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ANALYSIS OF FAILURE STATES OF FUNCTIONAL SYSTEMS OF AIRCRAFT SUCH AS BOEING 737 IN THE AIRLINE

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Abstract
The article presents the results of analysis of failures of the main functional systems units of aircraft Boeing 737 during the last 10 years of its operation in the national airline of Latvia 'Air Baltic Corporation'. Total flight time was T_{Σ} = 322,529 h and 184,538 cycles [1]. These data were obtained from daily reports of defects and unplanned consumption of spare parts for these systems. Failures of instrumental equipment of avionic systems were investigated in detail. Based on calculations of their failure probability and component replacement frequency, a comprehensive system including measures and their technical and instrumental support has been developed to improve maintenance productivity. Such a system requires relatively inexpensive components, is simple and can be used in the operation of this type of aircraft.

Keywords: aircraft equipment; aviation technology; probability of failure; components; functional systems
Type of the work: research article

1. INTRODUCTION

Modern aircraft are designed to be safer, more comfortable, more economical and more environmentally friendly. Fulfilling these requirements ensures aircraft airworthiness, which is confirmed through the certification process [2–4]. The challenge of maintaining the airworthiness in an airline environment is complex and multifaceted. Its most important component is the continuous monitoring and assurance of the required reliability of aircraft components [1]. Maintaining the required level of their reliability in the course of operation is carried out through a set of organisational and technical measures that are based on the assessment of the current reliability level [5–7]. An aircraft operator makes regular analyses of current reliability and, based on the statistics on component failures or replacements, calculates probabilities of no-failure operation, introduces preventive measures to eliminate future similar defects, may replace one or more component suppliers and may arrive at decisions needing to be made with regard to the organisations tasked with aircraft maintenance.

The purpose of this paper is to present the results of calculation of failure probabilities of Boeing 737 aircraft components based on the analysis of failure probability and replacement frequency during 10 years of operation in the Latvian airline 'Air Baltic Corporation' [1,8,9]. Based on the results obtained, possible solutions to improve reliability and uptime of the identified units are discussed.

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2. SAFETY ANALYSIS OF AIRCRAFT ESSENTIAL SYSTEMS

Generalised models can be used to determine aircraft safety parameters but they are not applicable to all devices and systems. For certain complex equipment or equipment that may result in particularly hazardous conditions, models adapted to the required mathematical operations are used. Since various basic aircraft systems are studied in this safety analysis, the mathematical calculations are simplified.

Tens of thousands of technical records have been made in the Air Baltic fleet over the 10 years of operation, and many components for B737 aircraft have been replaced. Excluding technical records of planned works, 45,513 defect records have been completed [10].

However, it must be understood that the total number of failures or defects will always be greater than the number of component replacements. This relationship is formed because a failure does not always indicate the need to replace a part [11]. The relative failure rate is a measure of intensity of failures in relation to the total number of defects.

$$\upsilon_s = \frac{n_s}{n_\Sigma}, \tag{1}$$

where n_s indicates the total number of system failures, and n_Σ the total number of aircraft failures.

In turn, the flow parameter will reflect similar data as the relative failure rate, only in this case it is a relation to hours flown.

$$\omega_s = \frac{n_s}{T_\Sigma},$$

where n_s indicates the total number of system failures, and T_Σ the flight hours of the aircraft in a given period of time.

The component replacement frequency indicates how often a component is replaced in the event of a component failure or system failure [12].

The data in the table are summarised in Figure 1 for greater transparency. In this diagram two significant parameters are represented: the total number of failures and the number of component replacements.

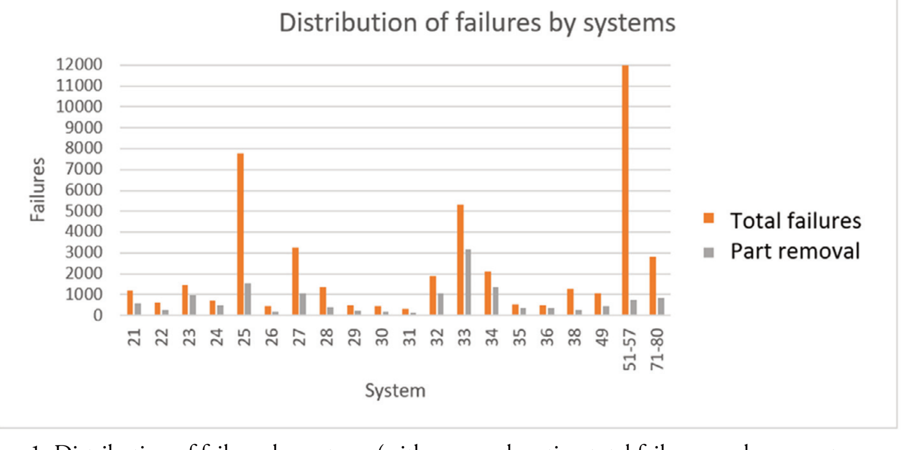

Figure 1. Distribution of failures by systems (with orange denoting total failures, and grey part removal).

The most defects are related to the structure of the aircraft, amounting to a total of 12,000 records. It may seem like a lot, but mostly the entries in the technical log about structural damage are related to things like paint damage, scratches, dents, corrosion, seal damage and so on. Therefore, with a relatively large number of defects, the number of component replacements is small, as the damaged surface or part is mostly repaired. The second highest figure is the ATA 25 – equipment and interior. The number of defects in this section is high because this ATA 25 applies to equipment installed in the cockpit and passenger compartment, toilet equipment, kitchen equipment, etc. In addition to this equipment, the ATA 25 also applies to emergency equipment available to both flight attendants and pilots. Defects are often the result of wear and tear, negligence or intentional damage by passengers. The number of components removed is also one of the largest, but it should be noted that mostly small and relatively low-cost parts are removed. In third place is the ATA 33 or lighting system. The lighting system provides lighting inside the aircraft and also outside the aircraft. The lighting system consists of cabin lighting, emergency lighting, exterior lighting, cargo compartment lighting and maintenance lighting. As the aircraft is equipped with so many lighting devices, the number of refusals is expected to be high. In most cases, the lamp is replaced and the system continues to operate without interruption.

The frequency of component replacement in relation to the number of faults is an important indicator. If a fault can be eliminated without removing the component, this is called a low-risk failure. On the other hand, three conditions can be identified in which many components are removed from system, requiring certain measures and process reorganisation:

- inadequate performance of the component;
- insufficient knowledge of technical staff; and
- planned maintenance of the system does not have the desired effect.

Examining the system does not give a clear indication of the most problematic components of the aircraft, and it is thus particularly important to keep an eye on the frequency with which individual parts are replaced.

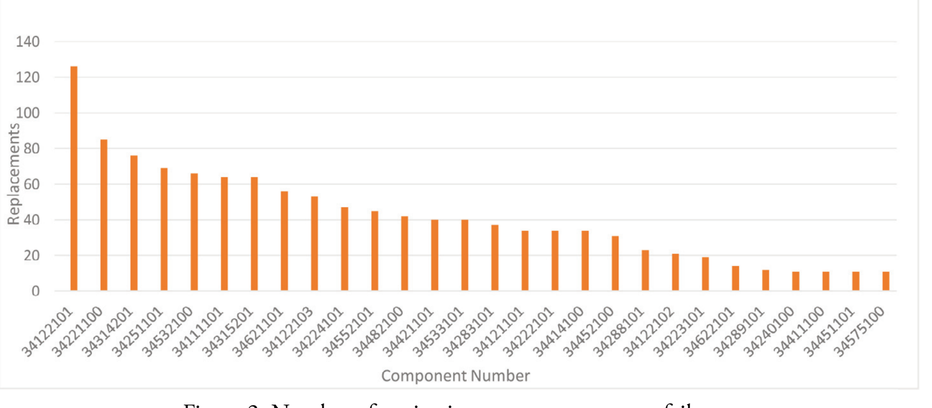

Figure 2. Number of navigation system component failures.

To reveal the details of the system component replacement, each component is assigned a unique number. In Figure 2 can be seen that at least 20 components were replaced in ATA 34 (navigation system). The one with the highest replacement number is component 34122101.

Air navigation system units with at least 50 unscheduled removals are the following: Airspeed indicator (34122101), EFIS control panel (34221100), VOR/ILS navigation unit (34314201), Standby horizon indicator (34251101), Air traffic control repeater (34532100), Pitot tube (34111101), VHF navigation control panel (34315201), FMS control panel (34621101) and Altimeter (34122103).

Analysis of such data revealed problematic points and components. However, the diagrams presented do not provide a complete picture of the safety profile of the systems. Due to the large amount of ATA and excessive analysis of each ATA, the most frequently removed components are filtered out for further analysis.

In order to carry out an in-depth examination of aircraft systems and parts and locate problematic assemblies, it is necessary to select those parts whose replacement has been unplanned.

Further in-depth component studies are carried out on avionics systems and equipment that can have a significant impact on flight safety and result in losses, delays and other additional costs to airlines. The most replaceable avionics equipment selected in the third method are shown in Table 1.

Table 1. The most frequently removed avionics devices.

No.	Name of object	Part number	Number of components replaced	t (h)	ωt	P(t)
1	Mach Airspeed indicator	2083-11-1	126	100 300 500	$1.95 \cdot 10^{-2}$ $5.85 \cdot 10^{-2}$ $9.76 \cdot 10^{-2}$	0.9807 0.9431 0.9070
2	Transmission assay constant speed	735511A	103	100 300 500	$1.60 \cdot 10^{-2}$ $4.79 \cdot 10^{-2}$ $7.98 \cdot 10^{-2}$	0.9842 0.9533 0.9233
3	EFIS Control panel	622-8001-350	70	100 300 500	$1.08 \cdot 10^{-2}$ $3.25 \cdot 10^{-2}$ $5.42 \cdot 10^{-2}$	0.9892 0.9680 0.9472
4	Standby horizon indicator	H341ANM1	69	100 300 500	$2.14 \cdot 10^{-2}$ $6.41 \cdot 10^{-2}$ $1.07 \cdot 10^{-1}$	0.9789 0.9379 0.8987
5	Panel audio select	5145-1-64	61	100 300 500	$6.30 \cdot 10^{-3}$ $1.89 \cdot 10^{-2}$ $3.15 \cdot 10^{-2}$	0.9937 0.9813 0.9690
6	VOR/ILS receiver	822-0761-001	61	100 300 500	$9.45 \cdot 10^{-3}$ $2.83 \cdot 10^{-2}$ $4.72 \cdot 10^{-2}$	0.9906 0.9721 0.9539
7	GCU	948F458-5	56	100 300 500	$5.78 \cdot 10^{-3}$ $1.73 \cdot 10^{-2}$ $2.89 \cdot 10^{-2}$	0.9942 0.9828 0.9715
8	generator	976J498-2	54	100 300 500	$5.58 \cdot 10^{-3}$ $1.67 \cdot 10^{-2}$ $2.79 \cdot 10^{-2}$	0.9944 0.9834 0.9725
9	Altimeter	2057-01-1	53	100 300 500	$8.21 \cdot 10^{-3}$ $2.46 \cdot 10^{-2}$ $4.10 \cdot 10^{-2}$	0.9918 0.9757 0.9598
10	Transponder	822-1338-003	49	100 300 500	$7.59 \cdot 10^{-3}$ $2.28 \cdot 10^{-2}$ $3.79 \cdot 10^{-2}$	0.9924 0.9775 0.9628
11	Symbol generator	622-9436-101	49	100 300 500	$7.59 \cdot 10^{-3}$ $2.28 \cdot 10^{-2}$ $3.79 \cdot 10^{-2}$	0.9924 0.9775 0.9628

The following table shows the part names, P/N and the number of components removed; the same table also additionally includes the calculation of probability of safe operation of aviation equipment of Boeing 737 Classic avionics, which is carried out according to Eq. (3).

$$P(t) = e^{-\omega t} \quad (3)$$

where ω indicates const.

The calculation of the probability of safe operation is an important component in assessing the performance and safety of components. Safe operation is calculated at different times to facilitate the possibility of estimating the number of flight hours for which a given component would be reasonably reliable. Calculations for better visibility are presented in Figure 3.

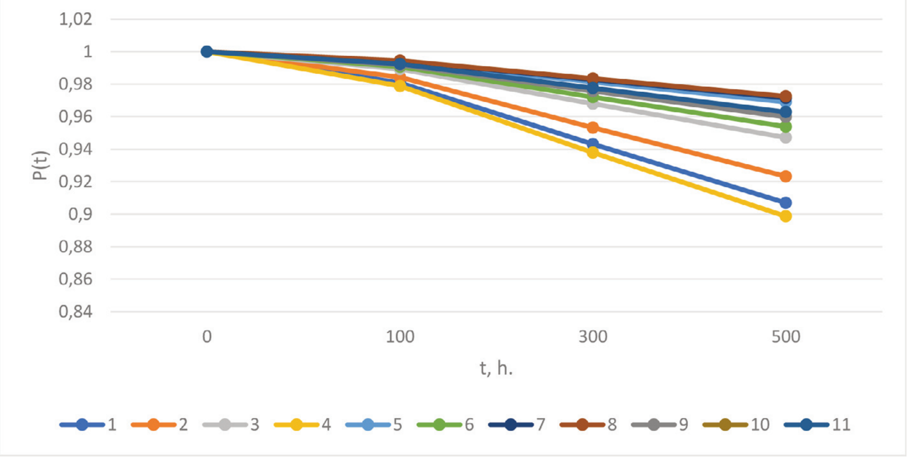

Figure 3. Visual material of probability of safe operation.

The most frequently replaced component will not always be the most dangerous, as the number of aircraft components is considered in the calculation. In this case, component No. 4 with batch number H341ANM1, which is the Standby horizon indicator, is considered to be the most dangerous of the selected devices. It is at the lowest level because there are relatively many replacements and there is only one such component on board. The most reliable unit is the generator: the number of replacements is one of the lowest, and the aircraft has three such units with part number 976J498-2.

3. POWER SUPPLY SYSTEM

The data obtained in Table 1 show that the highest number of unscheduled replacements of power supply system components is in the power generation unit. Generator replacements for the B737 have not been scheduled 54 times in 10 years and have averaged approximately 2,600 flight hours since the last overhaul. Due to generator problems, the airline experienced 28 flight delays with an average delay of 35 min. Figure 4 shows that pilot reports of problems with aircraft generators have decreased over time [10].

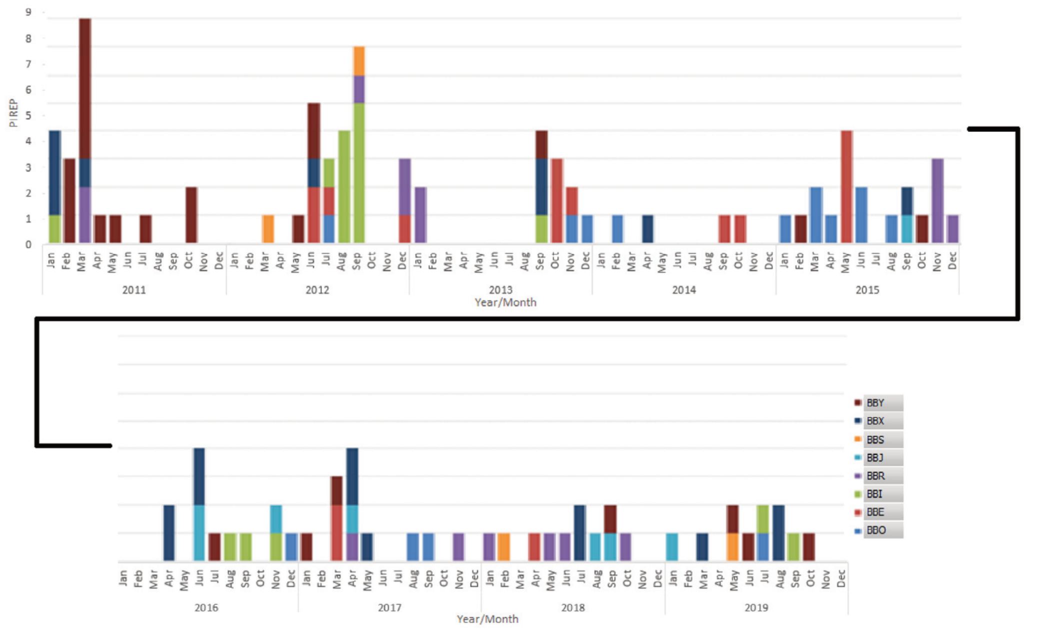

Figure 4. Trends of the PIREP (pilot report) generator.

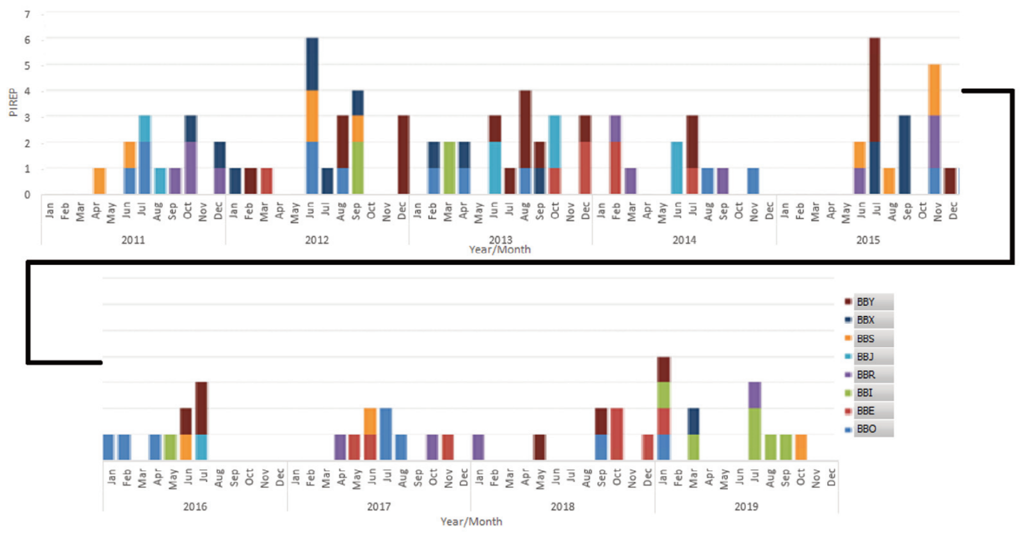

Figure 5. Trends in the PIREP (pilot report) generator drive mechanism.

Like all electrical devices, an aircraft requires a stable power supply. To ensure the correct operation of the generator, a constant mechanical drive from the engine must be provided. Since the mechanical power of the generator comes from the engine, which rotates at different speeds, a constant supply to the generator input shaft must be ensured. Excessive power fluctuations can damage control boards, blow out fuses or simply cause the lights to jerk. This is why a constant speed drive is located between the engine and the generator. A constant speed drive is a type of transmission in which the input shaft rotates at a wide range of speeds, transmitting this power to the output shaft, which rotates at a constant speed despite varying input speed. They are used to power machinery, usually electrical generators, which require a constant input speed [13]. As shown in Table 1, the drive mechanism is more problematic than the generator as replacement was unplanned 103 times. Generator drive failure manifested itself differently or the defect was non-uniform. There was often a problem with the generator drive oil system, where the pressure was too low, or the oil temperature reading was incorrect. The flight crew may have an indication that the generator is not working, but the real cause is the generator drive, which, for example, does not provide the required frequency [14]. In Figure 5 it is shown that the situation has improved due to the introduction of mass fluing by the airline [10].

4. ANALYSIS OF AIRCRAFT PILOT INSTRUMENT REFUSALS

Eq. (4), expressed as the average time between unplanned replacements, helps to assess the performance of the part and the frequency of failure.

$$MTBUR = \frac{FH * Q}{R_{unsch}} \tag{4}$$

where MTBUR indicates average time between unplanned replacements (h), FH flight hours (h), Q the number of components on board of the aircraft and R_{unsch} the number of unplanned part replacements.

Although the average MTBUR for the Airspeed indicator is quite high at 3,050 h, particular attention should be paid to the fact that approximately 37% of components removed have a life of less than 500 FH from the time they are fitted to the aircraft (Fig. 6).

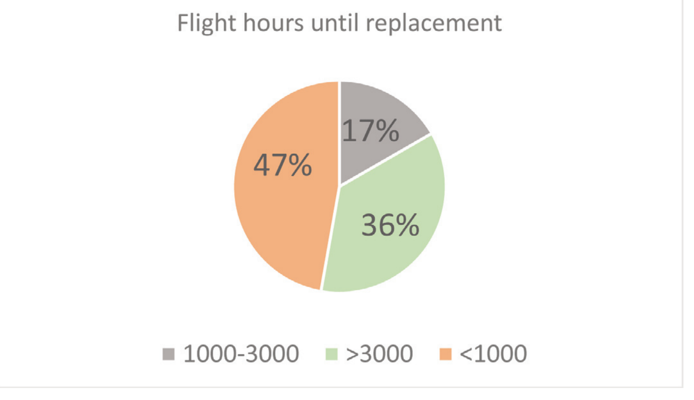

Figure 6. Unscheduled replacement of the airplane speed indicator after flight hours.

- Almost half or 47% of all components removed were installed on the aircraft in less than 6 months (1,000 FH).
- 36% of all components removed were installed on the aircraft more than 1.5 years ago (3,000 FH).
- 17% of the components were installed on the aircraft between 0.5 years and 1.5 years ago. (1,000–3,000 FH)

The safety and operability of the Airspeed indicator is not limited to one airline, but to all companies that use Airspeed indicator with that batch number [15]. This means that the problem is in the design of the parts and not the fault of the maintenance organisation, pilots or workshops. Industry data show that overall MTBUR has been decreasing over time. One reason is the failure of the power pack capacitor due to the high operating temperature. Therefore, the manufacturer has developed an upgrade or modification of the capacitor, and when the indicator is sent to the workshop for some reason, a new type of capacitor is installed.

5. CONCLUSIONS

1. The failure analysis of the Boeing 737 Classic considered both numbers of defect records and the number of unplanned part replacements over the past 10 years. Most of the defects were in the aircraft's structure, equipment and cabin, as well as in the lighting system. However, these types of defects are in the low-risk category, and it was thus the avionic equipment that was considered in more depth due to higher severity, although the reduction of number of in-flight failures can be accomplished based on the failure analysis.
2. The research in this area, particularly the failure analysis, can be used as a basis for conducting modelling of technical operation of the aircraft in the airline for the next calendar period. The fundamental process in aviation is carrying out forecasting. Therefore, study of and compliance with the measures that have been developed to improve the reliability of functional systems and their components is imperative.
3. The reduction of the number in-flight failures helps to lower the number of departure delays and downtime. Accordingly, the intensity of aircraft usage is highly increased, as well as the cost of their maintenance. At the same time, it makes possible to increase the volume of traffic without increasing the aircraft fleet. The increasing volume of maintenance will be provided not by attracting additional labour and material resources but by reducing the unit labour costs and funds for maintenance under conditions of the requirements for the reliability of aviation equipment and the regularity of dispatch.

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