Defense Technical Information Center
Compilation Part Notice

ADP010429

TITLE: What the Customer Wants. Maintenance-Free and Failure-Free Operating Periods to Improve Overall System Availability and Reliability

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Design for Low Cost Operation and Support [la Conception en vue d'une exploitation et d'un soutien a cout reduit]

To order the complete compilation report, use: ADA388024

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP010418 thru ADP010432

WHAT THE CUSTOMER WANTS

MAINTENANCE-FREE AND FAILURE-FREE OPERATING PERIODS TO IMPROVE OVERALL SYSTEM AVAILABILITY AND RELIABILITY

SQUADRON LEADER P MITCHELL
MSC BEng CEng MRAeS RAF
Logistics (OR) 5D Room F30
HQLC, RAF Brampton
Huntingdon, Cambs. PE18 8QL, UK

INTRODUCTION

BACKGROUND

1. Military commanders require high levels of mission effectiveness and supportability to ensure success in an inherently hostile environment. The emphasis must be on safe equipment operation under a variety of adverse environmental conditions and with a minimal logistics support footprint. In-service experience shows that unreliability of defence equipment remains a dominant factor during operations and training and that there are deficiencies in the traditional specification of military reliability requirements. Consequently, an alternative method for specifying reliability is required, one which is not subject to the uncertainties of characterising product reliability with a single failure-rate number or Mean Time Between Failure (MTBF). The traditional approach to reliability specification has been based on often unrealistic reliability predictions followed by potentially endless product testing to provide assurance, without the recognition that many failures can be prevented by attention to basic design details. Manufacturers need to develop a better understanding of materials and process conditions, and their effects on product reliability, in order to provide the customer with defence equipment that works when needed and continues operating for a defined period of time.

2. High mission effectiveness in future defence equipment is achieved by accurate predictions of in-service reliability and minimum system functionality. Thus, new reliability techniques are required that foster fault prevention and control and, most importantly, focus on user operational requirements. The ultimate goal is to reduce the dependence on characterising reliability by a single failure-rate number, ie MTBF, and to look for new methodologies which focus on causes of failure and their control or elimination, rather than measuring and responding to their effects. This leads to the twin concepts of Maintenance-Free and Failure-Free Operating Periods which are alternative, more practical, approaches to specifying, measuring and assuring product reliability. The implementation of this new approach would involve an evolutionary progression from the current system.

AIM

3. The aim of this paper is to promote the philosophy of Maintenance/Failure-Free Operating Periods (M/F-FOP) as an additional methodology for the specification and assurance of defence equipment reliability.

DEFINITIONS

4. Failure-Free Operating Period (F-FOP) is a period, measured in appropriate units, when the system is meeting its minimum operating capability.

5. Maintenance-Free Operating Period (M-FOP) is a period of operation during which the system must be able to carry out all its assigned missions without any maintenance action and without the operator being restricted in any way due to system faults or limitations.

PRODUCT RELIABILITY REQUIREMENTS

6. We, the customer, have allowed the current approach to reliability specification to prevail, in that we expect a MTBF or its reciprocal, a failure rate, to form part of a proposal from an equipment supplier. Vendors may then typically estimate the product's reliability by using commercial reliability models, such as Mil-Hdbk-217 in the specific case of electronics equipment. On other occasions an internal proprietary reliability model may have been developed and maintained, based on historical or test data and an assumed failure-rate. Often, the prediction methodology used assumes an exponential failure-rate, meaning that random failures and faults are inevitable. The use of MTBF has thus bred and sustained a culture of inevitable and acceptable failure, a tacit acceptance that equipment will fail randomly with little incentive to understand the mechanisms of when and why failures occur. Once an equipment has been allocated a particular reliability level, it has been traditional for most activities to then concentrate on nourishing this belief in random failure, using predictions and other statistical tools, based on the application of exponential theory, without addressing the underlying mechanistic reasons for failure.

7. The majority of random failure modes can be removed by study into the mechanics of failure followed by interactive design influence. In particular, most

Any views expressed are those of the author and do not necessarily represent those of the Ministry of Defence, United Kingdom. Document published with the permission of the Controller of Her Britannic Majesty's Stationery Office.

Paper presented at the RTO AVT Specialists' Meeting on "Design for Low Cost Operation and Support", held in Ottawa, Canada, 21-22 October 1999, and published in RTO MP-37.

avionics failures have been attributed to associated mechanical problems such as packing densities, quality assurance shortfalls, and heavy exposure to vibration, dust and moisture. Taking steps to remove these causes of failure reduces the number of random failures such that many of the remaining failure modes exhibit certain mechanics of failure that have non-random failure distributions. These failure distribution curves can then be plotted and used to determine overall product durability or a minimum required time to failure, eventually creating better generic design tools. . It is generally accepted that as equipment operating time increases, then the probability of failure increases: extending the durability of an element increases its probability of failure. Reliability requirements will need to be optimised in terms of durability and its associated probability of failure.

8. The nuclear and space industries aim to eradicate random failures from the outset and the car and rail sectors are following suit. In many defence related industries, the continuing acceptance of the random failure approach inhibits the most effective use of limited in-service support resources and will be a continuing factor impeding the effectiveness of future operations.

PRODUCT RELIABILITY ASSURANCE

9. Traditionally, reliability levels have been monitored through product development and testing. As technology approaches the boundaries of material and process capabilities, as ever greater levels of reliability are predicted, and as the demonstration of such levels is expected in shorter timescales, practical limits to the traditional approach of reliability demonstration are being reached. It is currently a reactive process, characterised by the use of sample tests as a means of monitoring product reliability levels and subsequent reaction to any signs of degradation. In contrast to this scenario the M/F-FOP approach is a new method of reliability specification, based on the identification and control of the causes of unreliability. It is intended to anticipate failure and design it out, rather than reacting to developmental failures. The aim is to provide greater assurance of enhancing equipment reliability and its predictability in service. This is achieved by understanding and controlling those elements in product design, manufacture and use which affect system and component reliability.

10. Military contracts often require suppliers to implement a prescribed reliability programme and to perform tests aimed at achieving specified contractual reliability requirements in terms of allowable failure rates. Many of these tasks are reactive in nature, in that they represent fault detection rather than prevention. Other activities, which are designed to be proactive, frequently turn out to be reactive because contractors pay lip-service to them, perhaps by conducting them far too late to be able to influence the design process. One such example is a Failure, Modes, Effects and Criticality Analysis which, when conducted at the relevant stage, can influence design and provide designers with an understanding of the consequences of failure, thus allowing effective alterations to be incorporated as necessary. However, it is often applied too late to have any meaningful impact on the design and is often regarded as a deliverable to the MOD rather than an aid to design

11. During testing, sample sizes required to resolve low failure rates become impracticably large and economically untenable. To present large numbers of components for confidence testing, either for qualification or monitoring purposes, is unrealistic. During such testing and initial production, few products are available at a time when manufacturers wish to maximise the number of parts for delivery to the customer. Even during full production, there is reluctance to divert large numbers of components for testing and suffer the consequent financial loss. Also, with small order quantities, there is every chance that the number of parts needed for testing would exceed the total number produced. Consequently, the return on investment in conducting tests to provide evidence of product reliability needs to be carefully evaluated as component reliability estimates increase. Testing for high MTBF potentially requires massive investment in parts and test time which manufacturers are understandably reluctant to do. This again leads to the 2 linked concepts of M/F-FOP, aimed at overcoming this dilemma whilst also providing the military commander with greater operational availability and mission reliability. M/F-FOP confidence would be obtained by a combination of progressive assurance during development and production supported by a tailored in-service demonstration.

FAILURE-FREE OPERATING PERIOD

12. A Failure-Free Operating Period (F-FOP) means that the equipment is able to operate to its full mission requirement for the period required or specified. There may well be faults which occur, however, the required system operation is unaffected and thereby no functional failure is recorded. Clearer comprehension of the mechanics of failure and ruggedness of components, together with better understanding of the operational environment can lead to a probability of time in-service before the occurrence of a failure. The ability to plan for known periods of high operational availability remains a key feature in the effective use of expensive assets. To achieve this, specifying reliability in terms of a F-FOP is a realistic option. The reliability requirements of some minor RAF equipment have already been specified in terms of a F-FOP. This does not mean that faults cannot occur, but rather that any faults which do arise are absorbed by the inherent fault tolerant architecture of the system. The application of a F-FOP maintains system functional capability whilst not necessarily restricting maintenance activity to certain periods, and as such is more applicable to CE systemsOne example of the application of a F-FOP is a ground-based radar installation, where the maintenance timing is not necessarily constrained.

MAINTENANCE-FREE OPERATING PERIOD

13. A Maintenance-Free Operating Period (M-FOP) for a weapon system is a period of operation during which a number of assigned back-to-back missions would be carried out, without any mission losses due to system faults and with no unscheduled maintenance activity. As with the F-FOP, this does not necessarily mean that the system must be fault free, rather that any fault which does occur must be absorbed by the system and not lead to system, and potentially mission, failure. Even if a fault occurs on the first sortie, the system must be able to continue to the end of the M-FOP with that fault still present. The only maintenance envisaged during the M-FOP would, for a military aircraft, be that typically carried out during flight servicings. This would include re-arming, refuelling and routine inspections. The M-FOP concept is currently being addressed within ST(A)425 Future Offensive Air System (FOAS) feasibility studies to demonstrate that in theory M-FOP is technically achievable and to reduce project risk from poor reliability.

MAINTENANCE RECOVERY PERIOD

14. When the equipment requires maintenance this would be carried out during a Maintenance Recovery Period (MRP). After each designated M-FOP there would be a MRP which would include all maintenance actions necessary to recover the weapon system to a state whereby it can complete the next M-FOP. The length and content of the MRP would be directly related to the length of the previous M-FOP and the required length of the subsequent M-FOP.

15. Within the MRP there would be different maintenance policies for different systems and equipment, but at this stage there should not be any pre-conceived solutions. This responsibility would fall to the Design Authority, who may need to make trade-off decisions about improving the reliability of one part of the design to achieve a more practical system or overall M-FOP. Generally, the aim would be for all maintenance to occur on a planned basis which would mean that the designer would have a much greater appreciation of how and when items fail.

ENABLING TECHNOLOGY

ACHIEVING A MAINTENANCE-FREE OR FAILURE-FREE OPERATING PERIOD

16. Fundamental to the achievement of a M/F-FOP will be a bottom-up approach to reliability with a clear understanding of why items fail and an ability to predict accurately when they will fail in use. Gathering relevant environmental data such as aircraft localised vibration, temperature and humidity, as well as indicative failure characteristics at the earliest stage in the development programme, will offer designers much better opportunities to design for durability and reliability. An early indication of design weaknesses will also allow precious resources to be focused in the appropriate development areas to maximise return on investment. Specifying reliability in terms of M/F-FOPs would motivate the designer to devise a fault tolerant architecture. Naturally, the reversionary configurations would need to meet relevant airworthiness requirements. An essential factor in such fault tolerance is detection using BIT and HUMS, together with an ability to override item failure. The following techniques and methods are relevant:

a. Condition Monitoring. Measurement and interpretation of data, condition indication, determination of maintenance requirement.

b. Redundancy. To achieve fault tolerance, using either hardware, software or data duplication in various forms. Can achieve significant reliability gains but at cost of potential increased complexity, weight, volume and power consumption.

c. Re-configuration. Recovery, automatic or otherwise, of a system after a failure without the need for the system to go off-line.

d. Advanced Diagnostics. To enable timely, accurate failure diagnostics to support minimum repair times during the MRP.

e. Prognostics. The capability to detect early warning of impending failure, enabling pre-emptive maintenance action to be carried out or to trigger re-configuration or redundancy processes.

f. Reversionary Modes. Allowing the software to back-up when a failure occurs and take a different path, thus bypassing failure causes.

g. N-version Programming. A software form of redundancy, involving voting between differently, often independently, developed software units.

h. Recovery Blocks and Self Healing. Backwards error recovery carried out by periodically saving the system state and reverting to it when necessary.

j. Exception Handling. Giving the software the ability to deal actively with failures, so avoiding system crashes or erroneous results.

CHANGING DURATION OF A MAINTENANCE-FREE OR FAILURE-FREE OPERATING PERIOD

17. Statistical analysis should substantiate the reliability of the proposed architecture and identify faults likely to occur during the operating period. Once equipment has reached a mature in-service phase, the

periods of maintenance-free operation may be amended in the light of further analysis of user experience. However, these changes would not be appropriate for immature equipment without the requisite field experience and supporting data.

CURRENT RESEARCH

18. Under the auspices of The Committee for Defence Equipment Reliability and Maintainability (CODERM), some practical aspects of specifying reliability using the M/F-FOP approach have been examined. Whilst much work remains to be conducted, desk level agreement has been reached that M/F-FOP is an acceptable alternative for the specification of reliability, provided that evolving results from continued conceptual development substantiate its future effective use. In addition, under the Society of British Aerospace Companies (SBAC) Foresight Action initiative, which aims to provide a national programme for aerospace growth through capability demonstration, the Ultra Reliable Aircraft programme is developing the application of M/F-FOP through modelling activities in particular. The current Future Offensive Air System (FOAS) feasibility study phase requires the contractor to examine M/F-FOPs with respect to FOAS. This is creating additional research in itself. Work in the United States, partly MOD funded and with active MOD participation, is investigating physics of failure mechanisms, the results of which will benefit designers working to M/F-FOP criteria. Through the presentation of papers and formal and informal contacts with defence industry representatives, the concept of M/F-FOP is becoming better understood and acknowledged as a potential significant contributor to enhanced weapon system reliability.

CONSEQUENCES

IMPACT OF A MAINTENANCE-FREE OR FAILURE-FREE OPERATING PERIOD

19. M/F-FOP approaches reliability from a different standpoint, focusing on determining and understanding causes of unreliability or failure and eliminating or controlling them. Not only does this allow potentially a new way of ensuring product reliability, but it also provides a methodology for improving it.

20. M/F-FOP involves a continuing search for, and implementation of, reliability-driven designs. Characteristics of such designs mean that a product should be more resistant to failure mechanisms, defects, and the degradation of materials and components. This obviously requires effective, informed communication between all disciplines involved in the design, development, manufacture and use of the system. Assuring and improving reliability requires an integrated effort between suppliers and customers, a responsibility which implies the removal of some organisational walls. In addition, current customer expectations of failure-rate predictions based on test data will have to be re-directed to be consistent with an emerging M/F-FOP methodology. To modify such expectations and promote the role of the customer in the M/F-FOP process, the degree of trust and communication between customers and suppliers must be increased substantially from current levels. This is precisely the message emanating from both MOD and the Defence Industry in the wake of SDR and Smart Procurement : there must be greater openness and trust to underpin mutually beneficial partnering arrangements.

BENEFITS

21. The fact that a weapon system will only need particular levels of maintenance at pre-determined intervals would greatly enhance the mission operational effectiveness. Systems would be available when needed and mission failures would be significantly reduced. Maintenance downtime would be programmed around operational commitments, with concomitant simplified supply chain management. Being able to make dramatic reductions in unscheduled maintenance arising rates would be a major advance. It would minimise logistics support and the costs to repair. To realise this objective will, however, require a significant culture change amongst many key defence contractors. Other potential benefits include:

a. M/F-FOP is simpler than MTBF. It therefore offers an improved basis upon which to contract for reliability.

b. Familiar and comfortable design practices would be abandoned and contractors would gain a deeper insight into their product. There would be greater research effort into failure mechanisms and development of the necessary design tools.

c. Reduced random component failures.

d. A physics of failure approach would be more likely to identify the true causes of failure than a statistical analysis involving MTBF.

e. The assumption of a constant failure rate would be challenged because system predictions would be built-up from the sum of the individual component failure distributions, rather than as a population, giving a more realistic bottom-up rather than top-down approach.

f. Using the principle of a failure-free period rather than failures randomly occurring would alter the basis of logistics planning. Compared with using reliability predictions based on constant failure models, more realistic spares provisioning should be possible, and expensive, inconvenient unscheduled maintenance should be minimised.

g. The approach would deliver a simple and more confident prediction of fleet costs and lease pricing details. Although contracting mechanisms for M/F-FOP need to be developed, they do lend themselves to alternative methods of logistics support.

RISKS AND COSTS

22. There are potential risks and costs in moving from MTBF to a M/F-FOP. The new approach may increase the frequency of inspection or refurbishment requirements for some parts. Other components may be scrapped before the end of their previously used life. Each component, LRU and system will require design analysis to establish its optimum M/F-FOP and associated cost. Some items will need little change, however, others may require design changes or an appraisal of whether inspection, refurbishment or scrapping would be more cost-effective. Modelling this scenario to determine potential manpower savings has proved difficult. In addition, there is the possible increase in acquisition cost as a result of the more rigorous design process. It will be essential that further work is undertaken to understand the trade-off between the investment in design/manufacture for M/F-FOP and the cost/operational consequences of today's poor equipment reliability.

23. There is the additional problem of aggregation of a large number of individual LRUs, sub-systems and system M/F-FOP into an overall weapon system M/F-FOP which needs skilled techniques and analysis to considerable depth. A clearer understanding of the M/F-FOP concept will require an integrated knowledge of engineering process design, an appreciation of practical in-use problems and an understanding of statistics. If the potential benefits are not to be negated at the systems integration stage, prime contractors will need to introduce process improvements and pay greater attention to detail during this phase. Partnership between sub-contractors, suppliers, prime contractors and customers will be essential. The greatest risks lie with system integration and participant motivation, yet the potential rewards are huge, both for producers and customer alike.

FUTURE AREAS OF STUDY

24. Further work is required to establish the main inter-relationships with operational effectiveness and logistics support when using M/F-FOP. This would include: application to different types of projects, for example, COTS; statistical inferences of M/F-FOP and associated confidence levels; contracting issues; methods for the assurance or demonstration of M/F-FOP; and how the use of M/F-FOP would interact with the ILS process. These are significant pieces of work, which have been brought to the attention of CODERM and which must be taken forward in partnership with industry. Moreover, experience to date suggests that reliability requirements for certain new projects should be specified in terms of a M/F-FOP whenever appropriate. Understanding, experience and knowledge will thus be enhanced. Furthermore, discussions and research through CODERM show the applicability of M/F-FOP across all defence environments. It is therefore essential that the approach is matured on a pan-PAO basis.

CONCLUSIONS

25. Current reliability specification methods do not take account of the understanding of fundamental failure processes. An alternative , M/F-FOP, embraces a logical, integrated approach to reliability, targeted at achieving greater accuracy in weapon system reliability predictions and hence, increased operational availability and reductions in life cycle costs. Product reliability assurance for items with high predicted MTBF and hence low failure rates becomes a costly, inaccurate process. Design to M/F-FOPs focuses on causes of failure, and their control or elimination, rather than on measuring and responding to their effects. The success of M/F-FOPs lies in the designer's clear understanding of failure mechanisms in the appropriate environment, a comprehensive, integrated design approach and the further maturity of key enabling techniques. Current limited work, supported by CODERM, is developing M/F-FOPs.

26. Progression of M/F-FOPswill require specific partnering between customers and suppliers at all levels. Additional potential benefits of such partnering would include a stronger basis on which to contract for reliability, greater insight into product design, enhanced realism in spares predictions and reduced logistics costs. Risks lie with enabling technologies not being sufficiently mature, particularly modelling techniques and the need to demonstrate clear cost reductions over a product's life cycle. Factors such as premature item replacement before useable life is consumed, the successful integration of a large number of items with different failure rate distributions and the need for additional up-front design will all have an impact on cost. It is, therefore essential that future areas of study are identified, prioritised and funded with MOD, through CODERM and in partnership with industry, playing a leading role.

Maintenance and Failure-Free Operating Periods

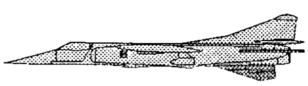
M/F-FOPs

Sqn Ldr P Mitchell RAF
LOGS(OR)5d
01480 52151 ext 6213
pm@logs4raf.demon.co.uk

WHAT DOES THE FUTURE HOLD?

- Pressure on Defence Budget
- Smaller RAF
- Less Manpower, more efficiency
- More deployments, more flexibility
- More complexity and more expense
- Global competition

THE KEY TO FUTURE AIR POWER



MISSION RELIABILITY

MISSION EFFECTIVENESS

Weapons that Work
Whenever Required
and keep on
Working
W[4]

WHAT THE CUSTOMER ACTUALLY NEEDS

Guaranteed Periods of Availability

result

Mission Effectiveness
Planning Certainty
Minimum Logistic Footprint

DEFINITIONS

- *Reliability* is: the ability of an item to perform a required function under stated conditions for a specified period of time. *Defence Standard 00-40 Part 1.*
- *OR:* the duration of failure free performance under stated conditions. *US Mil Std 785.*

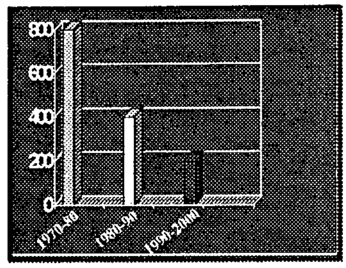
So Why Do We Use

The allowable number of faults in a given time

eg. 800 faults per 1000fg hrs

?

So What Next?



Predicting Failure Rates

VENDOR	Mil-Hdbk 217 prediction	MTBF observed
A	7247	1160
B	5765	74
C	3500	624
...E	2500	51
...G	1600	3612

Traditional R

MTBFs

- Failures are Inevitable
- Failures Occur Randomly
- Data is Aggregated
- Top-down Approach
- Accounts for Reliability

but

fails to Engineer a Solution

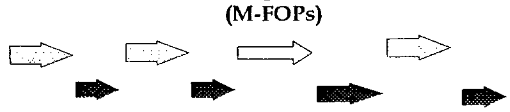
Traditional Approach to R

RAF specific problems with MTBFs:

- RAF ignores failure distribution and assumes constant failure rate.
  - Exponential Dist over 63% fail before MTBF
- Need to test all equipments to failure in order to substantiate a MTBF
- Large MTBFs mean long test times.
- Small sample sizes mean tests are statistically insignificant

The Way Forward

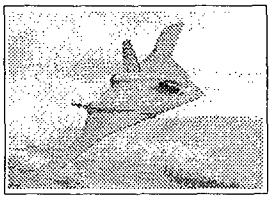
Maintenance-Free Operating Periods (M-FOPs)



Maintenance Recovery Periods

Twin Concept M/F-FOP

- Maintenance & Failure
- Free
- Operating
- Period



Definition of F-FOP

A period (measured in appropriate units) when the system is meeting its minimum required mission capability.

F-FOP APPLIED

- SR(A)1305 - UKADGE Command & Control System
- SR(A)0931 - Harrier GR7 ZEUS Upgrade

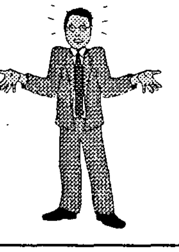
Definition of M-FOP

A period of operation during which the system must be able to carry out all its assigned missions without any significant maintenance action and without the operator being restricted in any way due to system faults or limitations.

M-FOP APPLICATION

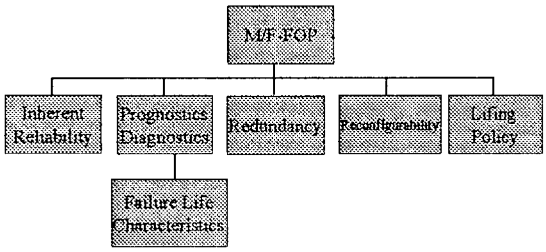
- MER 06/98 Satellite Communications System
- MMER(OE)(A) ALARP
- FOAS ST
- FLA
- INTERPRET
- Joint Strike Fighter
- FASM
- CV(F)

Platform M-FOP is the Challenge

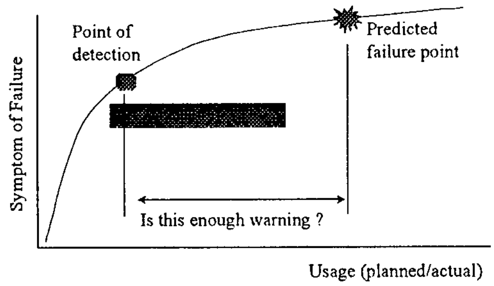


....how do we achieve it ?

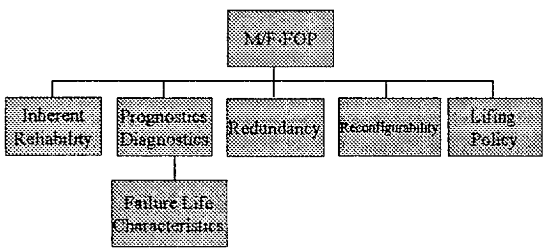
The M/F-FOP Options



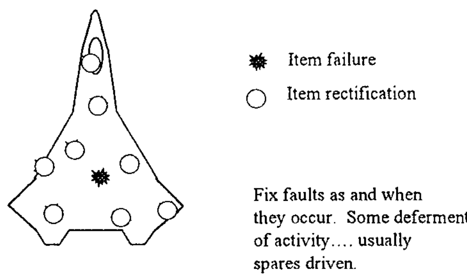
Failure Life Characteristics



The M/F-FOP Options

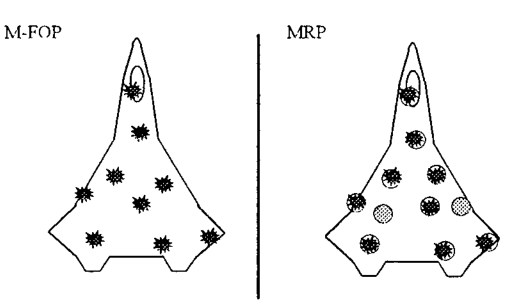


Current working practices



Fix faults as and when they occur. Some deferment of activity.... usually spares driven.

So what is different ?



Design Solutions

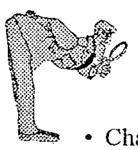
- SMART STRUCTURES
- SELF-DIAGNOSIS & CONDITION MONITORING
- EARLY INDICATION OF IMPENDING FAULTS
- FAULT TOLERANCE
- RE-CONFIGURABILITY
- SYSTEM REDUNDANCY

Design Solutions cont.

- DESIGN for LIFE
- GRACEFUL DEGRADATION WITHOUT MISSION LOSS
- NEW EMERGING TECHNOLOGY
- IMPROVED PROCESSES (IMPROVED RELIABILITY)

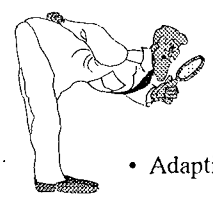
STRATEGY

- 1997
  - Main Focus on Problems of Current Reliability Approaches.
- 1998
  - Feasibility Studies and Apply to Minor Projects With Industry's Support.
- Post-PPB
  - Benefits & Cost Effectiveness of M/F-FOP.



The Risks

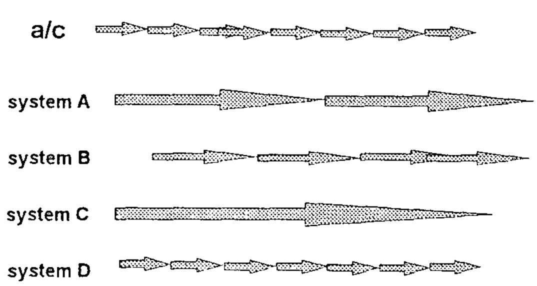
- Changing the Culture Throughout Industry
  - Including All Sub-contractors
- Perceived - or Real - Increase in Initial Costs
- Making the Partnership Work
  - So All Parties Benefit



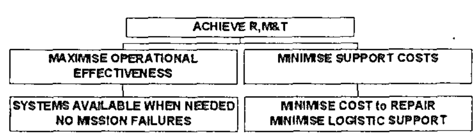
Continued.....

- Adapting and Developing New Tools
  - Mil-Hdbk 217F
  - LCC Models
- Contracting

M-FOPs



MOTIVATORS



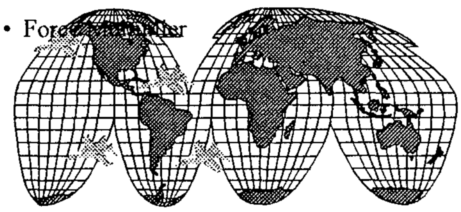
Reduced Downtime
Reduced Logistic Footprint
= M-FOPs

LEVERAGE

- TECHNOLOGY
- PHM
- DATA MANAGEMENT

The Benefits

- Force Multiplier



The Benefits

- Affordability
- Lethality
- Flexibility
- Availability
- Survivability