Maintenance Free Periods of Operation – The Holy Grail?

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ABSTRACT

The concept or Maintenance-Free Operating Period (M-FOP) was developed in the mid 1990s [1] by colleagues in the RAF's Department for Reliability & Maintainability(R&M) in an attempt to define mission and basic reliability requirements that would give operators what they really needed, periods of guaranteed availability with the minimum logistic footprint in support. The concept has synergy with the intent of the pure definitions of reliability contained in existing standards, yet we have come to accept poor levels of reliability in defence equipment which then needs a huge support effort to try and deliver what operational commanders need. Progress towards the achievement of M-FOP and its twin concept of Failure-Free Periods of Operation (F-FOP) have been slow, yet Defence is now required to do much more in the way of deployments and long periods of deployed operations from unfamiliar bases where traditional support is very difficult. This paper reviews these concepts, the justification for them and analyses progress towards the achievement of this holy grail.

1.0 CHALLENGING TRADITIONAL RELIABILITY THINKING

In essence the M-FOP concept challenges traditional reliability thinking and the way of specifying R&M. In designing new equipment we needed to get back to the designer's basic aim of designing for success, not, as has been so often interpreted, as having an acceptable level of failures. Indeed by changing, or re-affirming, what we really wanted meant we needed delivery of a Maintenance-free Period to improve planning certainty and maintenance effectiveness.

In the early 1990's there was a marked change in Defence thinking resulting from the UK Strategic Defence Review. This provided some defined motivations for change:

- Defence spending would continue to reduce in real terms.
- The RAF would need a quality product that had better availability and worked when needed for the whole mission or series of missions (i.e. better mission reliability).
- Affordable equipment without gold-plating was needed.
- There would be fewer personnel and less equipment employed on maintenance and support.
- Increased flexibility and more deployments would need to be supported and would be the norm.
- The future would involve more deployments to bare bases which would need to exist with the minimum logistic footprint.

The logistic organisation would be using the aircraft transport fleet for the increase in payload to support deployed operations with consumables and yet it needed to recognise though that this new concentration by UK forces on deployability had a prime and overriding need for sustainability. There was a need to minimise the logistic footprint because less spares and personnel needed to be deployed or re-supplied meaning more vital consumable supplies being able to be deployed such as ammunition.

2.0 WHAT ARE THE *REAL* CUSTOMER NEEDS IN THIS UNCERTAIN FUTURE?

In the face of these conclusions, the RAF tried to establish what were the real needs of the customer, particularly as it was in effect such an uncertain future. The conclusions were that firstly there would need to be guaranteed periods of availability because in the much smaller RAF, manpower and resources would be required to mount operations all over the world, causing severe over-stretch if the existing and traditional levels of support had to be maintained. With guaranteed availability, fewer manpower resources - both pilots and maintainers – could be used more efficiently, which would therefore be less costly to procure in the first place and to support throughout service.

Above all, what was needed was **mission effectiveness,** so that when for example a Combat Air Patrol of 2 ac for two back to back 2.5 hr missions were required, it was not necessary to plan on briefing double the number of aircraft to guarantee that the 2 could be launched and complete the mission successfully. Consequently there would be planning certainty which would allow the minimum resources to be organised to support the task and therefore also result in giving the desired minimum logistics footprint for a sustained deployment.

As a result of defining the real needs of the customer and revisiting the requirements from first principles a paradigm shift in thinking emerged [1]. Developments over the intervening years in both thinking and technologies which will deliver these customer needs have not changed the fundamental logic which is reviewed in the next sections of this paper, before a review of the current attitudes to the proposals.

2.1 Usual Definitions

Before considering the solutions it is necessary to understand what needs to change and to revisit existing definitions:

- **Reliability** is defined as:
  - The ability of an item to perform a required function under stated conditions for a specified period of time [2]; **or:**
  - The duration of failure free performance under stated conditions. [3]
- So why do we traditionally use:
  - The allowable number of faults in a given time?

For example the Reliability specification for the Tornado GR1, an MTBF of 1.25hrs, has always been translated as 800 faults per 1000fg hrs. MTBFs have always been converted this way and it is a practice which the mathematics supports but the definitions do not intend.

2.2 Traditional Reliability

Traditional reliability specifications have always used MTBFs. However, MTBFs are a trap for the unwary; for instance they encourage the notion that failures are inevitable and accept the notion of random failure. Data is aggregated to produce a mean and there is a top-down approach in design to allocate the "allowable" number of failures, system by system. This might produce the unsafe notion for instance of the ejection seat in a military aircraft being allocated 2 failures per 1000 flying hours! Pilots would certainly not be happy with such a situation!

Whilst this process of using MTBFs might **account** for reliability, it fails to "engineer-in" a solution. What must be done is to get rid of the idea of "random failures" and their inevitability.

3.0 NEW WAYS

Maintenance-Free Operating periods are a deceptively simple concept, but were the way forward that was devised to encapsulate what the customer's real intentions and needs were. M-FOPs would be interspersed with a defined period of recovery when maintenance could be planned and done to restore the system to full operation; this was defined as a Maintenance Recovery period (MRP). M-FOPs are applicable at the system and sub-system level, and it is believed eventually, at the major platform level. Neither successive M-FOP nor successive MRP lengths would be an equal length; flexibility of management and planning was in fact the key.

3.1 Definitions

3.1.1 Maintenance-Free Operating Period (M-FOP)

A Maintenance-Free Operating Period (M-FOP) is defined as:

- A period during which the equipment shall operate without failure and without the need for any maintenance; however, faults and minor planned contractually agreed maintenance are permissible. [4]

3.1.2 Maintenance Recovery Period (MRP)

The Maintenance Recovery Period (MRP) is:

- The time spent carrying out maintenance after an M-FOP has elapsed. The maintenance done should be enough to ensure that the equipment can start another M-FOP cycle. [4]

3.2 Design Achievement

In other words a pure M-FOP is about doing nothing between MRPs except:

- Operating the equipment, replenishing consumables, fuel, oil, tyres, etc. and pre-positioning spares and manpower which will be required for the next MRP.

The difference, however, is that it's a bottom up approach rather than the top-down allocation of failures and failure rates. A key aspect is to understand the equipment's operating parameters, usage (and abusage) and the operating environment, all factors where there is a surprising lack of knowledge by designers and operators alike. The designer must however, pay even more attention to understanding therefore the failure mechanisms that might result. That means he has to understand the true physics of failure of **all** aspects of the design. This in itself will need an understanding of the fact that these failures will change depending on the localised environment and the intended use, all of which must be fully understood. Finally there must be an understanding of the relative value of predictions versus the gaining of better data through increased testing at earlier stages.

Therefore on a fairly simplistic basis, considering how a designer will need to approach building up an aircraft M-FOP from the system level, assume 4 systems each with a different M-FOP which has been established by testing. The aircraft or platform M-FOP will be driven by the shortest M-FOP. What the designer now has to do is to seek to improve that system to at least the level of the next system. It is recognized that equipment usage and sub-system usage will vary dramatically and accurately measuring these is vital in determining a M-FOP and its probability of completion. With today’s technology an adequate method of monitoring and designing for sub-system or sub-sub-system or even component usage is certainly possible. Monitoring this during design and development phases would provide a database of vital information for design improvements. Extending this monitoring then into service to obtain and update with real service usage, will give the operator the ability to change the M-FOP to best suit his current operations and so make forecasting all the maintenance requirements much easier.

4.0 CONTRACTING FOR AVAILABILITY

In the UK, more and more contracts in the future are being required to be availability based. Furthermore, the aspiration is to move to contracts for capability in the future. This assumes that even contracting for availability can be done successfully and this is by no means easy as there is much misinformation and misconception in the understanding of availability. Nevertheless, M-FOPs are in effect a useable metric for such contracting.

M-FOPS fit well with existing current practices in fact and the need which will continue for the foreseeable future to undertake some scheduled maintenance on a periodic basis (preventative maintenance). At present though most, if not all failures on military aircraft, require immediate corrective action. In some cases, usually because there is a lack of manpower or spares, the fault may have its rectification deferred. In RAF terminology this requires a “red or green line” to be raised which identifies the fault as an acceptable one to be deferred (green line) or one that gives a limitation on the operation (red line). Consequently, as soon as a fault is reported the aircraft becomes unserviceable until rectification is carried out, or a deferment is exceptionally decided and entered as a green or red line. The norm though is to always fix faults when they occur, meaning that there are always unexpected periods of downtime.

The difference by adopting M-FOPs is that during the M-FOP the technology on the aircraft will allow faults to occur but there will be no mission effect whatsoever. Faults and the need for rectification and maintenance activity will be aggregated until the MRP, when all faults will be rectified, together with other scheduled or predicted maintenance that is required.

5.0 M-FOP SOLUTIONS

The real challenge of course is how to apply M-FOP at the overall platform level. There are many options that need to be designed in at the earliest stages. Designing inherent reliability into the platform is the first solution and is perhaps self-evident, but is still of course an essential action, as is deciding effective lifing policies component by component where required. Some designs will be able to employ redundancy better than others; some will not be able to employ it because of weight restrictions. However, reconfigurability might be possible as a design solution as it usually would not involve additional weight; a solution might also be to use sophisticated multi-tasking and shared use of systems. Similarly prognostics and improved diagnostics might involve extra complexity and weight, but can provide a significant increase in delivering availability and reducing periods of maintenance. Understanding the failure life characteristics is also an essential aspect of the designer's task.

It is now therefore up to the designer to evaluate all the design solutions. Some of the other options available are:

- Smart structures which possibly indicate faults.
- The various forms of condition monitoring, self test, self-diagnosis and self-correction systems.
- Early warning & indication of faults perhaps with sophisticated avionics & software measures such as neural networks.
- Fault tolerance and other the capabilities obtained from integrated modular avionics.
- Reconfigurability of avionic systems.
- System redundancy in all its forms, some of which might not involve additional weight.
- Knowledge of the life of the equipment.
- Graceful degradation of a system as long as it does not involve loss of the mission.
- New and emerging technologies that might give improvements.
- Improved processes for manufacture and repair which will enable an improvement in the inherent reliability.
- Sacrificial elements that give a warning of problems.
- Health and Usage Monitoring Systems (HUMS) which will enable improved knowledge of the health of the system and eventually will be developed into a prognostic ability.

All these systems can provide solutions to contribute to an M-FOP to a greater or lesser degree. Some may be expensive to apply even at the design stage, but to illustrate the improvement and motivation for its adoption, let us consider just one, HUMS.

5.1 HUMS

HUMS can be a key factor in providing effective application of fighting power by providing the knowledge of an equipment's health, which in turn allows planning certainty and the ability to select the best equipment from the scarce assets available; this will ensure the most effective use of scarce support resources, manpower and logistic support). Knowing the past usage and the current health with perhaps some developing capability to apply prognostics, will enable the right equipment to be selected that has the greatest expectation of being able to survive the mission or set of required missions. It might therefore be said that HUMS can deliver M-FOP almost single-handed!

However there are various views of HUMS. The customer's view is that the motivation to have a HUMS fit is that there will be gains in operational availability, efficiency & effectiveness by better selection and management of assets. In addition there will be gains from a reduction in Whole Life Costs (WLC). There is also the commercial or contractor's view of HUMS and the motivation for it which is to be able to react to the increasing interest from the customer for contractor logistic support (CLS) contracts. Contractors therefore see a pro-active reason for HUMS so that they can increase their appeal when bidding for support contracts which can offer CLS as an option with an associated inherent reduced risk. There is, however, some concern that WLC will increase. Whilst prognosis will improve operational availability it may bring a resultant increase in preventative maintenance (PM). Such increases may in fact aggregate to increase the WLC. However, there should also be an attendant reduction in corrective maintenance. Such concerns as to the balance achieved between these costs can only be addressed within each specific project and the analysis in the Cost of Ownership, Effectiveness and Investment Appraisal (COEIA) before acquisition and validated after a period in service. These analyses must try to balance any projected increase in PM against the attendant reduction in corrective maintenance, but this is likely to which is always going to be difficult before real data and experience is gained. It would seem though that the operational imperative should be pre-eminent; anything that contributes to a reduction in the logistic footprint and improves operational effectiveness, must be followed through.

5.2 Failure Life Characteristics

Considering another aspect of design activity is to consider the failure life characteristics where the length of M-FOP will include, at some time, the point when detection could have been achieved under normal inspection regimes. At some point after the end of the M-FOP period there will be the predicted point of failure. The time between the end of the M-FOP and the predicted failure point will give a safety period. The question that the designer and maintenance manager must address is whether that time period is enough time in safety terms. Is the warning period enough and is there an identifiable risk? Indeed the delivery of each M-FOP will be subject to a probability and we may never be able to entirely guarantee 100% certainty.

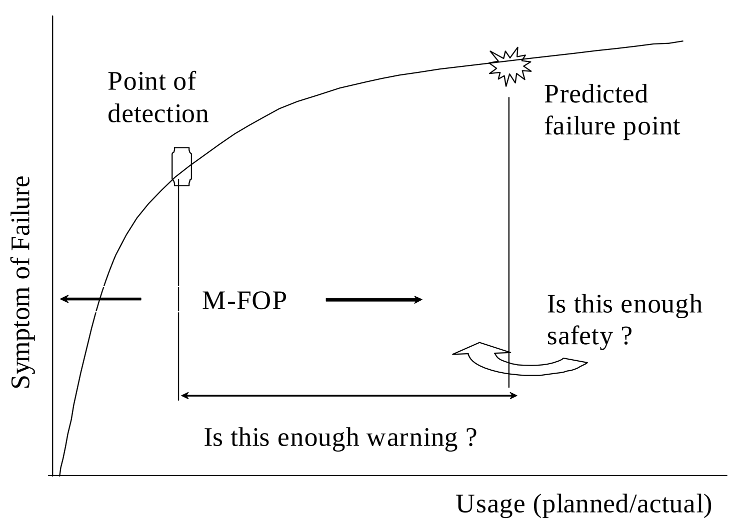

Figure 1: Failure Life characteristics.

5.3 Probability

In dealing with probability though we can at least aspire to minimize the risk of failure. The probability of completing an M-FOP will depend on the reliability of the system which will normally diminish as the equipment is used during its operating period. An M-FOP can be determined by plotting the reliability from time zero and overlaying the required probability of completion (Figure 2).

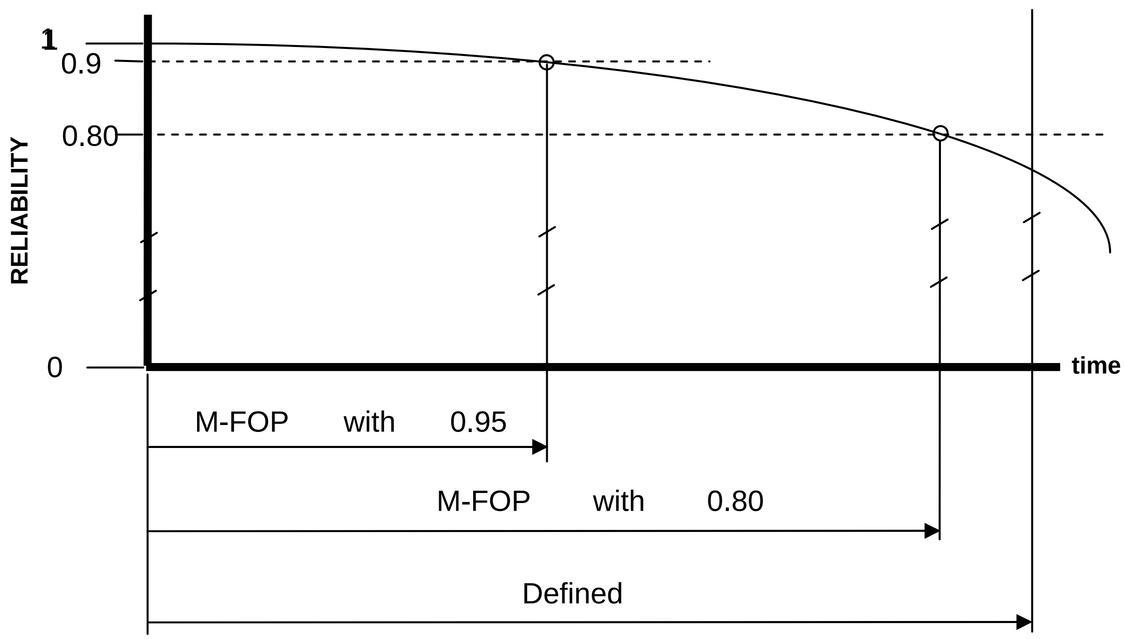

Figure 2 – Reliability vs. Time and Probability of M-FOP Completion.

Generally a higher requirement for success means a smaller M-FOP and visa-versa is true until the defined life is reached. The defined life is the allocation of useful life that could be achieved using, but not limited to, the allocation of useable life, condition monitoring / prognostics, fault tolerance, re-configuration and redundancy. Hence an M-FOP is determined by considering the defined life against the probability of completing an M-FOP that the user is prepared to accept.

Knowing the probability of completion of the individual M-FOP for each separate piece of equipment gives the user the ability and confidence to provide a specific number of equipments to carry out a task.

Working strictly to a system M-FOP may require the necessity to replace components more often than needed and it is possible that a contractor will design equipment with a specific M-FOP that is supplied to more than one customer. Each customer will have a need for a different M-FOP and use sub-systems for different times, so the concept of a Management M-FOP was developed by some excellent work presented by R. Burdaky to the 10th MIRCE Symposium.[5] It showed how M-FOP could be managed effectively to utilise a lot of sub-system life that might be thrown away by strict system M-FOP application and therefore enable more useful life to be consumed at the sub-system and component level, which must of course be a cost benefit.

Of course the ultimate enabler is to improve the basic reliability of not only the components but of the whole manufacturing process. When companies such as General Electric talk about a manufacturing process that produces no defect products, they are not talking about a pipe dream but believe it is a reasonable and indeed essential goal for their competitive advantage and customer satisfaction. M-FOPs & MRPs are an essential part of that philosophy in that the only downtime is planned for, timed and fully resourced; that philosophy delivers commercial success and operational success.

An example recently was one of the UK helicopter fleets which is almost entirely deployed to Iraq with one aircraft remaining in UK for training and one in depth servicing. The fleet manager needed to maximise his operational availability and asked if it was possible to reschedule the maintenance so as to ensure the minimum maintenance was done in theatre and for one aircraft at a time to be able to be flown back (inside a C-130) to UK for major depth overhaul and servicing. Here is an M-FOP being requested and Reliability Centred Maintenance (RCM) being used to deliver it!

6.0 DEVELOPMENTS AND REACTIONS IN INDUSTRY

Since 1998, Industry has continued to debate the achievement and the ability to deliver the possibilities. Their views and their progress are now reviewed, however, in the following summary it is unsurprising that the sources were not keen on being attributed. Therefore they must be treated as anecdotal and are offered to ensure that serious debate can be continued.

6.1 Terminology

Some definitions of M-FOPs now in current usage are:

- “The M-FOP is a period of time during which there is no need for scheduled or unscheduled maintenance”.
- “A maintenance free operating period (M-FOP) is defined as a period of time (or appropriate units) during which a system is both operational and is able to carry out its required function(s) without maintenance activities and without encountering failures”.

There are many others, which perhaps reinforces the willingness to move to this type of requirement, but these are still the most common way that the original definitions seem to have been massaged. However, these definitions are difficult to accurately specify for a major and complex platform such as an aircraft and above all else, the problem is that they are all open to interpretation!

6.2 Quotes and Observations on M-FOPS

Some quotes and observations on M-FOPs can be provided but cannot be attributed and can only be offered as anecdotal evidence!

- “The fundamental goal of M-FOP is to make virtually all maintenance scheduled by transferring what would currently be unscheduled maintenance into a predicted maintenance slot”.
- “It is not necessarily a maintenance-free period - systems element faults may happen, but, as a result of the inherent design of the system, the aircraft continues its operation uninterrupted”.
- “M-FOPs have the potential to offer the user an increase in the application effectiveness and enhanced operational availability of a system”.
- “Maintenance/failure free operating periods (M/F-FOPs) are measures of reliability and can be used to replace the traditional mean time between failure (MTBF) approach”.

There is a common theme however – the M-FOP is being described using other metrics.

6.3 M-FOPS – Practical Applications

The RAF Tornado was analysed using the Ultra Reliable Aircraft Software Model (URAM) [6] the resultant M-FOP could only be measured in fractions of an hour. The conclusions were:

- This was hardly surprising but makes the point that legacy aircraft simply do not have sufficient (if any) redundancy or re-configuration to allow a "pure" M-FOP to be applied.
- Military operators are not happy with the concept of Minimum Equipment Lists (MELs) that allow flight with unserviceable equipments or systems.
- The cost of modifying major in-service platforms would far exceed the benefits of "converting" to M-FOPs.
- Thus only new design(s) or new build(s) are worth expending effort on to respond to the challenge of specifying M-FOPs.

BUT, M-FOP investigations have definitely challenged the specification of A, R and M performance. Perhaps it has even provoked the evolution of availability (and similar) contracting metrics!

6.4 M-FOPS – The Correct Metric…?

Availability contracts, currently being negotiated on several platforms, can in some instances be interpreted as an answer to a M-FOP challenge, in the view of Industry. Examples are:

- "n" aircraft are to be ready to fly for a period of "x" hours during a typical training day.
- Aircraft that are not in "depth" servicing can be considered as "available".
- Maintenance Recovery (MRP) can be carried out at any time that the aircraft is not required (rather than not available).

The M-FOP has been *implied* but not actually specified. Furthermore, the definitions of "available", "not required" (not in use) and "maintenance-free" can be very similar and need to be carefully specified or agreed.

6.5 M-FOPS – The Move to Availability

Where Industry accepts an availability contract, the Customer is probably (and properly) only interested in the operational window: Maintenance is now "no longer his problem" The attitude of "…get me another one – this one is broken…" is becoming clear (quite correctly, given the contractual conditions).

Careful use of analysis techniques to predict failure, combined with accurately applied RCM techniques can move unscheduled maintenance into becoming scheduled maintenance. However, the following issues must be addressed:

- Is this an M-FOP by "stealth"?
- Substantial component life could be lost (at high cost) by anticipating failure too early – this has already been experienced in Contractor or Augmented Logistic Support (CLS/ALS) type contracts.
- There is a high reliance on accurate in-service data which may not always be a safe assumption.

6.6 M-FOPS – Some Issues (from a Contractor's Perspective)

In-service data capture, storage, analysis and distribution are already starting to suffer. Two information issues from a Contractor's perspective are prevalent:

- The majority of data is being seen as "not required" by the Customer if Industry is managing the fleet for him.
- Key Performance Indicators (KPIs) will become increasingly difficult to monitor and contract compliance could be compromised.

As aircraft support is taken over by Industry, it may no longer be relevant to specify an M-FOP as a performance parameter. Availability is certainly a more suitable metric for the front-line Commander, but does everyone understand availability and how to contract for availability? Many availability KPIs now being used are a mean or average over a period of time – this allows periods of ***total*** non-availability to be acceptable as long as the "mean" is maintained over the measurement period!

Industry is driven by cost and profit – it may make more financial sense to pay a financial performance penalty than take corrective action! The bottom line though should be to ***minimise servicing downtime*** and periods on unexpected downtime in order to ***maximise operational availability***.

7.0 M-FOPS – CONCLUSIONS AND DISCUSSION POINTS

- It is accepted that only new design(s) or new build(s) can be used to respond to a "pure" M-FOP specification.
- Military flying with reduced platform serviceability using the MEL concept has to be considered and accepted more widely for systems and equipments not required for the current mission.
- M-FOP has definitely challenged the specification of A,R&M performance and may well be attributed to the evolution of availability (and similar) contracting methods and metrics.
- Specifications must be carefully negotiated to minimise risk to both Customer and Industry:
  - Too strict and it will be unachievable or present a very high commercial risk (high cost).
  - Too loose and contractual compliance will never be proven and the specification will become ineffective (not cost-effective).
- Legacy aircraft can be shown as having what can approach the M-FOP concept by challenging definitions, using availability metrics as a better measure of performance, providing they are contracted for correctly, or by the correct and effective use of RCM techniques to develop better and more cost-effective servicing schedules.

8.0 REFERENCES

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