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ACQUISITION RESEARCH WORKING PAPER SERIES

Improving the Management of Reliability

31 August 2004

by

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Reliability isn't everything; it is the only thing!

At the present time, the most serious problem in logistics support for the life of a weapon system is the asymmetry of the demonstrated reliability of components and the inventory and maintenance infrastructure necessary to match that reliability.

Reliability is the single most dominant life cycle cost driver and is the key enabler of acceptable cost effective operational availability. The greater the time between failures of components, the less we require expensive maintenance, critical test equipment, unique training and high priced inventories as well as other logistics elements. The DoD and the Navy are struggling with the results of the imbalance of poor inherent reliability of components on the one hand, and the consequences of highly exaggerated reliability figures of merit used for life cycle support planning on the other. The DoD and the Navy have not understood the results of a continuing failure to properly acquire, measure, manage and support *demonstrated* reliability. We simply have too many demands for too few spare parts because of this asymmetry.

For the sake of a common reference, let's define reliability. Reliability is comprised of four components: *probability, satisfactory performance, time, and specified operating conditions*. Taking these four elements together, we define reliability as the probability that a system, component, or part will operate satisfactorily for a specified period of time under specified operating conditions.

Probability in this definition refers to a quantitative expression representing a percent specifying the number of hours we can expect a system to operate satisfactorily when we operate it. For example, if we state that the probability of satisfactory performance for a hydraulic actuator for 100 hours is .8, then we can expect the system to survive 100 hours 80% of the time. In an inventory of like hydraulic actuators we can expect the same probability of survival, but experience shows us that failures will occur at different times in a probabilistic manner.



Satisfactory performance relates to the specific criteria, which describes proper performance, i.e. operate a trailing edge flap when a control input is made.

Time is the key consideration when referring to reliability. Time is how we measure the probability of completing a mission or how often we have to do maintenance or gauging satisfactory performance with respect to time for spares inventory-planning purposes. We commonly define reliability in terms of mean time between failure (MTBF), mean time between maintenance, (MTBM) and mean time to failure, (MTTF). It follows that the more frequent the failures, the greater the number of spares required as well as increased requirements for all the other logistics elements.

Specified operating conditions define the way a system or component will be used, the environment it will be used in, and includes storage, packaging, handling and transportation.

The qualities of each of the four elements of reliability result from a design-requirement synergy. The resulting reliability is an inherent quality of that design. That design produces a component that has a physically constrained reliability; an inherent reliability that is the best we can achieve in an ideal operating and maintenance environment.

I have heard maintenance officers say that they can improve the reliability of a component by improving the maintenance. That simply is not possible for the reason I just stated. In 1982 I participated in a study at NAVAIR that showed that the only way to improve the inherent reliability of a system is to change the technology or physical construct of that system. The inertial platform that was used in the A-6E is a good example of this concept. Initially, the platform consisted of 3 mechanical gyros, one each for the X, Y, and Z axes with MTBFs in the low two-digits and in its final configuration with ring-laser gyros, the failure rate was three to four figures.



Some additional reliability measures to consider:

$$\text{Failure rate} = \frac{\lambda = \text{number of failures}}{\text{Total operating hours}}$$

$$\text{MTBF} = \frac{1}{\lambda}$$

For illustrative purposes we will assume a reliability function in terms of a Poisson distribution thus reliability or the probability of survival is expressed as

$$R(t) = e^{-K\lambda t}$$

Where R is reliability

e is the natural log base (2.7182)

K is the number of items used of a particular type

λ is the failure rate (1/MTBF)

t is the time period of interest

Some factors related to reliability to consider:

Inherent availability- is the probability that a system when used under specified conditions in an ideal environment (i.e. specified operating conditions, properly trained technicians, spares at the ready, tools etc.) will operate satisfactorily at any time required. This definition excludes scheduled maintenance, logistics delay time, and administrative delay time.

$$\text{The expression is- } A_i = \frac{\text{MTBF}}{\text{MTBF} + \overline{\text{Mct}}}$$

Where MTBF is the mean time between failure and $\overline{\text{Mct}}$ is the mean corrective maintenance time or mean time to repair.



Achieved availability- is the probability that a system operated and supported under specified conditions in an ideal support environment as above will perform as required at any time. Achieved availability includes scheduled maintenance but excludes logistics delay time and administrative delay time.

The expression is-
$$A_a = \frac{MTBM}{MTBM + \bar{M}}$$

Where MTBM is the mean time between maintenance and $\bar{M}$ is the mean active maintenance time.

Operational availability- is the probability that a system when used under specified conditions in an actual operational environment will operate satisfactorily when required.

The expression is -
$$A_o = \frac{MTBM}{MTBM + MDT}$$

Where MTBM is as above and MDT is the mean maintenance down time. The reciprocal of MTBM is the frequency of maintenance that includes scheduled and unscheduled maintenance. The mean time between unscheduled maintenance should be $\sim$ MTBF.

Spare part quantity determination is a function of a probability of having a spare part when needed, the **reliability** of the item in question and the quantity of items used in the system. (It is significant to point out that the F/A-18 item manager at NAVICP is using MTBD, meantime between demands, for inventory determination that in application bypasses the source of the problem)



The expression is -

$$P = \sum_{n=0}^{n=S} \left[\frac{R(1-\ln R)^n}{n!} \right]$$

where

P = the probability of having a spare of a particular item available when required

S = the number of spare parts carried in stock

R = composite reliability as stated above

K = quantity of parts used of a particular type

lnR = natural logarithm of R

Now that we have common references, let's examine the concerns about properly acquiring, measuring and managing reliability figures of merit as the key parameter of providing life cycle support.

First, we will consider how we acquire a reliability figure of merit for a component. Typically, a vendor will submit a reliability measure based on testing, estimates, expected reliability growth etc. Since operational Test and Evaluation is expensive and focuses on systems rather than individual components, component unreliability may go unexposed. For the lack of any other data the logistics managers tend to accept the contractor's claim of X hours MTBF. (It is noted here that with a paucity of data, it would serve us well to examine the history of performance of like items already in service being used in a similar way) Based on that reliability figure of merit, it is then applied to our spare part quantity calculation that yields the number of spares we should carry. (for illustration purposes, we are ignoring component cost, operational scenario etc.)

As an example we will consider the Trailing Edge Flap Actuator (TEF) for the F/A-18 A-D. In establishing initial support for the TEF we set its reliability figure of merit at 4000 (According to NAVAIR APML circa 1997) hours mean time between failure. From the above we show that the failure rate is .0025 in this case. Now let's assume we have an



airplane inventory of 200 airplanes, each of which is to operate 30 hours per month and we replenish stock every 90 days. Applying this failure rate to our equation to determine our spare parts requirement we will use the following:

P (protection level) is the Probability of having the part on hand when required in this case assumed to be .95

$K = 400$ parts (2 per airplane)

S = the number of spares to be determined

R = reliability $R = e^{-k\lambda t}$

$\ln R$ = natural log of R

$\lambda = .00025$ failures per hour

T = the stock replenishment cycle of 90 days or 3 months

$k\lambda t$ = number of items X the failure rate X operating time per airplane X stocking intervals

thus:

$k\lambda t = 400(.00025)(30)(3)$ or 400 parts operated 30 hours per month for 3 months at a failure rate of .00025 = 9

To facilitate solving our equation we use the NAVSHIPS 94324 nomograph and enter the $k\lambda t$ value of 9 and refer to the P value of .95 and we get 14 spares are required.

If we assume a protection level of .85, 10 spares are required

Taking the **demonstrated** failure rate we solve our equation again. According to the latest APML reliability figure of merit we have an MTBF of 138 hours for the TEF (Cdr. Ellen Coyne, NAVAIR, email 20 July 1999)

Now, $\lambda = 1/138 = .00722$ per hour. It follows that $k\lambda t = 400(.00722)(30)(3) = 259.9$.

Now we need ~ 300 spares. We have a situation where the failure rate is 29 times that predicted and the spares on hand are ~ 1/20th that required.



The F/A-18 item manager states the TEF is presently performing at an MTBD of 900 hours. If we assume an inventory calculation substituting MTBD for MTBF we derive the following:

$$\lambda = .0011$$

$$k\lambda t = 400(.0011)(30)(3) = 39.6$$

As in the above procedure we have a failure rate 4.3 times predicted and we require 50 spares which is ~3.5 times predicted.

The point here is that whichever reliability is correct, significant asymmetry exists.

The asymmetry shown in this example is one of many that have impeded the F/A-18 from achieving its inherent availability (A_i) since its introduction. We have a pattern of failure rates that far exceed unsubstantiated levels that have been used to provision support for the F/A-18 and other systems resulting in under-budgeting logistics support, cannibalization and its costs, increased workload on maintenance personnel, potential safety risks and most significantly an operational readiness potential that is unrealized. Although we know that the demonstrated reliability is not what was predicted we have not recomputed the spares required and have not made the necessary provisioning corrections and investments. Moreover we tend not to conduct a follow-on Level of Repair Analysis (LORA).

How can we improve the establishment of reliability figures of merit for the purposes of spare inventory symmetry? First, we should adopt a null hypothesis, which states that a claim of a reliability figure of merit for a given component is not true until proven by the contractor. (The Navy should verify contractor MTBFs in a DT/OT continuum) If the contractor's initial claim cannot be established, then we next ask what value can be proved and is that value acceptable? Once a value has been proved, then that is the value that should drive the spare inventory to support that given component.

Our experience in Naval Aviation has shown that reliability declines over time, but our support analyses are not recomputed to match those changes. It follows that logistics



managers and sustainment engineers should recompute support requirements in light of declining reliability and that budgets must be adjusted to support the derived requirements.

We have the tools at our disposal to correct the asymmetry of reliability and spares inventories for our weapon systems. We should strive for accuracy in establishing reliability measures for new programs. In order to ensure we have the best measure of reliability, we should employ the Null Hypothesis that says the contractor must prove claims of performance and not the Navy. Once a figure of merit is demonstrated we must ensure the inventory matches the reliability. Throughout the life of a system we should continuously analyze reliability performance and recompute spare parts inventories based on our analysis and finally we must make the financial commitment to make these efforts successful.



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