ICAS-88-2.11.2

RELIABILITY AND MAINTAINABILITY IN MODERN AVIONICS EQUIPMENT - A USER'S POINT OF VIEW -

Frans J. Kennis
Colonel Engineer
Belgian Senior National Representative
F-16 SPO, Dayton, Ohio.

Abstract

The purpose of this paper is to present the point of view of the user (i.e. Belgian Airforce) concerning the reliability and maintainability of modern avionics equipment on tactical fighter aircrafts.

Past experiences by the Belgian Airforce on aircrafts such as the F-84F,F-104G and MIRAGE III are highlighted. Maintainability problems related to the F-16 are analysed, causes of lack of maintainability are indicated and recommendations are made for improving maintainability.

A special analysis addresses the F-16 reliability improvement warranty (RIW)

An attempt is made to evaluate the cost/ effectiveness of such contract including estimated warranty benefits.

Finally a new approach is presented for a RIW contract which more evenly distributes the burdens and risks between the contractor and the government.

I INTRODUCTION

Confronted for many years with the problems associated with reliability and maintainability and actually being very close to the efforts made in this domaine by the USAF through the so called R&M 2000 project I will first make an analysis of the lessons learned on previous acquired weapon systems by the Belgian Airforce and thereafter I will present some ideas how we could improve reliability and maintainability in future weapon systems.

Definitions

As we are going both to address reliability and maintainability lets give a definition for each.

Maintainability: Is a level of effort (resources & time) required to keep or return a given weapon system to operating conditions (scheduled & unscheduled maintenance)

A parameter to measure maintainability could be maintenance man hours per flying hour (MMH/FH).

Reliability: a measure of all occurencies which place a demand on the logistics support structure whether or not the mission capability is affected. We could use as a parameter mean time between demand (MTBD), mean flight time between failure (MFTBF).

Availability: A measure of the degree to which a weapon system is in an operable and commitable state at the start of a mission when the mission is called for at a random time.Parameters used are sortie generation rate, missioncapable rate...

I added also the definition of availability, a term much more familiar to the operational community who finally will have to accomplish the mission.

Much work is actually going on to translate these operational parameters such as sortie rate, abort rate, mission capable rate in parameters directly related to reliability and maintainability. In this way a direct relationship is created between the operational demands and the technical definitions used by the engineering community.

II RELATIONSHIP BETWEEN RELIABILITY AND MAINTAINABILITY.

Reliability and maintainability are linked closely together. It can be stated as a rule of thumb that improving the reliability of a system by a factor of two will diminish the necessary maintenance effort by the same factor.

On the reverse improving maintainability will have no effect on the reliability.

This is the reason why in general more attention is given to improve the reliability of the system rather than the maintainability.

If we increase the reliability to such a point that the mean time between failure for the onboard equipment equals or exceeds the expected lifetime of the weapon system no maintenance will be needed.

Accessories with MTBF figures between 4.000 and 8.000 Hrs are now being installed on board of tactical aircrafts eliminating most of the need for unscheduled maintenance.

Notwithstanding those promising figures maintainability will remain an important issue in the design of modern aircraft as it will always have an impact on the turn-around time of the aircraft.

III PAST EXPERIENCE ON MAINTAINABILITY.

Why this growing interest in R&M, do we now only discover that there is a problem, what about the past ?

In the late fifties and early sixties the backbone of the Belgian Airforce was made up of the fighter bomber aircraft F84F and the recce version RF84F which were equiped with very simple and straight forward avionics.The installed equipment consisted of an UHF radio,an IFF, a TACAN and a gyrogunsight with radar ranging (which was not bad for that period).

Although the reliability of the equipment was not very high few if any problems were existing with regard to maintenance.

We had enough maintenance personnel and spare blackboxes available at the flight line for repair so that a quick turn-around of the

aircraft was assured.
On top of that the number of aircraft outnumbered the number of pilots so that even if there were some chronic failures, availability was not a problem and the maintenance personnel got plenty of time to repair the equipment at the intermediate level. Let's summarize by saying that maintainability was not a concern at that moment.

This situation was going to change rapidly: in 1963 the Belgian airforce introduced the F104G with more electronics. As the price of the aircraft increased so the price of the avionics package increased due to more complexity and sophistication.Each squadron received just the exact number of aircraft required, at the same time avionics spare blackboxes were limited to less than 20% of the total installed systems. With the industrial boom at that period most of our highly qualified personnel left the armed forces... the rich period was over and we had to organize ourselves to get the best out of it !
Reliability had not much improved and as a consequence maintainability became of importance... but unfortunately no provision had been made in the design of the onboard equipment for good maintainability.
Very simple fault indicators were existing on the aircraft, some avionics failures were indicated by mechanical flags.

The more complex equipment aboard was not so easy to troubleshoot at the flight line: we had already a sophisticated airborne radar with A/G, A/A, TA and CM modes, all these functions were spread over different blackboxes, the same was true for the inertial navigation system, the automatic pitch control and flight control system.
For troubleshooting of those equipments special flight line test equipment was developed. For the radar existed the so-called WORTAC, which was a trailer consisting of a huge anechoic chamber with a RF generator unit. The trailer was putted in front of the aircraft and used for alignment and troubleshooting of the radar. For the flight controls system the UG 1000 test set was used: a heavy trolly consisting of an analog computer with a punched paper tape program.
Besides those special test equipment an APU (auxiliary power unit) for electrical power was needed, a cooling unit and in some case a hydraulic power unit.

The next step was the integration of all this special flight line test equipment in one so-called automatic test unit. Every aircraft manufacturer was presenting some kind of special test unit under exotic names such as ATEC, SDAP, SESAME etc... The avionics equipment was linked through different cable runs with the automatic test unit. For certain tests you could have to connect 30 to 50 cables and some diagnostic tests took more than one hour. For more mobility the APU (auxiliary power unit), cooling unit and hydraulic power unit were mounted on a truck with a trailer.
Finally you could not see anymore the aircraft: it was an engineers dream and a pilot's nightmare. Everybody seemed to have forgotten the real purpose of a fighter aircraft which is to fly and to accomplish its mission.
Maintainability was becoming suddenly a concern, we had to decrease the turn-around time of the aircraft, we could not immobilize these weapon platforms on the ground for long and cumbersome troubleshooting procedures.

IV ACTUAL EXPERIENCE ON MAINTAINABILITY.

In the middle of the seventies with the introduction of the micro-computer in the avionics some dramatic changes were announced: BITE (built-in test equipment) was going to solve all the maintenance problems at the flight line, reducing the cost for expensive spare blackboxes, eliminating the need for highly qualified maintenance personnel at the flight line and nevertheless aircraft availability was going to improve.

On the F-16 once a faulty line replaceable unit (LRU) is detected by the BIT (built-in test) it is replaced and evacuated at the main base repair shop where the faulty LRU is repaired by exchange of shop replaceable units (SRU's) through the use of a performance and diagnostic test on an automatic test set called the AIS (avionics intermediate shop).
The avionics maintenance at the respective repair levels was going to be a heaven on earth.... but the reality is somewhat different.
Two complete new problems arose from this approach: the CND's (cannot duplicate) and the RTOK's (retest OK)
After a mission is accomplished and before stopping the engine the pilot reads the maintenance fault list which in fact is a list of the eventual detected faults by the BITE (built-in test equipment)
This list will be handled over to the maintenance personnel for further use. Now it happens that during actual troubleshooting on the aircraft by the maintenance personnel the presumed faults cannot anymore be duplicated: it is called a CND (cannot duplicate)
Actual figures from Belgian F-16 units indicate that the BITE will only detect 40% of all failures correctly with 30% of all failures detected being CND's and the other 30% needing additional troubleshooting beyond the BIT's capability.
As a result maintenance had never confidence in BIT. A second problem arises when a line replaceable unit (LRU) indicated by the built-in test as failed,is evacuated to the repair shop where it is tested again, by the avionics intermediate shop, and found OK, it is called retest OK (RTOK)
The main cause of the retest OK (RTOK) problem is due to a lack of vertical testing compatibility which means in clear that if the BIT performs a test to closer tolerances than the same test performed on the automatice test equipment of the base repair shop (AIS) a possibility exists for a RTOK (retest OK) problem to arise.
The same can be true between the base repair shop and the depot repair facility concerning the SRU's (shop replaceable units)

Another problem encountered at the base repair shop (AIS) and depot repair facility is also worth to be mentioned.
At these two locations performance test programs and diagnostic programs are used.
Generally the performance test programs give full satisfaction which however cannot be said of the diagnostic test programs who provide often erroneous indications and require a lot of experience from the maintenance personnel in order to detect the real failure.
We should therefore not be astonished if this maintenance personnel is requesting so called "golden boxes" (or reference units) to facilitate the repair task (meaning that they are returning to the good old try and error method)

The above problems indicate clearly a lack of maintainability in the system.

V CAUSES OF LACK OF MAINTAINABILITY

I will try, with the limited experience of the Belgian Airforce, to indicate some probable causes why actual modern aircrafts such as the F-16 have some lack of maintainability.

First concerning the incompletness of the BIT and its low confidence level.Although we may accept that in every new avionics project the BIT is designed-in and the BIT hardware developed at the same time as the other hardware, we have to admit that in many cases the actual performance testing of the BIT does not take place until after the prime hardware has been tested and released for production,i.e. the last performance testing done on a system is normally the BIT.
Sufficient time should be included in the development program for BIT performance testing and integration prior to production release.

The cause of the vertical testing compatibility or better incompatibility could presumably be found in the fact that all these different test programs are elaborated by different engineering groups.
The BIT program by the avionics manufacturer (vendor), the intermediate level test program by the engineering group who developed the special test equipment (AIS in the case of the F-16) and the depot level test program still by another manufacturer.

And with this I have touched another difficult problem which also could cause a degradation in the maintainability.
On the one side we have the avionics equipment manufacturer who produces a system with a BIT program incorporated written in a peculiar software language and on the other hand we have the aircraft manufacturer who has to integrate all the different avionics systems with each BIT program written in diffent software languages into one coherent and correct functioning (i.e. with a high confidence level) BIT.

VI RECOMMENDATION TO IMPROVE MAINTAINABILITY.

First of all we have to guarantee a quick turn-around of the aircraft at the flight line. Two conditions as a minimum should be fulfilled: a correct operating BIT (i.e. with a high confidence level) and an easy replacement of the failed unit or assembly on the aircraft.
To fulfill the first condition I am convinced that it is a must to develop and to test fully the BIT at the same time the prime hardware is developed and tested and anyway before production release.
The second condition is of equal importance: the time needed to perform a repair (or replacement) at the flight line should be kept to a minimum.

As many defects are situated in wiring harnesses, connectors, cables, motherboards and matrices special attention to easy replacement of those parts should also be given.
My following recommendation concerns the test programs at the different maintenance levels.
Special attention should be given to the vertical testing compatibility and if possible the test programs should be developed by the same engineering group. Anyhow those test programs should be coherent with tolerances getting tighter from BIT level through base repair up to depot repair level.
Care should be given to the diagnostic programs in order to improve their confidence level i.e. to define more accurately which part actually failed.

And finally when speaking about integrated avionics we should not only be thinking at the integration of different avionics functions but also at the integration of maintainability.
Although the actual hands-on maintenance only start after the aircraft and avionics package have been fully developed, tested, produced and delivered to the user, maintainability should concern the design engineering group at the very beginning of the design and development phase of the equipment, maintainability should be incorporated in the architecture of the avionics system itself.

VII ACTUAL EXPERIENCE ON RELIABILITY.

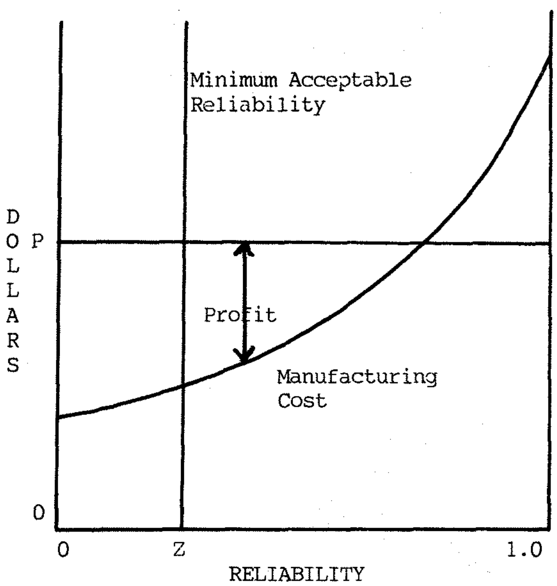
The F-16 had during the first production years (1979-1982) a very innovative warranty system for some of the most complex avionics system aboard such as the radar, head-up display,inertial navigation system and fire control computer.
This special warranty is called reliability improvement warranty (RIW).
The purpose of RIW is
a. to commit the contractor to meet the specified reliability in operational use.
b. to encourage system reliability improvements by the contractor during operational use.
c. to obtain contractor commitment to perform factory repairs at a fixed price for an extended period of time (3 to 5 years)
On site maintenance is done by the airforce, RIW does not cover components of a warranted item which are expected to need replacement,under normal use.
The essence of a RIW philosophy is that during the period of warranty coverage contractors will be encouraged to improve the reliability and to reduce repair costs of their equipment through the mechanisme of no-cost (to the airforce) modifications.
Once a fixed price is established for a RIW,the actualprofit realised by the contractor is dependent upon the equipment reliability in service use.

VIII F-16 RIW PROCUREMENT HISTORY.

Out of a list of 12 LRU's (line replaceable units) expected to account for at least 50% of the F-16 logistics support costs 9 LRU's were chosen for RIW from which two with guaranteed MTBF. The nine LRU's were warranted for a period of four years or 300.000 flying hours, whichever occured first. The flying hours applied to the first 250/192 USAF/EPG production aircrafts.
It is a fixed price contract for which the contractor will perform all depot repairs during the warranty period, for the LRU's with a guaranteed MTBF a pre-determined MTBF had to be reached before the end of this period.

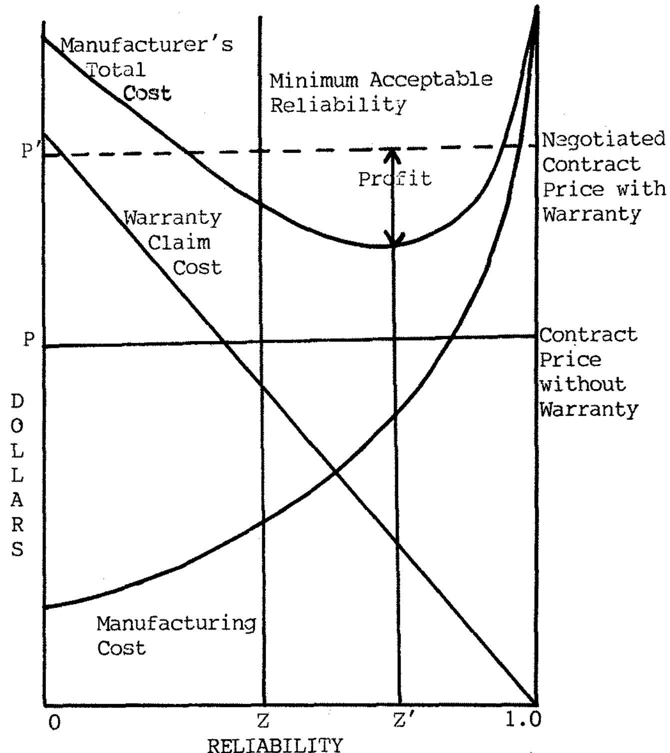
IX EVALUATION OF RIW.

Lets first analyse the economic situation for both the contractor and the Airforce under normal procurement practices by illustrating the typical contractual distribution of burdens and risks



Once a minimum acceptable reliability achieved the contractor has no incentive to improve the reliability, it will only lower its profit.Conversely following figure illustrates the same situation but assesses the impact with a warranty. Now the contractor must consider in its price not only the manufacturing costs but also the costs of meeting warranty claims

So in theory the contractor is not motivated to move back down on the manufacturing cost curve since below some optimum reliability (Z') profit would decrease instead of increase.
The cost for the Government will be the amount of any negociated upward adjustment of the contract price.



The costs associated with a warranty must be identified in order to be able to determine the cost-effectiveness of paying warranty claims and the costs to avoid paying those claims by building a more reliable product.
The government needs to know the impact of the warranty on his total costs relative to the non-warranty position.

Manufacturer costs: Actual costs of a failure, number of failures and the cost to built reliability into the product.
For the F-16 program some of these costs could be identified during contract performance by the Airforce. The contractor (General Dynamics) had to generate a semi-annual report including total repair manhours, costs of parts used and number of warranted failures, to this we have to add some administrative costs and overhead costs

Cost of building reliability: Once a weapon system design is established increases in reliability are realized through ECP's (engineering change proposals)
In theory a contractor will not be motivated to improve reliability when it is not to his economic avantage to do so.
Consequently under a fixed price warranty contract such as the F-16 if it is more costly to institute a fix for a failure than to continue repairing the failure a contractor will continue repairing rather than to implement the change.

X COST EVALUATION OF F-16 RIW

As the F-16 RIW was a complete separate contract the government costs for this additional warranty could be easily identified.
By use of the bi-annual reports of GENERAL DYNAMICS (at least the ones still available) an attempt was made to determine the manufacturer warranty claim costs.
The limit of 300.000 flying hours was not attained, the actual flying hours were 206.921 for which a price adjustment was made afterwards.

Following table compares the government costs versus the manufacturer costs.

LRU/SRU	VENDER	GOVERNMENT ADJUSTED COST ($)	TOTAL NB FAILURES	UNIT REPAIR COST ($)	TOTAL MANUFACTURER COST ($)	MFTBF	MTBF*
Flight Control	LEAR SIEGLER	2,175,466	610	2,333	1,423,130	339	-
HUD Processor*	MARCONI	2,569,407	338	4,101	1,386,138	612	500
HUD Pilot	MARCONI	9,441,604	595	3,948	2,349,060	347	-
INU	SINGER	8,685, 862	1,377	19,471	26,811,567	150	-
Radar TX*	WESTINGHOUSE	5,948,655	920	6,385	5,874,200	225	318
Radar Signal Proc	WESTINGHOUSE	2,662,607	455	6,385	2,905,175	455	-
Radar Computer	WESTINGHOUSE	3,882,290	592	6,385	3,779,920	350	-
Radar Receiver	WESTINGHOUSE	10,241,387	1,178	6,385	7,521,530	176	-
Radar Antenna	WESTINGHOUSE	2,569,407	1,204	6,385	7,687,540	172	-
TOTAL		54,514,140			59,738,260		

* With warranted MTBF

Summary of costs per vendor.

VENDOR	GOVERNMENT COST	MANUFACTURER COST
LEAR SIEGLER	2,175,466	1,423,130
MARCONI	12,011,011	3,735,198
SINGER	8,685,862	26,811,567
WESTINGHOUSE	25,304,346	27,768,365

1. For WESTINGHOUSE we could only obtain a mean repair price for all considered LRU/SRU's commingled

2. The manufacturer prices do not include other claim costs such as preparing reports, administration of the warranty and operating repair facilities. It is also worth to be noted as the contract was signed with the aircraft manufacturer GENERAL DYNAMICS those prices do not yet include overhead costs

3. On the other hand it is also true that the Airforce had additional costs for enforcing the warranty,documenting/complying with the claim provisions, transportation of failed units to and from the manufacturer and maintenance failure isolation costs.

XI MEASURING WARRANTY BENEFITS

There is an inherent difficulty in measuring quantitative benefits of a warranty: certain parameters of a weapon system have to be compared with what they might have been without a warranty. A study was performed which compared the reliability attributes of the F-16's warranted equipment to the functionally similar attributes of non-warranty equipment on the F-15.

It was concluded that the data cannot be said to favor the case for the F-16 RIW program having provided significantly higher reliability than would have occured without the RIW program. Also both F-16 LRU's that were procured under a MTBF guarantee exhibited significantly better reliability than their F-15 counterparts.

Anyhow a warranty extends a contractor's responsability to operational on the field performance for the period of the warranty coverage.

Consequently a warranty can provide increased assurance that operational performance will be as specified.

XII CONCLUSIONS OF THE F-16 RIW COVERAGE.

Although it has not been proven that reliability has improved under the F-16 RIW contract, (except maybe for the two LRU's with guaranteed MTBF) at least it forced the different manufacturer's to maintain high standards in the manufacturing process in order to achieve at least the predicted MTBF.

One important contribution of no major increase in reliability during the RIW contract was the fact that in most cases it was cheaper for the manufacturer to continue to repair the equipment rather than to fix the problem by a no-cost ECP (engineering change proposal) to the government.

It has to be made more attractive to the manufacturer to improve reliability during the warranty period: we have to redistribute the burdens and risks between the contractor and the government.

XIII PROPOSAL WITH EVEN DISTRIBUTION OF BURDENS AND RISKS

With the F-16 RIW experience in mind I would like to propose another approach to RIW which more evenly distributes the burdens and risks and could more easily motivate the contractor to improve the reliability of his product.

Basically it is a RIW contract with guaranteed mean flight time between failure (MFTBF). For ease of record keeping it is better to base the coverage on actual flying hours.

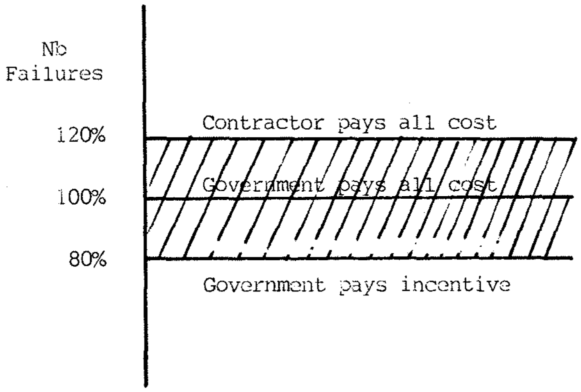
The warranty period should be at least 4 to 5 years. A growing MFTBF will be fixed for every year.

The considered MFTBF compared to the number of flying hours will generate a theoretical number of failures per year.

The government will pay all repair costs as long as the actual number of units to be repaired is situated within $\pm$ 20% of the theoretical number for that year.

Any failed unit exceeding 120% of the theoretical number will be repaired at the manufacturer expense.

If the number of failed units drops below 80% of the theoretical number the government will pay as an incentive a premium to the contractor to make up for at least 80% of the repairs.



$$100\% = \frac{\text{Total annual flying hours}}{\text{MFTBF}}$$

By doing so both parties are involved in the burdens and risks.

Again as in the F-16 RIW we will have an increased assurance that at least the predicted MTBF will be achieved but now the contractor has a more explicit incentive to build reliability into the system because the government will pay for a higher reliability which was less evident in the F-16 RIW formula.