maintenance, reliability,
RCM, failure, operation, analysis

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FAILURE ANALYSIS – BASIC STEP OF APPLYING RELIABILITY CENTERED MAINTENANCE IN GENERAL AVIATION

Summary. Performing a reliability analysis on a product or system can actually include a number of different analyses to determine how reliable the product or system is. A reliability centered maintenance program consists of a set of scheduled tasks generated on the basis of specific reliability characteristics of the equipment they are designed to protect. Complex equipment is composed of a vast number of parts and assemblies. All these items can be expected to fail at one time or another, but some of the failures have more serious consequences than others. Certain kinds of failures have a direct effect on operating safety, and others affect the operational capability of the equipment. The consequences of a particular failure depend on the design of the item and the equipment in which it is installed.

Although the environment in which the equipment is operated is sometimes an additional factor, the impact of failures on the equipment, and hence their consequences for the operating organization, are established primarily by the equipment designer. Failure consequences are therefore a primary inherent reliability characteristic.

ANALIZY AWARII – PODSTAWOWE KROKI ZASTOSOWANIA RELIABILITY CENTERED MAINTENANCE W LOTNICTWIE OGÓLNYM

Streszczenie. Przedstawiając analizy niezawodności na produkcie lub systemie, możemy, prawdę mówiąc, wymienić wiele różnych analiz, by określić, jak niezawodny jest dany produkt lub system. Program RCM składa się z zespołu harmonogramowanych zadań wygenerowanych na podstawie specyficznych charakterystyk wiarygodności sprzętu do ochrony, dla którego zostały zaprojektowane. Kompleksowe wyposażenie jest złożone z ogromnej liczby fragmentów i zespołów. Wszystkie te elementy mogą zawieść w tym czy innym czasie, lecz niektóre awarie mogą być poważniejsze niż inne.

Pewne rodzaje awarii mają bezpośredni wpływ na bezpieczeństwo operacyjne i inne afekty operacyjnej zdolności sprzętu. Konsekwencje poszczególnych awarii zależą od projektu elementu i sprzętu, na którym zostały zainstalowane.

Pomimo iż środowisko, w którym urządzenie funkcjonuje, jest czasami dodatkowym czynnikiem, wpływ awarii na sprzęt i w związku z tym ich konsekwencje dla organizacji operacyjnej są tworzone głównie przez projektantów wyposażenia. Konsekwencje awarii są więc podstawą naturalnych charakterystyk niezawodności.

1. INTRODUCTION

Reliability Centered Maintenance (RCM) analysis provides a structured framework for analyzing the functions and potential failures for a physical asset (such as an airplane, a manufacturing production line, etc.) with a focus on preserving system functions, rather than preserving equipment. RCM is used to develop scheduled maintenance plans that will provide an acceptable level of operability, with an acceptable level of risk, in an efficient and cost-effective manner [2].

Although there is a great deal of variation in the application of Reliability Centered Maintenance, most procedures include some or all of the seven steps shown below [3]:

1. Prepare for the Analysis
2. Select the Equipment to Be Analyzed
3. Identify Functions
4. Identify Functional Failures
5. Identify and Evaluate the Effects of Failure
6. Identify the Causes of Failure
7. Select Maintenance Tasks

2. BASIC ANALYSIS

2.1. Prepare for the analysis

As with almost any project, some preliminary work will be required to prepare for the RCM analysis. Some important up-front activities include assembling an appropriate cross-functional team, making sure that all members of the analysis team understand and accept the ground rules and conditions of the analysis (e.g. scope of the analysis, definition of "failure," etc.), gathering and review relevant documentation, etc [1].

2.2. Select the equipment to be analysed

Because RCM analysis requires an investment of time and resources, the organization may wish to focus analysis resources on selected pieces of equipment, based on safety, legal, economic and other considerations. Selection Questions and Criticality Factors are two methods of equipment selection that are commonly employed.

- The Selection Questions method consists of a set of Yes/No questions that are designed to identify whether RCM analysis is indicated for a particular piece of equipment. If the analyst answers Yes to at least one of the questions, then detailed analysis is indicated for the equipment.
- The Criticality Factors method consists of a set of factors designed to evaluate the criticality of the equipment in terms of safety, maintenance, operations, environmental impact, quality control, etc. Each factor is rated according to a pre-defined scale where higher ratings indicate higher criticality. The equipment’s criticality value can then be used as a ranking and/or as a threshold.

Other methods unreliability or other relevant metrics, may also be applied. Whichever method (or combination of methods) is selected, the goal is to focus RCM analysis resources on the equipment that will provide the maximum benefit to the organization in terms of safety, legal, operational, economic and related priorities.

3. FAILURE

3.1. Identify functional failures

Failure analysis is the process of collecting and analyzing data to determine the cause of a failure. A functional failure is defined as the inability of an asset to fulfill one or more intended function(s) to a standard of performance that is acceptable to the user of the asset. Functional failures may include:

- Complete failure to perform a function
- Poor performance of a function
- Over-performance of a function
- Performing an unintended function

We need to keep in mind that the focus of RCM is on preventing loss of function, not equipment. Also, remember that functional failures do not have to be simple definitions or a single statement. A function can have multiple failures.

Furthermore, failure definitions of an asset are closely related to its operating context. Therefore, we should generalize neither about functions of identical assets nor about their functional failures, in case the assets operate under different contexts or are used under different requirements and expectations.

3.2. Identify and evaluate the effects of failure

Failure effects analysis is concerned with what happens when a failure mode occurs. Revealing the effects of failure involves asking questions such as:

- What will be observed when the failure occurs?
- What is the impact on operations/production?
- What is the impact on the environment/safety?
- What physical change will occur to the equipment or adjacent equipment?
- What alarms or indications will be observed?

Effects can be defined at three different levels:

- Local Effect - What is observed at the individual component?
- Next Level Effect What is observed at the sub-system level?
- End Effect What will be observed at the system level?

Many RCM references contain logic diagrams that can be used to evaluate and categorize the effects of failure.

3.3. Identify the causes of failure - failure modes

The cause of failure (failure mode) represents the specific cause of the functional failure at the actionable level (i.e. the level at which it will be possible to apply a maintenance strategy to address the potential failure). Identifying causes (failure modes) is of paramount importance. It is a time- and effort-intensive step, but it is well worth it! The day-to-day issues of maintenance are mostly managed at the failure mode level (e.g. work orders issued to deal with specific failure modes, maintenance plans designed to deal with failure modes, product recalls due to a certain unexpected failure mode or frequent failure mode, emergency design or maintenance meetings triggered because of an occurrence of a failure mode, etc.) Extensive discussions about failure mode identification in this step of the RCM process will have a great beneficial impact on the success of the RCM project. It is what could make a difference between a reactive and a proactive maintenance management plan.

The causes of failure can be described to almost any level of detail. Different levels are appropriate in different situations. In some situations, it might be sufficient to state the direct reason of failure while in other situations, drilling down to the molecular level is needed.

If we plan to perform statistical data analyses, another crucial piece of information that needs to be collected is the time dimension. The exact times at which failure modes have occurred (or times between occurrences) need to be recorded (along with other information such as conditions in which the asset was used). Such data will be central to live data analysis and assessment of probability of occurrence. It is what will be used to quantify the "R" (reliability) in RCM. Failure modes that have not occurred but are considered to be real possibilities present a challenging aspect of the RCM process [2,3].

4. POSSIBILITY OF RCM APPLICATION

4.1. Maintenance tasks

Once you have identified the functions that equipment is intended to perform, the ways that it might fail to perform those intended functions and evaluated the consequences of these failures, the next step is to define the appropriate maintenance strategy for the equipment. The RCM analysis team's decision of which strategy (or strategies) to employ for each potential failure may be based on judgment/experience, a pre-defined logic diagram (connected to the failure effect categorization), cost comparisons or some combination of factors [4,5].

4.2. Failure analysis of the University of Žilina aircraft operator

The University of Žilina has been an aircraft operator for more than 50 years. Its fleet consists of 14 planes (type Zlin 42, Zlin 43, Zlin 142, L-200) – Figure 1, Table 1. Our research focuses on comparing different ways of ensuring modern and effective aircraft maintenance system. The RCM theory is also introduced as one of the most applicable systems for general aviation operators [6].

Fig. 1. Fleet of the University of Žilina
Rys. 1. Flota Uniwersytetu w Žilinie

Table 1

Aircraft types of the University of Žilina

Aircraft types			
Zlin Z-42	Zlin Z-43	Zlin Z-142	Morava L-200
OM-ALQ	OM-FOR	OM-KNO	OM-UHC
OM-ALR	OM-LOW	OM-MNW	OM-KMO
OM-DLS	OM-KOZ	OM-PNU	-
OM-ILR	-	OM-SNY	-
-	-	OM-UNA	-
-	-	OM-RNN	-

The University of Žilina aircraft operator (as well as other general aviation aircraft operators) runs so called preventive aircraft maintenance system. This system enables to prevent major aircraft failures and simplifies reliable aircraft operations. On the other hand, this type of maintenance system may increase operational costs of the operator and could lead to significant financial losses.

It is however recommended to introduce this new operating-reliability-focussed maintenance system and procedures into operations. It is also required to maintain the system by periodic surveys of the level of reliability and by comparison of the data with a specified level of operational reliability.

To ensure that system of evaluating reliability works well in real operations it is necessary to follow the list of actions (see the list below) defining actions from the moment when failure occurred up to the moment of final analysis of the failure and evaluation of its potential impact on airworthiness of particular aircraft:

1. Identification of aircraft failure by authorised maintenance staff
2. Passing the information about aircraft failure for further processing
3. Processing, evaluation and analysis of failure and its impact on reliability of aircraft operations
4. Informing competent supervising body about failure
5. Enhancing aircraft maintenance system

System of collecting data on aircraft failures should contain annual failure sheets for each aircraft. These sheets can be used as source data for compilation of lists of failures of all aircraft systems and subsystems. In our case, we focused mainly on the failure of the aircraft airframe and its components.

Particular intensities of failures can be computed according to data on failures collected and analyzed in particular years. These datas are essential for evaluation of operational reliability of the whole system [7].

For example in our case – Table 2.

Table 2
Numbers of non-critical failures in appropriate years – source data for computing

Total numbers of failures				
Year	Z-42	Z-43	Z-142	L-200
1975	0	0	-	-
1976	20	1	-	-
1977	14	4	-	-
1978	26	7	-	-
1979	23	6	-	-
1980	22	5	1	-
1981	20	3	3	-
1982	18	10	6	-
1983	21	13	22	-
1984	26	11	22	-
1985	34	16	10	-
1986	15	14	18	-
1987	17	14	21	-
1988	16	15	24	-
1989	26	6	36	-
1990	29	19	47	-
1991	10	7	5	-
1992	14	20	20	-
1993	16	11	32	4
1994	14	10	40	6
1995	16	16	32	4
1996	16	10	49	9
1997	13	12	29	10
1998	9	11	18	11
1999	8	6	19	8
2000	4	3	11	6
2001	6	6	11	5
2002	5	7	10	4
2003	7	10	19	3
2004	9	9	14	4
2005	10	8	13	5
2006	8	8	14	7
2007	7	6	9	5
2008	6	5	8	2
2009	9	6	9	1
2010	10	6	13	3

4.3. Failure Intensity

In reliability and quality control, failure intensity (density and failure rate or hazard) functions provide valuable information about the distribution of failure times. Shapes of failure intensity functions may contain characteristics of interest, such as number, location and features of modes, monotone increasing or decreasing features, and information about tail behaviour.

Having a quantifiable definition of reliability, such as failure intensity, is the key to being able to measure and track reliability. In this case we can define:

- How to "visualize" failure intensity
- About units of measure for failure intensity and what makes sense for our tasks.
- How reliability goals are set in terms of failure intensity,
- Ways of determining the right failure intensity objective for our tasks.

Denoting a non-negative random variable that represents failure time or lifetime by T, the survival function is:

$$F(t) = P(T \geq t), \qquad t \geq 0, \tag{1}$$

where: F(t) = 1 − F(t) is the cumulative distribution function of the lifetime distribution. If this function is differentiable, we may define the probability density function

$$f(t) = \lim_{\Delta \to 0} \frac{1}{\Delta} P(t \leq T < t + \Delta), \qquad t \geq 0, \tag{2}$$

and intensity of failure function

$$\lambda(t) = \lim_{\Delta \to 0} \frac{1}{\Delta} P(t + \Delta > T \geq t) = \frac{f(t)}{F(t)}. \tag{3}$$

The importance of the failure intensity λ in reliability is due to its interpretation as a risk function. Specifically, λ(t) quantifies imminent risk of failure at time t, and is related with the survival function *F* through [8]

$$F(t) = exp\left[-\int_0^t \lambda(u)du\right], \qquad \lambda(t) = -\frac{d}{dt} log[F(t)]. \tag{4}$$

Both density and failure intensity function characterize the failure time distribution. The transformations from density to failure intensity

$$\lambda(t) = \frac{f(t)}{1 - \int_0^t f(u)du}, \qquad f(t) = \lambda(t) exp\left[-\int_0^t \lambda(u)du\right]. \tag{5}$$

Failure intensity function for subsystems

$$\lambda(t) = \left(\frac{\beta}{\alpha}\right) . \left(\frac{S}{\alpha}\right)^{\beta - 1} \tag{6}$$

where α and β are statistical values for determining of subsystem reliability and S is number of failures.

Example of computing failure intensity for Z42 aircraft:

$\lambda(t)_{engine}$ = (1,58 / 108,3) * (19 / 108,3) $^{1,58 - 1}$ = 0,00531 failures/hour.

$\lambda(t)_{fuel\ system}$ = (1,44 / 89,7) ∗ (19 / 89,7) $^{1,44-1}$ = 0,00819 failures/hour.

$\lambda(t)_{prop}$ = (1,63 / 67,3) ∗ (19 / 67,3) $^{1,63-1}$ = 0,01091 failures/hour.

$\lambda(t)_{other}$ = (1,60 / 40,1) ∗ (19 / 40,1) $^{1,60-1}$ = 0,02548 failures/hour.

And final failure intensity for Zlin Z42 (1995) follows:

$\lambda(t) = \Sigma\, \lambda_i(t)$ = 0,0498 failures/hour.

Figures 2-4 presents failures intensity of Zlin Z-42, Z-43 and Z-142.

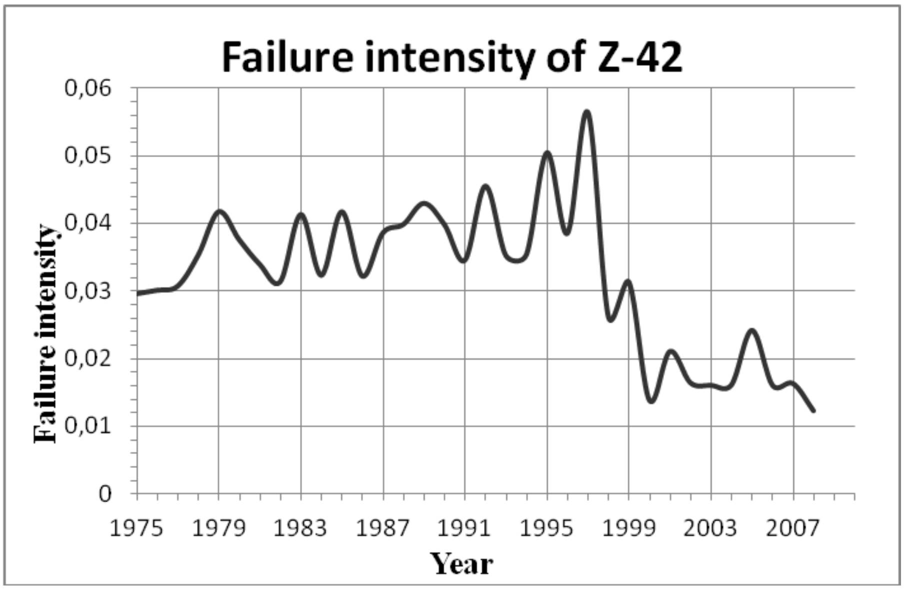

Fig. 2. Failure intensity of the aircraft ZLIN Z-42
Rys. 2. Awaryjność samolotów ZLIN Z-42

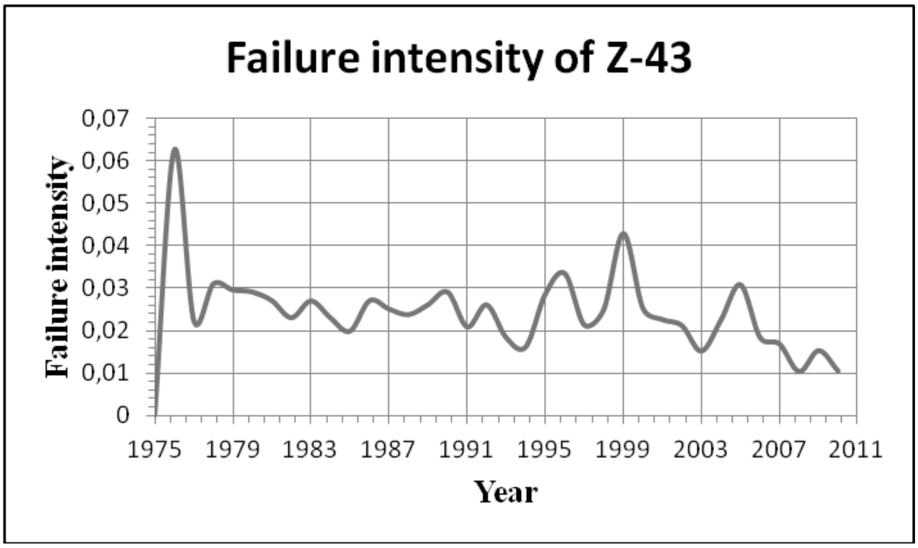

Fig. 3. Failure intensity of the aircraft ZLIN Z-43
Rys. 3. Awaryjność samolotów ZLIN Z-43

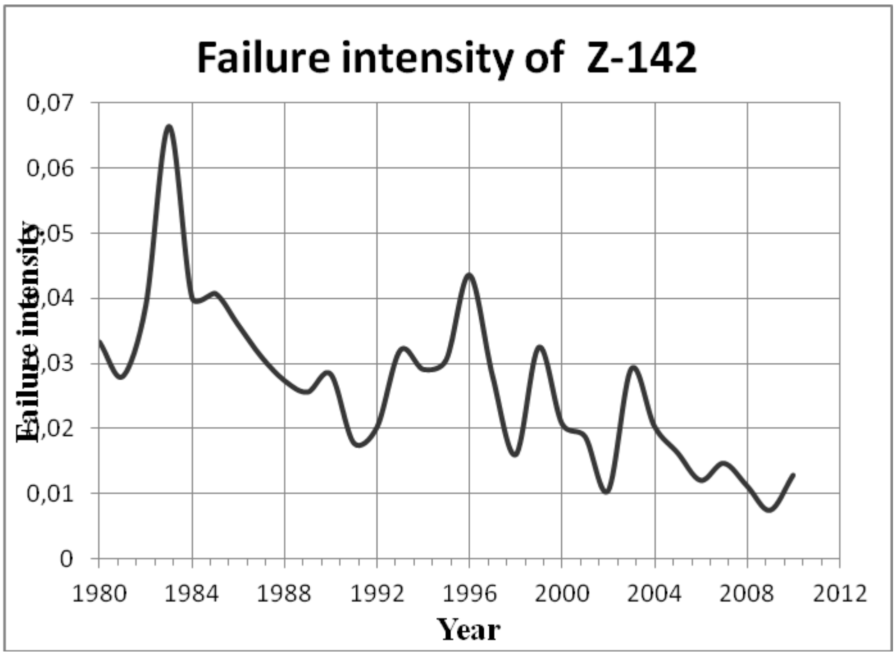

Fig. 4. Failure intensity of the aircraft ZLIN Z-142
Rys. 4. Awaryjność samolotów ZLIN Z-142

Failure Analysis is a critical step in the process that strives to discover „philosophy" that clearly identifies the cause of failure.

5. CONCLUSION

The article summarized the "analysis" or "investigative" steps in the RCM process, in which functional failures, the failure modes and failure analysis.

From the view of a particular elements failure intensity impact to system reliability it is possible to divide systems into four basic types in our case: engine, fuel system, propeller and other secondary subsystems. Consider i-th system element, the probability of its failure-free state occurrence is P_i and the probability of its failure state occurrence is F_i.

Failure intensity (Fig.1-4) of the aircraft shows different varies in values that have a different cause. Important is that all calculated values are in acceptable range.

Many RCM guidelines include task selection logic diagrams based on the Failure Effect Categorization. When safety is not an issue, another is to compare normalized cost values for the available maintenance strategies and select the maintenance task that provides the desired level of availability for the minimum cost. For example, if the cost per uptime of performing corrective maintenance only (run to failure) is less than the cost per uptime of performing a scheduled repair/replacement, and the run to failure approach provides an acceptable level of equipment availability (uptime), then the team may recommend no scheduled maintenance tasks for the equipment.

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Received 19.01.2011; accepted in revised form 15.01.2012

This paper is published as one of the scientific outputs of the project: Centre of Excellence for Air Transport ITMS 26220120065“

Operačný program VÝSKUM a VÝVOJ

Európska únia
Európsky fond regionálneho rozvoja

We support research activities in Slovakia/Project is co-financed by EU