

Supply of Technical Materials for the Aviation Warehouse in Accordance with the Basic Principles of Safe Flight

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Abstract – aviation industry develops so fast that manufacturers are unable to supply components in time. Aviation companies work on improvement of their warehouses by introducing various mathematical and statistical methods. These methods calculate component safety life. In accordance with the regulations of the European Aviation Safety Agency (EASA) all suppliers and maintenance organizations shall comply with certain restrictions. The study provides information on the basic principles of mathematical and statistical methods of component safety life. The article gives information about the warehouse work in accordance with EASA requirements.

Keywords – Analysis, components, flight safety, regulations, warehouse.

I. INTRODUCTION

Continuous amendments to aviation laws and the development of technologies in the industry cause the aircraft technical maintenance strategy to be more flexible and at the same time aviation companies to be more careful using all new products. Aviation industry hadn't been able to experience such a rapid development in terms of component change in the past as nowadays. Revenue information for the last nine years shows that some of airlines went bankrupt. Due to that new changes were introduced in companies like Air France-KLM and Lufthansa Group, AirBaltic, Qantas Group. At the same time, it brought new opportunities and different changes for long time [1]. Analysing data on technical depreciation of components and supplementing the existing data with new statistical data on the financial performance indicators in the aviation sector, it can be concluded that the demand for new components is increasing along with the aircraft operations. The current resources and production volumes are not able to provide the parts for such a significant increase in the operation of aircraft scheduled and unscheduled maintenance activities [2].

The spare part inventory management business is central to the operational efficiency of an airline. After calculating the demand for every individual part number, generally in a spreadsheet format, the next step would be to sort the main number of parts [3].

One of the key requirements for components is a must to have EASA Form 1 which is the Authorized Release Certificate released by a post holder for a product. It shows that the component was manufactured in accordance with approved/not approved design data. If the component does not have EASA Form 1, it has to be included in risk groups that affect the safe operation of the flight (EASA Annex 1). For more accurate and rigorous monitoring, it is necessary to comply with EASA Regulation (EU) 2015/1536, Annex I, Sub-paragraphs related to the removal and installation of aircraft components and certification requirements [4].

Form 1 defines how the tests are to be performed on a component, as well as the time limit for operating the component. The certificate is important for receiving components at a warehouse as well as for the further transfer of components under the supervision and installation by certified personnel on the aircraft. All Form 1 certification requirements must be met when ordering

components and sending them for storage in warehouses that are specifically identified by the requirements of the regulation, as well as for performing safe flight functions [4].

II. COMPONENT RELIABILITY IN A WAREHOUSE

The safe flight function component is determined by the operating time calculated by the formula:

$$R_t = 1 - P_t, \quad (1)$$

where

R_t – system working time;

P_t – period under certain operating conditions.

The formula given above determines the duration of operations of each system and the whole system operation. Since each sub-system includes more than one component, each of them has its own operating time.

In aviation, each component is divided into category groups according to aircraft systems and their specific use. Companies use ATA (Air Transportation Association) published a numbering system to learn and understand the technical features of an aircraft. ATA chapters make it easy to categorize components for use. All maintenance companies and such factories as Boeing and Airbus use the ATA system [5]–[13]. The largest component group is created after the running time components or hard time (HT) components are grouped. Hard time components require a specific action at a specific interval (overhaul, refurbishment, bench check, etc.) as prescribed by the manufacturer's recommendations. Soft time components are replaced after an interval chosen by an operator to be done at a specific interval but may be adjusted to fit their operational schedule. An interval for component replacement may be recommended by the manufacturer. Components are also replaced as soon as they have run out. It means a component has to be replaced if it is broken or its operating time is coming to an end. The next group is On-Condition and Condition Monitoring components which are inspected periodically or checked against some appropriate physical standard to determine if they can continue to be in service. The third group consists of components that are operated to failure. Most of these components are available and can be safely operated without failures.

Since there are aircraft components that do not have strictly defined operating time, it means that components are intended for a long period of time or the probability of component failure does not depend on the running time. In this case, there is no sense in performing maintenance at intervals.

It is more expedient to perform component monitoring. Therefore, it is recommended to use statistical data from databases owned by Boeing or other companies like Bombardier or Airbus which use data for component storage [1]. Statistical analyses are being gradually developed making it possible to build a record-keeping system. Component flow monitoring has to be used when the component works very well. All components wear out over time, their performance is reduced and component replacement or repair is required. Therefore, constantly researching such statistics, it is easier to make flow calculations, and, of course, sudden failures should also be considered. To evaluate the warehouse operation efficiency SWOT analysis is used. A SWOT (Strength, Weaknesses, Opportunity, Threats) analysis is a strategic tool for mapping out strengths, weakness, opportunities and threats a company is. In this study the analysis helps to analyse information on warehouse reliability [3].

III. THE EASA FORM 1

The EASA Commission Regulation (EU) 2015/1536, Section E, provides an overview of the Component Regulation which sets out how to install a component on an aircraft with the help of Form 1. The EASA Form 1 certificate is defined by the by the Commission Regulation (EU) of

3 August 2012 No 748/2012 Annex I (Part-21), Commission Regulation (EU) No 1321/2014 Annex I (Part M) and Annex II (Part-145) Section A [6]–[7].

The Form 1 is mandatory for installing a component on an aircraft, as well as for keeping component at storage. For the installation of components that are made of raw material or consumable materials it may be specified by the manufacturer. Aircraft component documentation should be described in the relevant maintenance documentation or as specified in Annex II Part-145. The materials and components used for the certain aircraft system must meet the production and delivery standards and the requirements for traceability from the manufacturer and distributor after the component has been accepted by the warehouse. All materials must be accompanied by supporting documentation clearly related to the component. Source of production and supply on the specification statement must be mentioned [7].

Components are delivered to the warehouse before being handed over to engineers and technicians. A trained person who receives a component from a supplier checks its condition and all accompanying documents confirming the quality. The maintenance organization and logistic department must carry out checks and verification prior to the installation of components on board, thus avoiding the reduction of flight safety.

Information about specific works and repairs of components is included in the maintenance manuals. For Boeing aircrafts, we can use Aircraft Maintenance Manual approved by EASA. All instructions for component repair and replacement are approved according to EASA (EU) 2015/1536 regulation of 16 September 2015, which includes information about all maintenance procedures.

The following procedure is carried out: firstly, the overall condition of the components and their packaging is checked for damage that could affect the integrity of the components; secondly, the expiry date of a component is checked; and finally, it is checked whether the item has been received in the appropriate package. A component should be packaged in an appropriate way according to the degree of hazard to prevent any damages. If a component is electrostatically sensitive, the packaging must meet the requirements for this device [8].

To prevent damages, before putting the component into service, the warehouse has to make sure that all plugs and caps of the received component are properly installed. The adhesive tape should not be used to cover electrical connections or fluid joints. The tape should not be used to cover electrical connections or fluid connections and openings, as adhesive residues can isolate electrical connections and contaminate hydraulic or fuel system components. The EASA Form 1 is only a small part of the in case of claim against the coordinator.

It should be noted that faulty parts can be removed from an aircraft only by certified personnel approved in accordance with Section A of subpart F of Annex I (Part-M) or Section A of Annex II (Part-145). The status of a component must be clearly stated a tag or component identification data must be provided and all the information about fault mentioned [9].

Information on the service life of a component should include the maintenance status, conservation status, failures, defects or malfunctions, or detriment to environment if the component caused an accident or injury. This means that company should have a certificate approved by Annex II (Part-145) to prevent undesirable use of the component in the future. Once a component contributed to the reduction of flight safety it is placed in a special place in a warehouse indicating the unfitness of the component for use. Components that were involved in incidents are immediately sent for examination [10]–[14].

Components that are out of service must be destroyed for preventing a “back to the market” scenario. Some airlines still use such “services” to get cheaper spare parts. The consequences can be fatal.

IV. CALCULATION OF COMPONENTS FAILURE

To calculate the probability of component failure, the following formula is used:

$$F(t) = \frac{n_F}{n}, \quad (2)$$

where

n_F – number of damaged components;

n – all components.

After determining the probability of failure, component safety can be determined by the following formula:

$$R(t) = \frac{n_s}{n}, \quad (3)$$

$$F(t) + R(t) = 1, \quad (4)$$

where

n_s – number of undamaged components;

n – all components.

The probability density of the failure is stated in (5).

$$f(t) = \left(\frac{n_{F,\Delta t \rightarrow 0}}{n} \right) \quad (5)$$

$f(t)$ from formula (5) gives (6).

$$F(t) = \int_0^t f(t) dt \quad (6)$$

The failure of each component can be determined in more detail. Below the failure rate per 1 FH or (Flight Hour which means each hour or part thereof elapsing from the moment at which the wheels of the aircraft leave the ground on the take-off of the aircraft until the wheels of the aircraft touch the ground on the landing of the aircraft following such take-off [15]) is used.

$$\lambda(t) = \frac{n_{F,\Delta t \rightarrow 0}}{n} \cdot \frac{n}{n_s} = f(t) \cdot \frac{1}{R(t)} \quad (7)$$

$$\lambda(t) = \frac{f(t)}{R(t)}, \quad (8)$$

where

λ – failure rate.

There is another formula that does not include infant mortality and there is no age degradation.

$$R(t) = e^{-\lambda t} \quad (9)$$

$$F(t) = 1 - R(t) = 1 - e^{-\lambda t} \quad (10)$$

$$f(t) = \frac{dF(t)}{dt} \quad (11)$$

$$f(t) = -(-\lambda) \cdot e^{-\lambda t} = \lambda \cdot e^{-\lambda t} \quad (12)$$

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\lambda \cdot e^{-\lambda t}}{e^{-\lambda t}} = \lambda = \text{const} \quad (13)$$

Similarly, the average time between failures or Mean Time Between Failures (*MTBF*).

$$MTBF = \frac{1}{\lambda} \tag{14}$$

As an example, the probability of failure for a component with $\lambda = 10^{-4}$ 1/ FH at 1 and 500 hours worked could be considered.

$$F(t) = 1 - e^{-\lambda t} = 1 - e^{-10^{-4} \cdot 1} = 10^{-4} \tag{15}$$

$$F(t) = 1 - e^{-\lambda t} = 1 - e^{-10^{-4} \cdot 500} = 0.049 \tag{16}$$

$$F(t) \approx \lambda \tag{17}$$

Based on the above calculations, the component running times are counted and the calculation of failure types is listed.

After receiving information about component specific running times (also maintenance information about repairs) it is easier to build the queueing data based on statistical and mathematical models. For mathematical basis warehouse statistics which can be put into the formula:

$$Q = Q_p + F, \tag{18}$$

where

Q – total amount of inventory required;

Q_p – Stock Volume Forecast;

F – predicted standard deviation.

After that, the total amount of components for a warehouse are calculated. To avoid the formation of surplus components in the warehouse, the minimum cost of stocks is calculated:

$$TC = C_{per} + C_s, \tag{19}$$

where

TC – total cost;

C_{per} – order costs;

C_s – storage costs.

The total cost in formula (19) is calculated by counting costs for each component if it stays in the warehouse. To calculate the cost at which discounting options are not offered (C_s) means there are no discount for these parts and the cost of storage C_s of the purchased batch order. The total cost of stock replenishment is TC_{per} .

$$TC = \frac{D}{Q} AC_{per} + I \cdot AC_s \cdot \frac{Q}{2}, \tag{20}$$

where

TC – total inventory replenishment costs;

$\frac{D}{Q} AC_{per}$ – order processing costs;

$AC_s \cdot \frac{Q}{2}$ – storage costs;

D – annual demand for goods;

AC_{per} – cost of one purchase batch order;

AC_s – item unit value in stock;

I – the ratio of storage costs to the value of the product as a percentage.

Partial differentiation of the (20) gives (21).

$$\frac{\partial TC}{\partial Q} = \frac{\left(\partial \frac{D}{Q} \cdot AC_{\text{per}} \right)}{\partial Q} + \frac{\left(I \cdot \frac{Q}{2} \cdot AC_s \right)}{\partial Q} \quad (21)$$

Expression (21) is equated to zero and the EOQ – Economic order quantity (22) is:

$$Q = \sqrt{\frac{2D \cdot AC_{\text{per}}}{I \cdot AC_s}} = EOQ \quad (22)$$

Dynamics of change as well as main parameters – average inventory level Q_{av} , stock reorder point (ROP) and order execution time, stock consumption rate, pull of demand (d) – these parameters are changed in formulas. The stock reordering point ROP corresponds to the stock balance in a warehouse at a pull of demand (d) and a predetermined order execution time (t), which guarantee that the next delivery will take place when the warehouse stock is exhausted.

$$Q_{\text{av}} = \frac{Q_{\text{max}}}{2} + 0 = \frac{Q_{\text{max}}}{2} = \frac{EOQ}{2} \quad (23)$$

Average time between purchases (24).

$$T_{\text{av}} = \frac{EOQ}{D} \quad (24)$$

Average number of shipments per year (25).

$$\eta = \frac{D}{EOQ} \quad (25)$$

If the deliveries take place instantly, but the consumption rate of goods is not the same. the balance of goods in the warehouse or time to place next order at a certain pull of demand (d), as with the time (t) is determined by:

$$ROP = d \cdot t, \quad (26)$$

where

d – consumption rate;

t – order execution time.

Considering the above calculations, it is possible to predict how many components the inventory needs to replenish the warehouse. The application and use of components shows accurate cost prediction [11]–[16].

V. GLOBAL STATISTICS OF FAILURES

Looking at the global statistics of International Air Transport Association, Magnetic MRO, Lufthansa-Technical company’s safety calculations of flights related with component failures were made. For example, the Federal Aviation Service processing statistical data determines the number

of incorrectly installed components. Which is one of the main reasons for accidents or incidents [1]–[9].

Graeber and Marx work was focused on human error in maintenance: according to their introduced the installation error taxonomy – wrong part refers to the installation of a part that does not comply with manufacturers' specifications or any supplemental service bulletins. Categories of installation error include wrong part, reversed installation, incorrect attachment, omission, and incorrect connection [17]. It means that a component does not comply with the manufacturer's specification. The installation category refers to aircraft components that are changed. Incorrect instructions result in the incorrect installation of a component which is only to be secured with two or more aircraft components (e.g. nuts, bolts, washers, brackets). An example of incorrect connection is a fuel line with a truncated action. Although the fuel line is connected to the fuel tank, fuel supply also has an additional fuel transportation function between the fuel tank and fuel intake system. Next is calculated the number of specific cases N when the fuel supply is disturbed or out of order. The following formula is used to calculate the probability of error.

$$N = \sqrt{4\chi} \quad (27)$$

Then, knowing the probability of error, we can calculate the probability coefficient p .

The coefficients of any system can be calculated in the same way. To calculate the coefficient more precisely, the surrounding conditions that influence the time of component use should be considered [12].

More often accidents occur due to incorrect components. To forecast accident, any component delivered to the warehouse must be accompanied by the EASA Form 1 indicating the status of the component. The EASA Form 1 ensures flight risk reduction, as it was previously discussed, and determines the conditions of on-board component evaluation. Component forms are prepared according to the EASA Commission Regulation (EU) No 1095/2010, 748/2012 [6], [7].

Consequently, both the airline and manufacturer are responsible for operating the component. Looking at the EASA statistics, the number of serious incidents with component failures decrease every year by 10–15 % [10]–[12].

Experts in the field of operation and responsibility of each component follow in order to avoid unnecessary accidents. Form 1 gives instructions about component circulation. Form 1 should contain a specific mark about component is safe for use. This requirement, as well as the certification of the warehouse reduce risks of failure component installation.

VI. CONCLUSIONS

According to the European Aviation Safety Agency Annex I (Part-M) and Annex II (Part-145) requirements an approved certificate for component replacement provide information for correct procedures for an aircraft technical maintenance. One of the additional component procedures is to use Form 1 for component replacement in accordance with Annex I.

Form 1 is mandatory for aircraft components not only during the replacement procedures but also in a warehouse. According to the quality and warehouse standards from Annex I and on the basis of the mathematical analysis and statistics, it is possible to obtain information on component costs in a warehouse. As per mathematical calculation, it is shown what the storage costs are if the unused component is stored for a long time. Based on the information received from the warehouse about the repair of components and damage, it is possible to compile safety reports. These reports are connected with the safe service life of details and records about the safe replacement of the components. After receiving information from such companies as Air France-KLM and Lufthansa Group, Qantas and others, one can easily predict and calculate the costs of unused components. The statements from different warehouses are in accordance with regulations and restrictions and mathematical

information stated makes it easier to calculate the warehouse costs. To improve work of the responsible employees in warehouse it is necessary to avoid all unnecessary risks also follow safety instructions in accordance with Aviation Safety Reports.

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