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DEVELOPMENT OF INSTRUCTIONS FOR CONTINUING AIRWORTHINESS AND AIRCRAFT LOGISTIC SUPPORT ANALYSIS

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Abstract

Development of Instructions for continuing airworthiness (ICA) for an aircraft is a long-term requirement of the standards of International Civil Aviation Organization and national aviation regulations. ICA is a necessary basis for aircraft operators to be used when developing their own maintenance programs vital to the aircraft effective operations and sustainment. Alternatively, military aviation community traditionally uses logistic support analysis (LSA) as a process for maintenance scheduling and support planning to achieve aircraft high supportability.

Internationally recognized approach to ICA development outlined in the known ATA MSG-3 document. However, this approach already old enough and cannot be effectively used in modern technologies for the integrated product life-cycle management (PLCM) including LSA as an example.

Proposed methodology integrates ICA development as part of LSA and, finally, as part of PLCM for the new types of aircraft. It allows to eliminate existing methodical deficiencies of current methods and accomplish effective ICA development using the LSA common data base and electronic definition of an aircraft.

1 Introduction

To fly safely an aircraft has to be airworthy. Airworthiness in civil aviation internationally defined as an aircraft or its parts fitness for flight. Continuing airworthiness is a set of processes, which include aircraft and parts safety monitoring, maintenance, repair and modification in order to keep aircraft compliance with airworthiness requirements. All these activities have to be accomplished using the instructions from ICA which is a set of manufacturers' documents and data outlining the maintenance tasks and procedures to prevent, rectify and restore possible failures endangering safety of flight. ICA can be supported by additional manufacturer's guidance like Master minimum equipment list (MMEL) which includes aircraft equipment failures not affecting safety of the intended flight under certain conditions and associated instructions on how to prepare the aircraft for such a flight.

For the military aviation an airworthiness itself is not the ultimate priority. Military aircraft must be combat effective and supportable at the operation stage with acceptable associated costs level. Supportability defined as an aircraft or part fitness for support at the operation stage. Process of achieving the required level of supportability is also based on manufacturers' analysis and development of documents and data outlining the maintenance tasks and procedures to prevent, rectify and restore possible failures affecting the aircraft operation. Starting point in this process is LSA defined as techniques and processes to analyze an aircraft type design in order to establish and comply effective scheduled maintenance and other supportability requirements and provisions throughout the life cycle of an aircraft.

Important to say that LSA is a core element of the whole set of PLCM technologies defined as a part of the development, production, operation, maintenance (repair, modification), and disposal (recycling) activities which include controlled influence on the aircraft type design, production environment, operation and maintenance systems intended to achieve an overall effectiveness of an aircraft with a reasonable level of its life cycle cost (LCC).

Highly integrated PLCM information environment for future aircraft requires revision of currently used methodologies for ICA development and LSA. The paper intended to present certain existing methodical issues and modified methodology for development of a new aircraft scheduled maintenance requirements and airworthiness limitations. New approach will provide for more effective ICA/LSA processes and add possibilities for airworthiness and supportability interface between the aircraft manufacturer and operator.

2 Airworthiness vs Supportability

2.1 Requirements and Procedures

Civil aircraft airworthiness requirements are a part of international and national air law, which include continuing airworthiness requirements and procedures within the international standards of Annex 8 to Chicago Convention and current aviation regulations (like USA FAR / EU Part 21, USA FAR / EU CS 25, USA FAR 121 / EU Parts M & OPS, etc.).

These requirements are reflect two necessary conditions to be achieved (Fig. 1):

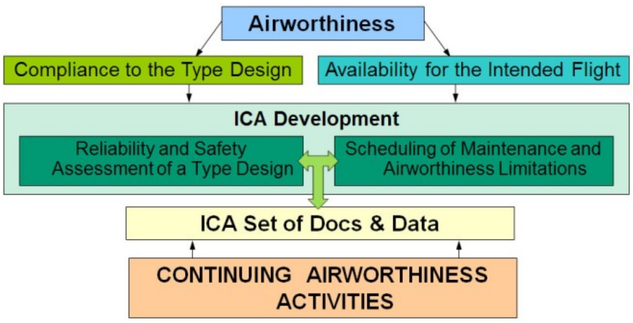

Fig. 1. Aircraft Airworthiness.

- Compliance of the aircraft or part to its approved type design; and
- Availability for the intended flight which means that the aircraft (its engine, propeller or part) are in a condition for safe operation.

Airworthiness assurance at the aircraft operation stage is based on continuing airworthiness processes by which the aircraft complies with the applicable airworthiness requirements and remains in a condition for safe operation throughout its operating life. ICA forms basic set of the instructions for operator to allow for successful continuing airworthiness processes.

To develop ICA manufacturer ought to perform reliability and safety assessment of the aircraft type design and subsequent special analysis needs to establish initial requirements and procedures for the aircraft maintenance and airworthiness limitations subject to approval by the state of design of the aircraft. ICA includes documentation (manuals) and data to be used by an operator when establishing his own aircraft maintenance program subject to approval by the state of registry of the aircraft.

Military aircraft supportability requirements are a part of military directives and standards, which include LSA required procedures within the adopted standards, handbooks and specifications (like USA DoD Directive 5000.1, Instruction 5000.2, MIL-HDBK-1388-1 & -2, DEF STAN 00-60, etc.).

These requirements have a lot of similarity with those for airworthiness (Fig. 2).

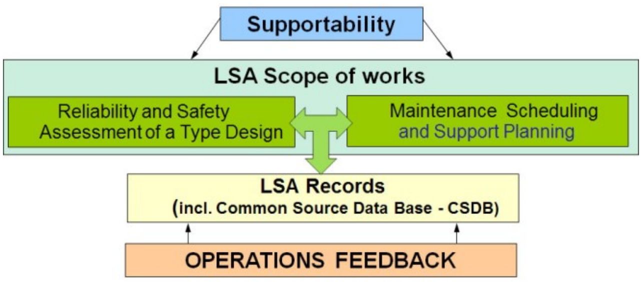

Fig. 2. Aircraft Supportability.

However, some specific takes place. Conditions of compliance of the aircraft or part to the approved type design and availability for the intended flight (condition for safe operation) also have to be met. At the same time military aircraft combat effectiveness and reasonable support expenses were always more important than just a flight safety. That's why military aircraft manufacturer also has a requirement to

perform reliability and safety assessment of an aircraft type design but not only for safety reasons. Additional LSA was introduced to cover both safety and support features of the aircraft. Results of the LSA include initial requirements and procedures for the aircraft maintenance and airworthiness limitations (very similar to ICA) complemented by additional documentation (manuals) and data on the aircraft support planning to be used by an operator when preparing an overall maintenance system for the aircraft acquired by him. New feature of LSA, which is very important for ICA improvement, is one LSA output namely electronic common source database (CSDB). CSDB integrates part of the analysis results in the form of different types of data modules containing all necessary information for the aircraft continuing airworthiness and support. All required ICA publications can be easily compiled from CSDB by selecting respective data modules.
Later on, this military-type approach became viable also for civil aircraft programs due to increased concerns with operations issues and LCC limitations. Either civil or military aviation operators faced a lack of investments and higher risks of doing business. As a result there is a trend to PLCM approach and a shift from traditional **product** support to **customer** support concept in relationship between aircraft manufacturers and operators (Fig. 3).

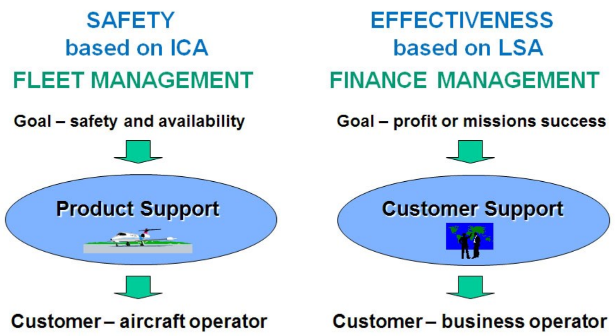

Fig. 3. Product to Customer Support Evolution.

These means safety based on ICA is not enough. Under product support concept ICA used to be a tool to achieve aircraft fleet safety and availability, intended for the customer who just keep aircraft flying. Concept of customer support is a part of PLCM and aimed at the operator's business to be profitable or - in military aviation - operations to be combat and economically effective.
In both cases the LCC level become important and can be evaluated and assured through the efficiently implemented LSA.

2.2 Current Methodical Approach

From the above mentioned it is clear that airworthiness and supportability requirements both aimed at aircraft operation support using the effective maintenance program that prevents dangerous failures consequences and has no unnecessary economic burden.
Development of the effective maintenance programs since 70^{th} years of the last century is based on the proven concept of the Reliability-Centered Maintenance (RCM) proposed by F. Nowlan and H. Heap (United Airlines, USA) [1]. Witin the civil aviation community this approach was implemented in the form of internationally recognized ATA MSG-3 guidance document [2] later used as a baseline for the military products guidance S4000M [3] published by the Aerospace and Defence Industries Association of Europe (ASD).
At the same timeframe LSA methodology was developed and implemented in military aviation. Most recent handbook (S3000L [4]) covering LSA methods and procedures is also published by ASD.

2.3 Need for Unified Methodology

Brief review presented above shows that civil and military aircraft historically have formally different but in fact very similar requirements concerning the airworthiness and supportability respectively. Moreover, there is a strong trend for integration of the airworthiness and supportability efforts in the PLCM technologies.
To achieve airworthiness and supportability goals both ICA and LSA processes are aimed at aircraft operating capabilities insurance (primarily availability, maintenance scheduling and control) under established airworthiness limitations and LCC target.
Both processes are based on the results of the aircraft type design reliability and safety assessment to be performed by manufacturer.

Due to commonality of input data joint reliability-maintenance model could be used in either ICA development or LSA processes. Joint electronic definition of the aircraft systems and structure would be implemented to decrease PLCM expenditures and overall aircraft LCC. Software tools also should be unified as much as possible.

From the other hand about forty years of developments have shown that initial RCM approach already old enough and cannot be effectively used in modern PLCM technologies. A number of issues within RCM methodology as it was outlined in the ATA MSG-3 document were found by international efforts (papers [5-7] for example). These known deficiencies could be summarized as follows:

1 Low level of formalization of procedures and algorithms, which leads to the high document user qualification requirements and need for the special policy and procedures handbooks for particular project. Direct use of the MSG-3 or S4000M is very difficult for those not well-experienced and could lead to mistakes in decision making.

2 Need to arrange special set of input data - "maintenance/structural significant items (MSI/SSI)", their possible failure modes (FM) and other parameters - instead of direct link to the database of the qualitative and quantitative results of reliability and safety assessments of the aircraft type design. This leads to additional burden because methodology not allow for direct use of common database.

3 MSI/SSI concept covers both systems and components. This leads to the uncertainty whether you analyze a system or component failure and could provoke mistakes.

4 MMEL considered as an input set of data, which is wrong because this list could only be developed as one of the RCM analysis results.

5 Indefinite "safety / operating capability / economic effects" of MSI/SSI failures is used instead of certain failure conditions (including aborted take-offs, in-flight diversions and more serious failure consequences) all already known from the reliability and safety assessments.

6 Lack of procedure to use data from the in-flight monitoring systems (like flight data recorders - FDR or centralized maintenance computers - CMC) that can facilitate finding of failures.

7 Lack of quantitative methods for maintenance intervals optimization. Only general guidance is provided in [1-3].

All these deficiencies should be revisited and eliminated to the maximum possible extent in the unified methodology to be developed.

3 Proposed Unified Methodology

3.1 Unification Approach

RCM concept can be kept as a basis after elimination of its above-mentioned deficiencies. Decision logic used in RCM process (ref. [1-3] for details) should be refined.

Tool for quantitative maintenance intervals optimization is essential and already developed for certain kind of maintenance tasks.

Analysis procedures should be defined more formally and clear to decrease qualification requirements for engineers-analysts.

Tools for solving additional LSA tasks should be proposed taking into account the need for integration of the whole methodology with the same:

- Math model;
- Set of initial data;
- Integrated output database.

3.2 Math Model

There is a strong need for such unified methodology to have a math model outlining mathematically correct but simple enough quantitative relations between aircraft safety, reliability and maintenance program.

Airworthiness requirements prescribe that all aircraft hidden (latent) failures need to be discovered and rectified in a timely manner. The methods for discovering hidden failures may include:

- Failure monitoring and warning systems;
- Scheduled maintenance (operational or functional checks of the on-board systems and components);
- Special kind of checks - "certification maintenance requirements" (CMR).

First and last ones of listed positions are comprise special area of interest for system engineers and safety-reliability analysts. Let's have a closer look at scheduled aircraft maintenance development for which the above-mentioned RCM principles postulate the inclusion into a maintenance program only effective tasks - means tasks intended to prevent or find and restore certain aircraft failures.

The idea of the methodology in general would be the logical extent of the failure mode and effect analysis data to the maintenance and supply planning processes since early stages of the aircraft design and testing.

It is clear that in most cases failures on-board the aircraft are inevitable. For analysis purposes all anticipated failure can be divided in two groups: (1) evident to the flight crew during performance of normal duties and (2) hidden which means non-evident to the crew.

Concept of failure-related aircraft safety is illustrated with Fig. 4.

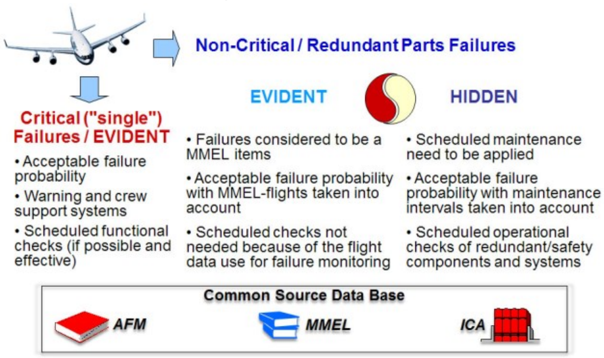

Fig. 4. Concept of Failure-Related Safety.

Hidden failures are subject for scheduled maintenance and timely restoration tasks to keep the aircraft airworthiness. Proposed intervals for the maintenance checks should be optimized to achieve low maintenance cost while maintaining required failure probabilities.

Within evident group any single hazardous failure principally shall be eliminated or - with limited design capabilities - the probability of such a failure shall be limited in accordance with the airworthiness requirements and a flight crew should be supported by the warning and flight parameters information systems.

Evident failures of redundant elements generally have no safety effect and could be treated the same way as hidden failures. Restoration tasks have to be established and their intervals to be optimized without necessity for establishing scheduled maintenance checks.

These tasks have the same physical nature as maintenance tasks listed in the maintenance program but they forms separate document - MMEL to be approved by the airworthiness authority separately or as a part of the aircraft flight manual (AFM).

It is important to note that within the proposed methodology all the data from above mentioned documents should be handled in the integrated database - CSDB in the unified form of data modules (more details on CSDB content could be found in ASD S1000D [7]). Later on the aircraft life cycle this CSDB data (or traditional paper manuals) are implemented by operator in his documents (operations manual, maintenance program, maintenance control manual, etc.).

Reason for the same nature of hidden and evident failures in the fault-tolerant systems is their similar restoration policy. For a hidden failure of redundant item restoration interval will be the interval of scheduled maintenance check with subsequent item repair. And for an evident failure (MMEL-covered) this restoration interval will be the allowed time for the component to be unserviceable.

Aircraft designer always have a choice when considers redundant items failures. Sometimes it is more effective to keep them hidden, not alerting the flight crew and not spending on failure warning systems, but with the mandatory development of scheduled maintenance task(s). In other cases on-board failure monitoring is preferable. Then redundant items failures have to be covered by the MMEL procedures but with elimination of the scheduled maintenance check(s).

Basic reliability assumptions for the aviation systems are as follows:

- In general terms an aircraft has a number of systems each may be regarded as consisting of a number of elements each having limited number of FM with constant failure rates;
- Failures are detected in flight and on the ground and are corrected (restored) during maintenance;

- Corrective maintenance (repair) after the failure finding assures system restoration in a specified time;
- For highly reliable aircraft systems repair time considered negligible with respect to mean time between failures;
- The inspections are nearly perfect (most failures under control are detected and fixed with no new failures introduced as a result of maintenance).

Under these assumptions the Markov homogeneous process may be used in the math model for the aircraft systems safety/reliability assessment and maintenance planning. These model was proposed earlier and considered in detail in the paper [8].

3.3 Initial Data

Unified set of initial data includes:
1 General technical data on aircraft systems and parts outlining their design and operation (electronic definition of the design and functions, logistic aircraft breakdown etc.).
2 Results of the aircraft failure mode and effect analysis (FMEA):

- Expected FM for the systems and components;
- Average probability per flight hour (FH) for each expected failure mode;
- Effect of each expected FM on the aircraft operation: failure condition in flight and dispatch reliability effect (DRE);
- Actual data or prognosis for each expected FM allowing to decide if its probability is a flight hour dependent (FHD) or not;
- Each component FM functionality parameter (FP) reflecting the component redundancy.

3 Initial data on the systems maintainability to support analytical decisions when choosing:

- Components primary maintenance processes (PMP);
- Maintenance tasks: operational/ functional checks, lubrication/servicing and restoration tasks);
- Mandatory redesign measures if needed for any reasons: redesign mandatory, safety accident (RMSA); RM, safety incident (RMSI); RM, dispatch reliability (RMDR); RM, operational check (RMOC); RM, functional check (RMFC); RM, lubrication/servicing (RMLS); RM, restoration of an item (RMRI).

3.4 Methods and Techniques

It is clear that generally, with all the necessary initial information available, the quantitative substantiation of an effective maintenance schedule means ensuring the required safety and effectiveness of an aircraft operation while minimizing the maintenance specific cost (per 1 FH) or LCC as a whole. Main difficulty here is a quantitative validation of meeting the aircraft design goals, which requires an adequate analytical model of maintenance influence on the aircraft safety and effectiveness criteria.
Real alternative for the accurate quantitative approach is the rational combination of the qualitative RCM-type engineering analysis, to select the PMPs and maintenance tasks, and quantitative maintenance intervals optimization. This allows to implement formal procedures to analyze influence of possible failures with applied scheduled maintenance and MMEL on aircraft safety, reliability and economics.
Aircraft scheduled maintenance analysis covers:

- PMPs and maintenance tasks selection for each component taking into account possible failures;
- Intervals optimization for the developed scope of maintenance tasks;
- MMEL development as a compliment to the maintenance schedule.

Below a general outline of the methodology is provided with more detail explanation just for certain novels. Additional reading on the matter could be found in publications [6, 8-11].
Maintenance tasks development requires three levels of RCM-type decision logic analysis: level 1 deals with systems failures, levels 2 and 3 deal with components failures.

Level 1 intended to categorize all possible FM for the particular system into four functionality effect categories (FEC, depending on severity of the FM consequences) and evaluate the necessity of the system scheduled operational checks which allow for timely finding of failures and timely system restoration.

Level 2 allows to categorize each component failure significance (SC) in accordance with:

- FM effect on system and aircraft operation (use FEC);
- Redundancy level (use FP);
- Anticipated probability and physical nature of the FM (use FHD and DRE).

In addition components PMPs (hard time, on-condition or failure monitoring) have to be selected at level 2 for logistic optimization and supply planning within the LSA process.

Level 3 analysis is the components design evaluation to select necessary scheduled maintenance tasks which preventing failures or timely finding failures out and timely restoring the component airworthiness taking into account the SC established for each component's FM.

Possible redesign to be proposed at all levels of analysis if system or component design and/or installation are not in compliance with the airworthiness and operational requirements (RMSA, RMSI, RMDR, RMOC categories of redesign) or component design and/or installation are not allow for accomplishment of required maintenance tasks (RMOC, RMFC, RMLS, RMRI categories of redesign).

Optimization of the maintenance intervals for redundant components checks divided in three steps (other maintenance intervals need expert assessment):

1 Determination of the unreliability functions for each system FM and maintenance cost function for the system using following data:

- Component FM and their probabilities;
- Typical flight and its phases duration;
- Parameters of unknown maintenance task intervals to be optimized;
- Scheduled and unscheduled maintenance tasks known or expected costs.

2 Optimization of each maintenance task interval using LaGrange's method for convex functions case and proposed math model.

3 It is also possible to form maintenance packages with associated rational intervals adopted from the optimized individual task interval values using known base maintenance intervals (A, B, C, D - checks structure).

4 MMEL development process is based on the same methodical approach and math model. It is aimed at development of instructions to aviation personnel on how to prepare a flight with certain failures on-board not affecting safety.

Significant improvement was made in the thorough dividing of the system's and components' anticipated failures analysis. Newly proposed level 1 and level 2 decision logic diagrams are intended to replace those of ATA MSG-3 and ASD S4000M [2, 3].

Decision logic diagram for system failures analysis (Fig. 5) considers a number of safety and operations aspects (most of them not covered in traditional RCM analysis):

- Evidence of the system FM to the flight crew (question 1 on the diagram);
- Most serious failure effect caused by the system FM (question 2);
- If system FM leads to an aborted take-off/diversion when in flight (question 3);
- If FDR/CMC recorded data allow for finding the system FM (question 4);
- If scheduled system operational check applicable and effective to find system FM (question 5).

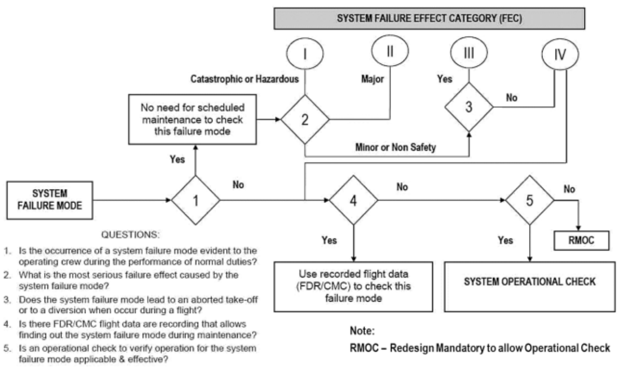

Fig. 5. Decision Logic Diagram for System Failures Analysis.

Level 2 decision logic for component failures analysis also differs very much from traditional RCM logic but more practical to present it in the form of decision matrix not schematic diagram.

Table 1 - Defining Significance Categories 1, 2 or 3 for Mechanical Failures (damage or jam).

Probability of failures & combinations there of	System failure mode with FEC I				System FM with FEC II		System FM with FEC III		System FM with FEC IV	
	$FP=1$	$FP=2^{EI+}$	$FP=2^{EI}$	$FP\geq3$	$FP=1$	$FP\geq2$	$FP=1$	$FP\geq2$	$FP=1$	$FP\geq2$
EI	**1**	**1**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
ER	**RMSA**	**1**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
R	**RMSA**	**1**	**3**	**3**	**2**	**3**	**3**	**3**	**3**	**3**
P	**RMSA**	**1**	**3**	**3**	**2**	**3**	**2**	**3**	**3**	**3**
P+	**RMSA**	**1**	**3**	**3**	**2**	**3**	**2**	**3**	**3**	**3**

Notes:

1 Probabilities thresholds (average, per 1 FH): probable (P) - $1\cdot10^{-4}$ ... $1\cdot10^{-2}$, remote (R) - $1\cdot10^{-7}$ ... $1\cdot10^{-5}$, extremely remote (ER) - $1\cdot10^{-9}$ ... $1\cdot10^{-7}$, extremely improbable (EI) - less than $1\cdot10^{-9}$

2 For each system FM of certain FEC (I, II, III и IV) a number of elements FM combinations to be considered each having its own functionality parameter FP (1, 2 & more, 3 & more)

3 For double failures causing FEC I system FM two cases to be considered:

1) when combination of 2 elements failures is not more than EI ($FP=2^{EI}$) and

2) when ore probable ($FP=2^{EI+}$)

4 All mechanical failures are considered as a flight hour dependent (FHD)

5 System considered to be redesigned if established analysis criteria are not met

Table 2 - Defining Significance Categories 1, 2 or 3 for Non-mechanical Failures (electrical, electronic, etc.).

Probability of failures & combinations there of		System failure mode with FEC I				System FM with FEC II		System FM with FEC III		System FM with FEC IV	
		$FP=1$	$FP=2^{EI+}$	$FP=2^{EI}$	$FP\geq3$	$FP=1$	$FP\geq2$	$FP=1$	$FP\geq2$	$FP=1$	$FP\geq2$
ER	FHD	**RMSA**	**1**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
	Non-FHD	**RMSA**	**RMSA**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
R	FHD	**RMSA**	**1**	**3**	**3**	**2**	**3**	**3**	**3**	**3**	**3**
	Non-FHD	**RMSA**	**1**	**3**	**3**	**RMSI**	**3**	**3**	**3**	**3**	**3**
P	FHD	**RMSA**	**1**	**3**	**3**	**2**	**3**	**3**	**3**	**3**	**3**
	Non-FHD	**RMSA**	**1**	**3**	**3**	**RMSI**	**3**	**3**	**3**	**3**	**3**
P+	FHD	**RMSA**	**1**	**3**	**3**	**2**	**3**	**3**	**3**	**3**	**3**
	Non-FHD Non-DRE	**RMSA**	**RMSA**	**3**	**3**	**RMSI**	**3**	**RMSI**	**3**	**3**	**3**
	Non-FHD DRE	**RMSA**	**RMSA**	**RMDR**	**RMDR**	**RMSI**	**RMDR**	**RMSI**	**RMDR**	**RMDR**	**3**

Notes:

1 Probabilities thresholds (average, per 1 FH): probable (P) - $1\cdot10^{-4}$ ... $1\cdot10^{-2}$, remote (R) - $1\cdot10^{-7}$ ... $1\cdot10^{-5}$, extremely remote (ER) - $1\cdot10^{-9}$ ... $1\cdot10^{-7}$, extremely improbable (EI) - less than $1\cdot10^{-9}$

2 For each system FM of certain FEC (I, II, III и IV) a number of elements FM combinations to be considered each having its own functionality parameter FP (1, 2 & more, 3 & more)

3 For double failures causing FEC I system FM two cases to be considered:

1) when combination of 2 elements failures is not more than EI ($FP=2^{EI}$) and

2) when ore probable ($FP=2^{EI+}$)

4 System considered to be redesigned if established analysis criteria are not met

Decision logic illustrated in the Tables 1 and 2 for two main groups of component failures (mechanical and non-mechanical) is based on the earlier defined categories to reflect severity of each failure consequences (depends on system failures FEC), redundancy level, anticipated probability and physical nature of each component FM.

Component SC are necessary to define its PMP which depends on the inherent system/component reliability and physical nature of possible failures.

Four kinds of FECs (ref. Fig. 5) for systems FM shows system failures influence on the flight safety from more (I) to less (IV). Three kinds of SCs for components shows component-level failure influence on the airworthiness and flight safety from more (1) to less (3).

For all three significance categories both hard time and on-condition component maintenance could be applicable and effective with certain maintainability and testability requirements.

Condition monitoring maintenance is only applicable for the components having SC 3.

Maintenance tasks development and optimization of maintenance intervals is not presented in detail for the following reasons:

- Proposed decision logic for components failures analysis are very similar to those of ATA MSG-3 [2] with some additions (like more detail decisions on functional vs operational checks, ref. [9-11]);
- Decision logic for the airframe structural elements analysis is well-defined in ASD S4000M, no additions proposed at the moment;
- Proposed methodology of maintenance intervals optimization is a mix of traditional expert approach for all tasks except set of tasks to find and restore redundant components failures, which covered by developed quantitative optimization technique.

Proposed method for optimization of the maintenance checks for redundant components failures is based on the following approach. All components FM numbered from 1 to B to identify unknown check interval τ_β $(1 \le \beta \le B)$ in FH, which is an interval of a β failure check and its subsequent restoration. In order to optimize τ_β it is necessary to have dependences of the system FM probability (Q_α, $1 \le \alpha \le A$) from the probabilities of the component failures q_β and τ_β

$$Q_\alpha = f(\tau_1, \ldots, \tau_\beta, \ldots \tau_B). \tag{1}$$

These dependences can be established using method described in [8] and have to be used in showing compliance with the airworthiness requirements distributed in "top-down" manner from the aircraft level up to the normative level of certain system α FM - Q^n_α - shown below

$$Q_\alpha = f(\tau_\beta) \le Q^n_\alpha. \tag{2}$$

Because of the variety of intervals satisfying (2) there is a need for optimization criteria which can be a specific direct maintenance cost (C_s):

$$C_s = C_{s.m} + C_{s.r}, \tag{3}$$

where $C_{s.m}$ - specific check cost (in money value per 1 FH) to be calculated as follows

$$C_{s.m} = f \cdot \sum_{\beta=1}^{B} \frac{T_\beta}{\tau_\beta}, \tag{4}$$

where T_β - labor expenses (in man-hours - MH) for scheduled check of the component's β FM;

f - average labor cost (in money value per 1 MH);

$C_{s.r}$ - specific replace cost (in money value per 1 FH) to be calculated as:

$$C_{s.r} = f \cdot \sum_{\beta=1}^{B} \frac{T_r}{\tau_\beta}, \tag{5}$$

where T_r - labor expenses (in MH) for replace of the component with β FM.

Minimum for C_s under conditions (2) can be found as follows:

1 Lagrangian is compiled

$$\boldsymbol{L}(\tau_\beta, U_\alpha) = C_s(\tau_\beta) + \\ + \sum_{\alpha=1}^{A} U_\alpha [Q_\alpha(\tau_\beta) - Q^n_\alpha], \tag{6}$$

were U_α - undetermined Lagrange's non-negative multipliers;

2 System of equations is developed that forms necessary and sufficient conditions for the existence of a saddle point of the Lagrangian:

$$\frac{dL}{d\tau_\beta} = 0,\ \beta = 1 \ldots B, \\ Q_\alpha(\tau_\beta) - Q^n_\alpha = 0. \tag{7}$$

3 System of equations (7) is solved and τ^*_β values for the Lagrangian's saddle point are found which minimize expression (3) in compliance with the conditions (2).

There are some additional features to solve correctly the discussing problem but them should be considered separately (ref. [6, 8, 10]).

Next step is MMEL development. This is an optimization task for the restoration intervals of anticipated evident failures of redundant components. Methodically this problem is completely similar to hidden failures restoration policy (these failures have to be covered by the scheduled maintenance tasks) with only change the maintenance check interval for the hidden failures with the restoration interval for the evident failures. Details of this process are also out of the frames of the paper.

Nevertheless, the overall methodical approach is comprehensive and allows logical integration of ICA development and LSA processes.

4 Conclusion

As have been shown above there are two coherent approaches:

- To develop aircraft ICA as an airworthiness tool for civil aircraft and
- To accomplish LSA as a supportability tool mostly for military aircraft.

Both approaches have a lot of commonality being, however, implemented separately. This commonality calls for unified methodology to achieve the goals of effective scheduling of an aircraft maintenance and operations support.

Unified methodology is proposed, which is based on the proven RCM concept with elimination of its known deficiencies and integration of existing and new tools for solving ICA/LSA issues using common:

- Math model allowing quantitative optimization of certain maintenance tasks intervals;
- Set of unified initial data;
- Integrated output database (LSA record/ CSDB).

New approach allows to link development of ICA with other LSA activities including, in particular, MMEL preparation as a tool to optimize an aircraft usage with certain allowable failures. ICA development have to be considered as part of LSA and, finally, as part of the PLCM set of technologies for the development of a new type of aircraft or other complex technical system.

Proposed methodology facilitates effective ICA development and LSA processes within PLCM using the common LSA database and electronic definition of aircraft [12].

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