

# Implementation of RCM theory in air operations

**M. BUGAJ**

University of Zilina, Faculty of Transport and Communication, Air Transport Department Univerzita 8215/1, 010 26 Žilina, Slovak Republic  
EMAIL: Martin.Bugaj@fpedas.uniza.sk

## **ABSTRACT**

Reliability-Centred Maintenance (RCM) implementation provides measures that signify progress towards implementing an RCM based maintenance program. Using numbers identified during the Analysis Phase as a basis, the metrics concentrate on the number and percentage of each category (new task, modified task, cancellation of specified old program tasks, design modifications, operational procedure changes, etc., that have actually been implemented.

Implementation will (or should) usually begin during the Analysis Phase of an RCM project, and may provide information for improvement of the analysis. Implementation involves many activities, such as: Identification of resources (money, time, manpower), Coordination with governing authorities or other parties affected, Procedure writing, walk down and approval, Procurement of special tools, parts and consumables needed to carry out the procedures mandated under the new program, Training or at least orientation on the new procedures for those who are to perform them, Planning and scheduling of new RCM based procedures, Actual execution the first time on the asset that was subject of the RCM Project

**KEYWORDS: Maintenance, reliability, RCM, failure, operation**

## **1. Introduction**

Maintenance is responding to changing expectations. These include a rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the connection between maintenance and product quality and increasing pressure to achieve high unit availability and to contain costs.

These changes are testing attitudes and skills in all branches of the air transport industry to the limit. In the aviation business the maintenance people are having to adopt completely new ways of thinking and acting engineers as well as managers. At the same time the limitations of maintenance systems are becoming increasingly apparent no matter how much they are computerized [3].

Reliability Centered Maintenance (RCM) is the concept of developing a maintenance scheme based on the reliability of the various components of the system or product in question. Implementing a preventative maintenance program using RCM can greatly reduce the cost of ownership of a product or system.

Developing an effective RCM program requires extensive knowledge about the reliability and maintainability of the system and all of its subsequent components. Important factors include the MTTR (Mean Time To Repair) and failure rate (total number of failures within a given time period) of the product or system.

Reliability-Centered Maintenance is the optimum mix of reactive, time- or interval-based, condition-based, and proactive maintenance practices. The basic application of each strategy is shown in Fig. 1. These principal maintenance strategies, rather than being applied independently,

are integrated to take advantage of their respective strengths in order to maximize facility and equipment reliability while minimizing life-cycle costs [1].

## 2. Concepts of reliability centered maintenance

A reliability-centred maintenance (RCM) program consists of a set of scheduled tasks generated on the basis of specific reliability characteristics of the aircraft they are designed to protect. The aircraft is composed of a number of systems and subsystems a vast number of parts and assemblies. Any these items can be expected to fail at one time or another, but some of the failures have more serious consequences than others. Certain kind of failures have a direct effect on operating safety whilst others affect the operational capability of an equipment. The consequences of a particular failure depend on the design of the item and the equipment in which it is installed.

One of the key goals of certification and continued airworthiness standards in aviation is that each safety-critical system have a reliability of at least 0.99999999—”nine 9’s”—per flight hour; in other words, the probability that a particular safety-critical system will fail is no more than one in a billion for each flight hour. Regulations seek to achieve this goal through a combination of requirements for design, analysis, test, inspection, maintenance and operations. The rulemaking process has been driven by the following factors [4]:

- Continued high levels of public and congressional concerns about air transportation safety.
- The introduction of new technologies, which have advanced the efficiency of the air transportation system and provided opportunities to improve aviation safety.
- Lessons learned from investigations of civil aviation accidents and incidents.
- Changes in international air transportation regulations and policies.

The operational conditions and environment in which the aircraft is operated define crucial factor. The impact of failures on the aircraft airworthiness and hence their consequences for the operating organization are predicted and established primarily by the aircraft designer. Failure consequences are therefore a primary inherent reliability characteristic.

There are of course many items whose failure has no significance on a system or the whole aircraft operating capability. These failures are tolerable in the sense that the cost of preventive maintenance would outweigh the benefits to be derived from it. It is less expensive to leave these items in service until they fail than it is to prevent

the failures. Most of such failures are evident to the operating crew at the time they occur and are reported to the maintenance crew for corrective action. Some items, however, have functions whose failure will not be evident to the operating crew. Although the loss of a hidden function has no direct consequences any uncorrected failure exposes the aircraft to the consequences of a possible multiple failure as a result of some later second failure. For this reason items with hidden functions require special treatment in a scheduled maintenance program.

The first step in the development of a maintenance program is to reduce the problem by a quick approximate, but conservative identification of a set of significant items - those items whose failure could affect operational safety or have major economic consequences. The definition of major economic consequences will vary from one organization to another, but in most cases it includes any failure that impairs the operational capability of the equipment or results in unusually high repair costs. At the same time all items with hidden functions must be identified, since they will be subjected to detailed analysis along with the significant items.

The analysis itself begins with an evaluation of the failure consequences for each type of failure to which the item is exposed. The logic used to organize this problem, leads to categories of failure consequences [6]:

- *Safety consequences*, which involve possible danger to the equipment and its occupants. Limits for random characteristics are standardised in aviation.
- *Operational consequences*, which involve an indirect economic loss in addition to the cost of repair. Preventive maintenance actions have an essential effect on operational costs in aviation.
- *No operational consequences*, which involve no economic loss other than the cost of repair applying RCM theory to aircraft. These failures have to be registered also, because of potential future missing can be signalled.

In the case of commercial aircraft continuous evolution of the design requirements promulgated by airworthiness authorities and the feedback of hardware information to designers by operating organizations have led to increasing capability for safe and reliable operation. Thus most modern aircraft enter service with design features for certain systems and items that allow easy identification of potential failures. Similarly, various parts of the airplane are designed for easy access when inspection is necessary or for easy removal and replacement of vulnerable items. A host of instruments and other indicators provide for monitoring of systems operation, and in nearly all cases essential functions are protected by some form of redundancy or by backup devices that reduce the consequences of failure to a less serious level.

Complex equipment of the older generations of aircraft that has not benefited from such design practices

will have different and less favourable reliability characteristics, and therefore less capability for reliable operation. Since preventive maintenance is limited by the inherent characteristics of the equipment, in many cases RCM analysis can do little more than recommend the design changes that would make effective maintenance feasible.

The role of civil aviation authorities is to work with the operators and manufacturers of aircraft and engines to define and implement a proactive process that includes the following key elements:

- data collection
- database management
- risk analysis
- risk management/action
- monitoring effectiveness

The principles of Reliability-Centred Maintenance still apply and the questions are the same. The answers to these questions, however, must reflect the design characteristics of the aircraft [5].

### 3. A summary of RCM principles

The complexity of modern aircraft makes it impossible to predict with any degree of accuracy when each part or each assembly is likely to fail. For this reason it is generally more productive to focus on those reliability characteristics that can be determined from the available information than to attempt to estimate failure behaviour that will not be known until the aircraft enters service. In developing an initial program, therefore, only a modest attempt is made to anticipate the operating reliability of every item. Instead, the governing factor in RCM analysis is the impact of a functional failure at the system level, and tasks are directed at a fairly small number of significant items - those whose failure might have safety or major economic consequences.

These items, along with all hidden-function items, are subjected to intensive study, first to classify them according to their failure consequences and then to determine whether there is some form of maintenance protection against these consequences.

The first step in this process is to organize the problem by partitioning the aircraft into object categories according to areas of engineering expertise. Within each of these areas the aircraft is further partitioned in decreasing order of complexity to identify significant items (those whose failure may have serious consequences for the aircraft as a whole), items with hidden functions (those whose failure will not be evident and might therefore go undetected), and non-significant items (those whose failure

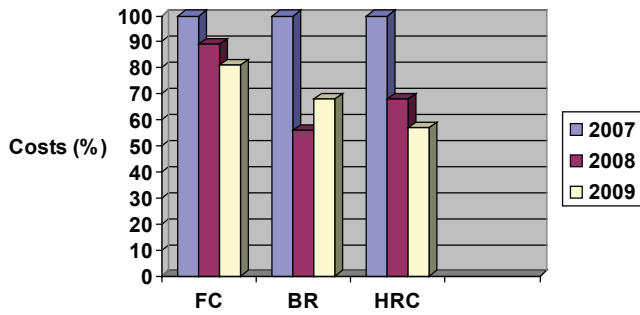
has no impact on operating capability). As this last group encompasses many thousands of items on an aircraft, this procedure focuses the problem of analysis on those items whose functions must be protected to ensure safe and reliable operation.

The next step is a detailed analysis of the failure consequences in each case. Each function of the item under consideration is examined to determine whether its failure will be evident to the operating crew; if not, a scheduled-maintenance task is required to find and correct hidden failures. Each failure mode of the item is then examined to determine whether it has safety or other serious consequences. If safety is involved, scheduled maintenance is required to avoid the risk of a critical failure. If there is no direct threat to safety, but a second failure in a chain of events would have safety consequences, then the first failure must be corrected at once and therefore has operational consequences. In this case the consequences are economic, but they include the cost of lost operating capability as well as the cost of repair [7].

Thus scheduled maintenance may be desirable on an economic basis, provided that its cost is less than the combined costs of failure. The consequences of a non operational failure are also economic, but they involve only the direct cost of repair. The classification by failure consequences also establishes the framework for evaluating proposed maintenance tasks. In the case of critical failures - those with direct safety consequences - a task is considered effective only if it reduces the likelihood of a functional failure to an acceptable level of risk.

Although hidden failures, by definition, have no direct impact on safety or operating capability, the criterion in this case is also risk; a task qualifies as effective only if it ensures adequate protection against the risk of a multiple failure. In the case of both operational and non operational failures task effectiveness is measured in economic terms. Thus a task may be applicable if it reduces the failure rate (and hence the frequency of the economic consequences), but it must also be cost-effective - that is, the total cost of scheduled maintenance should be less than the cost of the failures it prevents.

Whereas the criterion for task effectiveness depends on the failure consequences the task is intended to prevent, the applicability of each form of preventive maintenance depends on the failure characteristics of the item itself. For an on-condition task to be applicable there must be a definable potential failure condition and a reasonably predictable age interval between the point of potential failure and the point of functional failure. For a scheduled rework task to be applicable the reliability of the item must in fact be related to operating age; the age-reliability relationship must show an increase in the conditional probability of failure at



FC – fluid costs

BR - basic repairs costs (non-fatal failure)

HRC – human resource costs

Fig.1 Economic analysis

some identifiable age (wear out) and most units of the item must survive to that age. The applicability of discard tasks also depends on the age reliability relationship, except that for safe life items the life limit is set at some fraction of the average age at failure. Failure finding tasks are applicable to all hidden function items not covered by other tasks.

The process of developing an RCM program consists of determining which of these scheduled tasks, if any, are both applicable and effective for a given item. The fact that failure consequences govern the entire decision process makes it possible to use a structured decision diagram approach, both to establish maintenance requirements and to evaluate proposed tasks. The binary form of a decision diagram allows a clear focus of engineering judgment on each issue. It also provides the basic structure for a default strategy - the course of action to be taken if there is insufficient information to answer the question or if the study group is unable to reach a consensus. Thus if there is any uncertainty about whether a particular failure might have safety consequences, the default answer will be yes; similarly, if there is no basis for determining whether a proposed task will prove applicable, the answer, at least in an initial maintenance program, will be yes for on-condition tasks and no for rework tasks.

It is important to realize that the decision structure itself is specifically designed for the need to make decisions even with minimal information. For example, if the default strategy demands redesign and this is not feasible in the given timetable, then one alternative is to seek out more information in order to resolve the problem. However, this is the exception rather than the rule. In most cases the default path leads to no scheduled maintenance and the correction,

if any, comes naturally as real and applicable data come into being as a result of actual use of the aircraft in service [2].

The decision logic also plays the important role of specifying its own information requirements. The first question assures us that all failures will be detected and that any failures that might affect safety or operating capability will receive the first priority. The remaining steps provide for the selection of all applicable and effective tasks, but only those tasks that meet the criteria are included. Again, real data from operating experience will provide the basis for adjusting default decisions made in the absence of information. Thus a prior-to-service program consists primarily of on-condition and sample inspections, failure finding inspections for hidden function items and a few safe life discard tasks. As information is gathered to evaluate age reliability relationships and actual operating costs, rework and discard tasks are gradually added to the program where they are justified.

The net result of this careful binding of the decision process is a scheduled maintenance program which is based at every stage on the known reliability characteristics of the aircraft in the operating context in which it is used. In short, reliability-centred maintenance is a well tested answer to the paradox of modern aircraft maintenance - the problem of how to maintain the systems in a safe and economical fashion until we have accumulated enough information to know how to do it.

## 4. Conclusion

Reliability-Centred Maintenance will allow one to obtain the full design operating ability of the aircraft. It does not necessarily identify a new series of maintenance tasks. It identifies which tasks are most applicable, which are ineffective and provides a framework for developing an optimal preventive maintenance program.

The University of Žilina is an aircraft operator for more than 50 years and its flotilla consists of 30 planes (type Zlin 42, Zlin 43, Zlin 142, L-200, PA-28, PA-34). The main objective of our research in the aircraft maintenance area is ensuring modern and effective maintenance systems. The RCM theory is one of the most applicable systems for general aviation operators. We have applied this system in the maintenance program for all "Zlins" in 2008. End-years economic analysis indicates cost decrease (Fig.1). The University of Žilina had an inefficient Preventive aircraft maintenance system for all "Zlins" till the 2008.

In the time period mentioned we analyze the differences between various cost decreases and apply the RCM system for L200 aircraft.

## Bibliography

- [1] MOUBRAY J., 2001, *Reliability-centred maintenance II*, New York, Industrial Press inc.
- [2] SMITH A., 1992, *Reliability-centred maintenance II*, McGraw-Hill
- [3] AUGUST J., 2000, *Applied Reliability-centred maintenance II*, Pennwell Corp
- [4] KROES M. J., 1999, *Aircraft maintenance and repair*, McGraw-Hill College
- [5] BUGAJ M., 2004, *Fault tree analysis*, Studies of Faculty of operation and economics of transport and communications of University in Žilina, Vol.21
- [6] KANDERA B., 1999, *New trends in the development of aircraft equipment / - ISBN 80-7100-628-9*
- [7] <http://www.reliabilityweb.com>.