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STANDARDIZATION AND LOGISTIC SUPPORT COST EFFECTIVENESS OF ADVANCED AVIONICS SYSTEMS

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Standardization and Logistic Support Cost Effectiveness of Advanced Avionics Systems

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ABSTRACT

Modular standardization which has already been adopted within avionic systems can also be used to optimize the Logistic Support in terms of: performance (such as operative availability, maintainability, system reliability and testing) and costs (purchasing, maintenance, spare parts, technical documentation, training and ground support equipment). After a short description of the status of technological integration, hardware and software standardization nowdays available to date on avionic systems; a demonstration of the effectiveness of the new maintenance philosophy and concepts (elimination of the 2nd maintenance level) is given.

It should be noticed that the results derived can be extended also to naval and ground defense systems.

1. Introduction

To date, military or commercial product competitivity is gauged according to life cicle cost as well as performance.

Which means that products are not compared only on the ground of technical performance, but also on that of logistic support required. We all know that an unmaintained product will limit its life cycle to the time between its coming into operation and its first failure. Of recent, the main requirement to keep a product in operational readiness (and/or available) has taken an increasing importance.

In the following we shall see how suitably applied standardization can give way to the advantages required in the civil and military fields. Without going into the detail of standardization philosophies, we can say that the rule to be used to evaluate the degree of success and rationality consists of 4 factors, two technical and two economic:

- Technology to be applied must be mature
- Architecture must be functional
- Applicability must be as wide as possible
- Economic advantages have to be proven

Later on these aspects will be used to deal with avionic modular standardization but, as we shall see, they can be extended to other fields (such as Defence Systems).

2. Operational Availability and LCC

Lets now examine the factors which may enhance system operational availability:

$$Ao = \frac{MTBM}{MTBM + MDT} = \frac{UT}{UT + MDT}$$

Where:

MTBM = Mean time between maintenance

MDT = Mean Downtime. This includes active maintenance, logistic and administrative times of a logistic organization

UT = Time during which the system operates, measured as Duty Time (see fig. 1)*

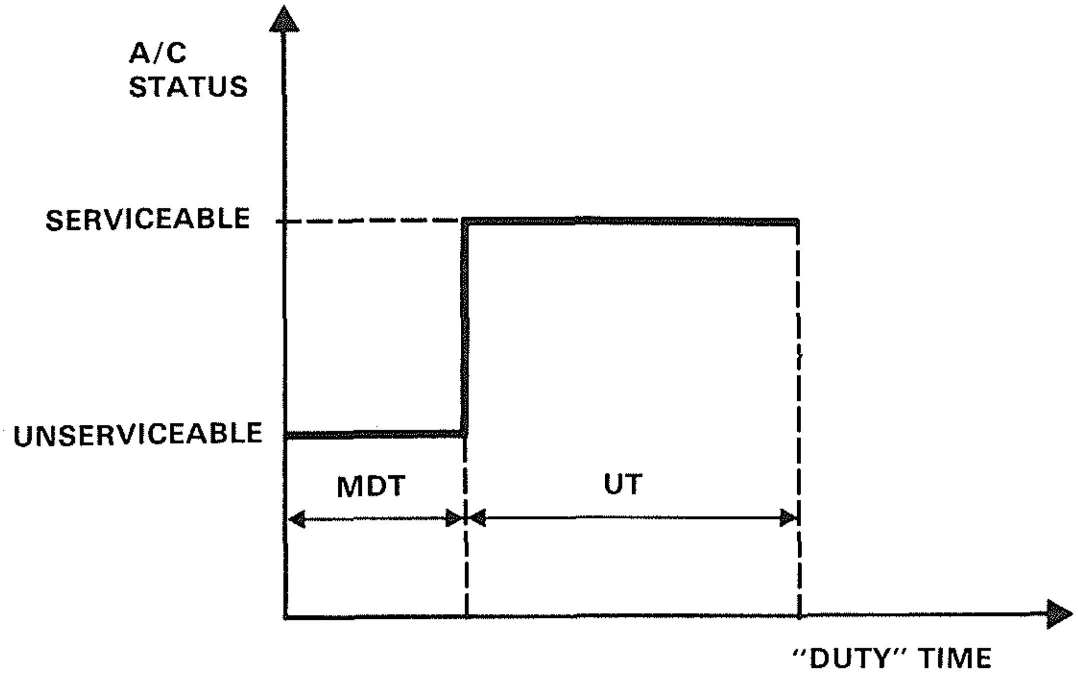

Fig. 1 — A/C Status as a Function of Time

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* **NOTE:** *Avionic Duty Time is not the same as solar time [1]. In peacetime duty time is less than solar time.*

MTBM values can never exceed those of MTBF, which is the mean time between failures (without preventive maintenance), while the most important factor on which we may act is the MDT, by reducing it.

We can act along different directions:

- Minimizing active maintenance time by reducing preventive maintenance to zero and reducing active maintenance times.
- Intervening on the logistic support organization to reduce logistic and administrative times.

Lets now see how we may meet the requirements above in a modern concept for Life Cycle Cost [2], [3].

The costs to examine are:

- System and logistic support acquisition costs (initial investment)
- Maintenance and administrative costs (operational and support costs)

By taking a real situation as an example we may check how this can lead to considerations relevant to other situations, so as to demonstrate applicability to fields other than the one considered.

The real situation examined here is that of civil and military avionics.

3. Preliminary Considerations on New Generation Avionics Modular Packaging

Without going into the integration levels available today for the different functions of a civil or military A/C, the main requirement not to burden the pilot or on board operator with complex, continuous and repetitive functions holds true.

From this consideration we experience a need for high function integration, alternative command and sensor development (voice, sound) and catering within the cockpit for multifunction presentation systems (EFIS - see fig. 1 b).

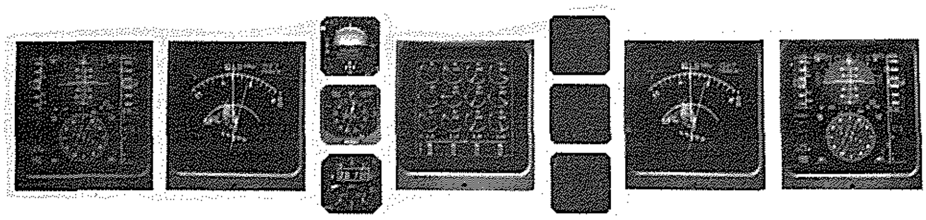


Fig. 1b — New Generation A/C Cockpit

All parts which are vital to navigation and mission are integrated within the functions to warrant survival in case of failure (failure tolerance and redundancy, on-line reconfiguration, mission dependent configurations).

With an almost exponentially growing cost increase of an avionic system now is probably the time to reconsider traditional support of such systems.

In the past, avionic systems were designed, acquired and maintained as black boxes (LRU) or units. As the cost of such units has increased considerably, it is increasingly more difficult to dispose of spares in sufficient number and variety. Of course each supplier guarantees LRU interchangeability. Therefore if part of an avionic system fails, the whole unit is removed from A/C (see fig. 2). Many system functions are still available and only a small part has failed. A solution may therefore be to replace only the failed module instead of the whole LRU (see fig. 3).

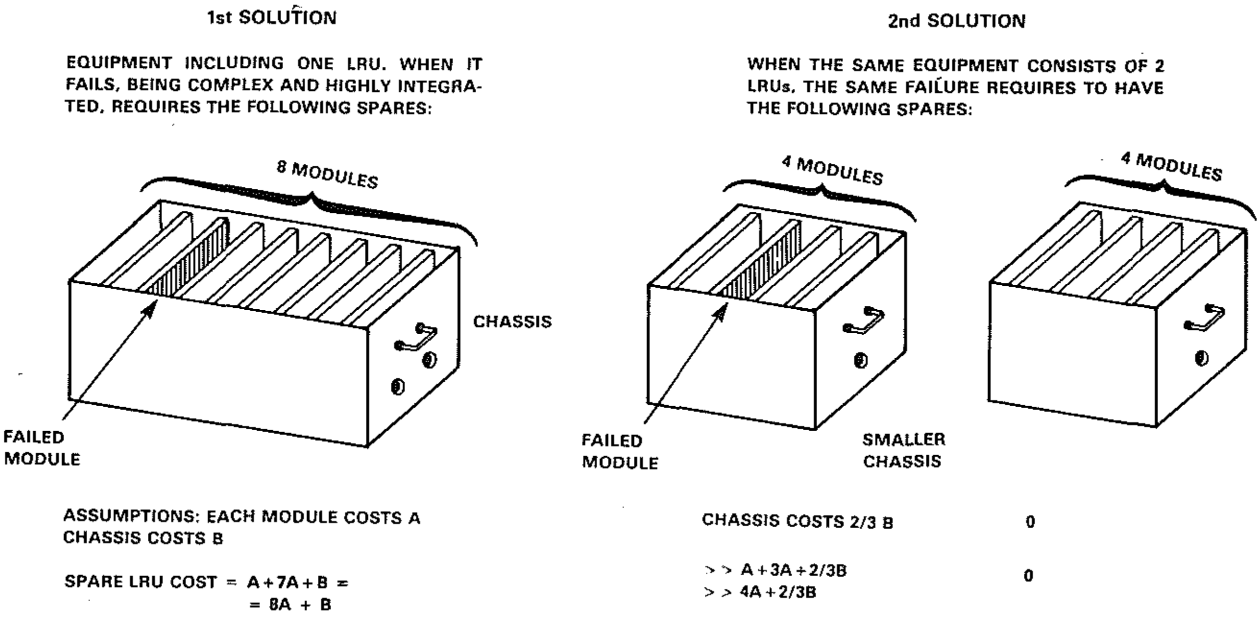


Fig. 2 — Modularity has an impact on Spares Cost

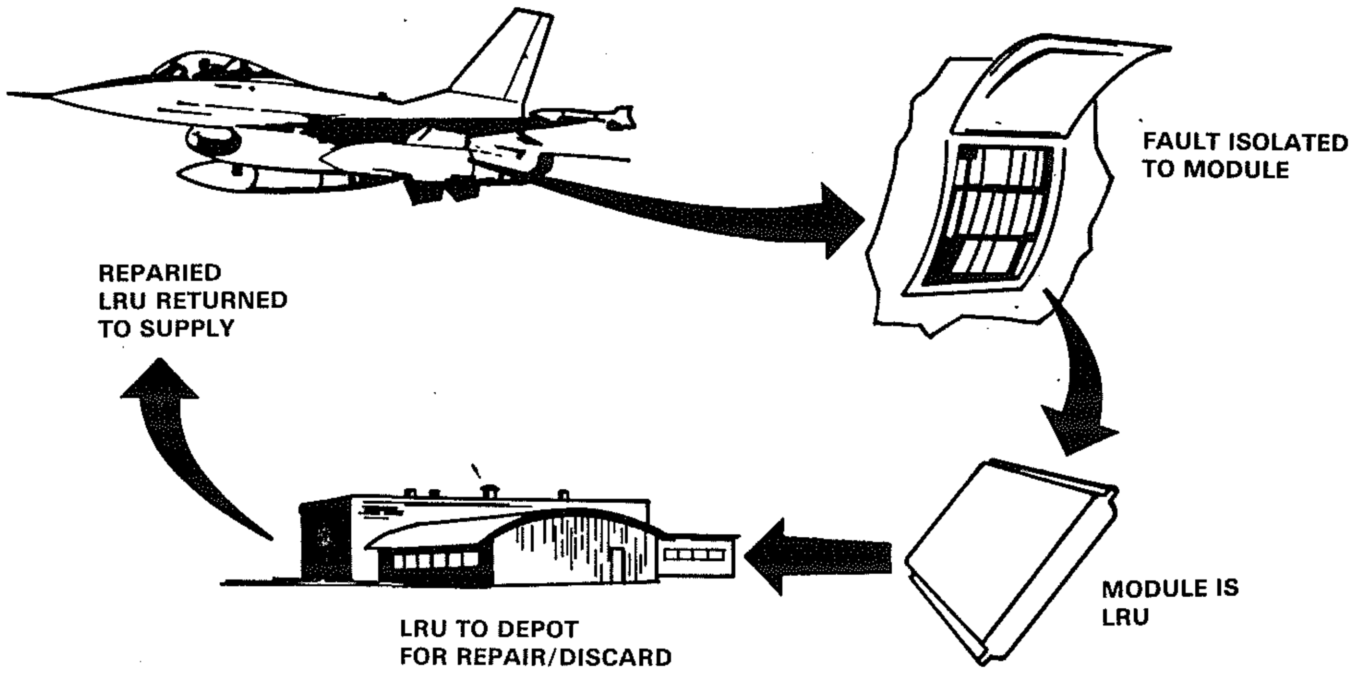


Fig. 3 — Standard Modules Support Simplified Maintenance

To achieve such ambitious maintenance program down to module level, integration techniques of the following types have to be developed:

- Advanced busses
- VLSI/VHSIC technologies
- Self diagnosis and fault localization
- Modular packaging
- S/W transport

Advanced busses decrease system faults considerably in the area of cables and connectors, which amount to a fair percentage of total faults.

By adopting VLSI and VHSIC technologies we can increase the number of functions within smaller volumes having fewer external interconnections. This way we can include single complex functions within a single module, which therefore may replace a whole LRU.

By using BITE fault diagnosis and location capability, we can replace the failed system module without making use of expensive GSE and highly skilled maintenance personnel.

Through use of this technique the cost and time required to maintain an avionic system are kept to a minimum. The goal may be met be introducing form-fit-function standard modules, boxes, integration racks.

There is also a requirement for maximum standardization and modularity at S/W level arising out of its high incidence on modern aircraft development total cost.

Lets now examine in detail some of the problems and technologies which will be adopted in the close future within the main avionic development programmes.

4. Problems arising in the Avionic Field

An overview of problems arising out of the adoption of new technologies applied to civil and military avionics, with particular regard to logistic support of digital avionic subsystems, is provided in the following.

4.1 AVIONIC COMMUNICATION BUS

Bidirectional communication busses between subsystem and LRU which are in advanced standardization are [4]:

A) ASCB - Avionic Standard Communication Bus, which is derived from Civil HDLC (High Level Data Link) by Sperry (see also International Standard ISO-3309) with data rate 1 Mbs.
B) HSDB - High Speed Data Bus by SAE (Society of Automative Enginneers) and IEEE 802 with data rate 20 Mbs.
C) MIL-STD-1773 using optical fibres. This bus has a protocol and data rate close to those of MIL-STD-1553B. Therefore it will eventually replace it to solve all EMI/EMP problems.

All standards under scrutiny are aimed at reducing the weight percentage of A/C cabling (in the past such weight was close to that of LRUs).

Further standardization is underway for specific applications such as MIL-STD-1760 "Aircraft/Store Electrical Interconnection System".

4.2 EFIS

Multifunction Electronic Flight Instrumentation System is a real thing [5]. Display Units are integrated with Symbol Generators. Such SGs are very complex and sophisticated because in view of quality, graphic presentation is by means of raster and strobe techniques. Liquid Crystal or thin film electrolumenescent displays available also in colour are in advanced development.

Today's EFIS trend is with an 8" × 8" colour video (see fig. 4).

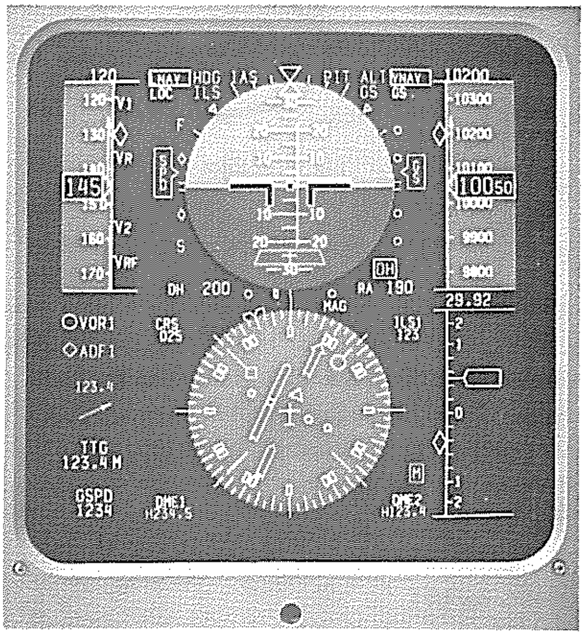


Fig. 4 — 8" × 8" EFIS Colour Display Example (by Sperry)

4.3 PILOT A/C INTERFACE

Interactive voice (identification and synthesis) will be used to reduce pilot's workload in the cockpit and a video helmet will be used (see fig. 5) and further information will be given to the pilot in synthesized vocal form.

For pilot's voice recognition, use will be made of a personalizing device based upon voice pitch.

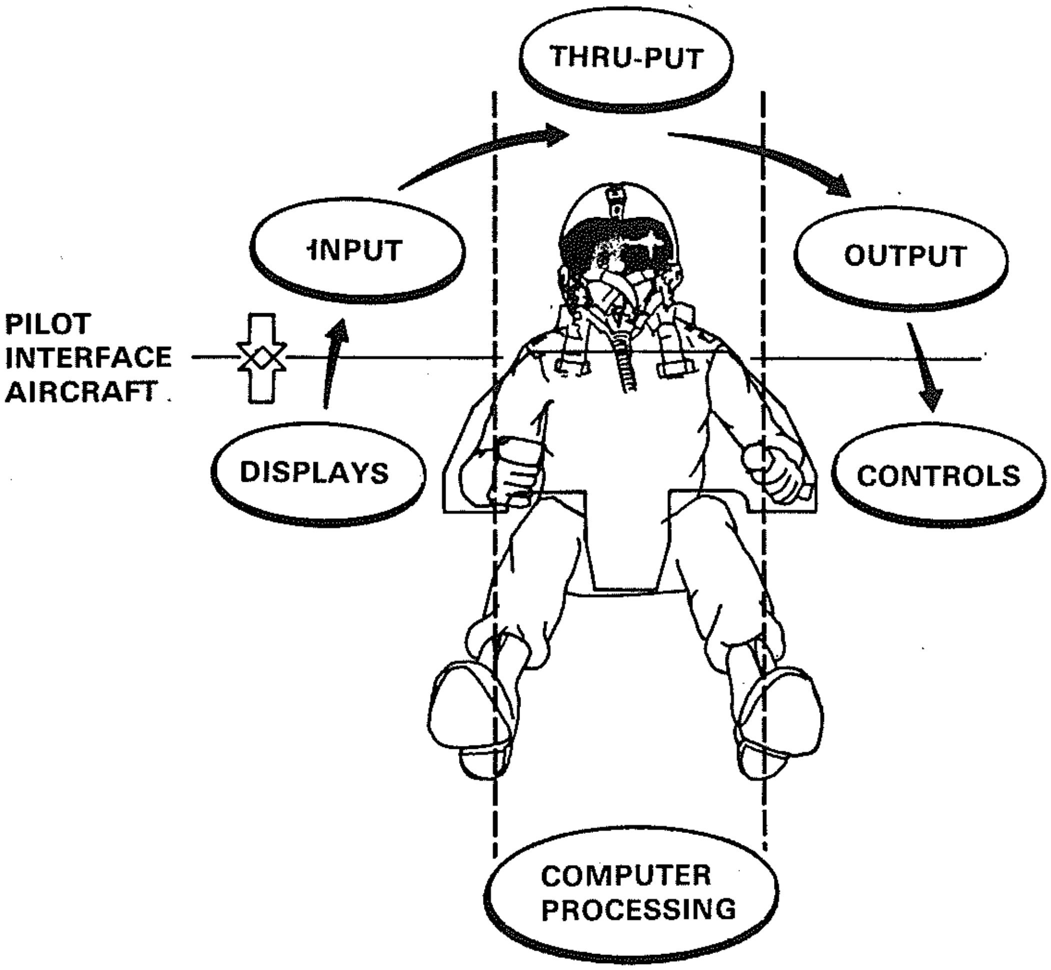


Fig. 5 — Pilot A/C Interface

4.4 BIT/BITE

BIT/BITE is increasingly required for in flight monitoring of subsystem status with possibility to memorize malfunctions in non volatile memories (continuous/switchon BIT).

BIT must give go/no go indications within a few minutes during preflight check of an A/C.

BIT will be increasingly integrated within reconfigurable systems. An increase in S/W for presentation, menue, dedicated routines for maintenance personnel to complete deeper tests to isolate faults at the LRU/module level. A few specific BIT requirements are shown in the following.

4.4.1 A Few Specific Requirements on BIT

There are two types of BIT:

a) on line or continuous BIT
b) off-line or interruptive BIT

BIT is a resident resource which is an integral part of the host system or subsystem.

This resource is used operationally or for 1st level maintenance diagnostic purposes. In this case it will provide an indication of faulty unit or module.

BIT may be a combination of H/W and S/W facilities, more so if we consider on board avionics.

It is important to specify fault detection (~98%) and location (~95%) coverage, specially with the arrival of modular standardization, multiple transmission busses and 2nd maintenance level elimination.

It is adviseable to specify BIT impact on some of system's performance in terms of reliability reduction (5%), and weigth increase (8%) and power consumption (2%) and fault indication false alarm (1%).

BIT input/output towards the operator can be any combination of audio, voice, video, panels, recorder or DTD etc.

4.5 MAINTAINABILITY REQUIREMENTS

Within the new maintenance concept, the main requirements may be summarized as follows:

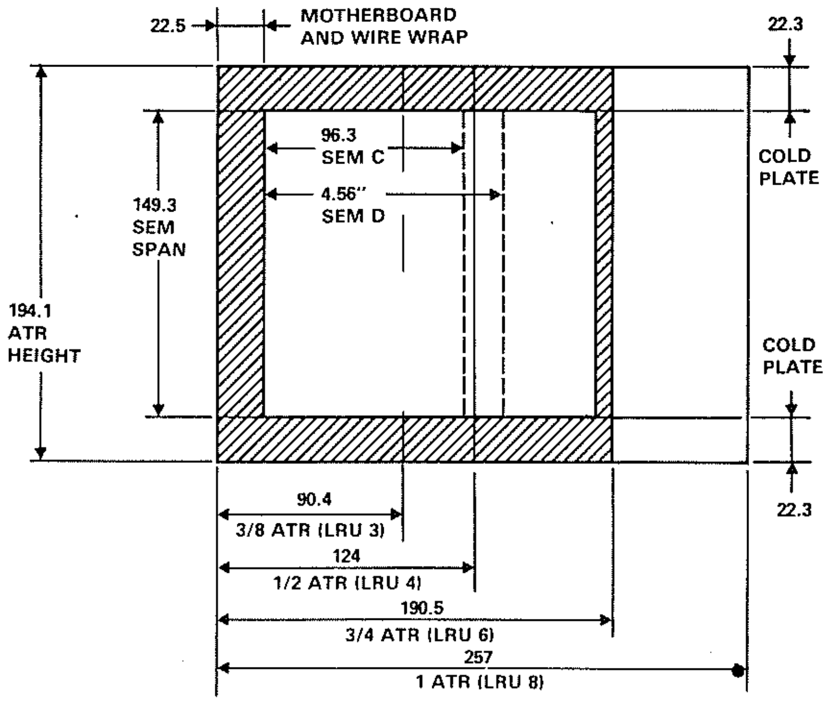
— Minimized 1st level maintenance with lesser training of personnel involved. On condition maintenance with a maximum interval of operating hours between LRU removal to keep spares requirement low.
— On line automatic reconfiguration using hot redundancies.
— Elimination of 2nd maintenance level by use of more effective BITE coverage and modular replacement.
— Elimination of failures flagged during mission which cannot be confirmed during maintenance and which give way to a number, often unacceptable, of modules and units replaced for repair and found to be serviceable.
— In flight data recording of random fault detection which would not be detectable during ground test.

4.6 TESTABILITY REQUIREMENTS

In addition to the already known design efforts to increase avionic system testability, today it is required to add a real time fault detection and location capability and to minimize false fault indications and consequent module/LRU removal from A/C.

4.7 AVIONIC PACKAGING AND INSTALLATION MODULAR STANDARD

Over the last few years, the USA have been working on the setting of standards, such as SEM modules (Navy Standard Electronic Module) in the A/C of the naval field. SEM module sizes are compared in figure 6 with civil avionics standard module dimensions.

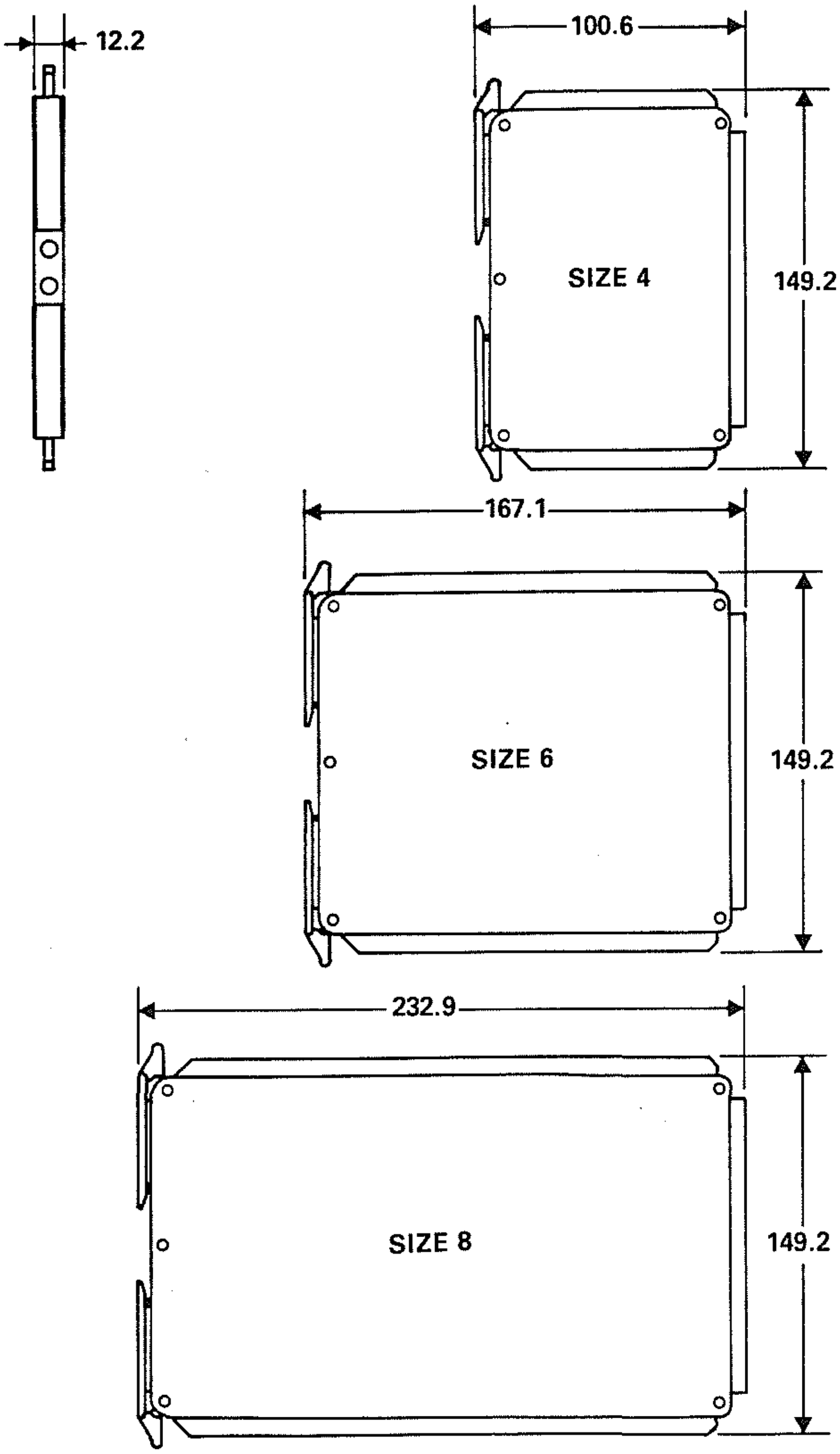


DIMENSIONS INDICATED ARE IN mm

Fig. 6 — Standard Dimensions of Civil (ATR) and of Military Avionic (SEM) Shipborne Modules

Major efforts are spent on implementing modular standards through use of advanced integration technologies in High Density Surface Mounting (HDSM) component assembly through a specific application [6].

Module dimensions are shown in figure 7. Physical composition of the module is generally of the sandwich type. The connector is on the module short side, but as it interfaces the sandwich, the number of pins is high.



DIMENSIONS INDICATED ARE IN mm

Fig. 7 — HDSM Module Dimensions [6]

As we can see from figure 8, modules may be handled and replaced at flight line (1st level see fig. 3) and an example of a cover free avionic module is shown in figure 9.

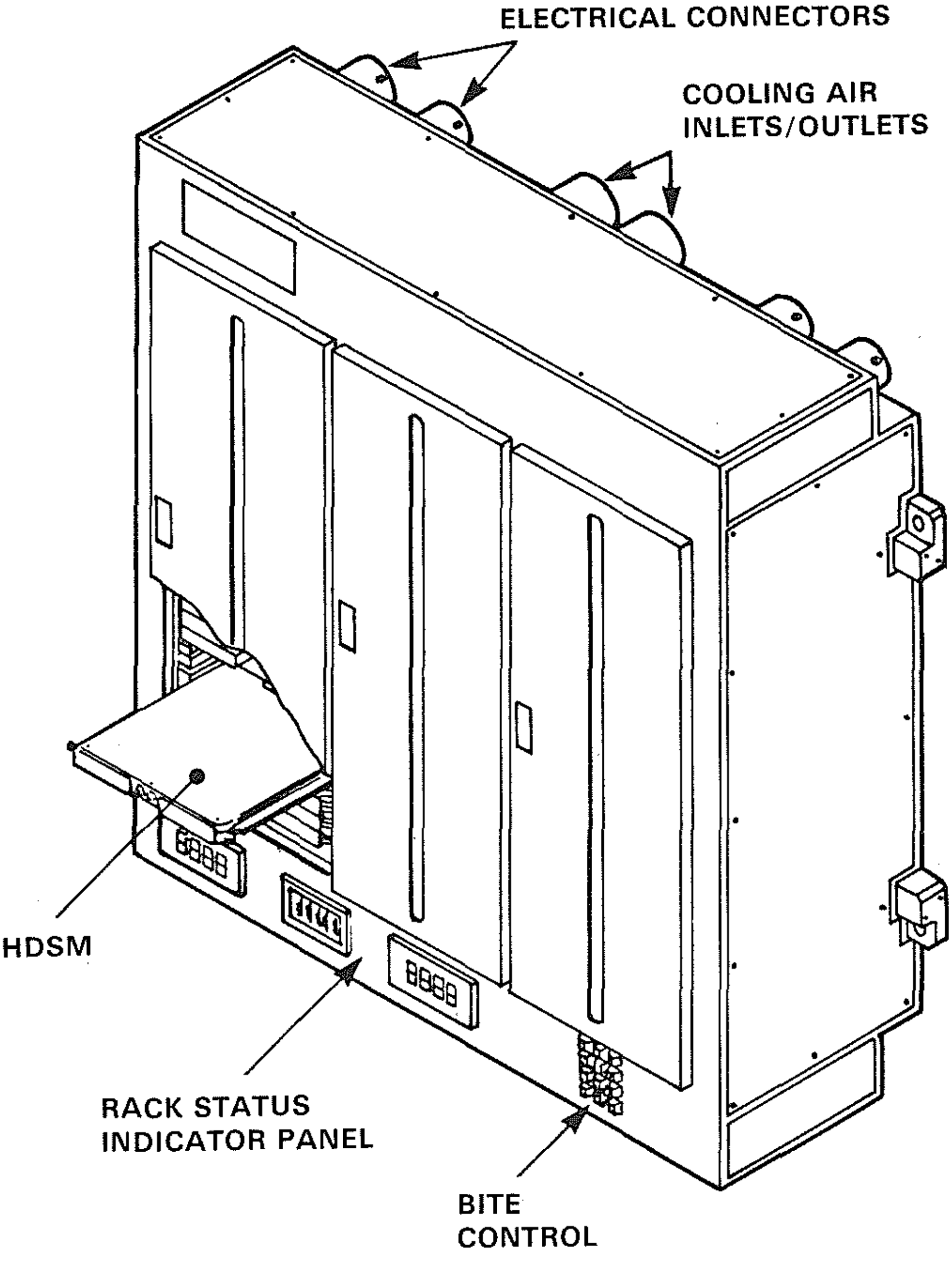


Fig. 8 — Avionic Module Integrated Rack

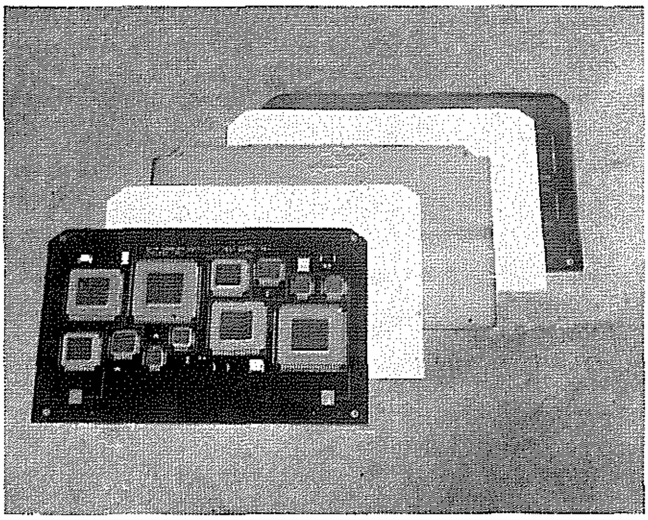


Fig. 9 — Cover Free Module Example with SMD Technology

Compatibility parameters have been defined (physical, thermal, environmental, electrical) while functional parameters, such as interchangeability, interoperation for modular standardization are being defined, as can be seen for single A/C type (fig. 10) and for more than one A/C type (fig. 11). Integration modules, units and racks are dealt with by DOD-STD-1788 "Avionics Interface Design Standard".

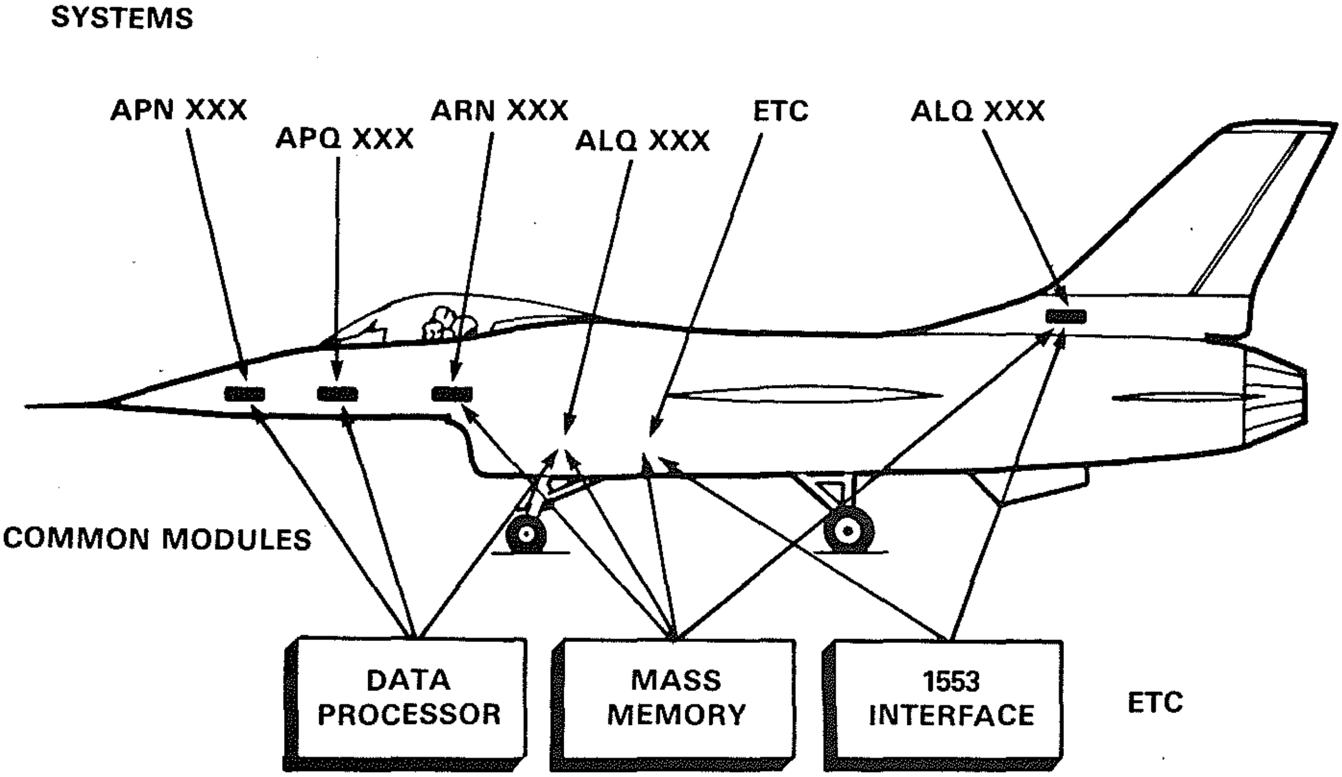


Fig. 10 — Same A/C Module Interchangeability (e.g. F-16)

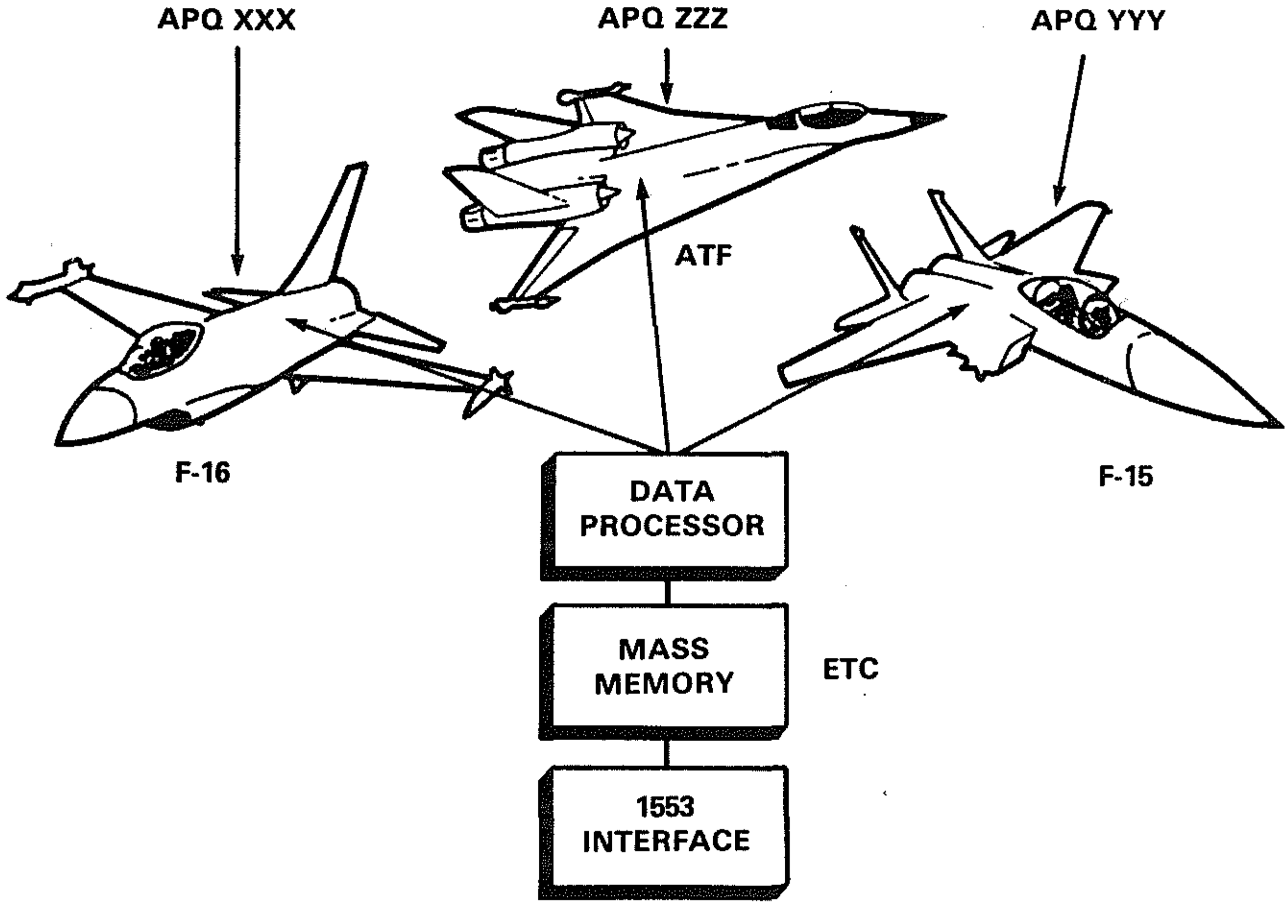


Fig. 11 — Different A/C Module Interchangeability (e.g. F-15, F-16, ATF)

Physical factors are: dimensions, packaging-type, connector, weight, extraction technique, boards for module, insertion force.

Technical factors are: heat transfer device, power dissipation.

Environmental factors are: EMI, EMP, humidity, temperature, pressure, vibration.

Electrical factors are: dc power supply, fail indicator, BUS interface, BIT requirements.

Interchangeability factors are: throughput, memory size, access time, software.

Interoperation factors are: data bus protocol, BIT protocol, data rate.

4.8 SOFTWARE AND PROCESSOR STANDARDIZATION

Without getting into details, ADA (see ANSI/MIL-STD-1815A*) is the used language for military applications and processing H/W is a precoded standard (MIL-STD-1750A+). VHSIC chip sets to be distributed on the market in the close future will be the relevant implementation, with instructions set architecture ISA compatible. This compatibility assures H/W & S/W interchangeability and after a first period, it will reduce times and costs of future program development.

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* *"ADA Programming Language"*

\+ *"16 Bit Computer Instruction Set Architecture"*

5. Life Cycle Cost (LCC)

All technological choices and modifications to existing standards should be governed by the following fundamental equation:

$$G = \text{Earnings} - \text{Costs}$$

where G is positive for a system user.

Earnings are affected by electrical, mechanical, operational, maintainability, reliability performances, while costs are affected by initial acquisition expenditure (investment) and operational costs (materials, personnel, maintenance, administration).

If we want to support any choice, all we have to do is to reduce costs and keep earnings constant. Hence it would be enough to check that LCC is reduced by modular standardization (see fig. 2).

LCC computation is anyway simplified by calculating only Logistic Support Investment + Maintenance costs along the likes of a model developed and adopted by Selenia [3]. This simplification, albeit incomplete and non exhaustive, provides a visible and simple proof.

All factors left aside in the calculation improve G in terms of performance:

- greater system reliability
- greater operational availability
- greater maintainability and supportability
- greater expandability and interchangeability
- greater supply source availability
- greater architectural growth possibility

and in terms of cost:

- lower initial development cost (lesser time)
- lesser production cost (materials, tests)
- lesser modification costs for increased performance
- lesser spare LRU-module cost/MTBR

Lets see how starting from simple concepts we may algebrically generate the incidence of spare parts and maintenance cost by adopting hardware modularity.

6. Cost Analysis

Lets suppose we have an equipment which could be installed as a single LRU or as a group of modules, to be installed and removed separately (in the following called items).

Items have the following characteristics:

C_i = i^{th} item unit cost (in Reference Units RU)
F_i = Frequency of removal or maintenance actions of the whole air fleet (in terms of removal/flight hours). Each action requires the availability of an i^{th} item spare part.
η_i = Fraction of the i^{th} item repair actions which cannot be effected at the 2nd level
T_{Ai} = Repair time or TAT at 2nd level of i^{th} item, in months
T_{Bi} = i^{th} item 3rd level repair time or TAT, in months
P = Utilization factor of A/C fitted with installed items (in flight hours/month)
N = Number of items making up the system

Quantity $P \cdot F_i$ is the total removal factor for the i^{th} item in the fleet of A/C considered.

Without considering that logistic organizations differ in the two cases (3 levels for the LRU case, 2 levels in the module case) we can see how we may find an analytical expression which proves the economic convenience of modular breakdown.

. For modules, the cost of spares is:

$$S_1 = P \cdot \sum_{i=1}^{N} C_i \cdot F_i \cdot [(1 - \eta_i) \cdot T_{Ai} + \eta_i \cdot T_{Bi}] \tag{1}$$

while for LRUs the cost of spares is:

$$S_2 = P \cdot [(1 - \eta_c) \cdot T_{Ac} + \eta_c \cdot T_{Bc}] \cdot C_c \cdot \sum_{i=1}^{N} F_i \tag{2}$$

where pedix c refers to LRUs.

If we want to make reasonable simplifications, whereby TATs are homogeneous and module costs make up LRU cost, i.e.:

$$\begin{aligned} \eta_i &= \eta_c \\ T_{Ai} &= T_{Ac} \\ T_{Bi} &= T_{Bc} \\ C_c &= \sum_{i=1}^{N} C_i \end{aligned} \tag{3}$$

Then the cost rate of spares for the 2 solutions becomes:

$$\frac{S_2}{S_1} = \frac{\sum_{i=1}^{N} C_i \sum_{i=1}^{N} F_i}{\sum_{i=1}^{N} C_i F_i} \tag{4}$$

With the following additional restriction

$$\begin{aligned} &C_1 \cdot C_2 \cdot \dots \cdot C_N \\ &F_1 \cdot F_2 \cdot \dots\dots \cdot F_N \end{aligned} \tag{5}$$

Applying Chebyshev's inequality, we have

$$S_2/S_1 \cdot N \tag{6}$$

In the ideal situation examined, the cost of LRU spares cannot be greater than N times the cost of the modules considered LRUs.

To prove the convenience also for modularity adoption and to eliminate 2nd level maintenance, the following provides a practical case which is not to far fetched. All assumptions are shown in the following and in table 1.

Lets suppose we have an avionic system consisting of one LRU to be fitted to each A/C of the fleet. Lets suppose the LRU consists of 8 modules + chassis and that the modular solution keeps the same functions and reliability in the same number of modules which have the same functional redundancy of the LRU. All modules are depot repairable for 100% of cases, while the LRU is 90% base repairable and 10% depot repairable.

The sum of the module initial costs is 95% LRU cost, considering the decrease due to chassis H/W and other optimization.

The results derived, although indicative, are a clear demonstration of economic convenience.

This without considering that 2nd level maintenance level elimination (base) also gets rid of other cost contributions due to GSE (manual or automatic), training courses, technical manuals and documentation, transport from base to depot, cost of maintenance personnel and spares management.

Such costs are greater than the greater costs of the same nature present at the Depot due to the lack of 2nd line maintenance.

Table 1
LCC CALCULATION EXAMPLE

P = 25 fh/month

T_{Ac} = 5 solar days = 1/6 month

T_{Bc} = 60 solar days = 2 months

F_c = 1 removal/squadron f.h. (it depends on LRU reliability and on number of A/C in the squadron - 24 in the example).

η_c = 0.1 (90% LRU repairs are at the base)

C_c = 100 RU

T_{B1} = ... = T_{B8} = 2 months

η_i = 1 (all module repairs are the depot)

$C_1 = C_2$ = 14 RU

$C_3 = C_4$ = 11 RU

$C_5 = C_6$ = 13 RU

$C_7 = C_8$ = 9 RU

$F_1 = F_2$ = 0.14 removals/fh

$F_3 = F_4$ = 0.12 removal/fh

$F_5 = F_6$ = 0.14 removal/fh

$F_7 = F_8$ = 0.10 removal/fh

SOLUTION A (spare LRU)		SOLUTION B (Spare modules, less 2nd level)			
		MOD. 1,2	MOD. 3,4	MOD. 5,6	MOD. 7,8
100	Unit cost (RU)	14	11	13	9
25	Removal/fh +	3.5	3	3.5	2.5
90	% base repairable	—	—	—	—
10	% depot repairable	100	100	100	100
9	Spare quantity *	7	6	7	5
900	Invest. costs (RU)	196	132	182	90

From equation (2)
S_2 = 900 RU

From equation (1)
S_1 = 600 RU

$S_2/S_1 = 1.5$

Result:
50% convenience for spares investment cost

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* Spare quantity has been approximated to the nearest integer.

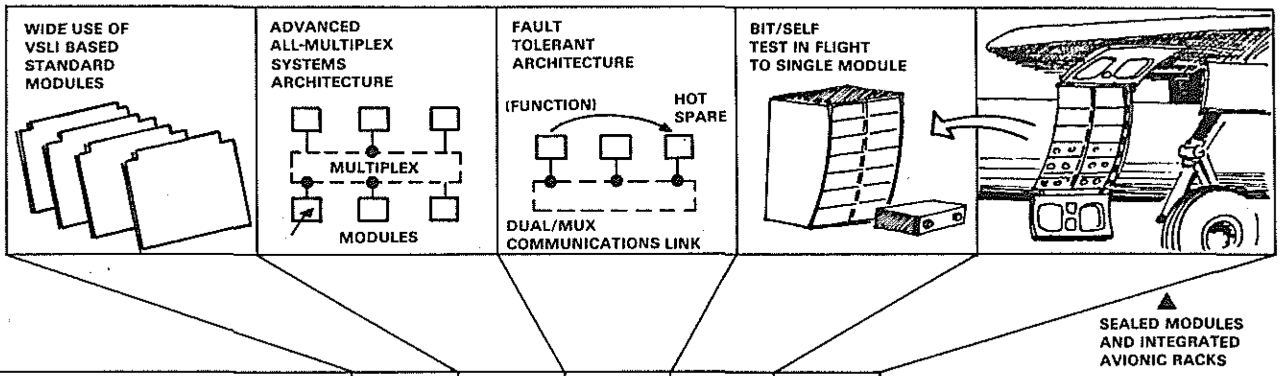
+ An equivalent total reliability has been assumed between the two solutions that is:

$$F_C = \sum_{i=1}^{8} F_i$$

7. Conclusions

7.1 ADVANTAGES OF AVIONIC MODULARITY

From the considerations above, we can see (ref. fig. 12) that:



	WIDE USE OF VSLI BASED STANDARD MODULES	ADVANCED ALL-MULTIPLEX SYSTEMS ARCHITECTURE	FAULT TOLERANT ARCHITECTURE	BIT/SELF TEST IN FLIGHT TO SINGLE MODULE	SEALED MODULES AND INTEGRATED AVIONIC RACKS
IMPROVED OPERATIONAL AVAILABILITY	■	■	■		■
REDUCED FAULT FALSE ALARM	■	■	■	■	■
REDUCED NUMBER OF TYPES OF SPARES	■			■	
REDUCED CONNECTIONS AND CABLES		■			
REDUCED N° OF HIGH COST SPARES	■				
REDUCED MAINTENANCE MANHOURS			■	■	■
ELIMINATION OF 2nd MAINT. LEVEL (BASE)		■		■	■
REDUCED TRAINING (1st/2nd LEV.)				■	■
ON A/C MODULE REPLACEMENT				■	■
REDUCED COST/MODULE	■				

Fig. 12 — Improvements to Logistic Support

- F^3I standardization decreases development costs with lesser design and production risks for the system (lesser H/W to be developed, lesser tests to be made) and shorter development times.
- The elimination of traditional 2nd level logistic support eliminates 2nd level acquisition costs (documentation, courses, initial spares, development and build of GSEs). Usually investment cost of 2nd level maintenance is one of the highest costs of global Logistic Support (≅ 50%). This cost is due to Spares and GSE. Furthermore it eliminates the facility and resources management and 2nd level maintenance administrative costs.

On condition maintenance (i.e. without preventive maintenance) will be another factor determining cost reduction and operational availability increase.

Modular standardization will surely afford reliability advantages (> MTBF) with same functions, and therefore with lesser Logistic Support costs in the life cycle (spares, maintenance) and a greater operational availability.

Functional standardization implies a smaller number of different modules, lesser documentation cost, lesser number of spares types and interchangeability of supplies, with technological growth at each supplier.

With reduced costs there will be a greater number of missions, better survivability and greater A/C or system considered self sufficiency.

But there will be drawbacks, as shown in the following.

7.2 AVIONIC MODULARITY DRAWBACKS

- Modular standardization implies a costly specification, design, development, test and qualification initial phase.
- 2nd level elimination means greater circuit integration and greater difficulties in 3rd level repair. However it is believed that large scale production of VHSIC chip sets will bring about a cost abatement for such components.
- The lack of 2nd level requires the availability of BITE with expanded fault location capabilities to minimize use of 1st level GSE for premission check. This affects final cost of each module by about 2%.
- Software will take on greater importance during development and integration test and greater weight in terms of cost (e.g. to predict failure consequences, fault propagation control and redundancy management).

GLOSSARY OF ABBREVIATIONS

ARINC = Aeronautical Inc.
ASCB = Avionic Standard Communication Bus
ATF = Advanced Tactical Fighter (USA)
BITE = Built-in Test Equipment
CAD = Computer Aided Design
DOD = Department of Defense
DTD = Data Transfer Device
DU = Display Unit
EFIS = Electronic Flight Instrumentation System
EMI = Electro Magnetic Interference
EMP = Electro Magnetic Pulse
F^3 = Form-Fit-Function
F-15 = Flighter 15 (USA)
GSE = Ground Support Equipment
HDSM = High Density Surface Mounting
HLDL = High Level Data Link
HSDB = High Speed Data Bus
IC = Integrated Circuit
IEEE = Institute of Electrical and Electronic Engineers
ISA = Instruction Set Architecture
LCC = Life Cycle Cost
LRU = Line Replacement Unit or Module
MDT = Mean Down Time
MTBF = Mean Time Between Failures
MTBM = Mean Time Between Maintenances
MTBR = Mean Time Between Removals
SEM = Standard Electronic Module
SG = Symbol Generator
TAT = Turn Around Time
UT = Up Time
VHSIC = Very High Scale Integration Circuit
VLSIC = Very Large Scale Integration Circuit

BIBLIOGRAPHY

[1] *J. Nilsson* — **A Discussion Paper Regarding the Availability Concept in Aircraft Applications** —
SAAB-SCANIA, 1984-12-04

[2] *V. Buontempo* — **An Example of Integrated Logistic Support Applied also to Production Testing** —
Rivista Tecnica Selenia, Vol. 9, n. 4, 1985

[3] *V. Buontempo* — **Life Cycle Cost Model for Avionics Systems** —
Tech. Spec. ES 32/85 4/4/86

[4] *D.L. Stanislaw* — **General Aviation Data Bus Update** —
6th Digital Avionics Systems Conf., Baltimore 1984, p. 180

[5] *J.A. Ogann* — **Current and Future General Aviation EFIS Developments** —
6th Digital Avionics System Conf., Baltimore 1984, p. 193

[6] *F. Poradish* — **High Density Modular Avionics Packaging** —
6th Digital Avionics Systems Conf., Baltimore 1984, p. 634