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Reliability Growth Management during Prototype Development

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ABSTRACT

Reliability growth is defined as positive improvement of system /equipment reliability through the systematic and permanent removal of specific failure mechanisms. Effective reliability growth is dependent upon the extent to which testing and other improvement techniques have been used during development and production to eliminate design and fabrication flaws, as well as on the rigour with which these flaws/deficiencies are analysed and corrected. In a prototype development scenario of a complex product such as a modern helicopter, reliability growth management has to consider various factors, such as the dynamic nature of design changes, usage environment, inherent reliability of constituent systems (both in-house fabricated and bought out items), quality aspects as well as users' expectations. Major factors contributing for the effective reliability growth management are continuous snag data analysis, reliability trend monitoring and design reviews.

This paper presents the details of reliability growth management aspects adopted during prototype development of advanced light helicopter, designed and developed by the Hindustan Aeronautics Ltd, Bangalore. The approach followed lay greater emphasis on regular and continuous snag data analysis, monitoring of efficacy of corrective actions, establishment of an adequate failure reporting and corrective action system, proper documentation, and above all, design review by the top management for assuring reliability. It has been observed that the above management approach has yielded positive results in reducing the number of reliability problems encountered during prototype development. It also provides scope for further reliability improvement in production versions.

Keywords: Reliability management, reliability growth models, prototype development, test and evaluation, reliability data, advanced light helicopter, reliability assurance

1. INTRODUCTION

Design and development of complex machines, such as aircraft or a helicopter is a process to meet the users' requirements in terms of performance and reliability. The design parameters of performance and reliability are validated on prototype models by a process of testing under specified loads and environmental conditions. The initial prototypes, especially those with advanced technologies, will invariably have significant reliability problems that could not be foreseen in the early design phases. The prototypes are, therefore, subjected to a development-testing programme to surface out problems so that the improvements in the system design can be made. The ensuing system reliability will depend upon the number and the effectiveness of these design modifications/improvements. In such a prototype development scenario, emphasis on reliability assurance, prior to final demonstration of the product, is accomplished by utilising reliability growth management techniques. This paper presents an approach to reliability growth adopted during the development of advanced light helicopter (ALH), providing details of failure reporting and classification, the reliability growth analysis, and the managerial aspects in accelerating corrective actions for achieving required reliability levels.

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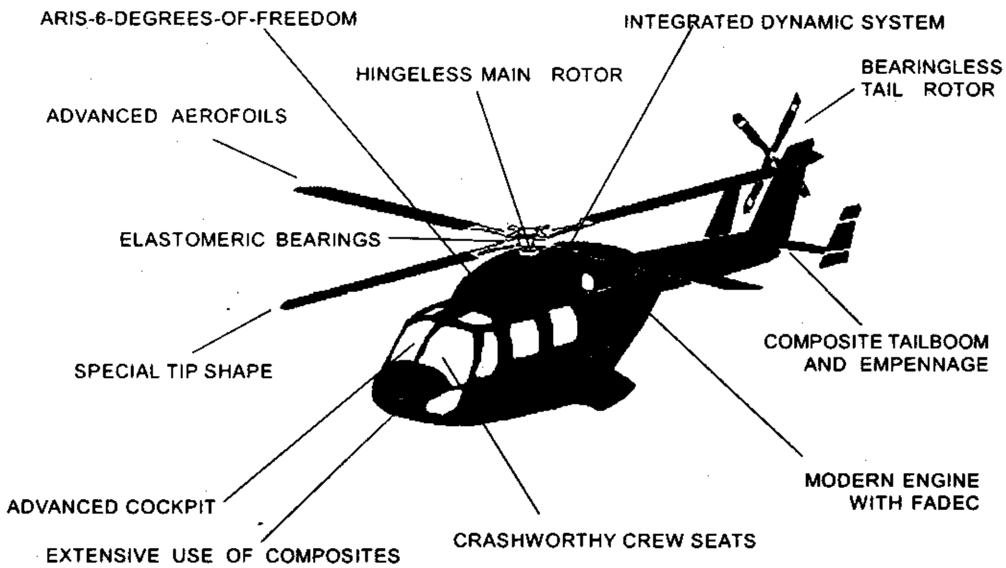

Figure 1. Advanced Technology features of ALH

2. ADVANCED LIGHT HELICOPTER

Advanced light helicopter is a multi-role, multi-mission helicopter in the 4.5 – 5.5 ton class, designed and developed by the Hindustan Aeronautics Ltd (HAL), Bangalore. The helicopter incorporates various advanced technology features (Fig. 1). Some of the major design objectives are:

- Good handling qualities to meet a single-pilot instrumented flight regulation (IFR) criterion
- Hot and high altitude performance
- Maximum cruise speed
- Crashworthy capabilities
- Good cockpit ergonomics with all-round vision
- Clamshell rear door for cargo loading
- Skid-type or wheeled landing gear
- Carrying underslung load (up to 1500 kg)
- Good yaw controllability
- High reliability, maintainability, interchangeability, survivability, and ballistic tolerance
- Optimum ratio of basic empty weight to all-up weight.

Four prototypes have been built and flight-tested under various operating conditions, which are representative of users' environment. The prototype development has followed the test-analyse-and-fix approach for resolving snags/failures encountered during development-testing.

3. RELIABILITY

3.1 Reliability Assurance during Design

The reliability assessment activities carried out during design are:

- Reliability apportionment
- System modelling and configuration freeze
- Failure modes and effects analysis/failure modes, effects, and criticality analysis
- Reliability specifications and interaction with the vendors
- Reliability predictions.

The iterative process of reliability prediction and re-apportionment is continued till such time, shortfalls in predicted values wrt the required reliability are overcome. Subsequently, the data from the component qualification tests, bench tests, and assembly tests serve as indicators to the actual reliability to be achieved.

3.2 Reliability Assurance during Prototype Development

After completion of limited qualification tests and ground tests, the functional systems are integrated in the most judicious manner and the integrated

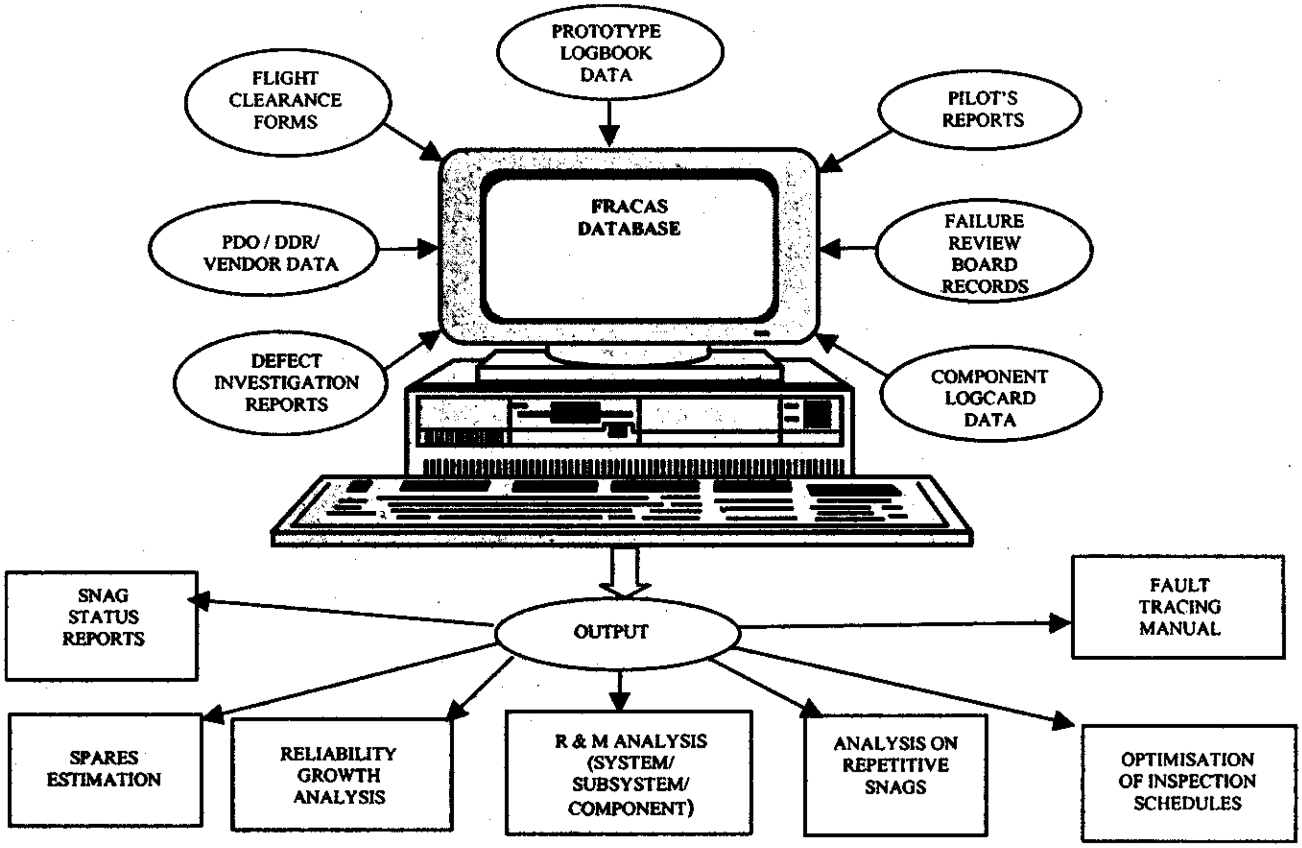

Figure 2. FRACAS adopted in advanced light helicopter programme

machine, i.e., the prototype helicopter is then tested, both on ground and in-flight, to verify and validate the design objectives. This phase of development-testing is associated with identifying, analysing, and correcting design flaws and deficiencies. The corrective actions include repair, re-work, replacement, re-design or selection of alternate vendor units, use of alternate manufacturing/installation processes, etc. The efficacy of the corrective actions implemented is then monitored for establishing reliability. This is termed as text-analyse-and-fix concept.

3.2.1 *Reliability Data*

The snag/failure data obtained from the development flight-testing of prototypes form the basis of reliability growth management. To facilitate reliability growth, it is necessary to keep accurate records of failures, the failure mechanisms, operating time, and details of corrective actions and their efficacy of resolving the defects/failures. This requires establishment of a closed-loop failure reporting, analysis and corrective action system (FRACAS) to keep track and eliminate failures identified during prototype testing phase (Fig. 2). In ALH programme, FRACAS is established and snag data is compiled from records, such as prototype logbooks, pilot's defect reports, pilot's assessment reports, flight clearance forms, defect investigation reports, component logcards, failure review board records.

3.2.2 *Data Analysis*

The raw data obtained from the above records are analysed from reliability point of view and categorised as repetitive and non-repetitive. The non-repetitive snags include snags due to human errors in assembly/inspection, isolated incidents and non-confirmed snags. The cause of concern, from reliability point of view, is the occurrence of repetitive snags in spite of implementing certain corrective actions. Such snags are analysed separately

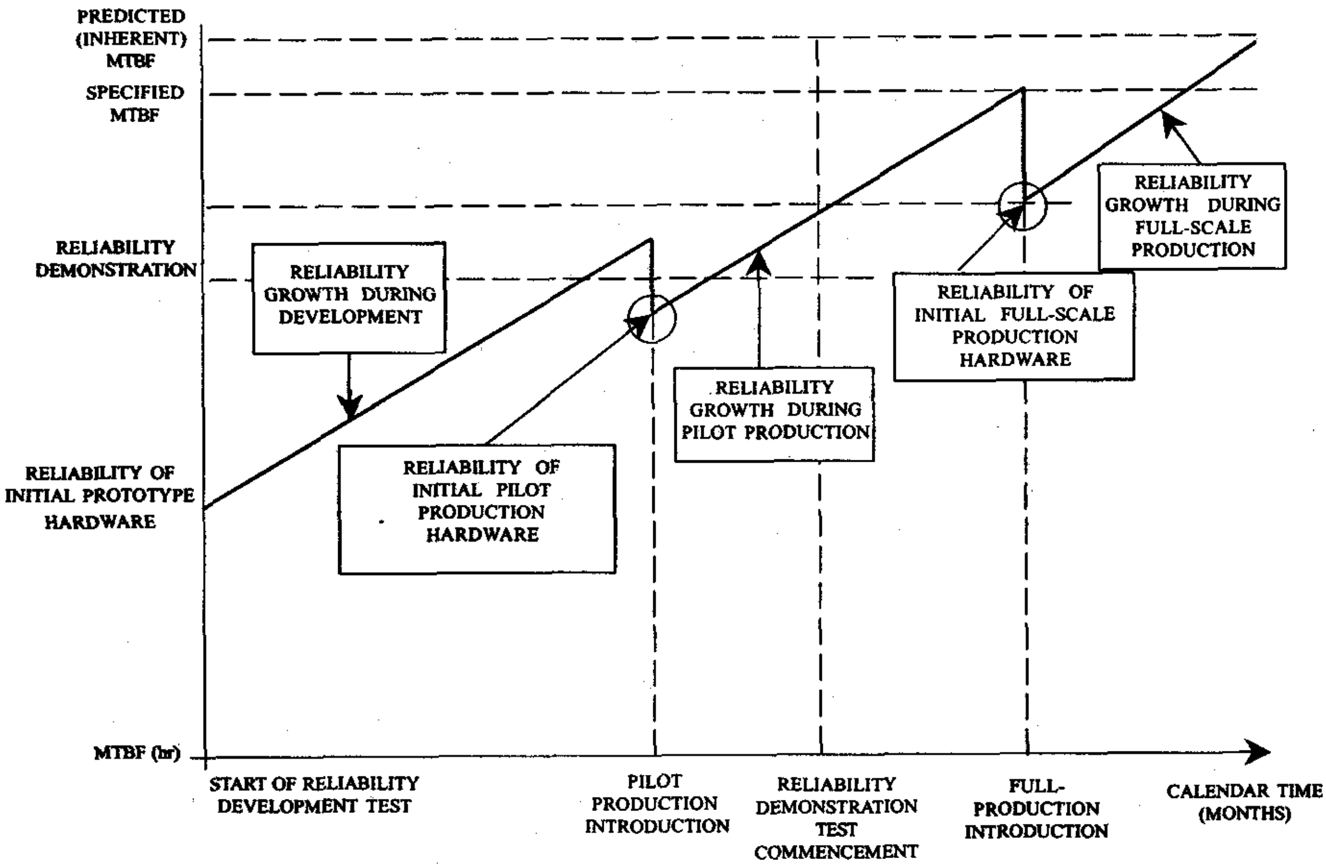

Figure 3. Reliability growth process

and reviewed periodically so that these can be resolved through suitable corrective actions. The repetitive snags are categorised as (i) snags that are resolved, (ii) snags for which rectification actions are under assessment on prototypes, (iii) snags for which rectification action is under implementation, and (iv) snags for which solution is yet to be found.

In such situations, the role of the management is to review status of each category and accelerate efforts so that all the snags eventually fall under the resolved category.

3.2.3 *Reliability Growth Analysis*

The reliability growth of a system takes place due to positive effect of changes introduced in the system in the development phase, where the design is considered to be immature. Figure 3 depicts a general trend in reliability growth process. To track reliability during development, a reliability growth management programme should be established which should essentially have the following:

- An active and accurate FRACAS
- Monitoring efficacy of corrective actions
- Reliability trend analysis using appropriate growth models
- Continuous review on reliability growth by the top management.

Figure 4 presents the reliability growth management model adopted for ALH programme.

3.2.3.1 *Reliability Growth Models*

To quantitatively measure reliability growth, it is essential to use an appropriate reliability growth model. There are various statistical reliability growth models, characterising growth in different ways–some use failure rate as a function of time, some use mean time between failures (MTBF), and others

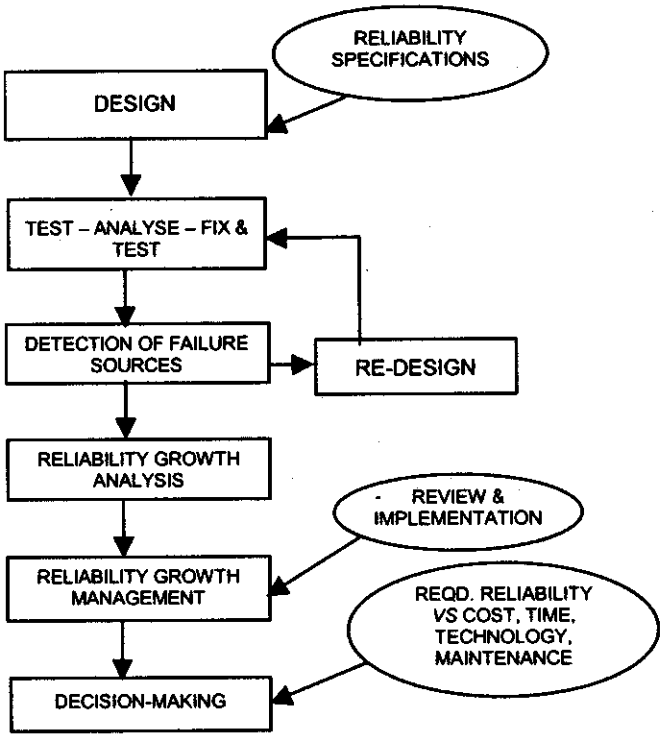

Figure 4. Reliability growth management model

based their models on the success probability. The purpose of reliability growth analysis during prototype development is to find and correct defects in design and fabrication of the system/equipment through systematic and permanent removal of specific failure mechanisms and infer results of prototype testing for managerial decisions on investment in terms of manhours, money, and technology, etc. to achieve the required growth levels, as well as to demonstrate reliability for a given confidence level.

Among the various reliability growth models explained in the literature, the three models – the Duane's model, the AMSAA model, and the Gompertz model were considered for analysis. Unlike other models which are applied for definite phases, the Duane's model was chosen for its simplicity in approach and use, as well as for its applicability for the entire development phase. According to the Duane's model, the plot of the logarithm of the cumulative number of failures per test time versus the logarithm of test time during growth testing is approximately linear.

This observation can be expressed mathematically and extrapolated to predict the growth in MTBF while the test-fix-test-fix cycle continues. Let

T = Total test time accumulated

$N(t)$ = Accumulated failures during time T

Then $n(T)/T$ is the cumulative failure rate, and $T/n(T)$ is the cumulative MTBF. If the plot is linear, then

$$\ln[T/n(T)] = a + b \ln T$$

and the cumulative mean time to failure

$$\text{MTBF}_c = T/n(T) = e^{a+b\ln T} = e^a T^b = kT^b$$

where b is the rate of growth, or the slope of the fitted straight line. The parameter b is called the growth factor and is a measure of effectiveness of the growth programme (Table 1).

Table 1. Effectiveness of reliability growth programme

Growth factor	Growth programmes
$b = 0.4 - 0.6$	Programme dedicated to reliability and removal of design weakness
$b = 0.3 - 0.4$	Programme well managed with reliability as a high priority
$b = 0.2 - 0.3$	Taking corrective action for important failure modes only
$b < 0.2$	Reliability has low priority

3.2.3.2 *Case Study*

The Duane's model was applied for assessing the reliability growth of two variants of ALH prototypes. The prototype data on mission reliability computed for five years was analysed. A sample analysis is presented here for illustration.

Table 2 provides data on time (in flight hours) and the corresponding number of mission-abort snags observed.

By plotting ln T *vs* ln $[T/n(T)]$ and using the least square method, the parameters a and b are estimated as

For prototype A: $a = -0.6552$, $b = 0.430$, $k = 0.5193$

For prototype B: $a = -0.1589$, $b = 0.426$, $k = 0.8531$

Table 2. Data on time (in flight hours) and the corresponding number of mission snags

T	$n(T)$	$T/n(T)$	ln (T)	ln$[T/n(T)]$
Prototype A				
50	16	3.1250	3.9120	1.1394
100	31	3.2258	4.6050	1.1711
150	35	4.2857	5.0106	1.4553
200	37	5.4054	5.2983	1.6873
250	46	5.4347	5.5215	1.6923
300	51	5.8823	5.7038	1.7719
350	54	6.4814	5.8579	1.8689
400	55	7.2727	5.9915	1.9841
450	61	7.3770	6.1092	1.9983
500	68	7.3529	6.2146	1.9951
Prototype B				
20	7	2.8571	2.9957	1.0498
40	8	5.0000	3.6889	1.6094
60	13	4.6154	4.0943	1.5292
80	17	4.7059	4.3820	1.5488
100	17	5.8823	4.6057	1.7719
120	18	6.6667	4.7875	1.8972
140	20	7.0000	4.9416	1.9459
160	20	8.0000	5.0752	2.0794
180	21	8.5714	5.1929	2.1484
200	23	8.6956	5.2983	2.1628
220	27	8.1481	5.3936	2.0978
240	27	8.8888	5.4806	2.1848
260	32	8.1250	5.5607	2.0949

The plots applying the Duane's model are shown in Fig. 5. From the above analysis, it is evident that with a factor $b > 0.4$, the programme is dedicated to improve the reliability by continuous elimination of design deficiencies. The results based on analysis for both the prototypes are given in Table 3.

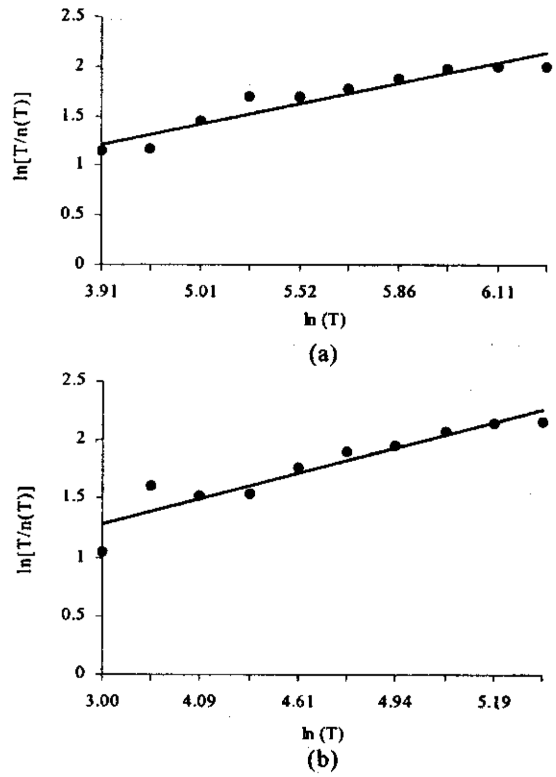

Figure 5. Plots applying Duane's model: (a) for prototype A (b) for prototype B.

The additional information that can be inferred from the analysis includes the time required for further testing to achieve the required MTBF-level and the MTBF-levels at future point of time.

3.2.3.3 *Benefits of Reliability Growth Analysis*

A reliability growth management programme enables the management

- To take advantage of experience gained in previous programme
- To evaluate different potential test plans and select the appropriate one

Table 3. Results based on analysis of prototypes A and B

Reliability parameter	Prototype A (h)	Prototype B (h)
Required MTBF	19.5	10.0
Cumulative MTBF achieved	7.5 (at 500 h of testing)	9.0 (at 260 h of testing)
Instantaneous MTBF	13.2	16.0

- To evaluate possible course of failures and appropriate corrective actions when an ongoing programme is facing problems
- To assess the progress of an ongoing programme.

The reliability growth analysis also helps to

- Determine the intensity of test-analyse-and-fix approach to reach reliability objectives.
- Predict whether stated reliability objectives will be achieved.
- Correlate reliability changes with reliability activities and to track the progress.
- Plan for a reliability demonstration test.
- Compute confidence limits to satisfy reliability requirements.

4. ROLE OF MANAGEMENT

A project of complex nature can achieve its intended goal of assuring adequate reliability only with active and continuous support of its management. The top management needs to lay emphasis on reliability assurance, right from early design, and continue their efforts during manufacturing, testing, and certification. This can be achieved through the following:

- Management information system on reliability problems collated from FRACAS by a dedicated team of reliability engineers
- Continuous trend monitoring and reliability analysis at various levels, such as system, subsystem, component/equipment, prototype, boughtout/in-house fabricated items, etc.
- Establishing a system of learning for better awareness on quality and reliability through proper training, conducting workshops, seminars, etc.
- Periodic review on the progress of reliability achievement and the implementation of corrective actions

The most important aspect of management in reliability growth is that of decision making for building-in reliability, if the achieved levels do not meet the requirements. In such situations, decision has to be made based on various factors, such as the available/affordable technology, the time required, the cost involved, the maintenance aspects due to incorporation of new features, and the impact on delivery schedules. A practical approach would be to implement reliability improvement activities in a phased manner with interim goals.

5. CONCLUSION

Reliability growth, in essence, is the result of an iterative design process. As the design matures, the problems are identified, failure sources detected and suitable corrective measures taken. The efficacy of corrective actions is assessed with the aim to monitor reliability growth. The rate at which the reliability growth takes place depends on how rapidly the above actions are accomplished. This rate of reliability growth can be accelerated by a dedicated reliability growth management programme equipped with adequate reliability tools, such as FRACAS and also by reliability growth analysis.

This paper describes the general aspects of reliability growth management, detailing the purpose, methodology, and benefits of such management. A sample data analysis of a modern helicopter mission reliability growth using Duane's growth model has been presented. It is observed that in a design and development scenario, continuous reliability data analysis and reliability growth monitoring with the support of the top management, by means of review and prompt decision making, has the benefit of increasing not only the MTBF or reliability of the product, but also the confidence of the certifying agencies, as well as the users.

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