Design for Reliability in Aviation
(A must to improve Life Cycle Cost, Safety and Availability)

Driss Ouedghiri [(1)], Stuart Baskcomb [(2)]

[(1)] C.A.S.E.S sarl (au), 16 Rue Jilali El Oraibi, Casablanca 20000, Morocco.
Email: drissoued@hotmail.co.uk
[(2)] Delta System Solutions GmbH, Packenreiterstr. 40, 81247 Munich, Germany.
Email: stuart.baskcomb@delta-system-solutions.com

ABSTRACT

Reliability assessments and their processes have been implemented only recently in complex aircraft programs. The authors, during their combined time working in the aviation industry, have developed a comprehensive Design for Reliability process.

In today's new complex aircraft programs, reliability helps:

- to lower the life cycle cost of the product,
- to enhance aircraft/system availability,
- to enhance the design for aftermarket services
- to inherently improve safety through the improvement of the aircraft/system failure rate
- and to increase customer satisfaction

The reliability assessment process on complex aircraft program, starts at the concept phase and supports the program throughout all its stages. A systematic reliability analysis of existing and future technical systems is a paramount precondition to lower the program risks and increase the operational efficiency of the system.

This paper makes recommendations to space applications based on reliability practices utilized on aircraft programs that have been certified in recent years.

1 INTRODUCTION

1.1 Brief history of reliability in aerospace applications

In the aircraft industry, reliability started to be of major interest after the First World War [1]. Whilst today's practices were far and beyond those that were performed in the past, comparisons were made between various aircrafts to assess which configurations was the safest: single engine aircraft or multiple engine aircraft? At that time, most attempts at reliability improvement were based on trial and error. When something failed, its replacement would be designed and manufactured using any improvement in technology, together with experienced gained from investigating the failure.

Then, after a while, information was gradually collected on system failures which led naturally to the concept of expressing reliability in terms of failure rate for a particular type of aircraft or system. Also, quantification gradually became part of the design specification.

A good example where the application of reliability concepts proved very useful in the missile and space industry was the V1 missile. Mathematical tools were used alongside quality assurance which resulted in a dramatic improvement of the missile's reliability.

The American armed forces took an increasing interest in reliability and its measurement in the Second World War because the unreliability of vital equipment was causing significant problems. In parallel in the UK, it was also noted that the lack of reliability and maintainability of military equipment was forcing the armed services to spend over half of its resources on maintenance rather than operations.

Both armed forces started to appreciate the importance of reliability and maintainability, and a series of US Department of Defense Standards (MIL-STDs) were introduced and implemented. Subsequently the UK Ministry of Defense also introduced similar standards (Defence Standards).

1.2 What is reliability?

Reliability is "…the measure of the probability of successful performance of the system over a period of time". Quantitative reliability is generally defined as the probability that an item (component, equipment or system) will operate without failure for a stated period of time under specified conditions [1].

Reliability and risk assessment methods are both employed in safety studies to identify the various combinations of faults which can lead to reduced safety.

Reliability assessment should be carried out during every stage of the project. A formal reliability program is essential on all projects of any size or importance. The reliability program should begin at the earliest stage in a project and must be defined in outline before the concept design phase starts [2].

Reliability, where safety is not an issue, is relatively straightforward. Its affects the company's cash flow and image because an unreliable aircraft flies less than its intended utilization and causes many disruptions affecting availability. In many cases, the reliability program can be cancelled or significantly reduced due to budget constraints or the program running over-budget. In this case, it should be noted that any add-on reliability features after the aircraft enters service will always be significantly more expensive and in some cases might not get to the intended reliability improvement.

1.3 Scope

This paper will discuss the reliability process in complex aircraft programs and how to generate and implement a sound Design for Reliability process that can be carried out at every stage of the project.

Recommendations to space applications based on reliability practices utilized on aircraft programs that have been certified in recent years are also listed in this paper.

2 RELIABILITY IN AIRCRAFT PROGRAMS

2.1 Component Reliability

A lot of emphasis is placed upon the failure rate or Mean Time Between Failures of a component or element within the system analyzed to express its reliability. This clearly calls into question how reliability values for different type of component are established. There are two main methods of determining component reliability [3] [4]:

- Analytical by component count
- Historical by means of accumulated in-service experience and lessons learned

2.1.1 Analytical Methods

Many standards have been developed in the last years to use an analytical bottom-up approach to predicting reliability. This method uses a component/part count to build up an analysis of the reliability of the unit. This approach has best been applied to electronic equipment over the years (though it is also used for mechanical components regularly). This method uses type of component, environment and quality factor as major discriminators in predicting the failure of a particular component, module and system.

The issues associated with this method:

1. It is only as good as the database of components and the factors used.
2. Experience has shown that in general, predicted values are generally pessimistic, generating predicted failure rates worse than might be expected in real life.
3. The technique has merit in comparing competing design options in a quantitative manner when using a common baseline for each design.
4. It is difficult to continue to update the database, particularly with the growing levels of integration of Integrated Circuit, which makes device failure rate difficult to establish.
5. The increasing number of Commercial Off-The-Shelf components also confuses the comparison.

There are internationally accepted reliability databases reliability prediction methods [6]. The reliability prediction tools are used to predict the failure rate (λ) and the Mean Time Between Failures (MTBF).

The most common tool used for the reliability predictions of complex mechanical system is NPRD-2011 (which supersedes NPRD-95) developed by the Reliability Information Analysis Center (RIAC). The RIAC is the U. S. Department of Defense chartered Center of Excellence. NPRD-2011 contains failure rate data on a wide variety of electrical, electromechanical and mechanical components. The database contains data obtained by long-term monitoring of the components in the field. The collecting of the data was last from the early 1970's through 2010 for NPRD-2011.

For the reliability prediction of complex electronic system there are two databases that are commonly used:

1. EPRD-97, which is also developed by the RIAC. The database contains failure rate data on electronic components, namely capacitors, diodes, integrated circuits, optoelectronic devices, resistors, thyristors, transformers and transistors. The collecting of the data was last from the early 1970's through 1996. NPRD-11 and EPRD-97 complement one another and do not contain duplicated data.

2. *The MIL-HDBK-217F – Military Handbook: Reliability Prediction of Electronic Equipment* was developed by the U. S. Department of Defense and support was terminated in 1995. This standard was primarily developed for military electronic components, though is it is commonly used nowadays in civil applications. This is the standard that is the most used in the field of electronic reliability predictions. The values contained in the database are derived from statistical analysis of actual field failures and are used to calculate failure rates. The standard contains prediction for generic types of electronic components, namely microcircuits, semiconductors, tubes, lasers, resistors, capacitors, inductive devices, rotating devices, relays, switches, connectors, interconnection assemblies, meters, quartz crystals, lamps, electronics filters and fuses.

2.1.2 In-service data

The use of in-service data is the best way to assess mechanical components and predict their failure rates when used in the same environment. However caution should be exercised to ensure that the components which field data are used for reliability predictions are subjected to similar load and environmental conditions. The reliability engineer's role is to ensure that the service/filed data gathered is presented to the design and project team and that the new conditions are similar or that the variations/deviations can be quantified in the reliability predictions. Any significant variation in the component usage, technology baseline, or location in the aircraft/environment may nullify the comparison. Nevertheless, when used in conjunction with other methods, this is a valid method. The manufacturers of civil and fighter aircraft and helicopters and their associated suppliers will generally be able to make "industry standard" estimates using this technique [1].

Generating component reliability data from service experience can be a lengthy and difficult process. Sometimes, by the time it takes to get a good overview of the product's reliability, the product has become obsolete.

2.2 Dispatch Reliability

Aircraft availability and dispatch reliability are two vital signs of any aviation operation. Availability refers to whether the aircraft is available for a flight, whether scheduled or not. An aircraft in for maintenance cannot be flown, and thus is not available.

Dispatch reliability is key to an aircraft fulfilling its mission, whether a military or civil aircraft [1]. The ability to be able to continue to dispatch an aircraft with given faults has been given a big push by the commercial pressures of the air transport environment, where multiple redundancy for integrity reasons has also been used to aid aircraft dispatch.

This means of specifying the dispatch requirement of part of an aircraft system leads to an operational philosophy far beyond a 'get-you-home' mode of operation. In fact it is the first step towards a philosophy of no unscheduled maintenance.

This leads to a more subtle requirement to meet integrity requirements when several failures have already occurred, and this requires different techniques. Dispatch Reliability is expressed as the percentage of flights that depart within a specified time of the scheduled departure time.

The airlines recognize the importance of the dispatch reliability and availability metrics and spend a lot of time and resources defining and tracking this sort of information. To the airlines, a standard reliability window is a departure from the gate within 15 minutes of schedule. They exclude non-aircraft issues such as air traffic delays, bad weather, connection delays… The goal for most airlines is a dispatch reliability rate in excess of 99%.

On time departures improve customer satisfaction and the airline's image, which in turn improves the company's profitability. Many airlines take these metrics seriously and review them very regularly (sometimes on a daily basis). A cancelled airline flight means increased costs and the possibility of lost revenue in the future, if passengers fly a different airline.

3 DESIGN FOR RELIABILITY PROCESS

3.1 Overview

In today's modern aircraft complex programs, safety is vital for the certification and operation of the aircraft and its systems. In addition, reliability helps to lower the life cycle cost of the product, enhance aircraft/system availability, support long term maintenance agreements, improve availability (and dispatch reliability) and increase customer satisfaction.

The processes of safety and reliability on complex aircraft programs start at the concept phase and support the program through the development, certification and in-service phases. These disciplines are not "add-ons" or nice to have activities, but constitute a vital element in the success of any complex engineering project [5].

Therefore a systematic safety and reliability analysis of existing and future technical systems is a paramount

precondition to lower the program risks, enable a smooth entry into service and increase the operational efficiency of the system.

The authors of this paper have developed a design for reliability process that can be implemented at concept and can support the design of any complex system during the development, testing, validation and in-service phases. The main benefits are an improvement in safety and a significant reduction in the life cycle cost of the product by:

- Identifying those systems/components with low reliability rates.
- Using statistical data from previous similar applications to identify low reliability components.
- Organizing Design for Reliability workshops with designers and system specialists to identify areas of concern, how to address them and identify areas where novel designs can be implemented with low risk and minimal impact on the operation of the system.
- Tracking the progress of various designs and identifying validation testing requirement to demonstrate the system/component reliability (e.g. Highly Accelerated Life Testing, Highly Accelerated Stress Screening).
- Identifying those components with an inherent unreliability that need continuous monitoring and tracking once the product enters service.
- Identifying potential design modifications to improve system/product during the operational phase and increase customer satisfaction through the improvement of product reliability and availability.

3.2 Design for Reliability Process

The Design for Reliability exercise needs a systematic approach that will improve the probabilities (failure rate, MTBF and MTTR) in the direction of the required reliability.

3.2.1 Reliability specifications

The reliability program should begin at the earliest stage in a project and must be defined in outline before the concept phase starts. It is at this stage that fundamental decisions involving trade-offs between reliability, performance, complexity and price are made. The reliability engineer will be involved in the assessment of these trade-offs and the generation of specific reliability objectives. Reliability specifications should also be based on the goal of the user.

The reliability requirements should be generated at the same time as those of the safety requirements in order to generate precise and concise requirements that support the aircraft development program. There should be a dedicated set of reliability requirements that needs to be generated and accepted at project level and should support the aircraft safety and certification requirements. After all, the failure rates used in the safety documentation in support of aircraft certification are generated in the reliability prediction reports.

Like safety [5], when a dedicated reliability requirements suite is used, explicitly documented and integrated into the requirements management process of the system design and development, it provides the advantage of:

- increased confidence in the reliability assessment reflecting accurately the system design,
- increasing the influence on design (optimization)
- supporting the integration of the reliability engineer/department into the design/project team
- getting an in-sight into what needs to be done during the design and development phase to make the product more robust
- simplifying, and increasing, the capture of lessons learned from one project to the next.

Finally, reliability requirements need to reflect the business model of the company designing and developing the system. It should be reminded that reliability costs money and in some cases it has been recognized that to achieve a high reliability may not be economically viable. If the business model of the company developing the product relies on spares, and the product exhibits reliability far and beyond those of the requirements, then this would result in a bad business case. However if on the other hand, the business model of the company developing the product relies on aftermarket services, and , and the product exhibits reliability far and beyond those of the requirements, then this would result in increased profits and an improved image for the company.

3.2.2 Design Analysis

Once the reliability specifications have been agreed and set, the system needs to be analyzed and broken down to its subassemblies and components. In order to understand the design and influence it from a

reliability point of view, the reliability engineer and the project engineer need to organize Design for Reliability (DfR) workshops with designers and system specialists.

The two principles aims of the DfR workshops are:

- To get the whole design and project teams to understand and integrate reliability requirements into the system design.
- To identify and single out the main reliability risks of each system/sub-system and agree on mitigation strategies to remove or reduce the risk significantly.

To assess and identify potential design improvement, as part of a "Design for Reliability" drive; a risk assessment of potential reliability issues needs to be performed on the various system and sub-system designs. The process of identification of reliability risks can based on the company's heritage review (e.g. FRACAS), current in-service events and data that has been captured and analyzed, lessons learned and the company's list of critical failure scenarios. Data can also be obtained from sources not previously used in-house but that have been by others, i.e. from data books or component manufacturers [2]. However, this must be done with care. In the authors' experience, it is always best to use in-house in-service data.

The findings need to be reviewed during a meeting with the system specialists, Work Package Owner, the Chiefs Design Engineer and System Safety engineer. The identified risks from this process need to be included in the module or system risk register in order to mitigate, track and buy-off according to the project risk management policy.

Actions arising from the DfR workshop session and associated to the system's reliability risks need to be attached to the DfR report. The identified risks from the session need to be included in the system's risk register by the Work Package Owner.

3.2.3 Reliability Analysis

As the design evolves to reach the critical design phases of the program, all identified reliability risks need to be addressed and mitigations put in place to ensure the system meets it reliability targets at entry into service.

Quantitative methods, e.g. FMECA, can be developed to derive reliability predictions and failure rates to assist in this process, identify further items of reliability risks and assess design changes. Fault Tree Analysis, can also be used to estimate failure rates for combined failure scenarios. Both methods are used to identify critical assemblies and components.

Design/technology utilized on previous projects must also be reviewed in the new design to understand how the variations in their use can affect the system's reliability. If there are any variations of significance, then a detailed review of the system and its components will be necessary. Each component must be analyzed in its new environment, and it must be ensured that it is utilized in the same way or that variations will not reduce its reliability.

After all the analysis work has been completed, an overall assessment is needed to verify whether the reliability specifications can be met. The aim is to identify those subassemblies/components with the lowest reliability and generate mitigation strategies. The mitigation strategies can be as follows:

- Improve the design of the subassembly/component to improve its reliability.
- Improve the maintainability of the system/subsystem so that it can be easily removed/replaced and repaired.
- Develop a scheduled maintenance inspection interval and task for the system/subsystem to ensure the product meets it reliability targets or requirements.

The last two strategies have a cost implication associated with the extra maintenance tasks and will affect availability and perhaps dispatch reliability.

In reliability engineering it is important to maximize the use of proven technology on the system design and limit the introduction of new/unproven features into the design. However, when the program requires the inclusion of new/unproven technology into the system, sufficient budget must be allocated during the development for testing, in order to achieve a sufficiently mature design for entry into-service. Finally, the design team and the reliability engineer must be aware of the limitations that have to be faced [2] and that in some cases the reliability specifications cannot be met due to the system complexity and/or unproven design. The last two mitigation strategies listed can then be utilized to minimize the program risk.

3.2.4 Reliability Monitor

The purpose of the reliability monitor is to identify and track the key failure modes within the design of the system/sub-system, which could potentially impact the reliability of the system. Reliability monitor reviews are necessary to single out the main reliability risks for each system/subsystem and develop adequate mitigation strategies. The identified reliability risks from these sessions need to be summarized and included in the reliability monitor report. The

reliability monitor is a living document and the purpose of this report is to present a status snapshot. The reliability monitor needs to be updated regularly, as risks are mitigated, or added throughout the design and development phases.

As well as general consideration of issues as they arise during the development program, the reliability monitor should also consider supporting the various subsystem FMECAs as they are produced. The reliability monitor should contain fields that include the owner of the reliability risk identified, the description of the risk and potential effect at system level, proposed mitigation to address the risk, the status (see Section 3.2.4.1) and the predicted closure date.

A reliability monitor report needs to include a few features which are listed below:

3.2.4.1 Reliability Monitor status

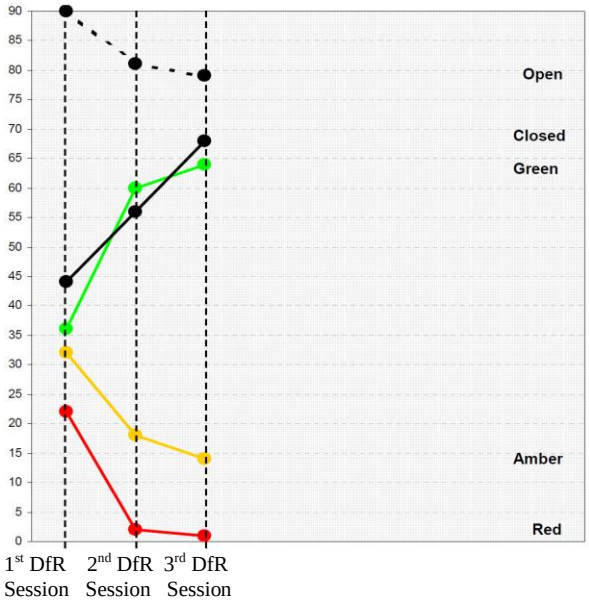

Figure 1. Example of a reliability monitor status

The color codes are:

- Black: Reliability risk closed. Mitigation has been completed and/or traceable documentation is available.
- Green: Reliability mitigation has been planned and agreed, target dates are being achieved. Many reliability risks identified require the successful completion of program development tests or specific dedicated test in order to be closed (specified in the reliability monitor)
- Amber: Reliability mitigation has been planned, the plan is not yet agreed; or

  its adequacy to mitigate the reliability risk is not assured; or

  the plan is behind schedule, not impacting major program milestones
- Red: Reliability mitigation has not been planned; or

  the plan is significantly behind schedule, impacting major program milestones

3.2.4.2 Reliability proposed methods of mitigation

Mitigation methods proposed by the reliability group need to be included for each identified reliability risk. There are various mean of mitigation and these should be considered in the following order of priority:

1. Elimination of the reliability by design change or analysis to demonstrate that the risk does not exist
2. Justification through heritage review, lessons learnt and in-service events (of similar parts in a comparable environment) that the reliability risk is acceptable
3. Control of the reliability risk through maintenance, instructions (special manufacturing processes, quality checks, life limits…)

3.2.4.3 Reliability Monitor Burn-down chart

The purpose of the reliability burn-down chart is to list the expected closure dates for all identified reliability risks. The burn-down chart needs to be updated following sessions with the validation group in which key development testing programs need to be identified in order to close certain reliability risks. Some reliability risks need the accumulation of cycles/hours and the full completion of the system testing program to ensure the reliability risks have been adequately addressed.

An example of a reliability monitor burn-down chart is given below:

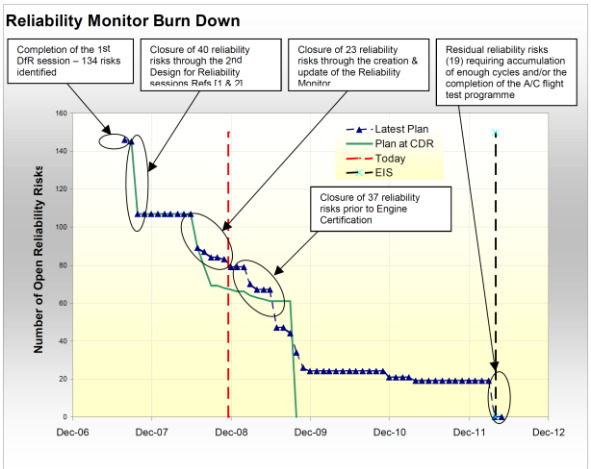

Figure 2. Example of a burn-down chart for a reliability monitor.

3.2.5 Reliability Testing

To complete the Design for Reliability process, validation testing requirements and in-service management requirements need to be agreed between the validation group and the design and project groups.

Finally, a Declaration of Reliability Accomplishment report summarizing the reliability risks, how they will be / have been addressed and how the design improvements will be / have been validated during the development phase needs to be issued. This report should be issued near the end of the development program.

The introduction of a new product has generally a high failure rate. Extensive prototype testing may be needed to bring the product up to maturity and identify the key failure modes before entry-into-service.

3.2.6 Reliability improvement programs

Many in-service failures are due to operating conditions that are not specified or foreseen by the designer. Reliability improvement is then dependent on in-service data feedback. A schedule of reliability reassessment is needed for the review of failures experienced, inspection reports and maintenance activities, in order to identify modifications, any research or testing requirements that may be needed. A regular review of maintenance and inspection schedules must also take place to account for these findings [2].

Development of items for reliability once the product enters service is more expensive than if the reliability activities were performed systematically during the concept, design and development phases. Time is required to collect valid and meaningful field data. Different operators will have different operating conditions, which result in the need for obtaining data from many samples over a long period of time. Periods between maintenance and inspection can only be increased with caution, based on solid operating experience and the resolution of the failure modes encountered.

4 REINFORCED TESTING

Testing for reliability and robustness is different from qualification testing, which relies on trying to pass the test by discounting any failure as unusual and not relevant. The HALT/HASS test methods are aimed at finding and fixing weak links in the product in the design phase and then finding and fixing process flaws during production [7]. The other aim of these tests is to improve the intrinsic reliability of the product. The HALT/HASS tests are also known as reinforced testing.

The HALT and HASS techniques represent a major shift in model testing compared to the traditional technique of qualification testing which rely on a successful outcome. Reinforced testing tries to rapidly detect latent defects, induced during design and production processes, analyze them and suggest corrective action to increase product robustness. The focus is to establish that components are able to function reliably and durably in all in service conditions.

Aeronautical system integrators recommend conducting these tests systematically on electrical, mechanical, hydro-mechanical, electromechanical-equipment that contain:

- electronic components of new design,
- components performing safety critical functions,
- components using technologies with no in-service experience,
- components similar to those with bad in-service experience.

A brief description of both methods of testing is given below.

4.1 Highly Accelerated Life Testing (HALT)

HALT is a test method that is conducted on systems sub-systems that are integrated into the aircraft, during the design phase, preferably before any design verification testing has been carried out. The aim is to identify design flaws in order to improve product reliability, product maturity, life cycle cost and increase customer satisfaction. The other aim of the test is to stress the product far beyond its design

specifications as well as that beyond which the product will encounter it its operational environment.

As stated by Hobbs [7], who has been developing HALT/HASS methods for years: “The stresses are stepped up to well beyond the expected field environments until the "fundamental limit of the technology" is reached in robustness. Reaching the fundamental limit generally requires fixing everything relevant found even if found at above the "qualification" levels!”

4.2 Highly Accelerated Stress Screens (HASS)

The limits discovered during HALT are used as the basis for the implementation of HASS, which is a production screen test performed on products built as part of the production process. The test method uses the highest possible stresses well beyond the qualification levels, in order to reach the necessary time compression in the screens. HASS should be performed following a comprehensive and successful HALT program, in order to test a robust product (which has been improved following the HALT findings), as the stresses will be too high for the original/unmodified design [7].

5 THE ROLE OF RELIABILITY ON AFTERMARKET SERVICES

Many aerospace manufacturers, including system providers, offer aftermarket services beyond the sale of their products. For example, the Rolls-Royce TotalCare™ package offers long term maintenance agreements to its customers, where the customer pays an agreed fee (monthly or by the hour) above that of the sale of the product. The maintenance contract requires the manufacturer to take responsibility for all covered repairs and maintenance (bird strikes, operational exceedance and outside hazards are excluded) [8].

Since the company needs to cover and take responsibility of all the repair and maintenance costs for its product, the product reliability is vital to support the company’s aftermarket business case. The risk in this case, comes from the extra maintenance costs that have not been anticipated by the manufacturer (e.g. low reliability of the product requiring more regular inspections, maintenance actions or replacement). However, the benefits are both to the manufacturer and operator with a reliable product requiring less maintenance and therefore providing direct cost savings to both parties. Designing for aftermarket services require engineers and managers to understand the reliability of the product and the causes and impacts of the failures.

From a business point of view, the reliability process with its systematic approach, should support the program, by allowing the project managers (such as chief engineers) to make quicker, better, and more informed decisions. The reliability process listed in Section 3.1 supports the design for aftermarket services.

Finally, to effectively support the project, the reliability process must use analysis methods and predictive/modeling tools that account for the component aging, the company’s maintenance strategies and effective design upgrades. Good service data collected at the lowest level, analyzed and understood is necessary to derive accurate reliability predictions. A cultural change within the company and the establishment of project integrated teams might be required to design for aftermarket services [9].

6 CONCLUSIONS

Whilst design for reliability has been documented and suggested for a long time, it is only in recent complex aircraft programs, that it has been implemented effectively. This is the result of a cultural change within the aerospace community, which places a lot of emphasis on improving the product life cycle cost and subsequently the business case model (for both the Original Equipment Manufacturer and the operator).

The authors of this article have worked in such an environment and were tasked with developing and implementing an effective design for reliability process.

As shown in Figure 3 below (describing the product timeline for an engine application), design for reliability activities should start at the concept phase and support the product development beyond its entry-into-service.

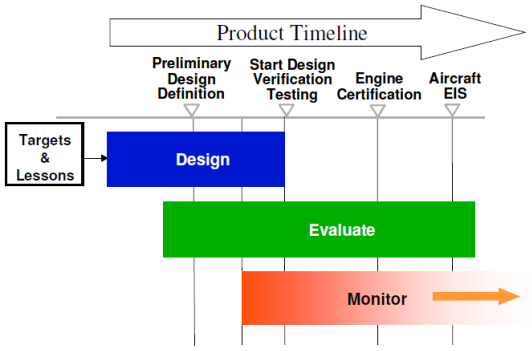

Figure 3. Overview of the design for reliability timeline [9].

The benefits of such a process on safety, availability and aftermarket services are numerous and summarized in the body of this report.

In order to obtain a mature, robust and reliable product at entry into service, it is essential that all parties

involved in the design and development of the product (design engineers, system specialists, project engineers, validation engineers and vendors/suppliers…), are made aware of the importance of the DfR process and how to design and develop the product to meet the reliability and aftermarket requirements.

The design for reliability process discussed in this article is detailed enough to enable any reliability engineer with good experience to adopt it and it can be applied to any other industry, including that of space.

7 ABBREVIATIONS AND ACRONYMS

COTS	Commercial Off-The Shelf
DfR	Design for Reliability
EIS	Entry Into Service
FMECA	Failure Mode Effects and Criticality Analysis
FTA	Fault Tree Analysis
FRACAS	Failure Reporting And Corrective Action System
HALT	Highly Accelerated Life Tests
HASS	Highly Accelerated Stress Screens
IC	Integrated Circuit
LCC	Life Cycle Cost
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
OEM	Original Equipment Manufacturer
SSA	System Safety Assessment

8 REFERENCES

1. J D Andrews and T R Moss (2002). *Reliability and Risk Assessment*. Second Edition. Professional Engineering Publishing. pp02-04
2. W Wong (2002). *How Did That Happen? Engineering Safety and Reliability*. Professional Engineering Publishing. pp148-154
3. Ian Moir and Allan Seabridge (2001). *Aircraft Systems, Mechanical, electrical and avionics subsystem integration, Second Edition.* Professional Engineering Publishing. pp289-302
4. Ian Moir and Allan Seabridge (2003). *Civil Avionics Systems.* Professional Engineering Publishing. pp33-48
5. S. Baskcomb, D. Ouedghiri (2014). *SAFETY IN NUMBERS? (LESSONS LEARNED FROM AVIATION SAFETY ASSESSMENT TECHNIQUES).* 7th IAASS Conference 2014 – Safety is not an option. ppxx-xx
6. M. Vintr, 12th IFToMM World Congress, Besançon, France, (June18-21, 2007). *Reliability Assessment for Components of Complex Mechanisms and Machines.* Brno University of Technology (Czech Republic). pp01-04
7. Gregg K. Hobbs, Ph.D., P.E. (13 August 2002). *HALT AND HASS, THE NEW QUALITY AND RELIABILITY PARADIGM (Publication).* Hobbs Engineering Corporation. HALT and HASS Seminar.
8. Michael A. Burkett (2006). *EXPANDING THE RELIABILITY PROCESS TO MORE ACCURATELY ASSESS BUSINESS RISKS AND OPPORTUNITIES ASSOCIATED WITH LONG-TERM MAINTENANCE CONTRACTS.* ASME Turbo Expo 2006: Power for Land, Sea and Air. May 8-11, 2006, Barcelona, Spain.
9. Andrew Harrison (2006). *DESIGN FOR SERVICE – HARMONISING PRODUCT DESIGN WITH A SERVICES STRATEG* . ASME Turbo Expo 2006: Power for Land, Sea and Air. May 8-11, 2006, Barcelona, Spain.