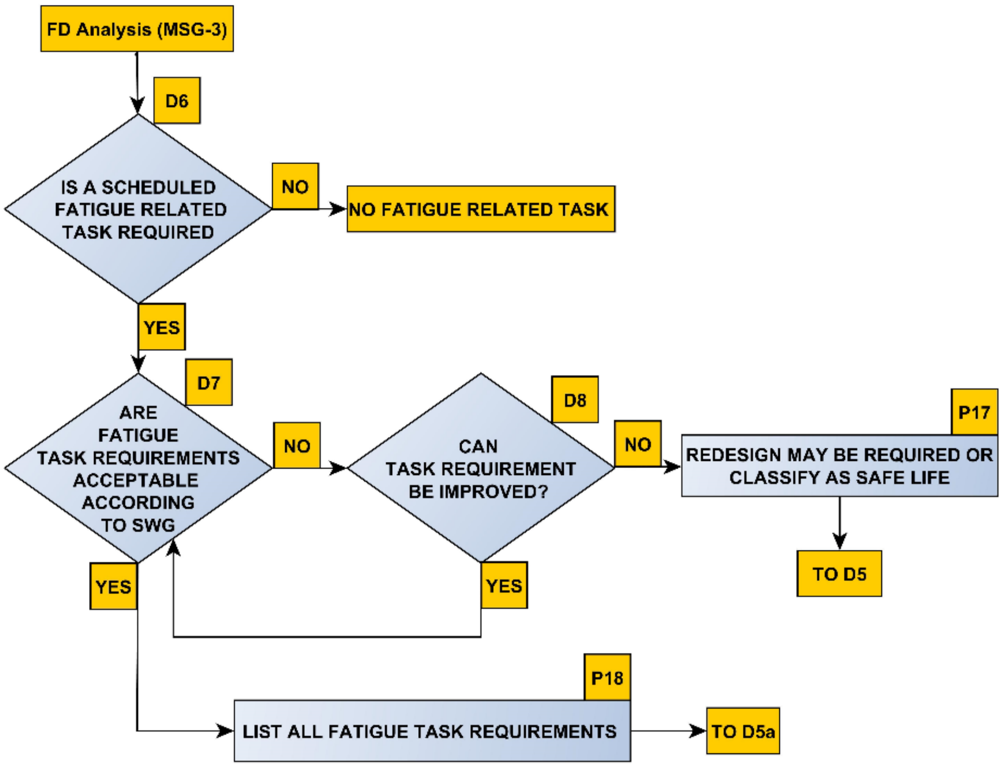

Fig. 1: MSG-3 Fatigue Damage Analysis Logic Diagram (FDALD).

2. Multiple-Criteria Decision Analysis

Multiple-criteria decision analysis (MCDA) described in textbook (Fiala et al., 1997) is the process of multiple variant evaluation using several criteria. As a variant is taken type of inspection. The main goal of this process is to sort multiple variants by their suitability, eliminate non-effective variants and find the best ranked variant.

Proposed method is using selected MSG-3 tasks- **GVI**, **DET** and **SDI** inspection. **SDI** inspection is further divided into particular methods applicable on metal or non-metal (composite) aircraft structures, for example penetration tests, eddy currents methods, ultrasonic testing, radiographic method and magnetic defectoscopy.

MCDA uses qualitative and quantitative criteria to represent various attributes and characteristics of a structure. Through these criteria particular variants are compared. As basic criteria are selected- Intervals between inspections, Inspection cost, Inspection time and Inspection complexity.

Particular criteria are not equal. There are preferences among the criteria to represent its importance in relation to other rules. There are used three types of criteria preference- **NO PREFENENCE**, **ASPIRATION LEVEL, ORDINAL** (see Tab. 1.

Tab. 1: Criteria preference definition.

CRITERIA PREFERENCE	DEFINITION	APPLICABLE METHODS
NO PREFERENCE	No criteria preferences. *Example: preliminary methods selection at the start of the aircraft development.*	Scoring method
ASPIRATION LEVEL	Threshold values are given to the criteria, which has to be fulfilled and then taken as usable variants (compromise). *Example: Final stage of maintenance creation when inspection interval is established to 4000 hours and inspection time has to be up to 30 minutes on the particular item.*	PRIAM Conjunctive Disjunctive
ORDINAL	Analyst has to know sequence of preference from the most preferred to the lowest. It is favorable for the aircraft operators, who are able adjust maintenance accreting to their requirements. *Example: Inspection cost => inspection complexity (required equipment) => Inspections intervals => Inspection time*.	ORESTE Lexicographic method

In this case, MCDA is implemented into MSG-3 Fatigue Damage Logic Diagram (Fig. 1), the analysis itself is performed between D6 and D7 points of FDLD in Fig. 1. At first, a set of possible methods is established. For each of these methods, detectable crack size is calculated (based on methodology by Bent (2010)) and time intervals are determined according to the equation (1).

$$\mathrm{T_I} = \frac{\mathrm{T_{Crit}} - \mathrm{T_{Det}}}{\mathrm{R}F} \tag{1}$$

T_I is the interval between inspections. T_{Crit} is time of unstable crack, which is established by the calculation or fatigue tests. T_{Det} is time until the detectable size of crack occurs. *RF* is scattering factor. Further, the cost, time, inspection complexity, etc., factors are taken into a process.

3. A Case Study

As a case study was chosen a small area (ca. 240 cm^2) on root part of flange on wing main spar of EASA CS-23 Commuter aircraft. The aim was maintenance interval extension from 2400 flight hours to the 3200 flight hours. Selected structure was designed according to the DAMAGE TOLERANCE philosophy with 50 000 hours' calculated lifetime.

Possible maintenance variants: GVI, DET, Eddy current, Penetration tests. **Considered variants:** Inspection cost, Inspection time, Interval between inspections, Inspection complexity.

Tab. 2: Definition of basic values for flange inspection.

VARIANT	CRITERIA			
	Price [USD]	Time interval between inspections [hour]*	Inspection Time [min]	Inspection complexity [-]**
GVI	5	733	35	Very low
DET	6	2400	40	Low
Eddy current	10	10667	45	High
Penetrating methods	12	3900	100	Low

* Conversion to the minimization volumes $y_{2jmin} = y_{23} - y_{2j}$

** Quantification by using the score tables: **1** (Very low) – **3** (High)

Resulting decision matrix, A (Minimized criteria values => lower is better):

$$\mathbf{A}=\begin{pmatrix} 5 & 9934 & 35 & 1 \\ 6 & 8267 & 40 & 2 \\ 10 & 0 & 45 & 3 \\ 12 & 6767 & 100 & 2 \end{pmatrix} \tag{2}$$

Flange maintenance requirements: Price 8 USD (changeable aspiration level), Interval between inspection 3200 hours (fixed), Inspection time 60 minutes (changeable aspiration level), Inspection complexity High (fixed).

Among all possible variants A_i, acceptable variants M_i will be variant with volume (according to the all considered aspects) equal to the preselected aspiration level volume $y*_j$. See (4).

$$M = \{A_i | y_{ij} \leq y_j^*, \forall_j = 1, 2, \dots, n\} \tag{3}$$

While aspiration levels reach $y^{(1)} = (8, 7467, 60, 3)$, it occurs, that $M = 0$. In this case, it is necessary to lower the aspiration levels. The aspirations levels were changed to $y^{(2)} = (12,\ 7467, 120, 3)$. After aspiration levels change, the result was, that two options (Eddy current, Penetration test) reached given requirements. Through to aspiration levels change, it is possible to select one variant among all available variants.

In this case, the compromise variant is inspection by using eddy currents. **It results in maintenance interval extension from 2400 hours to the 3200 hours.** Alternative variant is usage of penetration methods (lower score volume compared to the eddy currents).

4. Conclusions

Intelligent scheduled maintenance methodology based on ATA MSG-3 and multiple- criteria decision analysis is discussed in this paper. ATA MSG-3 maintenance methodology is nowadays commonly used in airliner FAR 25/ CS-25 category. Further latest development of certification procedures described in FAA Advisory Circular documentation (FAA AC-121-22C, 2012) aims to mandatory application of MSG-3 procedures for civil airplanes with more than 10 passengers or maximal takeoff weight higher than 33000 pounds.

Proposed intelligent maintenance methodology extends MSG-3 procedures by multiple-criteria decision making analysis. Paper presents results of prepared case study, which is a part of dissertation thesis **"Modern maintenance procedures for airframe inspections for general aviation category aircraft"**. The dissertation thesis contains methodology, how to use multiple criteria decision making based usage of the ordinal criteria, aspiration levels criteria and without preferred criteria.

This paper presents example of multiple criteria decision making application, more precisely aspiration levels usage. Example goal was to extend interval between inspections of particular aircraft structure using proposed intelligent maintenance methodology. Results show, that it is possible to extend this interval from 2400 hour to the 3200 hours using the eddy currents inspection method.

In future, presented methodology could be used for aircraft structure critical parts (from the inspection point of view) and Structure Health Monitoring application.

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