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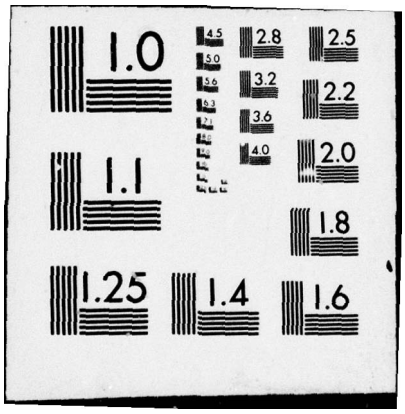
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FUNCTION AND CONFIGURATION ANALYSIS PROGRAM

HUGHES AIRCRAFT COMPANY, CULVER CITY, CALIFORNIA

OCTOBER 1976

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AFAL-TR-76-122

FUNCTION AND CONFIGURATION ANALYSIS PROGRAM

HUGHES AIRCRAFT CO.
CULVER CITY, CA 90230

OCTOBER 1976

TECHNICAL REPORT AFAL-TR-76-122
FINAL REPORT FOR PERIOD MAY 1975 - OCTOBER 1975

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GARY L. MALLALEY, 1/LT, PROJECT ENGINEER

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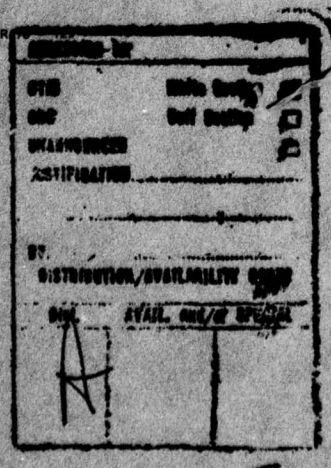

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The objective of this effort is to perform studies to investigate the feasibility, practicality, and implementation of standard electronics modules (SEM) for avionics. Tradeoff studies are used to provide quantitative data to assist the Air Force Engineers in selecting the SEM format(s) in a timely fashion. This report describes the details of the study with conclusions made and recommendations for future work to be considered.

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PREFACE

This Technical Report covers the work performed between 1 May 1975 and 31 October 1975 under Contract No. F33615-75-C-1270, Project No. 6096 "Function and Configuration Analysis Program". It was prepared by the Hughes Aircraft Company, Culver City, California for the Air Force Avionics Laboratory, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The Program Monitor was 1/Lt Gary L. Mallaley, AFAL/DHE.

Mr. Millard H. Martin is the Technical Coordinator and Mr. M. H. Rosengard is the Principal Investigator.

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I. BACKGROUND AND SUMMARY

BACKGROUND

During the performance of this study to assist the Air Force in selecting a standard electronics module, material was drawn from many sources:

1. Twenty-six years of Hughes experience in the design and manufacture of airborne electronics.
2. Air Force/industry workshops.
3. Hughes/industry workshops held specifically for this program.
4. Internal Hughes studies directed specifically for this program.

Monthly status reports and minutes of the status report meetings were submitted to the Air Force Project Engineer and should be available to interested parties from his office.

We would like to acknowledge the contributions made by Dr. Gene K. Baxter of the General Electric Company, Mr. Lou Laermar of the Singer Co. Kearfott Division, and Dr. Bruno Pagnani of the IBM Corporation, and in addition the many others within Hughes as well as in industry whose comments are included in this report.

SUMMARY

The standard electronics module for the avionics program is an effort designed to provide Air Force engineers with sufficient quantitative data to enable the timely selection of a standard module format. Since present avionics systems are characterized by a proliferation of unique packaging schemes, which represent rapidly rising maintenance and logistics costs, the development and enforcement of an avionics module standardization are the keys to potential cost savings, increased reliability and reduced maintenance requirements.

To develop a meaningful set of recommendations, it has been necessary to conduct investigative studies of existing avionics systems, to take an active participatory role in several Air Force/industry workshops, and to seek assistance from competent and recognized experts in various disciplines. The data gathered have been categorized, normalized and evaluated; the proposed recommendations are given in Section VI.

At first, the data were categorized into a matrix consisting of 58 elements pertinent to the evaluation of existing avionics systems. Such elements as module physical characteristics, type of technology, logic partitioning, components used and power dissipation were included. After an iterative process, the original 58 elements grew to 61. Realizing the overpowering nature of such a vast complex of data, the elements were carefully screened to eliminate those of secondary importance while retaining those that would be of prime concern in the final evaluation.

The final module data matrix contains four categories of prime concern:

1. Physical characteristics
2. Power capabilities
3. Components
4. Module interface.

The table also includes systems presently in use as represented by the IBM, G.E., Delco and Hughes systems, as well as a summary of the proposed new standard avionics modules.

The U.S. Air Force Avionics Laboratory-sponsored Air Force/Industry Standard Electronic Module Workshops provided valuable data and guidelines

to be used in this study. The workshops consisted of the following specific panels:

1. Mechanical and Environmental Interface Panel
2. Functional Partitioning Panel
3. Technology Impact Panel
4. Maintenance Concepts Panel.

In this report, Section II deals with the Mechanical and Environmental Interface; Section III with Functional Partitioning; Section IV with Technology Impact, and Section V with Maintenance Concepts.

The resultant recommendations are offered here as a meaningful step in the direction of packaging standardization.

Unit Size	1/2 ATR	
Module Size (inches)	H) 3.40	W) 5.12
Number of Cells	84	
Number of I/O Contacts	168	
Maximum Power Capability	35 Watts	

Unit Size	1/2 ATR	
Module Size (inches)	H) 3.40	W) 6.50
Number of Cells	108	
Number of I/O Contacts	220	
Maximum Power Capability	9 Watts	

Unit Size	3/4 ATR	
Module Size (inches)	H) 6.00	W) 5.12
Number of Cells	154	
Number of I/O Contacts	168	
Maximum Power Capability	65 Watts	

Unit Size	3/4 ATR	
Module Size (inches)	H) 6.00	W) 6.50
Number of Cells	198	
Number of I/O Contacts	220	
Maximum Power Capability	16 Watts	

Unit Size	1 ATR	
Module Size (inches)	H) 6.17	W) 6.91
Number of Cells	240	
Number of I/O Contacts	240	
Maximum Power Capability	101 Watts	

Unit Size	1 ATR	
Module Size (inches)	H) 6.17	W) 8.70
Number of Cells	312	
Number of I/O Contacts	300	
Maximum Power Capability	25 Watts	

Advanced Technology Module		
Module Size (inches)	H) 5.20	W) 9.00
Number of Cells	252	
Number of I/O Contacts	300	
Maximum Power Capability	106 Watts	

These module parameters are predicated on several basic conditions and factors:

1. Component cell size is 0.450 x 0.630;
2. Module I/O connector is of the fork/blade variety;

MODULE DATA MATRIX

Physical Characteristics	System									1/2 ATR Module		3/4 ATR Module		1 ATR Module		Advanced Technology Module	
			IBM							Power		Power		Power			
	DELCO 632 Computer	GE CP-16 Computer	AP-1 Computer	AP-1A Computer	APG-63 Radar Signal Processor	Modular Program Signal Processor	Modular Digital Scan Converter	JTIDS Signal Processor	All Applications Digital Computer	Low	High	Low	High	Low	High	High Power	Bulk Memory
Module Height (inches)	3.9	6.3	3.2	3.2	5.2	5.2	5.6	5.4	3.8	3.4	3.4	6.0	6.0	6.2	6.2	5.2	5.2
Module Width (inches)	6.3	9.5	8.0	8.0	6.8	10.9	5.6	6.1	4.8	6.5	5.1	6.5	5.1	8.7	6.9	9.0	9.0
Module Pitch (inches)	0.4	0.6	0.5	0.5	0.5	0.6	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
Module Weight (pounds)	N/A	N/A	N/A	N/A	0.4	1.4	0.3	0.4	0.4	0.4	0.3	0.7	0.5	1.1	0.8	1.20	1.25
Aspect Ratio H/W	0.62	0.66	0.40	0.40	0.76	0.48	1.0	0.89	0.79	0.52	0.66	0.92	1.17	0.71	0.89	0.58	0.58
Power Dissipation																	
Maximum Module Power (watts)	10	70	15	39	40	80	15	10	20	9	35	16	65	25	101	106	118
Maximum Allowable δj (°C)	105	125	N/A	N/A	105	105	125	N/A	90	125	125	125	125	125	125	125	125
Reference Point Temperature (°C)	N/A	N/A	37.8	37.8	29	18.3	N/A	N/A	29	29	29	29	29	29	29	29	29
Thermal Gradient (Δt) (°C)	N/A	30	22	22	41	25	N/A	N/A	40	41	41	41	41	41	41	41	41
Components																	
Number of IC Locations	150	330	170	170	168	280	50	50	80	108	84	198	154	312	240	252	282
Number of IC Pins/Location	16	16	14	14	16	16	18	16	16	16	16	16	16	16	16	16	16
Type of Component Enclosure*	FP	FP	FP	FP	FP	FP	DIP	DIP	FP	FP	FP	FP	FP	FP	FP	FP	FP
Technology	T^2L	T^2L	T^2L	T^2L	T^2L	ECL	T^2L	T^2L	T^2L								
I/O Tactical – Test																	
Maximum Contacts – Tactical	130	300	196	240	200	304	90	100	152	168	220	168	220	240	300	300	300
Maximum Contacts – Test	128	140	128	128	100	60	30	32		188	244	188	244	260	332	344	344
Connector Type – Tactical*	P/S	P/S	P/S	P/S	F/B	F/B	F/B	P/S	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B	F/B
Back Plane Grid – Tactical	N/A	0.10 x 0.10 Staggered	X = 0.10	Y = 0.06/0.08/0.06	0.10 x 0.10	0.10 x 0.10	0.10 x 0.10	N/A	0.10 x 0.10	0.10 x 0.10		0.10 x 0.10		0.10 x 0.10		0.10 x 0.10	

*N/A = Data Not Available FP = Flatpak Enclosure DIP = Dual-In-Line Enclosure P/S = Pin and Socket F/B = Fork and Blade

3. Unit intraconnections are made with a wirewrapped backplane;
4. Component power dissipation has been assigned two values: 0.420 and 0.080 watt per integrated circuit package, to allow for high and low power situations;
5. Thermal calculations are based on a cooling air supply of 3 to 4 pounds per minute per kilowatt;
6. Integrated circuit packages are all flatpacks;
7. The higher power dissipating modules, 35 watts and over, are of the hollow-card type construction;
8. The lower powered modules, those under 35 watts, use a solid core heat exchanger.

The module size determinations were made after the anticipated unit sizes (ATR) and the required functional partitioning selection of integrated circuit packages were considered. This coupled with allowances for cooling air plenums and backplane volume, formed the basis for selection of the seven recommendations for standard avionics modules.

The flatpack microelectronic package configuration has been selected over the dual-in-line (DIP) package despite the lower initial procurement cost of integrated circuits in dual-in-lines because of the following factors:

1. Weight and volume
2. Higher packaging density resulting in fewer modules required per unit including all the storage, paperwork and ancilliary costs associated with each separate assembly.
3. Lower mean case operating temperatures.
4. Resultant lower life cycle costs.

The selection of the flatpack over the dual-in-line has been reaffirmed by subsequent studies performed at Hughes not in time for inclusion of this report.

It is recommended that further studies be made in which a viable inter-system function, such as the JTIDS Fighter Terminal, is taken to implement these standards for all of its applications. It is also recommended that the study include at the very least a metal mockup of the selected design and that in the next phase of working prototype be fabricated and tested. It is the personal opinion of the principal investigator that the Standard Avionics Module Program will not be accepted within either government or industry until it can be shown that the selected design standards can be implemented with working hardware.

II. MECHANICAL AND ENVIRONMENTAL INTERFACE

SUMMARY

The mechanical and environmental interface studies are directed toward the definition of a standard avionics module as viewed from mechanical design parameters. Such considerations that might influence a standard module have been evaluated and include:

1. Unit size to house standard modules
2. Module size
3. Equipment classification
4. Module thermal control
5. Tactical connector requirements (I/O)
6. Environmental considerations such as shock and vibration.

UNIT SIZE

The general concensus of opinion of the surveyed industry members is that any standard avionics module should be compatible with a unit housing of the ATR, or MIL-C-172C, specifications. Because of the preponderance of various ATR case sizes now in use, it appears valid to include these as a basic module housing form. Within this context, term "ATR" is used to describe a two-dimensional form factor – height and width. Since the specific equipment being packaged will be the determining factor as to how many modules will be required, at this time it is not plausible to impose undue restrictions on the cognizant packaging designer as to the depth of unit that must be used. The height and width dimensions, therefore, as noted in the appropriate specifications, will be used as a basis for the ATR compatible module housing.

In addition to the ATR compatible module sizes, an additional module designed as 5.20 inches high by 9.00 inches wide is being developed. This will necessitate a unit size other than an ATR dimensioned case. For this proposed Advanced Technology Module (ATM), a unit size to accommodate the required cooling air plenums and the backplane interconnection panel will

be enclosed in an envelope size 6.70 inches high by 11.00 inches wide. As previously noted, the unit depth dimension is determined by the particular application dictates of the number of modules required to perform the desired task; therefore, the unit depth dimension will not be preassigned.

The dimensions of the proposed housing units are shown in Figure 1.

MODULE SIZE

A module must be of sufficient size and form factor that it will enable the required equipment to be packaged within a housing that in turn can be fitted within its intended airframe space allocation. The module design and construction must allow proper cooling to be achieved, significant input-output contacts to satsify the demands of the module's functional partitioning, and be large enough to permit the module to be a viable functional entity. Too small a module, while providing for greater commonality, would result in too many modules being required to perform the intended task. Since space and weight factors are of prime importance in aircraft equipment concepts, it is not feasible to propose a standard avionics module of small proportions. On the other hand, a module too large offers other considerations and problems such as thermal control, cost of replacement and lack of commonality.

A module size somewhere in between these two extremes is desirable. It should accommodate a functional partitioning, be capable of dissipating the required power, have sufficient width so as to provide room for a large number of I/O contacts, and at the same time be cost effective.

The module sizes being recommended for the standard avionics module concept have been selected to meet the present, as well as the future, requirements as can now be anticipated. The seven proposed module sizes will permit a great degree of freedom to the system designer in that the range of packaging configuration is broad enough to effectively accommodate any avioncs system functional partitioning.

The selected modules vary in component count from a low of 84 integrated circuit locations of the 1/2 ATR size, to a high of 282 locations for the bulk memory configuration of an ATM size. A full spectrum of module power dissipation has been accounted for – from a 9-watt module to one that can handle over 100 watts.

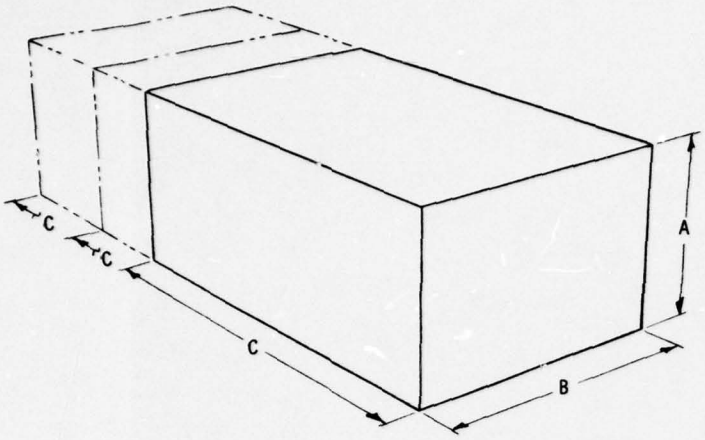

FIGURE	PART NUMBER	"A" HEIGHT	"B" WIDTH	"C" LENGTH
1A	MS91403-A1B	4.88 ± 0.03	7.62 ± 0.03	12.56 ± 0.03
1B	MS92403-A1C			15.56 ± 0.03
1C	MS91403-A1D			19.56 ± 0.03

1/2 ATR BOX

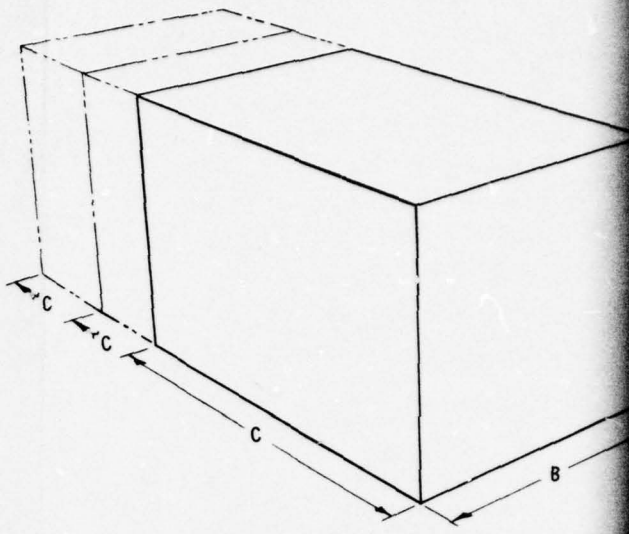

FIGURE	PART NUMBER	"A" HEIGHT	"B" WIDTH	"C" LEN
2A		7.50 ± 0.03	7.62 ± 0.03	12.56 ±
2B				15.56 ±
2C				19.56 ±

3/4 ATR BOX

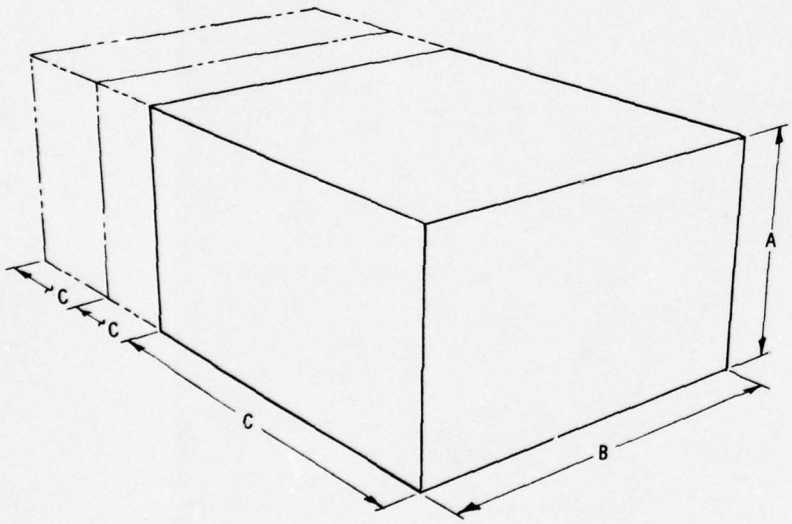

FIGURE	PART NUMBER	"A" HEIGHT	"B" WIDTH	"C" LENGTH
4A		6.70 ± 0.03	11.00 ± 0.03	12.56 ± 0.03
4B				15.56 ± 0.03
4C				19.56 ± 0.03

ATM BOX

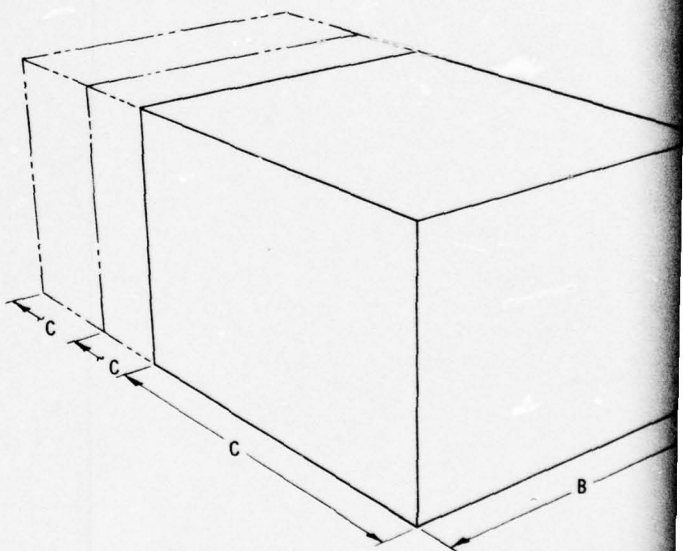

FIGURE	PART NUMBER	"A" HEIGHT	"B" WIDTH	"C" LENGTH
3A	MS91403-B1B	7.62 ± 0.03	10.12 ± 0.03	12.56 ± 0.03
3B	MS91403-B1C			15.56 ± 0.03
3C	MS91403-B1D			19.56 ± 0.03

1 ATR BOX

Figure 1. Proposed Housing Un

For the above stated reasons, and to retain the ATR unit size where possible, the proposed modules will prove both efficient and reliable while presenting a cost effective answer to the modular standardization of avionics equipment.

The module sizes being recommended are given in Figure 2.

EQUIPMENT CLASSIFICATION

The electronic equipment intended for this study shall be per MIL-E-5400, Class 2. This class includes equipment designed for 70,000 feet altitude and continuous sea level operations over the temperature range of -54 to +71°C (+95°C intermittent operation).

See Table 1 and Figure 3 for applicable details of MIL-E-5400.

MODULE THERMAL CONTROL

The ability to dissipate failure-causing heat is of prime concern in the design of electronic equipment, particularly when dealing with avionics systems where component failure could mean mission failure. It is, therefore, mandatory to design a favorable thermal control scheme into the units. One such scheme, that has proven practical, is the use of a hollow-card type module. In this type of construction, two printed wiring boards are used per module. A heat exchanger of aluminum fin stock is sandwiched between the boards. Cooling air is forced through the fin stock effectively dissipating the heat generated by the module. This cooling technique can handle high powered modules, while at the same time providing for a more even thermal distribution across the module surface than could be realized by other means of cooling. This type of cooling and construction is in accordance with MIL-E-5400, paragraph 3.2.5.

In addition to the hollow-card technique for high power dissipation, there is also a demand for modules of a lesser power density, those under 35 watts per module. In these cases a conduction type of module thermal control is recommended. The aluminum fin stock heat exchanger is replaced by a solid aluminum core. Heat generated in the components is conducted through the multilayer printed wiring board to the aluminum module core and out to the structure cooling wall. The cardguide-thermal clips located on the unit walls are used to transfer heat from the core. The unit walls themselves are the air plenums to carry off the heat so transferred. This combination of conduction and convection cooling has been proven effective in aircraft installations.

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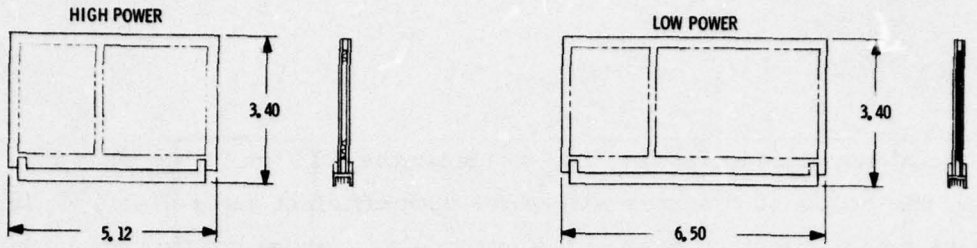
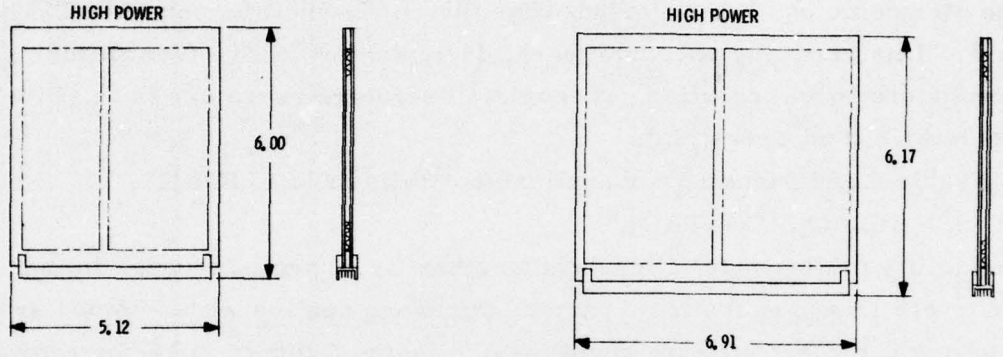
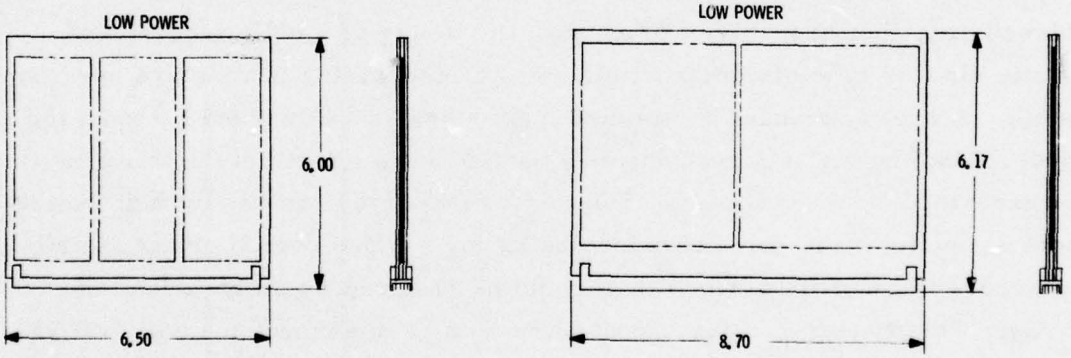


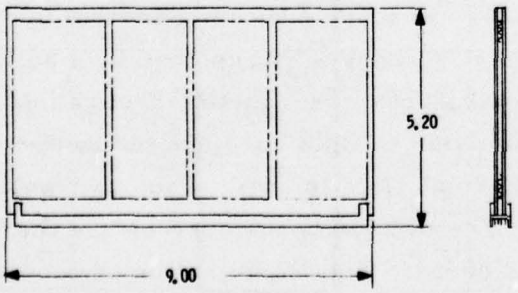
1/2 ATR MODULE SIZES





3/4 ATR MODULE SIZES

1 ATR MODULE SIZES



ADVANCED TECHNOLOGY MODULE SIZE

Figure 2. Recommended Module Sizes

TABLE I

ENVIRONMENTAL CONDITIONS FOR CLASS 2, MIL-E-5400

Equipment operating								Equipment operating and nonoperating	Equipment nonoperating	
Temperature extremes for the chamber (without external cooling provisions)				Combined temperature-altitude			Temperature shock	Altitude	Temperature extremes	Temperature shock
Equipment class	Column I continuous	Column II intermittent	Column III short-time	Column IV	Column V	Column VI	Column VII	Column VIII	Column IX	Column X
Class 1	-54° C +55° C	30 min. +71° C	---	Defined by curve A, figure 3, (sheet 1)	Defined by curve B, figure 3, (sheet 1)	---	-54° C to +71° C	Sea level (30.0 in. Hg.) (3.4 in. Hg.) 50,000 ft.	-62° C to +85° C	-62° C to +85° C
Class 1A	-54° C +55° C	30 min. +71° C	---	Defined by curve A, figure 3, (sheet 1)	Defined by curve B figure (sheet	---	-54° C	Sea level	-62° C to 85° C	-62° C to +85° C
Class 1B	-40° C +55° C	30 min. +71° C	---	Defined by curve A, figure 3, (sheet 1)	Define curve figure 3, (sheet 1)		+71° C	(16.89 in. Hg.) 15,000 ft. 1/	62° C to +85° C	-62° C to +85° C
Class 2	-54° C +71° C	30 min. +95° C	---	Defined by curve A, figure 3, (sheet 2)	Defined by curve B, figure 3, (sheet 2)	---	-54° C to +95° C	Sea level (30.0 in. Hg.) (1.32 in. Hg.) 70,000 ft.	-62° C to +95° C	-62° C to +95° C
Class 3	-54° C +95° C	30 min. +125° C	10 min. +150° C	Defined by curve A, figure 3, (sheet 3)	Defined by curve B, figure 3, (sheet 3)	Defined by curve C, figure 3, (sheet 3)	-54° C to +125° C	Sea level (30.0 in. Hg.) (0.32 in. Hg.) 100,000 ft.	-62° C to +125° C	-62° C to +125° C
Class 4	-54° C +125° C	30 min. +150° C	10 min. +260° C	Defined by curve A, figure 3, (sheet 4)	Defined by curve B, figure 3, (sheet 4)	Defined by curve C, figure 3, (sheet 4)	-54° C to +150° C	Sea level (30.0 in. Hg.) (0.32 in. Hg.) 100,000 ft.	-62° C to +150° C	-62° C to +150° C

SEE FIGURE 3
OF THIS REPORT

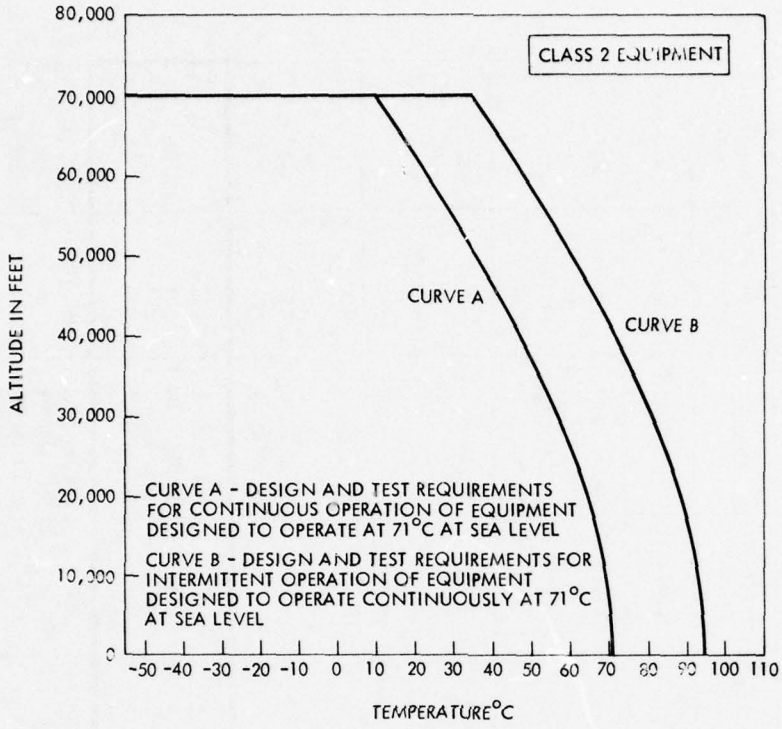


Figure 3. Operational Requirements for Class 2 Airborne Electronic Equipment(Temperature Versus Altitude)

Both the hollow-card convection method and the solid core conduction system are in accordance with MIL-E-5400 equipment cooling techniques.

TACTICAL CONNECTOR REQUIREMENTS – MODULE I/O

When considering the increased demand for module I/O pins, the limited module area available and the complexity of backplane wiring, it becomes evident that the module tactical connector should be both mechanically and electrically capable of satisfying these needs and also be readily available, reliable and cost effective. These requirements are best met by the use of a fork and blade arrangement which interconnects the individual modules by a wire-wrapped backplane. The fork and blade principle has been used extensively in military applications, with many present day avionics systems being so designed.

The proposal to use the fork and blade approach is not intended to preclude other interconnect methods, such as pin and socket connectors. It is

felt, at this time, that the wirewrap back panel offers the greatest flexibility for unit intraconnections at the lowest cost. The cost factor being considered as part of the updating, revision and circuit design changes is inevitable in any system design.

Printed wiring backplanes should be utilized when the quantity and cost deem them advantageous. In this case, a two-piece connector of the pin and socket variety may offer a greater I/O pin density than is now enjoyed by using the wire wrappable fork and blade configuration. If a printed wiring board backplane is used, the module height may be increased because of the reduced demand for unit space that would normally be used for the wirewrap pins.

ENVIRONMENTAL CONSIDERATIONS

The objective of establishing design and test requirements covering the dynamic environments for the standard module is easily stated. The requirements should be sufficiently general that the module, qualified to these requirements, can be incorporated in avionics equipment which may be installed in any location in any aircraft, fixed or rotary wing. However, establishing these requirements so that an undue penalty is not imposed on the module design and cost is less easily accomplished.

The factors that must be considered in establishing requirements are discussed here, and a tentative set of requirements is given.

Description of Dynamic Environments

The dynamic environments for avionics equipment are described separately under shock, vibration and acoustics since testing for these environments traditionally has been performed independently, even though environments generally occur simultaneously.

Shock. Relatively little technical effort has been expended in attempting a precise description of the shock environment for avionics, even for such situations as the catapult and arrested landing of naval aircraft. Typical design and test requirements consist of classical shock pulses such as halfsine and test requirements consist of classical shock pulses such as halfsine and terminal peak sawtooth waveforms, which certainly bear little resemblance to the combinations of exponentially decaying sinusoids which typify the field environment. This lack of effort probably reflects the fact that the shocks

or transients in the field appear to cause few if any problems. Further, experience in the laboratory has consistently shown that equipment qualified under vibration will seldom, if ever, fail when subjected to any of the standard, e.g., MIL-STD-810, shock tests.

Vibration

The sources of vibration in jet aircraft are primarily acoustic. The acoustic excitation then generates mechanical vibration of the aircraft structure and installed equipment. In addition, some mechanically generated vibration is encountered in the neighborhood of the engine(s). In propeller driven aircraft and rotary wing aircraft, the excitation is both mechanical and acoustic and the contribution from each is not well understood. For all vehicles so armed, the vibration due to gunfire must also be considered. Again, this vibration is primarily acoustically induced. For purposes of defining requirements for a standard avionics module, the characteristics of the vibration at equipment locations caused by the above sources should be understood. Of primary interest is the vibration in jet aircraft due to boundary layer turbulence. This vibration consists of a broadband random vibration whose acceleration spectral density, in g^2/Hz, is approximately proportional to the square of the free stream dynamic pressure, q, in psf. The constant of proportionality varies greatly as a function of frequency, location and direction, and can only be described statistically. This vibration is the governing source for equipment in the forward fuselage, cockpit and equipment bays often located immediately aft of the cockpit, i.e., the most common locations for avionics. It should be noted that the environment for equipment in external pods or missiles can be similarly characterized.

Equipment located further aft in the fuselage is primarily influenced by engine induced vibration, whether the engine is tail-mounted or whether the aft fuselage is excited strongly by the acoustic field of wing pylon-mounted engines. This vibration is primarily a broadband random vibration but may have some sinusoidal components excited by the rotating equipment. Ground run-up and take-off are the governing conditions.

Usually the vibration of propeller driven and rotary wing aircraft is periodic and contains a number of harmonics above the fundamental. However, this environment should be less damaging than that for jet aircraft.

The vibration caused by gunfire is a complex-wave periodic vibration with a fundamental frequency equal to the firing rate. Significant harmonics exist up to 1 or 2 kHz. The intensity of the vibration attenuates quite rapidly with distance from the gun-muzzle and attenuates more rapidly aft of the muzzle compared to forward.

Acoustics

The origin and nature of the acoustic environment for equipment have been described under "vibration" above and is not repeated. Acoustic testing of avionics equipment has not been widespread. However, limited experience indicates, as in the case of shock, that equipment qualified in vibration is not susceptible to acoustic failures except for items such as antennas which have large areas and low mass density/unit area.

Physical Design Considerations

The above descriptions of the dynamic environments are taken from data measured on aircraft primary structures and at the attachment points of avionics equipment. Quantified requirements are also specified at such points. While the character of the vibration will not change, the vibration levels at an avionics module will be different than these attachment points, due to the physical design of the equipment in which the module is installed. Some of the physical design factors that must be considered in setting module requirements are discussed in this section.

The physical design feature which will most strongly affect the module environment is the use of vibration isolators to mount the equipment. Since most equipment is hardmounted whenever possible, the module requirements should be based on hard mounted equipment and, therefore, should be more than adequate when isolators are employed. It is assumed, of course, that an adequate isolation system is designed and that isolation frequencies are not coupled to frequencies of the equipment or the module itself.

For a given environment at the equipment attachment points, the environment for the module is governed by the transfer functions, i.e., transmissibilities, between the attachment points and the module. These transfer functions are influenced by: (1) the manner in which the enclosure is attached to the supporting structure, e.g., pins, swing bolts, etc.; (2) the dynamic characteristics of the enclosure itself; and (3) the manner in which the module

is installed in the enclosure. Poor design of one or more of these three facets of the overall design can adversely affect the environment of the module. However, it does not appear reasonable to establish requirements on the module which penalize the module to make up for deficiencies in the remainder of the equipment design. For example, a standard module of a given size will have a fundamental plate or "oil canning" natural frequency. An enclosure which, when loaded with modules, has a natural mode and frequency closely coupled to the module frequency is clearly unsatisfactory. It is also clear that the enclosure should be changed to decouple these frequencies rather than penalize the modules.

The third facet mentioned above can be accounted for in establishing the module requirements as discussed later under the recommended method of testing in Section VI.

III. FUNCTIONAL PARTITIONING

Design standardization of one form or another as applied to airborne radar signal processing systems and the difficulties of standardization are discussed in this section. Initially, one might indicate that addressing the difficulties is really not the proper approach to making anything successful, but the difficulties could eventually defeat the standardization program unless they are fully understood.

At the beginning of any program the incentives on any of the designers or the design organization are not those that are directed toward standardization but rather those imposed by (1) the system spec as defined by the customer and (2) the volume and weight criteria as imposed by the airframe manufacturer. Without going into very much detail, it can be recognized from experience that the system spec and the allowable volume and weight are almost incompatible. The advance of technology allows this at first incompatible situation to be solved by squeezing as much system performance as possible out of something that has a finite, not to exceed, weight, volume and acquisition cost. These incentives drive the design to be tailor-fit to the system spec. To tailor-fit a signal processor to the system spec, multiple use of common hardware reconfigured for the different modes is a necessity in a multimode situation. Also in the digital area, the tailoring of the number of bits must be carried through for an example in a similar manner as a gain distribution program in the analog world. That is, the number of bits is reduced to the minimum value to allow the dynamic range necessary for that particular point in the processing. As an example, if an 8-bit pulse compression network were adequate, then extra hardware would be carried on if a standard "10-bit" pulse compression network were used. By this example, the number of bits is one measurement parameter for a subunit called pulse compression. Having taken pulse compression as an example, the options of the type and length of code (Barker code 13, Frank code, etc.) which are really different ways of

approximating the exact theoretical pulse compression, are two more measurement parameters. Thus it is recognized that in the rather simple case of the subunit called pulse compression, the number of bits carried and the type of code used negate any single standard for pulse compression but, in fact, develop a family of standards. If other subunits like filter processing or post processing were examined, the same problem would be found. Examining a coarse block diagram, similarities of functions can be seen from one radar to another but as one delves further into the actual design, the similarity ceases. In no case is there a single standard for any subunit, but there is really, indeed, a family of standards. Furthermore, the choice of which device would be used is a balance of tradeoffs as far as minimizing hardware and maximizing performance within the weight and volume profile.

If any one organization, like Hughes, had an actual dollar incentive for a processing standard, the company would have achieved this goal; however, such an incentive does not exist for airborne processors. The fastest progressing field in radars today is associated with signal processing either in analog or more so in digital circuits. Furthermore, the availability of larger and larger integrated circuits as tools to achieve a greater system performance demands change.

To impose standardization does, in fact, impose penalties of one form or another. Generally this penalty will be in the form of larger weight and volume for a specific system parameter. One extreme is the use of the NAFI concept in which the module is mainly an IC holder and all the logic design is performed in the wirewrap plate. It can be seen that an increase in weight and volume for a specific performance factor is imposed quickly.

As one tries to move away from that concept into one in which a functional block could be defined as a module, it is much more difficult to define a functional block that is usable by more than one user, as shown by the previous pulse compression example. The basic problem becomes trying to define a single function such that it meets multi-functional needs. The F-15 processor, a multimode hardwired processor, is reconfigured depending on mode into about 70 different configurations. It was tailored to fit the system spec with 4-1/2 percent spare module slots.

Modules from a programmable signal processor, although at first look like a potential choice for standardization, may only be standard for a particular architecture developed by one company and not necessarily be adaptable to another architecture. Another way of describing the difficulties of standardization is that if a standard functional block could be used, and, in fact, if enough of these blocks could be used to make a standard family of signal processing elements, a standard system could be achieved because these blocks in effect are the system. This standard system would then infer that instead of worrying about a standard module concept functionally, the specifications should be restricted so that a standard family of radars can be used. This may seem to be a pathological end to things, but one driving force for a non-standard processor is the same spec parameters themselves.

Examine the commercial world. The TV sets of today, color if you wish, have to meet the same system specs as the color TV sets of many years ago. The system spec is the same, yet has any manufacturer really achieved complete standardization with themselves or any other manufacturer? In the case of military radars, the system spec cannot stay stationary since the margin of win or lose is probably the very thin margin of having a better system than the enemy.

Although in preceding discussion a digital type of signal processor is inferred, the analog world is briefly examined here. Intermediate frequency amplifiers, otherwise known as IF amplifiers, have been in use for years — years before digital processing, in fact. And yet what standardization has been achieved? Standardization has not been obtained because again if the specs required of the signal processor are used, we again have tailored analog circuits so that a certain function can be performed with a minimum amount of hardware. Thus as technology advances, this design includes the latest technology advances to give the edge over the competition. What edge is that? It's again the edge of win or lose. Is the system spec met? Is the processor within the weight and volume constraints of the rack? Is the acquisition cost to the customer at the point where it should be to win over the competition?

Optimization of signal processing has been and will be continued into the future. To incur a functional standardization, the customer has to be prepared to take the consequences of imposing that standardization. The customer conceivably could put an incentive clause that says the more standardization incurred, the more profit can be made, except that the alternative factor has to be addressed again by the customer. This factor is the increase in the weight and volume which will inherently go along with this and the net decrease in the system performance either by the fact that the airframe manufacturer has to impose a larger airframe to carry all the electronics necessary or the system is not quite as capable as it might be.

If functional partitioning of standardization becomes inherently too difficult, a less encompassing result can be obtained by product design standardization. Again, without too much difficult one can get into the quagmire of trying to define what that standardization should be. To develop a module standard, particularly a PC board standard, the number of layers has to be defined, number of pins, and size of the module, the method of cooling, etc. These all can be accomplished, but as soon as a standard module is defined for one family of parts introduction of a new family of parts such as ECL where stripline technology or at least terminated lines might become important, another family of physically standard modules is obtained. There is more chance of success in trying to standardize on the physical parts of a standard module which includes the number of layers, the standard footprints, the number of footprints per module, some of the dimensions themselves, the type of PC boards, etc. At least it would allow some potential cost savings in the computer design routing costs and automatic integrated placement and soldering costs. These are mostly associated with automatic equipment, and standardizing on good patterns, etc., might be a way of achieving some savings. But again, this will probably be a family of standards rather than a singular standard.

IV. TECHNOLOGY IMPACT

As advanced technologies are developed their applications supply the competitive edge to both industry when competing with one another and, of course, to the U.S. Air Force in ultimate system usage. Any standardization program must perforce accommodate or permit deviations to accommodate these advances. In particular, the advances in applications of large scale integrated circuits permit additional weapon systems capability. Many studies have been made that project advancements over 10 to 15 year intervals. In most cases these studies, which at the time seemed optimistic, really have turned out to be pessimistic. Developments for the commercial and military worlds have cross fertilized to the benefit of both. The recommended module sizes contained in this report consist of a large enough family of designs to accommodate these advances.

V. MAINTENANCE CONCEPTS

The impact of standard avionics modules on maintainability of weapon systems is quite significant. The impact affects all echelons of maintenance, starting from built-in-test (BIT) down to the depot level. Some of the effects require close, coordinated design and planning between the design and maintainability disciplines from the onset of any weapon system program which adopts the use of standard avionics modules.

SUBSYSTEM/SYSTEM LEVEL TESTING

Along with the current technological advances in the direction of integration/miniaturization of functional elements in the regions of DC through RF, the pressure for performing organizational maintenance without the use of aerospace ground equipment (AGE) grows more persistent. Therefore, the design of BIT circuitry should also be included within the design of standard avionics modules. The function of the BIT circuit could be either a self-determining type (i.e., local GO/NO-GO decision making) or simply a set of signal monitoring points appropriately buffered. The latter requires that the decision making function be located at the next hierarchy, either at the ATR unit level or at subsystem/system levels.

It is true that the architecture of the BIT scheme is dependent on the nature, complexity, and structure of the subsystem/system itself. Experience on various Hughes fire control systems has shown that simpler systems are more difficult to test than complex systems, especially in the area of fault isolation testing. This conclusion which runs contrary to intuition can be better understood if one considers that each element within an electronics system can be used as some form of "test equipment". Therefore, the complex systems tend to provide more "test equipment" functions.

Complex systems also provide opportunities for applying the technique of deductive isolation to a greater accuracy because complex systems generally offer several ways to test a given function. Coupled with an onboard computer, this testing tool becomes very effective.

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Therefore, it is reasonable to conclude that the design and implementation of BIT are subsystem (or system) oriented. It is questionable that designing a complete BIT into every standard avionics module would be an asset; depending on the type of module, it may become a detriment in terms of adding unnecessary costs and failure rates to the configured tactical system.

For larger standard modules, especially those consisting of MSI and LSI devices, the recommendation would tend to favor incorporating BIT functions that are of the local self-determining type. These functions could be included within each MSI and LSI device at virtually no added recurring costs and space/weight penalties. Unfortunately, the added failure rates of the BIT functions will affect the overall MTBF of the configured tactical system.

On the other hand, smaller standard modules containing simple functions generally should avoid local decision-making capabilities. The criteria in this situation is the assessment of how much additional hardware is required to implement such a BIT. The latitude for adding components for BIT reduces considerably if the standard module consists of discrete components. The problem is more acute in analog type modules than in the digital types.

For the smaller and simple types of modules, it is quite reasonable to provide only access to important signals which are not available on the module operational connector. Depending on the nature of the functions which the signals represent, these access signals can either be in the raw form or in a derivative form such as scaled, detected, synthesized, etc. If a form of standard interface can be established for digital signals, these access signals may be converted readily to such a standard form for compatibility. Standard modules with this form of BIT will require a higher hierarchy to perform the pass/fail decision-making process.

Certain basic circuit functions could be standardized either as circuits for inclusion within a standard avionics module or as standard avionics modules by themselves. An excellent example is the microprocessor with its attendant memory and input/output functions. Such functions may be placed on a single standard module and be used at the unit level for controlling BIT sequences and signals as well as making degraded mode assessments and the final GO/NO-GO decisions.

The selection of other BIT functions for the sole purpose of standardizing BIT oriented standard avionics modules, of course, is a study in itself. Once defined, however, these standard avionics modules can then be used in conjunction with other existing standard avionics modules to structure a BIT for most subsystem/systems. One disadvantage of this "building block" concept is that the BIT hardware tends to occupy more space, add more weight, and contribute an additional failure rate, far in excess of acceptable levels in terms of operational penalties which the weapon system must incur.

It is recommended that contractors who design standard avionics modules be required to include some form of BIT capability in each module. This requirement should not specify or imply the methodology of the implementation, but rather specify explicitly the inclusion of capabilities to detect "X" percent of its failures based on reliability. The contractor can then determine the most effective means of meeting such requirements by analyzing failure modes and subsequently determining what must be tested. In some cases, it may be most effective to provide both stimuli and evaluation circuitry; in others, providing only the means of ingressing and egressing test signals may be the best approach. In one application, a specific function of a selected standard module may serve as a utility role; whereas in another application, the same function may be considered essential to the completion of a mission. Hence, the requirement for BIT should not be so structured that the configured BIT unnecessarily penalizes the system in cost, weight, volume, failure rate, and effectiveness.

UNIT LEVEL TESTING

The most significant impact of standard avionics modules on field maintenance activities is at the intermediate and depot levels of maintenance where unit testing generally takes place. If the standard avionics modules are low enough in cost, it would obviously be more cost effective to merely discard the entire module rather than to repair it.

The so-called "throw-away" concept requires that the test equipment be capable of isolating unit malfunction to a single standard avionics module without a thread of ambiguity. The present day ambiguity factors (inability to identify the single module responsible for the unit malfunction) of 15% to 20% are not acceptable in the throw-away concept. Herein lies the heart of the maintenance problem at the unit level.

If the BIT resident within the unit-under-test (UUT) is not able to localize the unit malfunction, then the designated test equipment must localize the failure. Unfortunately, the ability of the test equipment to perform this feat is dependent on the unit functional partitioning (into standard avionics modules) and how well test access (TA) signals have been implemented in the unit design.

The fault isolation testing strategy may be implemented such that the identification of the faulty standard avionics module is deduced by evaluating the unit operational signals. For those situations where ambiguity between several modules results from this approach, access to the inter-module signals must be provided for the test equipment.

The unit level TA usually involves only intermodule operational signals which do not appear at the unit operational connectors. Whether or not module signals appear at the unit operational connectors, of course, depends on the standard avionics modules selected and on the manner in which they are connected to configure a given unit. Therefore, unit level TA has minimal requirements on the design of the standard avionics modules.

Functional partitioning, on the other hand, has a significant impact on unit level testing. The worst possible functional partitioning is probably the most attractive from the standardization point of view; that is, where circuit elements or signal flows are divided into separate modules, such as all diodes on one module, all power transistors on another module, etc. Units designed with modules of this type have proven to be a fault isolation nightmare during unit maintenance since the available space in the units precluded incorporation of sufficient TA signals. Units designed in this manner require TA signals which are equal to the number of intermodule signals used. Deductive isolation techniques using only the unit operational signals become nearly impossible, especially on analog-oriented units; digital-type units have some possibilities in that known output signal patterns can be established

MODULE LEVEL TESTING

The maintenance of standard avionics modules at the module level face the same problems encountered at the unit level, except the level of isolation is now at the piece part component. The test equipment designated to functionally test and subsequently fault isolate faulty standard avionics modules must depend on the test access (TA) provided by the standard avionics module.

Test access by its very nature generally runs contrary to the ultimate mechanical packaging designs where the first objective is to package as much as possible into the smallest volume. High density of functions result in assemblies with little surface areas. Yet, this type of module requires the most signal monitor lines for effective piece part level of fault isolation. Usually it is difficult enough to provide high pin-count module connectors for operational usage, but to add another one for TA purposes alone generally results in a token effort. Therefore, it is recommended that any standard avionics module which is deemed repairable must make provisions for an adequate number of TA signals appropriately buffered for test equipment usage. Thus maintenance requirements for such standard avionics modules must be established by the ultimate users so that contractors can treat TA requirements at the same level as functional partitioning and mechanical packaging requirements from the onset of the standard avionics module design effort.

One significant byproduct of standard avionics modules is their impact on module test equipment. Once the module interfaces (both functionally and physically) are standardized, the quantity of "module-to-test equipment" adaptive hardware normally associated with all module test stations can be significantly reduced. Also, a single test specification can be generated for each standard module, which in turn can be translated into a standard test procedure or computer-oriented test applications program. It is also conceivable that the module test station itself can be standardized; that is, automatic module test stations along with their attendant operating and compiler software can be designed once for each functional type of standard avionics modules. The test applications program for each module can also be prepared once and controlled with the module test specifications. All of this can be made available to both the industry and the military, thus reducing the costs for factory implementation and field/depot support equipment.

VI. STANDARD AVIONICS MODULE RECOMMENDATIONS

UNIT HOUSING SIZE

It is recommended that standard avionics modules be compatible with a unit housing dimensioned by MIL-C-172C, or ARINC (Aeronautical Radio, Inc.). These are commonly referred to as ATR cases. Three sizes are suggested:

1. 1/2 ATR
2. 3/4 ATR
3. 1 ATR

As specified in Military Standard MS 91403, unit sizes comparable to 1/2 ATR and 3/4 ATR exhibit the following envelope dimensions:

Case Size	Height, inches	Width, inches
1/2 ATR (MS 91403-A1X)	7.62	4.88
1 ATR (MS 91403-B1X)	7.62	10.12

The depth, signified by the "X" in the MX number, is a variable that is dependent on the requirements of the system and the restrictions of the appropriate airframe space allocation. A unit, designed to comply with MS 91403, can have a depth of 12.56 inches, 15.56 inches or 19.56 inches. The 3/4 ATR size, although not listed in MS 91403, is a recognized industry unit. Its envelope dimensions are the same as the 1/2 ATR except that the width of the 3/4 ATR is 7.62 inches.

To more fully meet the packaging demands of avionics systems, a fourth unit housing is being presented. This unit size is designed to accommodate the proposed Advanced Technology Module (ATM). Its envelope dimensions, for height and width, are 6.70 inches and 11.00 inches, respectively.

Recognizing that no one consistent module size will permit an effective standardization policy, it necessarily follows that there is no one consistent unit size either. Therefore, the unit sizes have been chosen as an aid to implementation of a policy of standardization. The family of modules being

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proposed requires a family of housings designed not only to be compatible with the modules, but also to be designed so as to fit within the framework of the allotted aircraft avionics bay.

Unit housing sizes, therefore, have been selected on the basis of avionics equipment bay allocations, system functional partitioning and the need to have available a large enough variety of packaging sizes so as to be able to efficiently handle all avionics systems.

The recommended unit housing to accommodate the standard avionics modules are shown in Figure 4.

MODULE SIZE

Consistent with the selection of a unit size, 1/2 ATR, 3/4 ATR or 1 ATR, a module to fit the unit, while allowing for cooling plenums and a module interconnection backplane, will have the following dimensions:

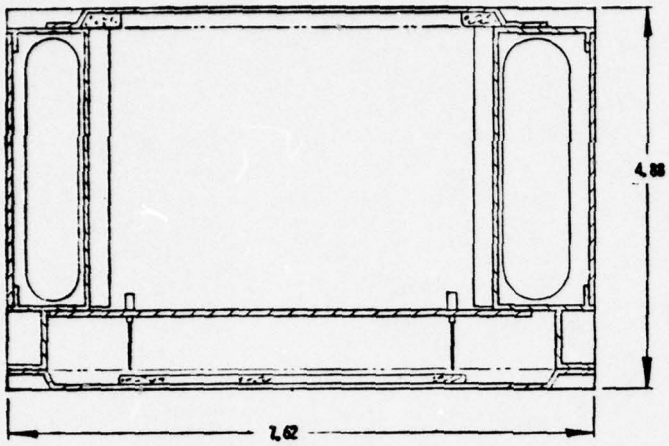
	Module Size, inches	
Unit Size	Height	Width
1/2 ATR	3.40	5.12
3/4 ATR	6.00	5.12
1 ATR	6.17	6.91

These sizes are for high power dissipating modules. For lower power dissipations the module dimensions will be:

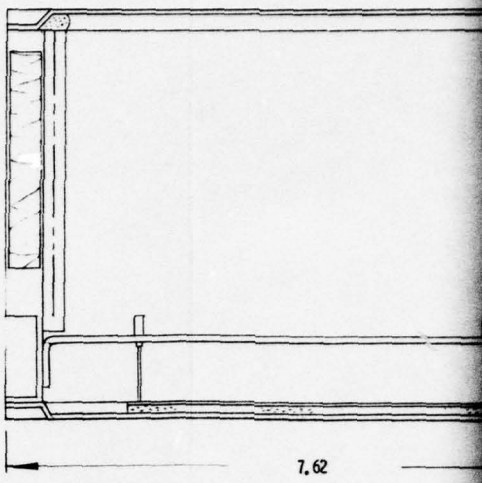
	Module Size, inches	
Unit Size	Height	Width
1/2 ATR	3.40	6.50
3/4 ATR	6.00	6.50
1 ATR	6.17	8.70

In addition to the six module sizes listed above, the Advanced Technology Module is being included in these recommendations. The ATM is characterized by its ability to contain a large number of integrated circuits, its low module height which results in the desirable aspect ratio (H/W) of 0.58, and its power dissipation capability of over 100 watts.

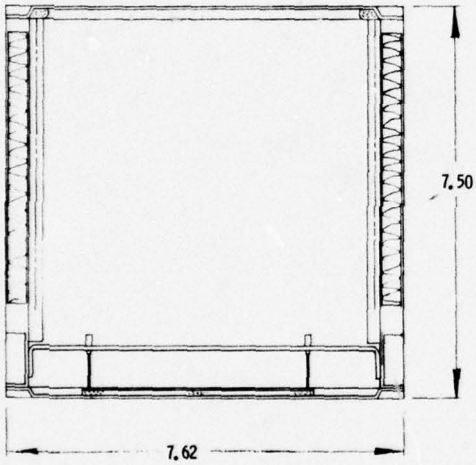
The ability to dissipate component generated heat requires the unit housing to be designed so as to offer a cooling medium, air, to the module in sufficient volume to maintain the components within their specified operation temperatures. Thus air plenums of proper size must be designed as part of the unit



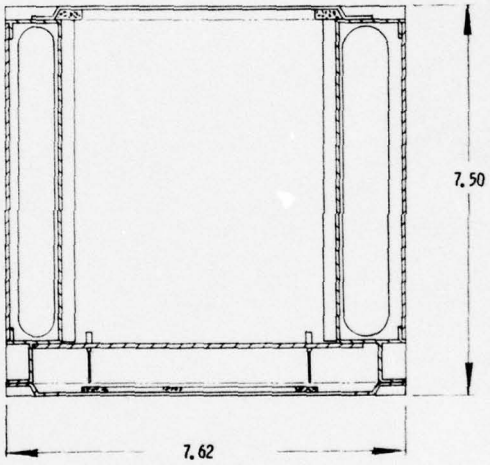
1/2 ATR HIGH POWER UNIT CROSS SECTION



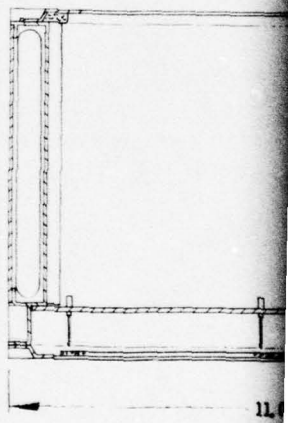
1/2 ATR LOW POWER UNIT CROSS SECTIO



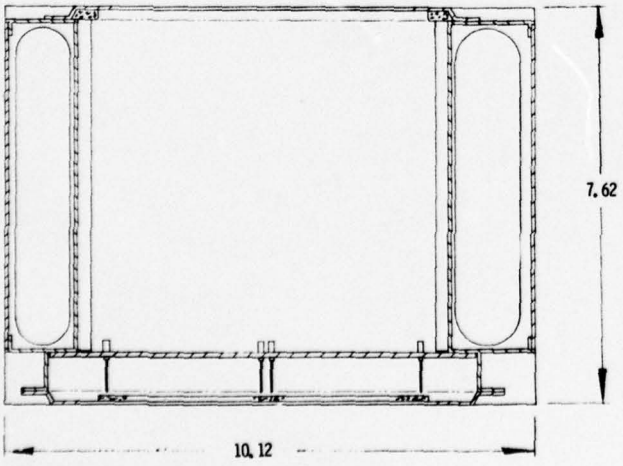
3/4 ATR LOW POWER UNIT CROSS SECTION



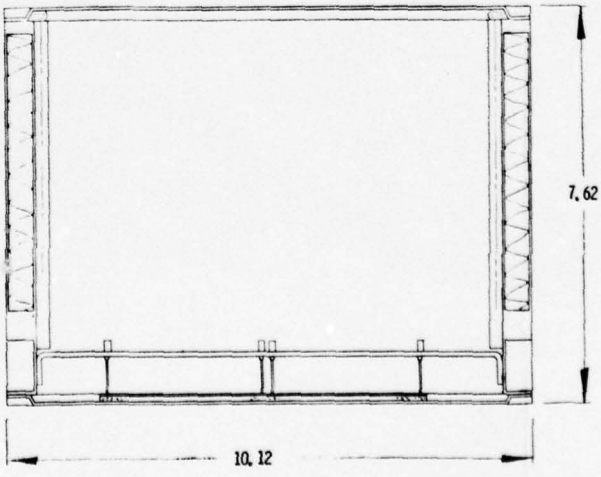
3/4 ATR HIGH POWER UNIT CROSS SECTION



ADVANCED TECHNOLOGY

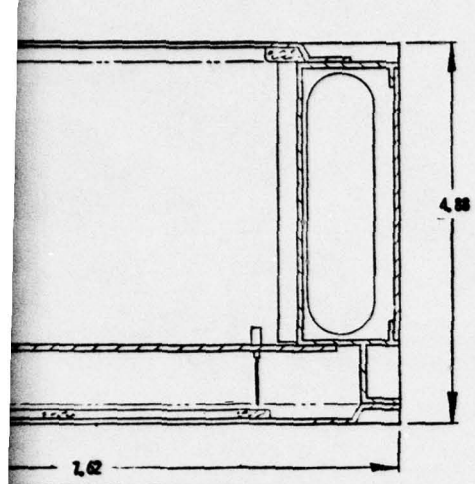


1 ATR HIGH POWER UNIT CROSS SECTION

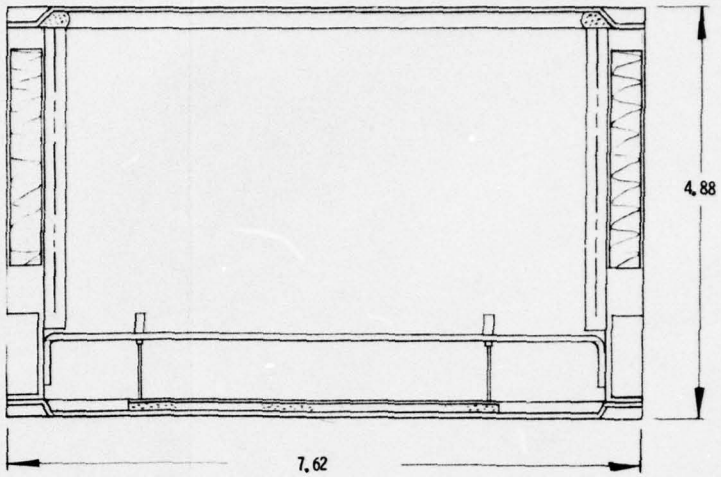


1 ATR LOW POWER UNIT CROSS SECTION

Figure 4.



IGH POWER UNIT CROSS SECTION



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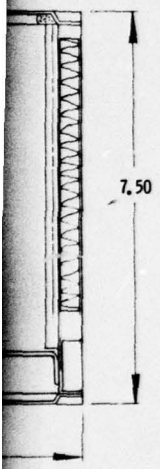

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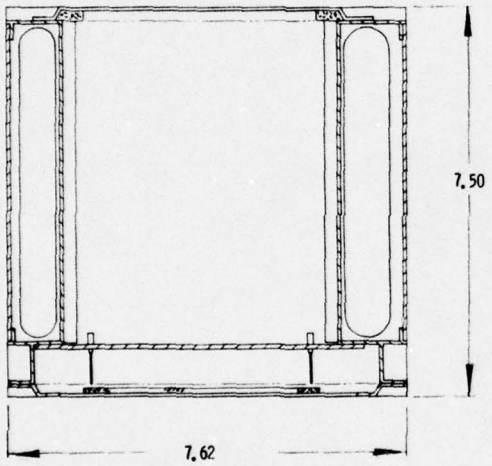

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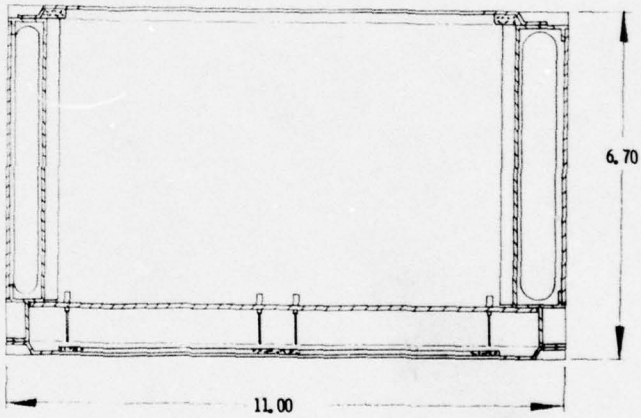
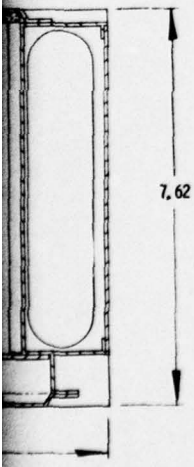
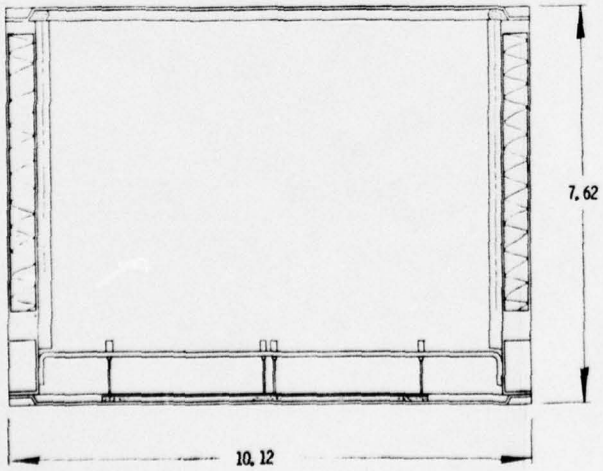


ADVANCED TECHNOLOGY MODULE UNIT CROSS SECTION





1 ATR LOW POWER UNIT CROSS SECTION

Figure 4. Recommended Unit Housings

structure. Since the plenum size will vary with the amount of heat to be dissipated, any calculation of plenum size is dependent on the total power to be dissipated, the inlet air temperature, and the volume of air available.

A second consideration in determining module size, particularly as it affects the module pitch, is the pressure drop across the hollow-card high power modules. By varying the module core thickness, the pressure drop across the module will be changed.

Depending on the power dissipation of the module, the core material thickness can be varied, which in turn can cause the module pitch to change. In most applications the standard modules can be inserted into their respective unit housings on a 0.500 inch pitch. However, to reduce the pressure drop and permit greater dissipation, the use of a thicker core material (such as 0.150 inch) would require a pitch of 0.600 inch.

With the proposed seven module family, the majority of avionics system packaging demands can be fulfilled. The variety of module sizes, both in physical parameters and logic capabilities, tend to preclude the need for a "non-standard" module design.

These module sizes have been determined by evaluating industry surveys, the Air Force/Industry Workshops, data concerning systems presently in service and the experience of Hughes Aircraft Company as related to the packaging of avionics hardware. Considerations of thermal density, and its associated design problems, module input-output connector requirements and functional partitioning have been a part of these module size determinations.

The proposed sizes for standard avionics modules are given in Table 2. The details of the proposed standard avionics modules are given in Figure 5.

POWER DISSIPATION

To accommodate the spectrum of anticipated technologies, at this time, a greater power dissipation demand must be assigned to each integrated circuit location of the recommended standard modules. Therefore, the recommended high power standard avionics modules have been designed at a level of 0.420 watt per integrated circuit location. The lower power modules have been designed with a dissipation of 0.080 watt per location. These values of power dissipation approximate 1.60 watts per square inch of usable module

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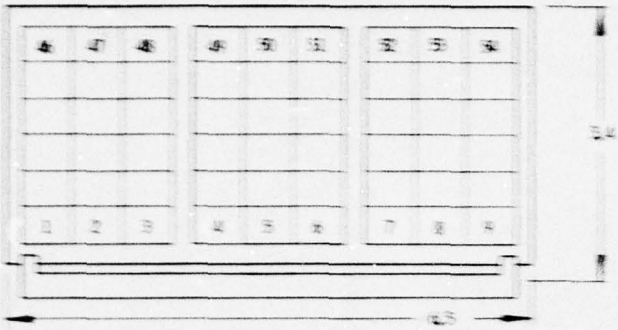
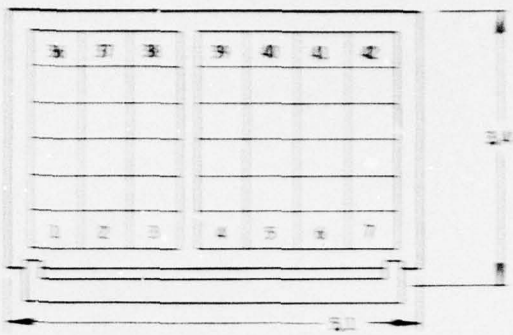
TABLE 2
PROPOSED SIZES FOR STANDARD AVIONICS MODULES

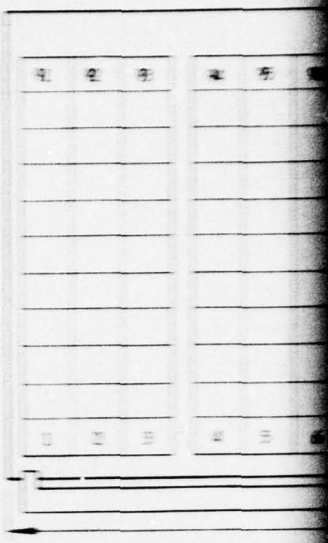
Unit Size	High Power	Low Power
1/2 ATR		
Module	Figure 17	Figure 18
Height (inches)	3.40	3.40
Width (inches)	5.12	6.50
Pitch (inches)	.50	.50
Volume (inches^3)	8.70	11.05
Aspect Ratio H/W	.66	.52
3/4 ATR		
Module	Figure 19	Figure 20
Height (inches)	6.00	6.00
Width (inches)	5.12	6.50
Pitch (inches)	.50	.50
Volume (inches^3)	15.36	19.50
Aspect Ratio H/W	1.17	.92
1 ATR		
Module	Figure 21	Figure 22
Height (inches)	6.17	6.17
Width (inches)	6.91	8.70
Pitch (inches)	.50	.50
Volume (inches^3)	21.31	26.84
Aspect Ratio H/W	.89	.71
Advanced Technology Module (6.70 x 11.00)		
	High Power	Bulk Memory
Module	Figure 23	Figure 24
Height (inches)	5.20	5.20
Width (inches)	9.00	9.00
Pitch (inches)	.60	.60
Volume (inches^3)	28.08	28.08
Aspect Ratio H/W	.58	.58



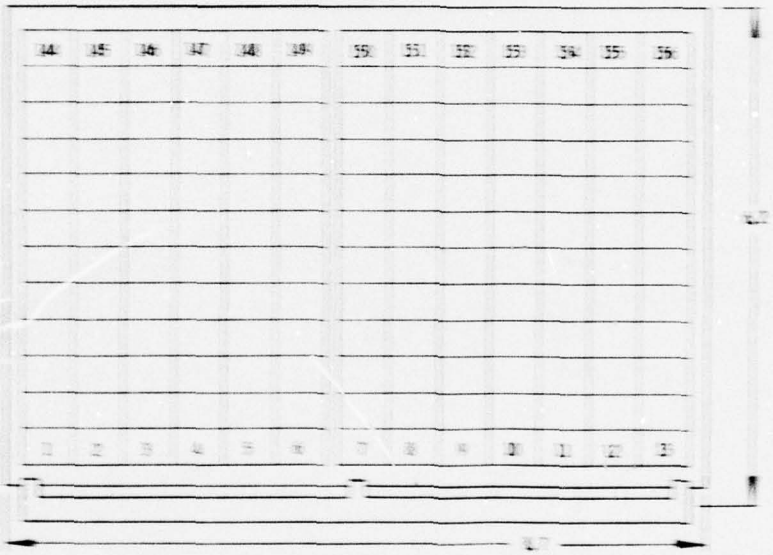
12 ATR LOW POWER MODULE



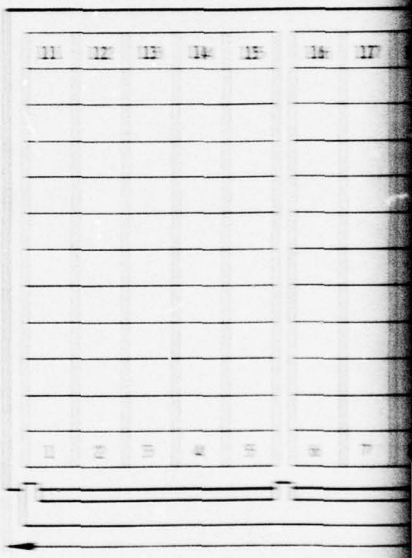
12 ATR HIGH POWER MODULE



34 ATR LOW POWER



ATR LOW POWER MODULE



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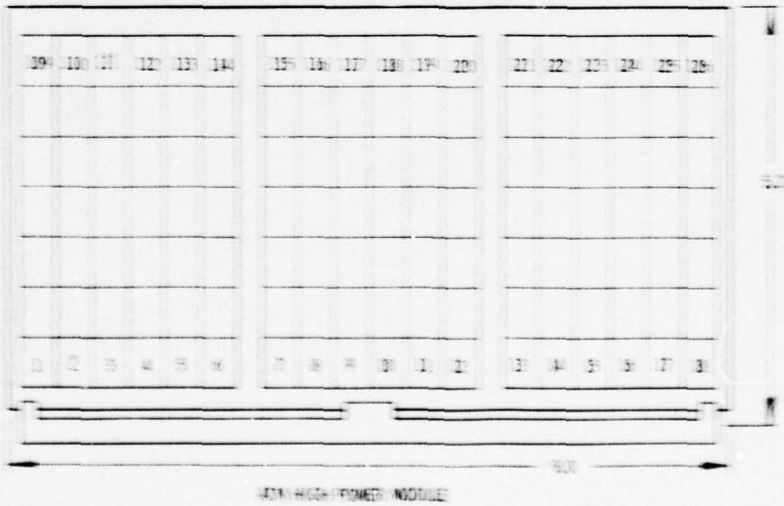
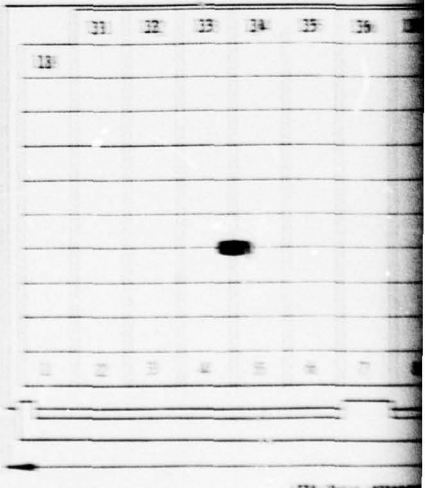


ATR HIGH POWER MODULE



ATR

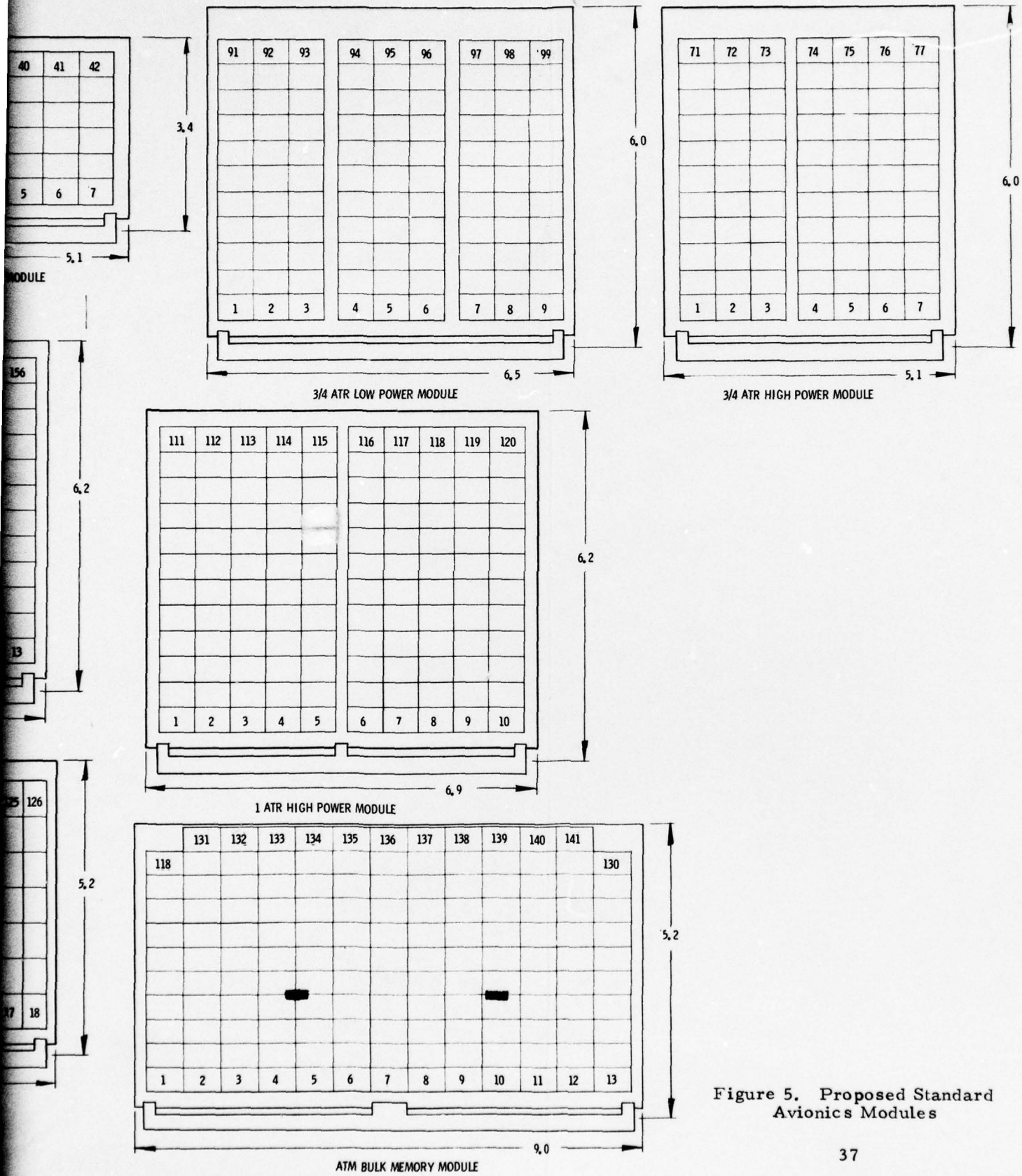


Figure 5. Proposed Standard Avionics Modules

surface for the high power design and approximately 0.300 watt per square inch for the lower powered module designs.

THERMAL CONTROL

Forced convection cooling air is the preferred method of module thermal control. By employing a hollow-card module construction technique, an acceptable component temperature can be maintained by the forced cooling air.

Since there are two distinct thermal groups in the proposed standard avionics modules, those under 35 watts and those with a dissipation greater than 35 watts, the internal dimensions of the unit housing must be adjusted accordingly. The higher powered modules will require more cooling air and, consequently, larger air plenums than the lower power dissipators. The lower powered modules, being constructed with a solid core as opposed to a hollow fin stock core, will require a thermal clip arrangement for the conduction of the heat from the module core to the structure cold wall air plenum. Being of lower power, the air plenums in this case can be considerably smaller than those employed in the flow through module design. The smaller air plenums allow the module width to be increased with a resultant increase in the printed wiring board available for component mounting, thus more components can be accommodated in the lower powered modules for any given unit housing size.

The thermal design of the standard avionics module will be such that the junction region of any semiconductor will not exceed 125°C during operation of the equipment.

The cooling air flow rate will be 3 to 4 pounds per minute per kilowatt, and the exhaust air temperature will not exceed 71°C. A typical cooling air flow pattern for semiconductors in flatpack enclosures is shown in Figure 6. Dual-in-line enclosures are wave soldered to etched circuit boards which have laminated heat sinks of either aluminum or copper (as a function of heat load) that are essentially fingers running between the body of the dual-in-line enclosure and the etched circuit board. They provide a thermal path to heat exchangers which are part of the total unit structure via thermal clips.

The cooling technique tradeoffs are summarized in Table 3. The AWG-9 system illustrated in this table is a typical dual-in-line implemented system as just described.

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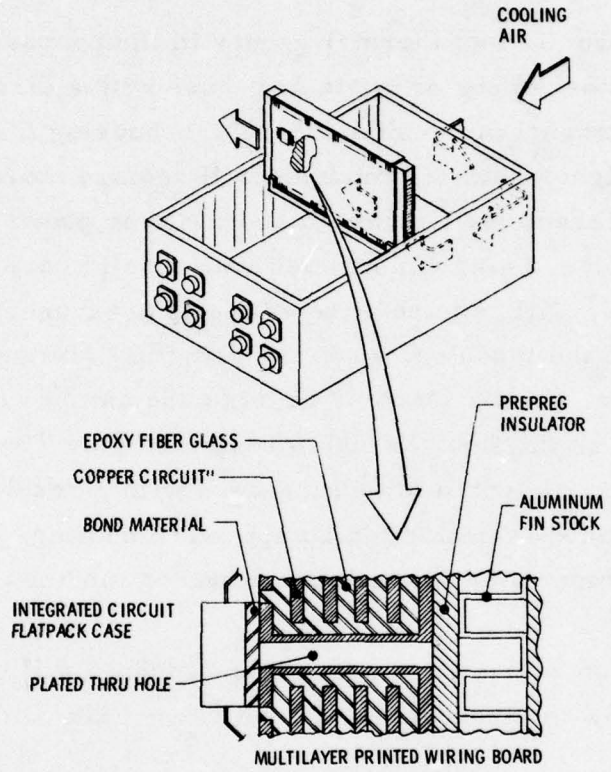


Figure 6. Unit Cooling Flow Path

TABLE 3
SUMMARY OF COOLING TECHNIQUE TRADE STUDY – DIRECT AND INDIRECT FORCED AIR COOLING

Cooling Technique	Hughes Aircraft System on Which Used	Surfaces Through Which Heat is Transferred to Cooling Air	Module Heat Dissipation, watts	Cooling Air Temperature		ΔT Cooling Air to Component Case	Average Heat Exchange Temperature, °F	ΔT Heat Exchanger to Module, °F	ΔT Module Edge to Center, °F	ΔT Module Center to Component Case, °F	ΔT Component Case to Junction, °F	Average Component Junction Operating Temperature		Overall Unit Pressure Drop, Inches of H_2O	Relative Cooling Effectiveness*
				Inlet, °F	Exhaust, °F							°F	°C		
Direct air cooling	MG-10 MG-13, MA-1 and ASG-18	Module and components	5	85	160	27.0					13.5	163.0	73.0	2.0	0.962
			10	85	160	42.9					27.0	192.4	89.0	2.0	0.698
			20	85	160	67.2					54.0	242.7	118.0	2.0	0.473
Indirect air cooling with unit side panel heat exchangers	AWG-9	High performance fin material – rectangular offset	5	85	160		145.4	6.8	6.7	2.7	2.3	163.9	73.0	2.0	0.950
			10	85	160		145.4	13.8	13.3	5.4	4.5	182.4	84.0	2.0	0.770
			20	85	160		145.4	27.6	26.5	10.8	9.0	219.3	104.0	2.0	0.568
Indirect air cooling with module integral edge heat exchanger	F-15	High performance fin material – rectangular offset	5	85	160		152.6		6.7	2.7	2.3	164.3	73.0	2.0	0.946
			10	85	160		152.6		13.3	5.4	4.5	175.8	80.0	2.0	0.825
			20	85	160		152.6		26.5	10.8	9.0	198.9	93.0	2.0	0.659
Indirect air cooling with module central integral heat exchanger	F-15	High performance fin material – rectangular offset	5	85	160		145.4	1.3		2.7	2.3	151.7	67.0	2.0	1.130
			10	85	160		145.4	2.6		5.4	4.5	157.9	70.0	2.0	1.030
			20	85	160		145.4	5.2		10.8	9.0	170.4	77.0	2.0	0.877

*Relative cooling effectiveness = $\frac{T_{exhaust} - T_{inlet}}{T_{component\ junction} - T_{inlet}}$

EQUIPMENT CLASSIFICATION

The standard avionics modules being recommended are designed to meet the requirements of MIL-E-5400, Class 2.

VIBRATION AND SHOCK

Based on the numerous factors that influence the dynamic environment of a module in an equipment in a vehicle, a set of practical requirements for a module must be a gross simplification of the actual environment or environments. It is clearly impractical to define a set of environments to which the module must be serially qualified without being unduly conservative. However, it is believed that the tentative requirements and test method described below, and admittedly based on judgement rather than quantitative derivation, will provide a module which is adequate for almost all airborne applications, given that the equipment installation and the enclosure design are not deficient in some respect which evidences itself as an apparent deficiency of the module.

Vibration Conditions

The standard avionics module will be undamaged by and will operate satisfactorily when exposed to random vibration with an acceleration spectral density of 0.1 g^2/Hz between 50 and 1000 Hz ($\approx$ 10 g) for a period of 3 hours in each of three orthogonal axes.

Test Method

For vibration testing, the module will be installed in a fixture which simulates, insofar as practical, the support flexibilities of an equipment enclosure. In particular, the vertical edges of the module will be supported in typical guides which are attached to rigid fixturing to simulate enclosure walls. The bottom edge of the module, i.e., the male connector, will be inserted into a female connector mounted to a plate whose flexibility is representative of the flexibility of typical motherboards. The module will be restrained vertically in the guides by a top cover whose flexibility is also representative of enclosure covers which would be used with the module. The input acceleration spectral density will be controlled by power-averaging the accelerations measured on the fixture in the neighborhood of the four corners of the module.

Justification

The vibration conditions and test method recommended above have been made as simple as possible. Some of the judgements made while arriving at these requirements are described here.

First, the requirements include only random vibration. As mentioned previously, it is believed that shock and acoustic requirements and/or tests would not yield significant results. Potential use environments for the module include sinusoidal, complex-wave period (gunfire) and random vibration. Based on the results of testing numerous Hughes equipments, a random vibration requirement and test must be prescribed. Thus it must still be decided if additional sinusoidal and/or complex wave requirements are necessary. The above requirements obviously reflect a conclusion that these are not necessary. It is believed that the environment for applications of the standard avionics module for which a sinusoidal requirement is appropriate will, if reasonably specified, be less severe than the recommended random vibration.

The gunfire environment, if applicable, is an additional vibration exposure above the flight environment, be it random or sinusoidal. Extensive testing of avionic equipment at Hughes to both random and complex wave periodic excitations has shown that the damage potential of each type of excitation is comparable for comparable levels. Thus, the additional complexity of specifying both types of tests, especially when many test labs may not have the capability to perform the complex wave periodic tests, can be avoided by extension of the random vibration test duration.

The recommended test method is clearly intended to take into account the transfer function characteristics of the module hold-down, by defining the requirement at the enclosure. It still must be shown that the requirement is reasonably defined at this point. First, a white noise, i. e., constant spectral density, spectrum is defined. Clearly the field environment at the enclosure walls will not be a flat spectrum. Further, under worst flight conditions, peaks in the acceleration spectral density (ASD) in excess of 0.1 g^2/Hz may well occur. However, over most of the frequency range, the ASD will be 10 to 20 dB below this value. It is believed the recommended level avoids the extreme conservatism of enveloping expected maxima across

the entire frequency range while defining a level sufficiently stringent to equal the damage potential of expected environments.

The specified frequency range of 50 to 1000 Hz warrants some justification. It may be surprising that no level is specified below 50 Hz. However, since the standard module fundamental frequency and the fundamental frequency of any reasonably designed enclosure will be well in excess of 50 Hz, excitation below this frequency does not contribute to the damage potential of the test.

Most random vibration specifications require excitation to 2000 Hz, with the spectral density between 1 kHz and 2 kHz often decreasing at 6 dB/octave. Termination occurs at 2 kHz because vibration systems are generally limited to this upper frequency, instead of any belief that the environment cuts off at this frequency. The corollary to this point is that these specifications cover the range up to 2 kHz because vibration systems are able to do so, rather than any real knowledge that damage potential is significant to 2 kHz. However, it is known that fixture design and required vibration system size are considerably impacted by the requirements above 1 kHz. In selecting the upper frequency of 1 kHz for the module tests, in order to simplify the specification and the testing requirements, cognizance of the following factors was made. First, typical transfer functions between the attachment points of the unit and the structure which supports the module show significant attenuation as frequency increases. Second, the transfer function between the module support and the module itself will show considerable attenuation in the direction normal to the plane of the module – probably the most damaging vibration direction. Third, displacements, and more significantly, relative displacements are inversely proportional to the square of the frequency.

Summary

The characteristics of dynamic environments to which a standard avionics module may be exposed have been briefly reviewed in the previous sections. Based on this review, random vibration requirements and an associated test method have been defined. These requirements have been made as simple as possible to simplify analyses and specify economical tests. At the same time, it is believed the requirements will provide a module design satisfactory for general application while avoiding the common tendency for over-specification.

However, it must be remembered that the requirements are based on the assumption of use in a satisfactorily designed enclosure adequately installed in the airborne vehicle.

The MIL-E-5400 vibration requirements are shown in Figure 7.

MODULE COMPONENT PARTS

The recommended standard avionics modules are based on the use of similar components, such as the tactical or I/O connector, test points/ crossovers, module core and module keying configuration. These, in conjunction with a standard set of design parameters, will present a cost effective approach to a standard module family.

Printed Wiring Board

The printed wiring boards to be used in the standard avionics modules will conform to specifications as defined in MIL-E-5400.

In most applications, the use of multilayer printed wiring boards will be required, due to the quantity of circuit components and the complexity of the module intraconnections.

Module Core

To maintain proper thermal control of the standard modules, a hollow-card type of construction is being proposed. Then a central exchanger will have to be included as an integral part of the module. Such a device is the lanced offset fin stock core material as used in many avionics applications presently in service.

This aluminum material supplies module rigidity at a low weight cost, while at the same time possessing high heat transfer capabilities. A typical fin stock material, readily available from many manufacturers, is shown in Figure 8. The same fin stock, depicting the anticipated pressure drop across a 4.50 x 9.00 inch section under varying air flow conditions, is shown in Figure 9.

The lower powered modules, those under 35 watts dissipation, will use a solid aluminum heat exchanger as the module core. A thermal clip arrangement will be required to transfer the heat from the module core to the unit housing air plenum which will be the structure cold wall.

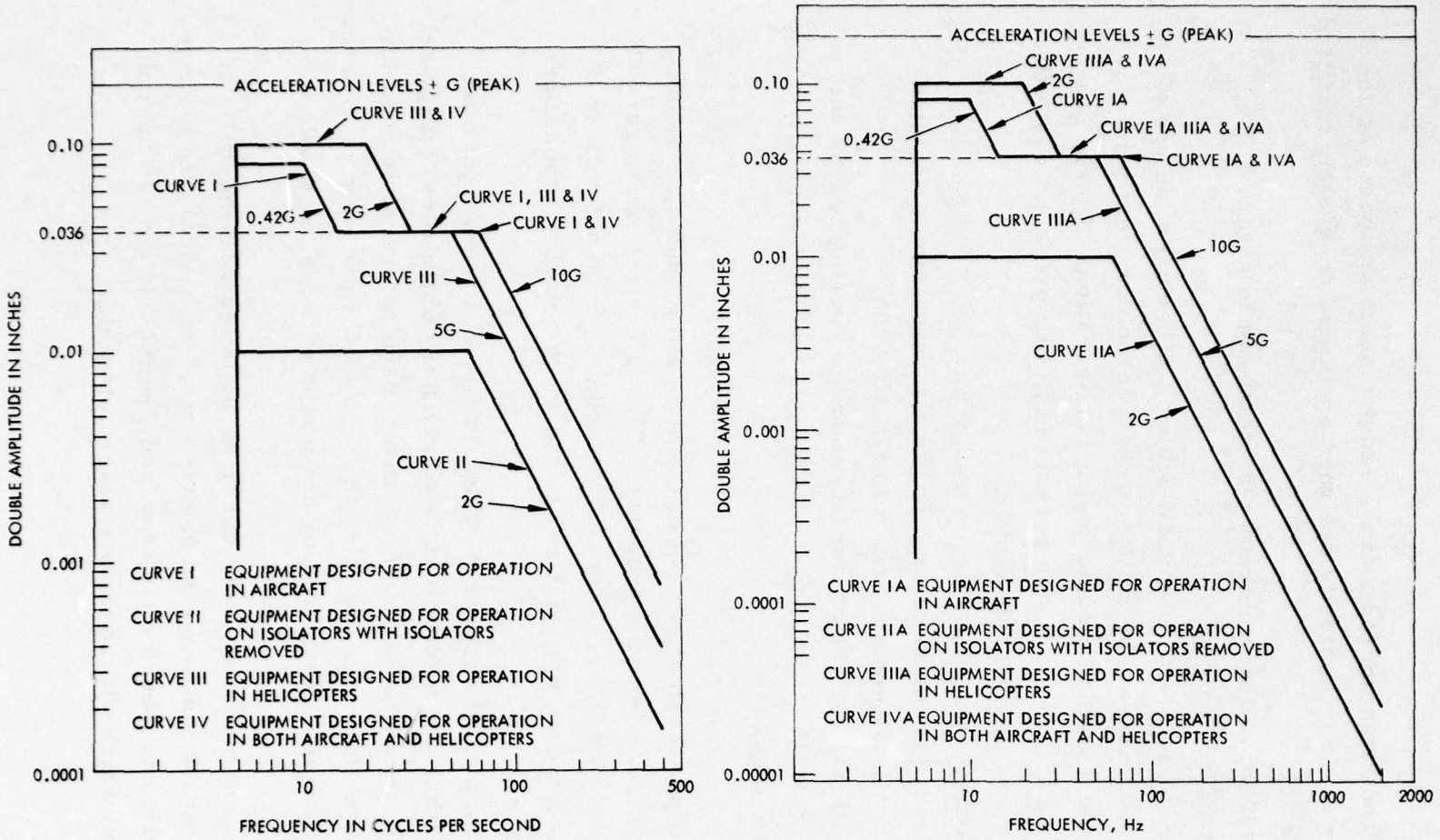
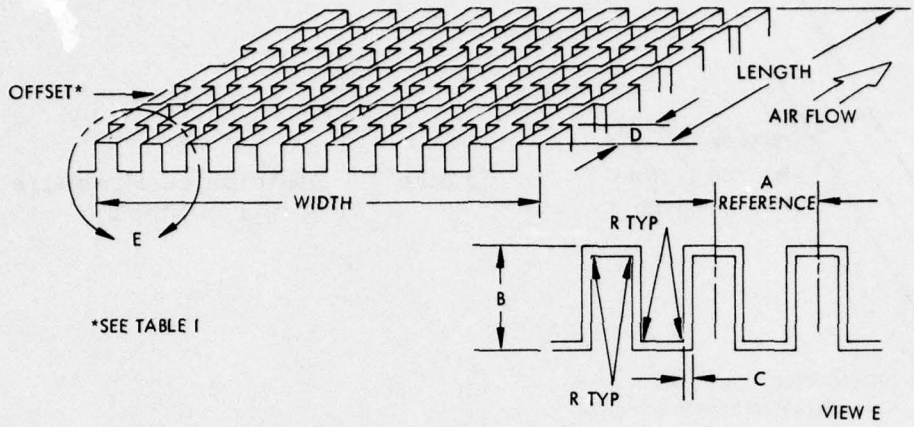


Figure 7. Vibration requirements



BEND RADII	R = BEND RADII, 0.005 TO 0.030 INCH
MATERIAL	(1) 3003 ALUMINUM ALLOY PER QQ-A-250/2, TEMPER F
	(2) 1100 ALUMINUM ALLOY PER QQ-A-250/1, TEMPER 0
	(3) 6061 ALUMINUM ALLOY PER QQ-A250/11, TEMPER T62 1/
	(4) 6061 ALUMINUM ALLOY PER QQ-A-250/11, TEMPER 0
	1/ HEAT TREATMENT OF 6061 MATERIAL TO THE T62 TEMPER SHALL BE PERFORMED PER MIL-H-6088
WORKMANSHIP	THE FIN MATERIAL SHALL BE CLEAN, SOUND AND SMOOTH AND SHALL BE FREE OF FOREIGN MATERIAL, TEARS, HOLES, AND LOOSE BURRS AND SLIVERS
FINISH	THE FIN MATERIAL SHALL BE FREE OF BURRS AND UNLESS OTHERWISE SPECIFIED, SHALL BE COATED WITH PRESERVATIVE OIL PER MILITARY STANDARD NO. 649
LENGTH	LENGTH IN THE DIRECTION OF AIR FLOW SHALL BE AS SPECIFIED-NOT TO EXCEED 12 INCHES
WIDTH	WIDTH TRANSVERSE TO THE AIR FLOW SHALL BE AS SPECIFIED

TABLE 1. SIZES

DASH NO.	REF. 1/ A (INCH)	OFFSET % OF A	B (INCH) ± 0.003	C (INCH) ± 0.001	D (INCH) ± 0.010	FINS PER INCH ± 1.0 FIN	MATERIAL
1	0.125	16-33	0.100	0.006	0.125	16.0	(3)
2	0.125	16-33	0.125	0.006	0.125	16.0	(3)
3	0.125	16-33	0.150	0.006	0.125	16.0	(3)

Figure 8. Module Core Material – Fin Stock

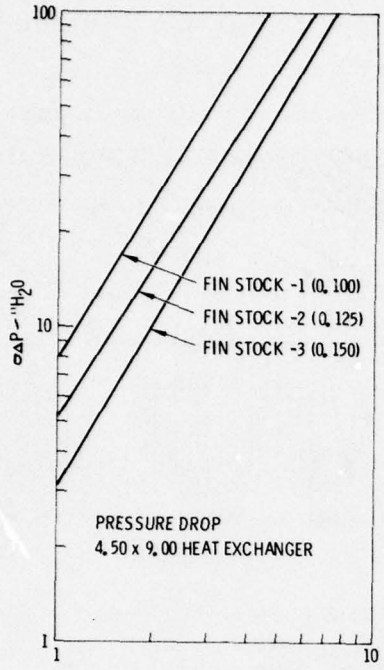


Figure 9. Anticipated Pressure Drop of Fin Stock

Test Points and Signal Crossovers

Due to the functional partitioning, module component capacity and the need to intraconnect various circuit elements, a device that enables board-to-board signal continuity within a given module is essential. The method of achieving these connections is a "crossover". A "crossover" is merely a set of conductors, imbedded within an insulating material, that is attached to a module so as to effect printed circuit continuity between the two printed wiring boards. This is most aptly applied at the top edge of the module.

In conjunction with the signal crossover leads, the ability to perform certain module circuit tests is desirable. This can be accomplished by a modified crossover lead, wherein the crossover conductor is a non-continuous lead open at the center of the module top. This, in effect, is equivalent to two separate leads, one from each printed wiring board.

These test point leads, as well as the crossover leads, can be accessed by a test point connector. The use of a test connector to interface with the crossover assembly is in agreement with MIL-E-5400P in that the metal tabs (leads) of the crossover assembly are mated with the metal contacts of the

test connector; there is not the usual card-edge type connection utilizing the printed wiring board conductor pattern as an interface contact.

The printed wiring conductor pattern for the described crossover assembly allows for the conductive tabs to be located on 0.050 inch centers, permitting a large number of crossovers or test points, dependent only on the printed wiring board width dimension.

The end result of this type of two-piece crossover-test point/test connector assembly is that virtually every crossover can be considered as another test point while the module weight is not increased by the addition of a separate test connector.

Details of the crossover/test point subassembly are shown in Figure 10.

A conceptual approach to a test connector designed to interface with the above proposed crossover/test point assembly is shown in Figure 11.

Module Tactical Connector

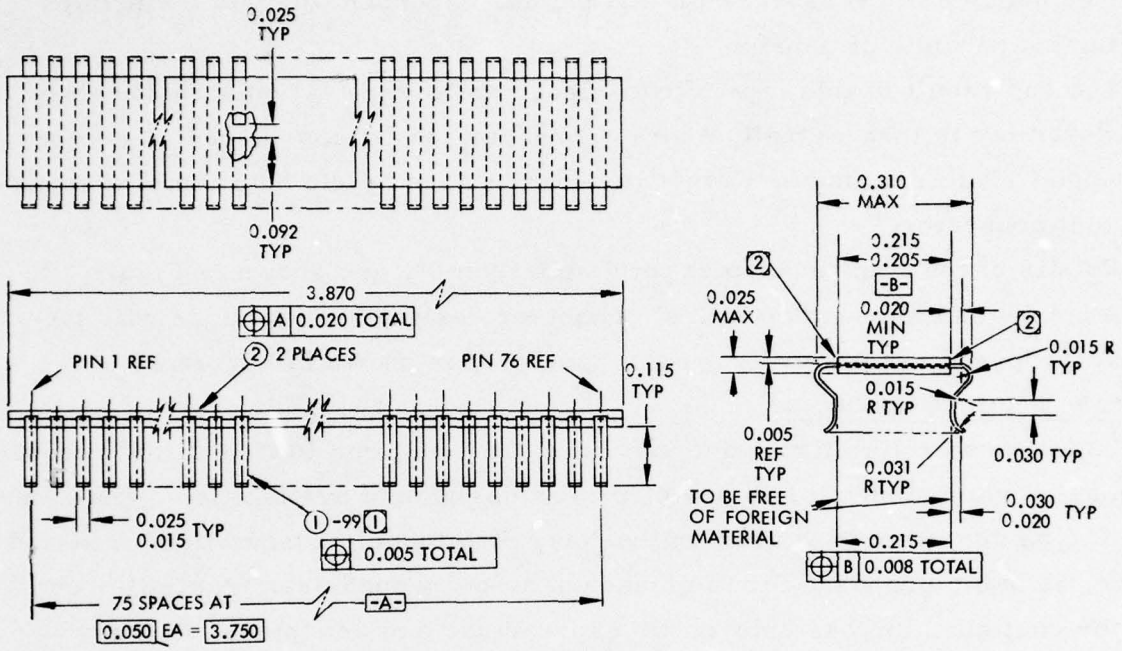
To increase reliability and at the same time retain a low cost, the recommended module connector is one of proven design and availability. The same basic type connector now used on the Navy SHP module assemblies, fork and blade, is being proposed for the standard avionics modules. A similar connector configuration has enjoyed widespread use and acceptance in many military applications.

The male contact consists of a blade, which engages the female (tuning fork) contact, and a terminal end which is soldered to the printed wiring board circuitry.

The female contact consists of a tuning fork spring end, which engages the male contact, and a terminal end (0.025 inch square post) which is designed to be wire wrappable.

The module connector is a header block containing the appropriate number of male contacts, proper keying brushings and suitable mechanical mounting tabs. If the header block material is conductive, an insulator must be used in conjunction with each contact. The insulator is pressed into the header plate, the contact is then pressed into the insulator.

The module connector contacts are to be located on a 0.100 x 0.100 inch grid system. This pattern is most conductive to automatic wire wrapping of the unit backplane.



NOTES-UNLESS OTHERWISE SPECIFIED

1. HOT SOLDER COAT PER MIL-F-14072, FINISH M258 (0.001/0.0015 THICK).
2. FLASH PERMISSIBLE ON THIS SURFACE
3. COMPLETED PART MUST BE CAPABLE OF WITHSTANDING 650°F FOR 1/2 MINUTE
4. ELECTRICAL TEST PER MIL-STD-202 C METHOD 301; 500 VDC APPROX 1000 MEGOHM IMPEDANCE, 1 SECOND DURATION
5. ALTERNATE MATERIAL: 0.005 SHEET BERYLLIUM COPPER, QQ-C-533 ALLOY 172, COND 1/2 HARD

LIST OF MATERIAL

FIND NO.		DESCRIPTION
1	CONTRACT	0.005 BRASS PER QQ-B-613 1/2 HARD CONDITION
2	INSULATOR	0.005 THICK SHEET POLYIMIDE (KAPTON) PER MIL-P-46112

Figure 10. Crossover/Test Point Assembly

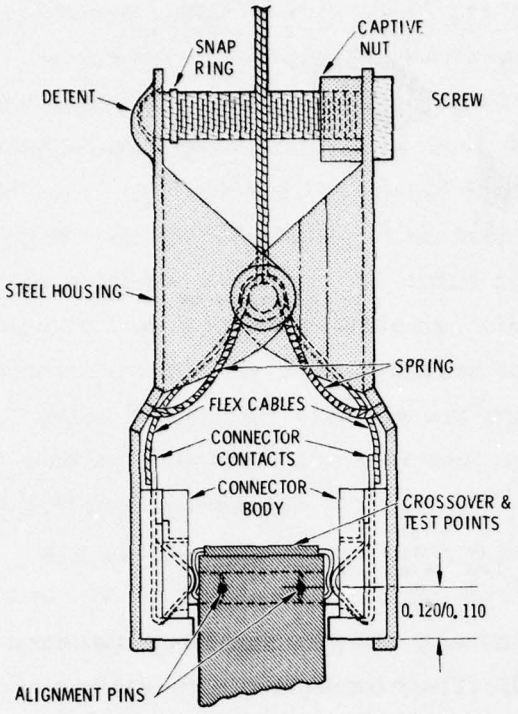


Figure 11. Module Test Connector Concept

An important feature of the proposed connector is the inclusion of contact-protecting side skirts as an integral part of the header. A typical connector configuration is shown in Figure 12. These skirts will aid in preventing undue damage to the module contacts when the module is not inserted into its corresponding receptacle.

Since the number of connector contacts is a function of the length of the connector and the connector length is determined by the width of the printed wiring board, the proposed standard modules will each have a connector that, although similar in nature, will be different with respect to the quantity of contacts. The connector pin count is shown below:

Module Size	1/2 ATR	3/4 ATR	1 ATR	ATM
High Power	168	168	240	300
Low Power	220	220	300	

Module Keying

The method of keying each individual module to prevent the installation of the module in all but the proper location has long been recognized as an essential element of any modularized packaging system. For the proposed standard

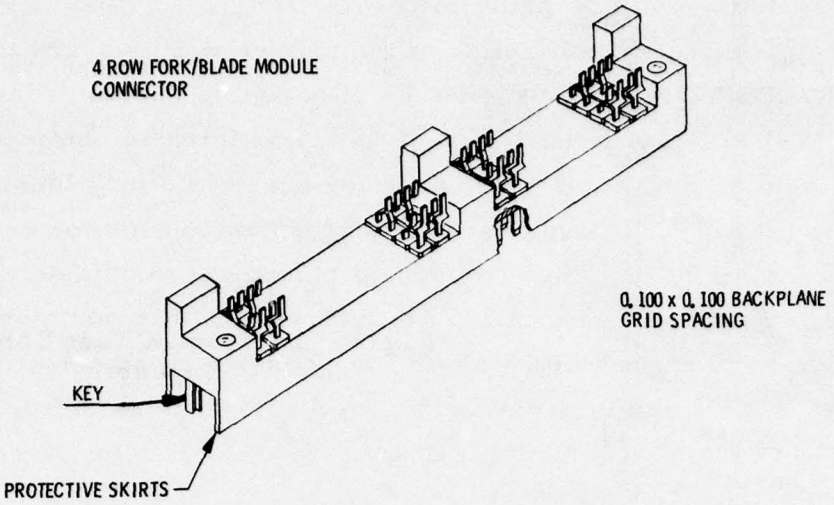


Figure 12. Typical Module Tactical Connector

avionics modules, the same type of keying as now used by the Navy Standard Hardware Program (SHP) is recommended. The elements of this keying method are the insulated bushing and the metal keyway that is inserted into the bushing. The metal keyway, being octagonal in shape, allows for eight rotational positions to be employed as a means of providing the many required keys for a set of modules. This key system is shown in Figure 13.

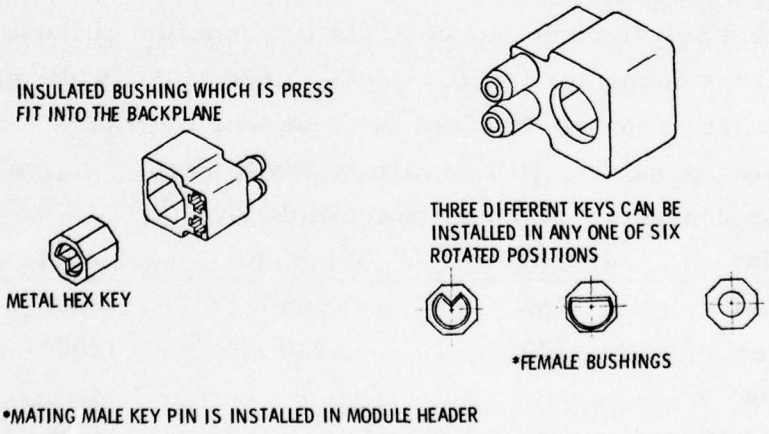


Figure 13. Module Key System

Component Cell Size and Footprint Pattern

To initiate the effective utilization of the printed wiring board in an orderly and efficient manner, real estate must be allocated to accommodate those components presently being used as well as the anticipated components of the future. By dividing the usable printed wiring board into locations or cells and providing the ability to contain various size components for each cell, it becomes a matter of judicious component placement to complete a satisfactory board layout. Orderly cells, arrayed so that they complement each other, provide the required area to facilitate component placement.

Since integrated circuits are manufactured with their external leads on 0.050 inch centers, the footprint or pad pattern must also be based on this 0.050 inch dimension.

The ability to perform the necessary routing of the printed wiring circuitry is another consideration in the determination of what cell size to use. As the logic, and consequently the printed wiring, become more complex, the possibility exists of too dense a packaging factor which might cause a routing problem. Multilayer printed wiring boards, being dependent on plated through holes for interlayer connections, must be designed with an allowance for both vertical and horizontal wiring paths. Granted, any printed wiring board circuitry could be routed, if sufficient layers were available upon which to do the wiring. At this point the questions of manufacturability, yield, reliability and cost come into focus. The multilayer printed wiring board costs increase with the number of layers and the number of different hole sizes to be drilled – the greater the number of layers or drill sizes, the greater the manufacturing cost to fabricate the printed wiring board.

From the results of the Bergamo Workshop and assuming that lightest weight and highest volumetric efficiency are desired for the standard avionics module, the flatpack cell size discussed below has been designated for use on the standard avionics module program (Figure 14). The footprint pattern in this design is detailed for a 16-load device. Similar allocations of cell sizes can be designated for dual-in-line closures; however, this discussion has been directed to the flatpack enclosure.

The cell size and printed circuit pattern shown are usable for the installation of 14, 16 or 24 lead flatpack devices. Ample wiring paths are allowed

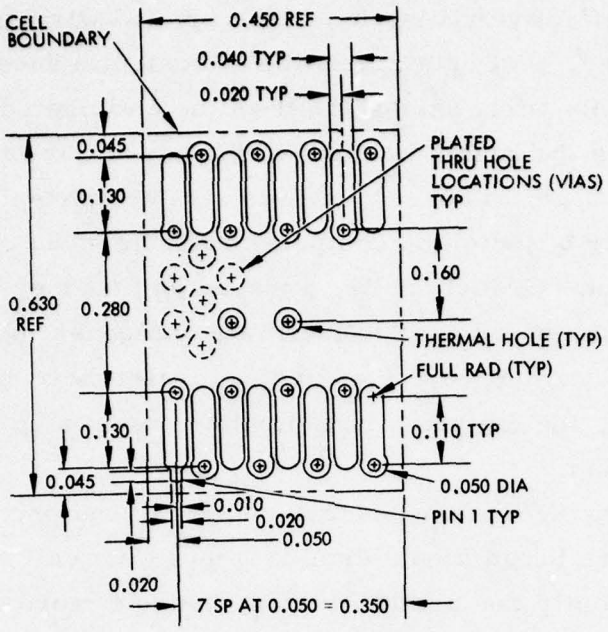


Figure 14. Typical Component Cell and Footprint Pattern for 10, 14, and 16 Lead Flat Pack

in both the vertical and the horizontal direction. Many different size hole diameters are not necessary, and because of the hole locations and spacing, conductive traces can be of sufficient width so as not to require too restrictive a printed circuit design specification. This cell size also permits the inclusion of specific areas of the printed wiring board to be designated for the location of decoupling capacitors as may be required.

The printed wiring board designed for the Advanced Technology Module uses the same cell size as the ATR designed modules, except the cell is rotated 90 degrees. Thus three capacitor alleys can be located across the printed wiring board.

Another version of the ATM is a printed wiring board designed to be used as a bulk memory module. In this instance, the printed wiring board area usually reserved for crossover/test point functions has been allocated to provide room for an additional row of component cells. The module layout for the bulk memory configuration of an ATM is shown in Figure 15. As

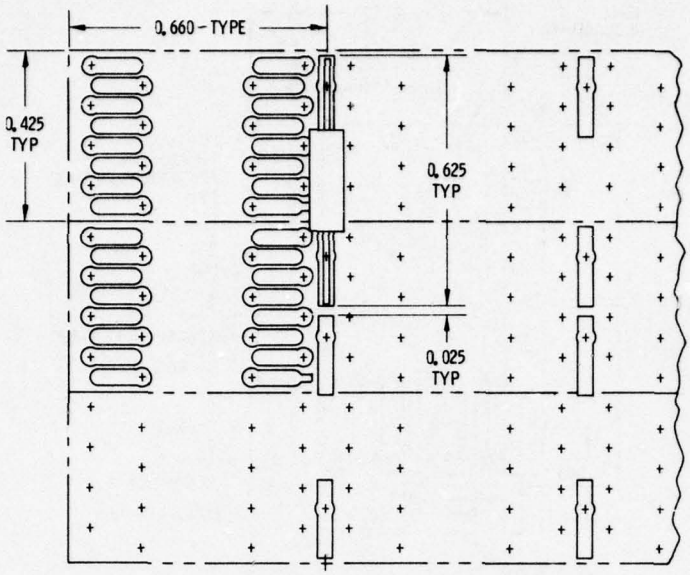


Figure 15. Component Cell and Footprint Pattern for ATM Bulk Memory Module

noted on the layout, the cell size has been changed to 0.425 x 0.660 inch. This size permits the increased cell count while at the same time allowing for the installation of capacitors between the cells. The corresponding cell layout including the installation locations of the decoupling capacitors is shown in Figure 16.

Figure 17 shows how the cell pattern can handle 14, 16 or 24 lead devices.

Module Keel

To ensure finished module thickness, steps must be taken beforehand to permit accurate assembly of the module component parts. Included is the board-to-board (front to rear) registration of the module printed wiring boards. This registration is important to the module assembly process because of the I/O tactical connector and the crossover subassembly that must be mated to both faces of the module.

The module thickness is controlled by accurately fabricated module keels, one at the top of the module and one at the bottom. The keels are merely aluminum blocks sized to each particular module requirement. The appropriate keels for each proposed standard module are shown in Figure 18.

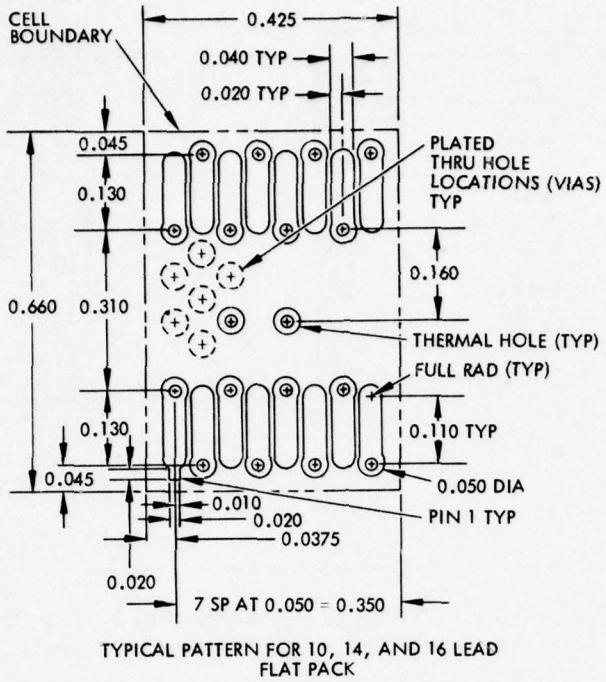


Figure 16. Bulk Memory Capacitor Layout

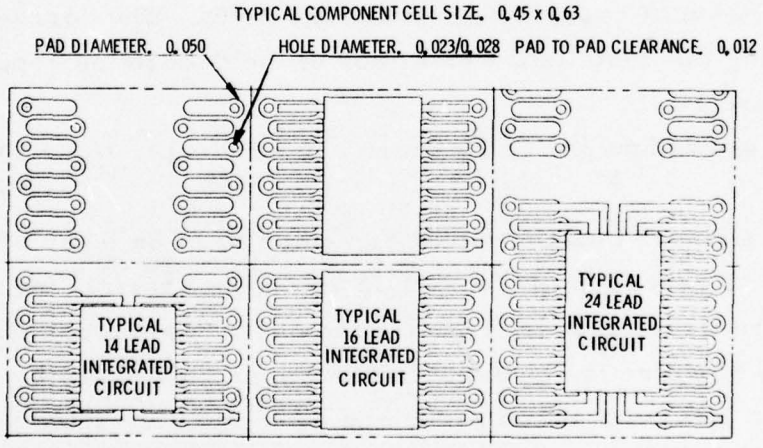
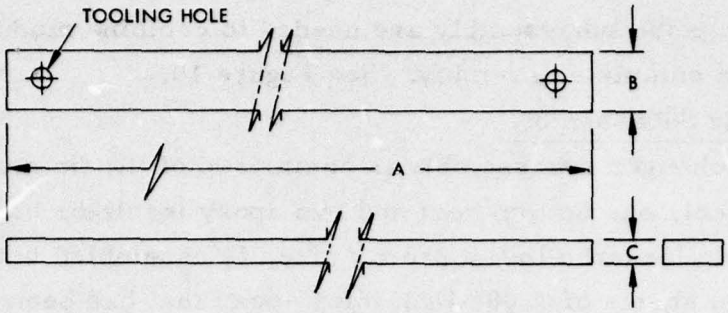


Figure 17. Typical Cell Arrangement Showing Intermix of 14, 16 and 24 Lead Integrated Circuit Packages



MATERIAL: A1 ALLOY 6061-T6, QQ-A250/11 TEMP T6

FINISH: CHROMATE CONVERSION COAT PER MIL-C-5541, CLASS 1A

NOTE: "C" DIMENSION BASED ON 0.500 INCH MODULE PITCH USING 0.100 THICK CORE STOCK AND 0.600 INCH MODULE PITCH USING 0.150 THICK CORE STOCK.

DASH NO.	MODULE		A	B	C	MODULE PITCH
1	1/2 ATR	HIGH POWER	5.120	0.250	0.097 0.094	0.500
2		LOW POWER	6.500			
3	3/4 ATR	HIGH POWER	5.120			
4		LOW POWER	6.500			
5	1 ATR	HIGH POWER	6.910			
6		LOW POWER	8.700			
7	ATM		9.000		0.147 0.144	0.600

Figure 18. Typical Module Keel

Insulator

The hollow-core module construction requires a central heat exchanger as an integral part of each module. To create this heat exchanger subassembly, a bonding operation is needed to provide an insulator between the aluminum fin stock and the printed wiring boards. The bonding agent and insulator are a laminate composed of a fully cured thin laminate (C-stage) and a resin-preimpregnated glass cloth (B-stage). The composite thickness of the material to be used is 0.006 inch with a tolerance of ±0.0015 inch.

For the lower powered modules, the solid core heat exchanger is also insulated from the printed wiring boards with a C-stage/B-stage material that acts as the insulator as well as the bonding agent.

MODULE CONSTRUCTION

The design and fabrication of the heat exchanger subassembly, module top keel, module bottom keel, printed wiring boards, I/O tactical connector, and

crossover/test point subassembly are needed to combine module component elements into a complete assembly. See Figure 19.

Heat Exchanger Subassembly

The heat exchanger subassembly is comprised of the fin stock core material, one top keel, one bottom keel and two epoxy insulator bonding covers.

The fin stock, ordered in the proper size, is assembled between the two adhesive coated sheets of 0.006 inch thick epoxy that has been cut to size; the top and bottom keels are placed in position and the entire assembly is then subjected to pressure and heat to effectuate a bond.

To assure alignment of the heat exchanger parts at this stage of assembly as well as to provide a means of aligning the two printed wiring boards at a subsequent assembly stage, an assembly tool must be used. This tooling may consist of a metal plate with four accurately located tooling posts so positioned as to engage the tooling holes located in the module keels, insulators and printed wiring boards.

The order of assembly for the heat exchanger is given below:

1. Place one adhesive coated insulator, adhesive side up, over the four tooling posts.

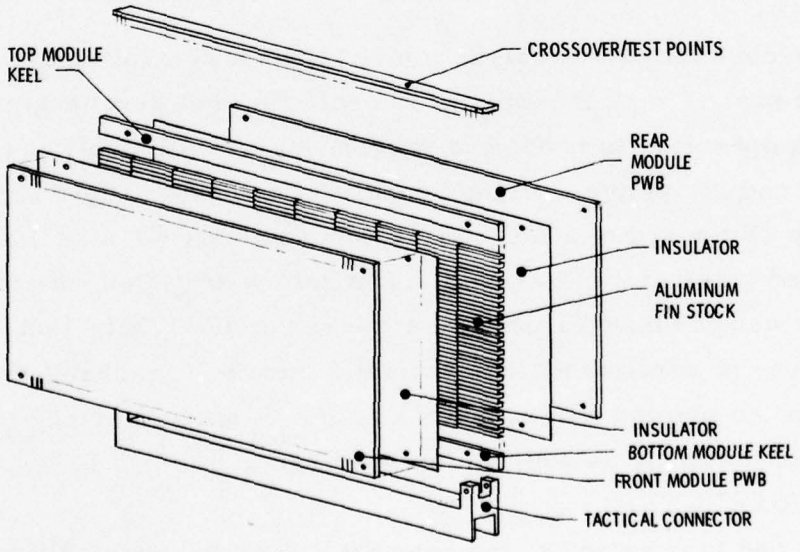


Figure 19. Typical Standard Avionics Module, Exploded View

2. Place the top keel over the two upper tooling posts, on top of the adhesive surface of the insulator.
3. Place the bottom keel over the two lower tooling posts, on top of the adhesive surface of the insulator.
4. Place the pre-sized fin stock over the adhesive surface of the insulator layer, centered between the top and bottom keels.
5. Place the second insulator, adhesive side down, over the four tooling posts to complete the exchanger stack.
6. Subject the entire stack to pressure and temperature as required to cause the bonding to be completed. Usually a pressure of 100-250 psi at 157 ± 9°C for 80 ± 20 minutes will be sufficient.

One item of prime concern is the tooling holes and posts. The tooling holes must be accurately located and drilled in each item of the module, the printed wiring boards, the keels, the prepreg material and the insulators. The matching tooling posts also must be positioned and machined to a close tolerance. Only in this manner can the assurance of module alignment be maintained.

The heat exchanger assembly is shown in Figure 20.

Module Bonding

Using the same tooling as for the heat exchanger, the bonding of the two printed wiring boards to the heat exchanger subassembly follows much the same process.

First, the module rear printed wiring board, with the component mounting surface facing down, is placed over the four tooling posts, then a film adhesive layer is added, followed by the heat exchanger subassembly, another film adhesive layer, and finally the front printed wiring board. Against, the component mounting surface must now be facing up. Once more heat and pressure are applied to the stack to cause the bonding to be completed. The film adhesive material used to bond the printed wiring boards to the heat exchanger is composed of two layers of 1 mil thick American Cyanamide FM 1044R film adhesive, or equivalent. In this instance, 160°C to 165°C at 50 psi for 90 minutes should suffice. Figure 21 shows the stages of this operation.

This view is for the high power modules that dissipate more than 35 watts. However, the module bonding operation is essentially the same for the lower dissipating modules. In these cases, the difference is only in the heat

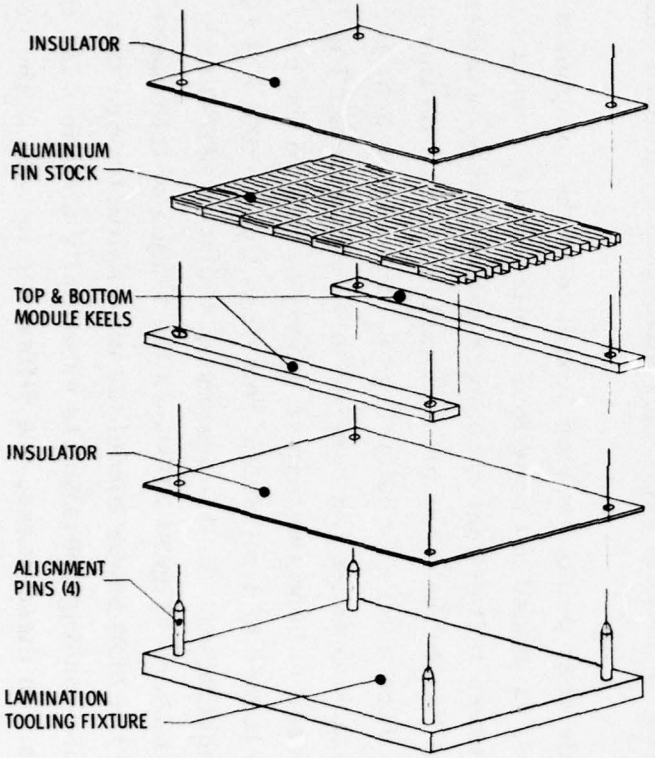


Figure 20. Heat Exchanger Assembly

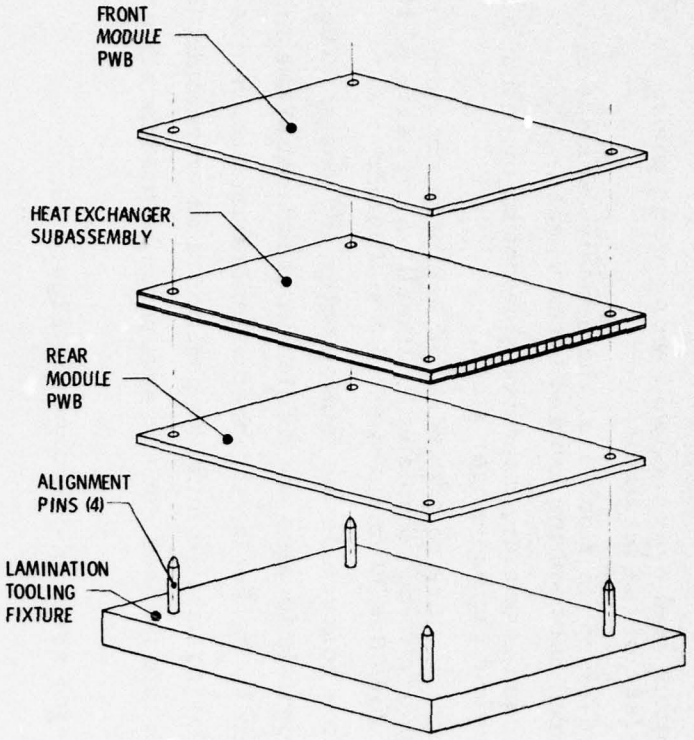


Figure 21. Printed Wiring Boards and Heat Exchanger Assembly

exchanger subassembly. Instead of a hollow-core fin stock and keel assembly, the heat exchanger for the lower powered modules will be a solid aluminum plate. The plate will replace the fin stock, as well as both keels and be bonded to the printed wiring boards in much the same manner as shown in Figure 21. The plate thickness is anticipated as 0.062 inch which is sufficient to handle the module dissipation of the proposed low power family.

Final Assembly

The heat exchanger/printed wiring board assembly is now ready for the installation of the I/O connector, crossover subassembly and the circuit components.

The I/O connector, depending on its final design, may be installed with small screws (2-56) directly into the bottom keel or with roll pins or screws through the board assembly. In either case, the tabs of the connector are then soldered to the corresponding printed circuit conductors at the edge of the two printed wiring boards.

Then the crossover subassembly is soldered across the top of the module, once more utilizing the printed circuit conductors designed to receive the tabs of the crossover unit. Then a reflow solder technique can be used to attach the integrated circuits and capacitors, or other components to their proper cell location.

An exploded view of a typical standard module assembled as described above was shown in Figure 18.

SUMMARY OF STANDARD AVIONICS MODULE RECOMMENDATIONS

In light of the previous discussions, Table 4 is a complete listing of the recommendations for a family of standard avionics modules. In all instances, except as might be noted, the following conditions prevail for all module designs:

1. Component cell size is 0.450 x 0.630 inch.
2. The I/O tactical connector is of the fork/blade configuration.
3. The anticipated integrated circuit packages are of the flatpack variety.
4. The power dissipation factors used for all calculations are
   0.420 watt per cell location for high power
   0.080 watt per cell location for low power

TABLE 4
SUMMARY OF RECOMMENDATIONS

	UNIT SIZE, Inches		MODULE SIZE, Inches			ASPECT RATIO	USABLE PWB SPACE, Inches			NUMBER OF CELLS	NUMBER OF I/O CONTACTS		MODULE POWER CAPABILITY,	MAXIMUM CROSSOVER LEADS	MODULE VOLUME,	CELLS PER IN^3	WATTS PER IN^3
	H	W	H	W	P	H/W	H	W	Area/Module	Per Module	Per Module	Per Cell	Watts		Inches^3		
1/2 ATR	4.88	7.62															
HIGH POWER			3.40	5.12	.50	.66	2.70	4.72	25.49	84	168	2.00	35	94	8.70	9.66	4.02
LOW POWER			3.40	6.50	.50	.52	2.70	6.10	32.94	108	220	2.04	9	122	11.05	9.77	.81
3/4 ATR	7.50	7.62															
HIGH POWER			6.00	5.12	.50	1.17	4.95	4.72	46.73	154	168	1.09	65	94	15.36	10.03	4.23
LOW POWER			6.00	6.50	.50	.92	4.95	6.10	60.39	198	220	1.11	16	122	19.50	10.15	.82
1 ATR	7.62	10.12															
HIGH POWER			6.17	6.91	.50	.89	5.40	6.51	70.31	240	240	1.00	101	130	21.32	11.26	4.74
LOW POWER			6.17	8.70	.50	.71	5.40	8.30	89.64	312	300	.96	25	166	26.84	11.62	.93
ADVANCED TECHNOLOGY MODULE	6.70	11.00															
HIGH POWER			5.20	9.00	.60	.58	4.41	8.60	75.85	252	300	1.19	106	172	28.08	8.97	3.77
BULK MEMORY			5.20	9.00	.60	.58	4.70	8.60	80.84	282*	300	1.06	118	172	28.08	10.04	4.20

*CELL SIZE: .660 HIGH X .425 WIDE

5. The mix of crossovers and test points is to be decided on an individual module design basis.

6. Two printed wiring boards are used per module.

7. All module crossovers or test points are on 0.050 inch centers.

The terminology of high power and low power is used to distinguish the different technologies that might be implemented. The high power modules are for systems employing technology such as Emitter Coupled Logic (ECL) or its equivalent. The low power designs would include transistor-transistor logic (T^2L) and integrated injection logic (I^2L) types of circuit designs.

VII. COSTS

A preliminary life cycle cost (LCC) analysis has been completed for each module described in this study. To evaluate each module throughout its full life cycle, it was necessary to consider a unit using each of the modules in a theoretical processor that could be configured using either T^2L or ECL devices. The analysis considered the reduction in parts count caused by improved efficiencies of the high speed ECL technology as well as a processor that used a constant number of parts independent of functional or technical requirements. Advantage was taken of earlier work performed in the Hughes Signal Processor Laboratory to arrive at functionally equivalent processors. This earlier work defined the parts count needed to perform a digital doppler radar processor function using MSI T^2L and MSI ECL devices. The processor employing MSI T^2L required 2063 devices while an equivalent processor using the higher speed ECL devices required only 1480. The preliminary LCC analysis assumed this ratio of 2083 T^2L to 1480 ECL devices as a method of defining a functionally equivalent processor unit.

Life cycle cost is the sum of development, acquisition, and support costs over the life of a system. Development costs for processors will, of course, vary dependent upon processor complexity, deliverable development units, schedule, test criteria and documentation required. It was assumed that development costs are the same for processor using other type devices. Acquisition costs will vary as a function of processor complexity, test criteria, documentation and delivery schedule. To simplify and thus ease the interpretation of the LCC analysis; test criteria, documentation and delivery schedule were held constant. Acquisition costs were developed from the number of circuits on each module and number of interconnects, unit chassis, fabrication and test. A Hughes modified version of the AFLC LSC model that allows evaluation of a system down to the SRU (module) level was used to develop logistics support costs.

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The modules and processors evaluated are summarized in Table 5. Reliability and costs for each of the modules varied as a function of the number of ICs contained on the module. Normalized reliability and cost values are provided to aid in interpreting the various modules and processors. Life cycle and logistic support costs are primarily a function of unit reliability and cost. The method used to evaluate the various configuration modules and processors is described here.

The LSC model consists of equations or submodels, each representing a cost of resources necessary to operate the logistics system. The model is simply a summation of these equations and computes the expected major resource costs associated with logistics experienced during operation and maintenance.

Each equation is first evaluated for the individual LRUs, then for the SRU comprising each LRU. The results are then aggregated for subsystems and the total system. The 10 equations and a brief explanation of each are given in Table 6. The actual equations are shown in Appendix 1.

Key data inputs and assumptions included:

1. 1000 unit acquisition
2. 2.41 million flying hours
3. 18,420 peak flying hours per month
4. 15-year life cycle
5. 7 bases

An MTBF derating factor of 1.4 was applied to all predicted reliability values.

1. 10 percent of the TTL MSI circuits would be new to the supply inventory
2. 90 percent of the ECL MSI circuits would be new to the supply inventory

Cost to repair values assume a fault isolation capability to a single component and that all modules will be repaired; in actual practice fault isolation to several components may occur on the larger modules, thus increasing the cost of repair or a discard at failure support concept could be applicable to the higher reliability, lower cost modules. An Optimum Repair Level Analysis (ORLA) normally would be performed to gain added insight into the total support picture. Modules to be discarded at failure typically reduce the AGE, training, and data requirements.

TABLE 5
SUMMARY DESCRIPTION OF MODULES AND PROCESSORS EVALUATED

MODULE

	Description	Size	No. ICs	Reliability	Normalized Reliability	Cost	Normalized Cost
1A	High power 1/2 ATR	3.40 x 5.12 x 0.50	84	32725	1.0	687	1.0
2A	High power 1/2 ATR	3.40 x 5.12 x 0.50	84	32725		687	
1B	Low power 1/2 ATR	3.40 x 5.12 x 0.50	108	29545	0.903	883	1.285
2B	Low power 1/2 ATR	3.40 x 5.12 x 0.50	108	29545		883	
1C	High power 3/4 ATR	6.00 x 5.12 x 0.50	154	17850	0.545	1259	1.832
2C	High power 3/4 ATR	6.00 x 5.12 x 0.50	154	17850		1259	
1D	Low power 3/4 ATR	6.00 x 5.12 x 0.50	198	16115	0.492	1619	2.789
2D	Low power 3/4 ATR	6.00 x 5.12 x 0.50	198	16115		1619	
1E	High power 1 ATR	6.17 x 6.91 x 0.50	240	11455	0.350	1962	2.856
2E	High power 1 ATR	6.17 x 6.91 x 0.50	240	11455		1962	
1F	Low power 1 ATR	6.17 x 6.91 x 0.50	312	10255	0.313	2550	3.712
2F	Low power 1 ATR	6.17 x 6.91 x 0.50	312	10255		2550	
1G	High power Advanced Technology Model	5.20 x 9.00 x 0.60	252	10910	0.333	2060	2.998
2G	High power Advanced Technology Model	5.20 x 9.00 x 0.60	252	10910		2060	

TABLE 5
SUMMARY DESCRIPTION OF MODULES AND PROCESSORS EVALUATED

UNIT

Processor Category	No. ICs	No. of Modules	Reliability	Normalized Reliability	Cost	Normalized Cost	Weight Lbs.
Functionally equivalent	1595	19	1689	1.0	25013	1.0	23.0
Constant parts count	2063	25	1283	0.759	32161	1.285	28.6
Functionally equivalent	2268	21	1379	0.816	34532	1.380	31.6
Constant parts count	2063	19	1524	0.902	31471	1.258	30.8
Functionally equivalent	1540	10	1750	1.036	24209	0.968	15.6
Constant parts count	2063	13	1346	0.797	30760	1.229	17.1
Functionally equivalent	2178	11	1436	0.850	33260	1.329	21.6
Constant parts count	2063	10	1579	0.935	30453	1.217	21.6
Functionally equivalent	1480	7	1604	0.949	26193	1.047	15.5
Constant parts count	2063	9	1247	0.738	32998	1.319	17.1
Functionally equivalent	2100	7	1436	0.850	33331	1.333	19.7
Constant parts count	2063	7	1436	0.850	33331	1.333	19.7
Functionally equivalent	1480	6	1782	1.055	23812	.952	17.3
Constant parts count	2063	8	1337	0.792	30956	1.238	22.5

TABLE 6
LSC MODEL EQUATIONS

Equation	Explanation
C_1 Initial and Replacement LRU Spares Cost	The initial investment cost of spares necessary to support the repair pipelines and the purchase cost of spares to replace condemned units/modules. The computation includes a spares safety level quantity to provide protection against fluctuation in item demands. An expected backorder criterion determines this quantity.
C_2 On-Equipment Maintenance Cost	The flight-line maintenance labor costs to perform corrective maintemance in place or to remove and replace LRUs for subsequent repair. It also includes the labor costs to perform scheduled maintenance and inspections on the subsystem.
C_3 Off-Equipment Maintenance Cost	Labor and material costs for base and depot maintenance facilities to diagnose, repair or attempt to repair LRUs. Associated packing and shipping costs incurred for NRTS items are included.
C_4 Inventory Entry and Supply Management Cost	The management cost to introduce new line items into the Air Force inventory as well as recurring supply management costs.
C_5 Support Equipment Cost	The cost of peculiar support equipment based on the anticipated workload and servicing capability. The cost of additional units of common support equipment is also included.
C_6 Cost of Personnel Training and Training Equipment	The initial and recurring costs to train maintenance personnel (instruction and training materials) and the cost of peculiar training equipment required for the subsystem.
C_7 Cost of Management and Technical Data	The costs for Technical Orders (TOs), overhaul manuals, and other special technical documentation or repair instructions. It also computes the maintenance labor costs to complete on- and off-equipment maintenance records, supply transaction records and transportation forms.

Detail input data sheets are provided along with the computer model outputs. These include:

1. AGE cost for digital unit test station $289,100 with a 10 percent per year maintenance cost was assumed for all configurations.
2. AGE cost for digital module test station $206,000 with a 10 percent per year maintenance cost.

The cost breakout for each logistic support cost equation is shown for each of the systems evaluated. It is significant to note the high percentage of support costs are attributed to AGE. An AGE analysis is performed as part of the support cost model. One test station is required at each of the seven bases with utilization rates of 26 and 53 percent; no module test stations are required at the bases since the modules are not required at the intermediate (base) level. Depot AGE requirements have also been analyzed. It is interesting to note that AGE costs represented more than 80 percent of the support costs for all configurations considered. System 1B had the highest AGE requirements with four LRU test stations and one module position. The analysis clearly indicates a need to consider support AGE during the definition of a standard module.

The life cycle cost summarized in Figure 22 represents the sum of development, acquisition and support costs for each configuration considered. As stated earlier, development costs were considered to be constant and, therefore, did not contribute to the relative values of each configuration. Acquisition costs for a 1000 unit buy are simply the unit costs multiplied by 1000. The support costs used were the computer model outputs contained in this report.

Preliminary LCC analysis shown in Figure 22 indicates that functionally equivalent processor units containing the high power modules (1C) or 3/4 ATR size (6.0 x 5.12 x 0.5 inches) offer the lowest life cycle cost with the ATM module (1G) with the high power modules of the 1/2 ATR (1A) and 1 ATR (1E) being reasonably close. This result is expected because of the typically lower unit costs resulting from the reduced parts count and increased reliability that are obtained through the use of the higher speed ECL devices for functionally equivalent processors. When the parts count is held constant, the analysis shows the 3/4 ATR (2D) has the lowest LCC.

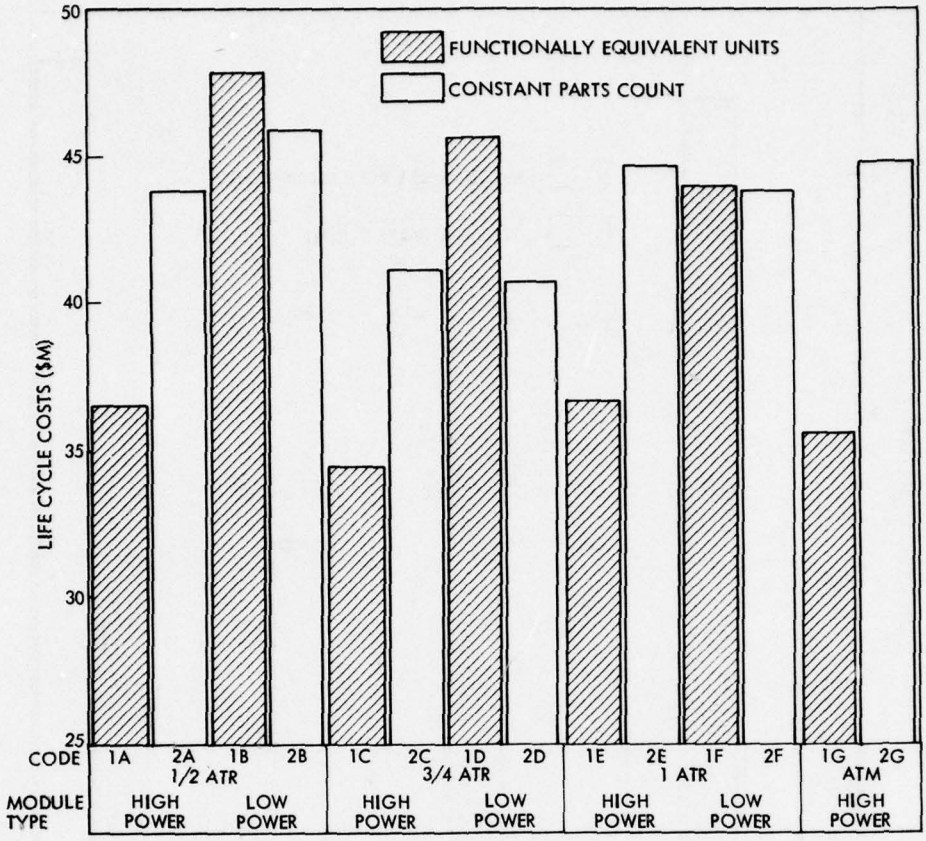

Figure 22. Life Cycle Costs

A review of the logistic support costs (LSC) summarized in Figure 23 indicates that the 3/4 ATR size high power module (1C) has the lowest support costs, due primarily to the combination of the low unit cost with good reliability. It is emphasized that Figure 23 represents the support costs only. Development and acquisition costs should be considered in greater detail before final judgements are made.

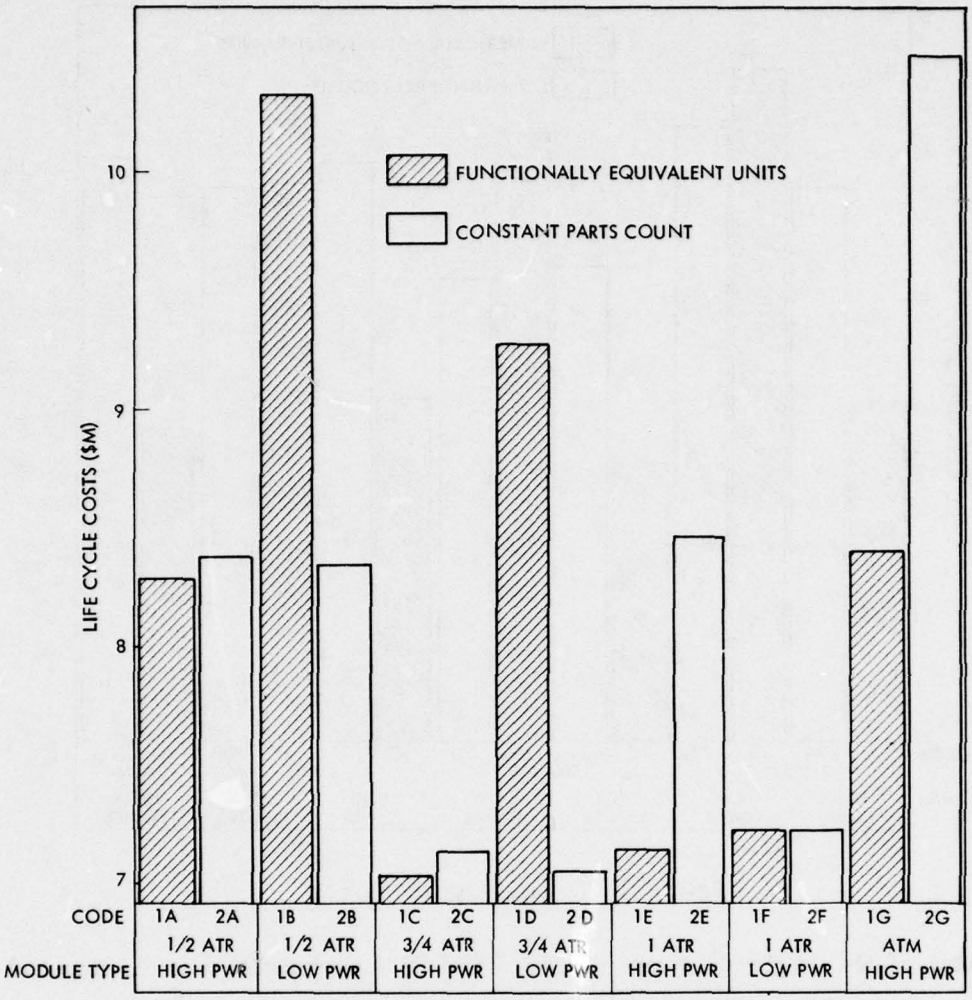

Figure 23. Logistic Support Costs

APPENDIX A

LOGISTIC SUPPORT COST ANALYSIS

LSC MODEL DATA ELEMENTS

System Variables

1. EBO - Standard established for expected backorders. (G)

2. IAC - Initial inventory management cost to introduce a new "P" coded reparable assembly into the Air Force inventory. (G) (S = $145.11/item)

3. ANS - Indicator (Y or N) whether or not the system contains a propulsion subsystem.

4. IPC - Initial inventory management cost to introduce a new consumable item into the Air Force inventory. (G) (S = $145.11/item)

5. M - Number of operating base locations. (G)

6. MRF - Average manhours per maintenance action to complete off-equipment maintenance records. (G) (S = .24 hours)

7. MRO - Average manhours per maintenance action to complete on-equipment maintenance records. (G) (S = .08 hours)

8. NSUB - Number of subsystems in the system. (C)

9. OS - Fraction of total force deployed to overseas locations. (G)

10. OSTCON - Average order and shipping time within CONUS. (G) (S = .36 months)

11. OSTOS - Average order and shipping time to overseas locations. (G) (S = .53 months)

12. PFFH - Expected peak force flying hours per month. (G)

13. PIUP - Operational service life of the system in years (Program Inventory Usage Period). (G)

14. PMB - Direct productive manhours per man per year at base level (includes "touch time", transportation time and set-up time). (G) (S = 1500 hours/man/year)

15. PMD - Direct productive manhours per man per year at the depot (see PMB). (G) (S = 1500 hours/man/year)

16. PSC - Average packing and shipping cost for CONUS locations. (G) (S = $0.53/pound)

17. PSO - Average packing and shipping cost for overseas locations. (G) (S = $0.99/pound)

18. RAC - Recurring inventory management cost to maintain a reparable assembly in the wholesale system. (G) (S = $104.20/item/year)

19. RPC - Recurring inventory management cost to maintain a consumable item in the wholesale system. (G) (S = $104.20/item/year)

20. SA - Annual base supply inventory management cost. (G) (S = $20.20/item/year)

21. SR - Average manhours per maintenance action to complete supply transaction records. (G) (S = .25 hours)

22. TD - Cost of original technical documentation. (G) (S = $220.00/page)

23. TFFH - Expected total force flying hours over the Program Inventory Usage Period. (G)

24. TR - Average manhours per maintenance action to complete supply transaction forms. (G) (S = .16 hours)

25. TRB - Annual turnover rate for base personnel. (G) (S = .33)

26. TRD - Annual turnover rate for depot personnel. (G) (S = .15)

Subsystem Variables

1.	BA	-	Apportioned cost of additional common base shop support equipment. (C)
2.	BAA	-	Available work time in the base shop, in manhours per month, per unit of AGE. (G)
3.	BLR	-	Average base level labor rate. (G) (S = $11.70/manhour)
4.	CS	-	Cost of software to utilize existing automatic test equipment (ATE). (C)
5.	DA	-	Apportioned cost of additional common depot support equipment. (C)
6.	DAA	-	Available work time in the depot, in manhours per month, per unit of AGE. (G)
7.	DLR	-	Average depot level labor rate. (G) (S = $12.44/manhour)
8.	FB	-	Cost of special base facilities per base (including utilities) necessary for operation and maintenance of the subsystem. (C)
9.	FD	-	Cost of special depot facilities (including utilities) necessary for maintenance of the subsystem. (C)
10.	FLA	-	Cost of additional common or peculiar flightline AGE. (C)
11.	H	-	Number of pages of depot level technical orders and special repair instructions. (C)
12.	IH	-	Cost of interconnecting hardware to utilize existing ATE. (C)
13.	JJ	-	Number of pages of organizational and intermediate level technical orders. (C)
14.	N	-	Number of LRUs in the subsystem. (C)
15.	SMH	-	Average manhours to perform scheduled maintenance including preventive maintenance, preflight, postflight, and periodic inspections. (C)
16.	SMI	-	Scheduled maintenance interval in flying hours. (C)
17.	TCB	-	Cost of peculiar training per man at base level including instruction and training materials. (C)

18.	TCD	-	Cost of peculiar training per man at depot including instruction and training materials. (C)
19.	TE	-	Cost of peculiar training equipment. (C)
20	XSUB	-	Subsystem identification. (G)

LRU Variables

1.	BMC	-	Average material cost per base maintenance action expressed as a fraction of the unit cost (UC). It includes the mean dollar value of the consumables utilized in repair of an LRU and any subordinate reparables. (C)
2.	BMH	-	Average manhours at base level to diagnose, repair or attempt to repair an LRU. (C)
3.	BRCT	-	Average base repair cycle time. (G) (S = .33 months)
4.	COND	-	Fraction of removals expected to result in condemnation at base level. (C)
5.	DMC	-	Same as BMC except refers to depot maintenance actions. (C)
6.	DMH	-	Same as BMH except refers to depot. (C)
7.	DRCT	-	Average depot repair cycle time. (G) (S = 2.0 months for organic repair; 2.5 months for contract repair)
8.	IMH	-	Average manhours to perform corrective maintenance in place. (C)
9.	K	-	Number of line items of peculiar AGE used in repair of an LRU. (C)
10.	MFTBMA	-	Mean flying time between maintenance action for an LRU in the mature system. (C)
11.	NRTS	-	Fraction of removals expected to be returned to depot for repair. (C)
12.	PA	-	Number of new "P" coded reparable assemblies. (C)
13.	PP	-	Number of new "P" coded consumables. (C)
14.	QPA	-	Quantity of an LRU in the subsystem (quantity per application). (C)
15.	RIP	-	Fraction of operational failures which can be repaired in place. (C)
16.	RMH	-	Average manhours to remove and replace an LRU. (C)
17.	RTS	-	Fraction of removals expected to be repaired at base level. (C)

18.	SP	-	Number of standard (already stock-listed) parts. (C)
19.	UC	-	Expected unit cost; i.e., the cost expected to be exhibited at the time of initial provisioning. (C)
20.	W	-	Unit weight in pounds. (C)
21.	XLRU	-	LRU identification. (G)

AGE Variables

1.	BUR	-	Base level utilization rate. (C)
2.	CAB	-	Cost per unit of peculiar AGE for base level. (C)
3.	CAD	-	Same as CAB except refers to depot AGE. (C)
4.	COB	-	Annual cost to operate a unit of peculiar base AGE. (C)
5.	COD	-	Same as COB except refers to depot AGE. (C)
6.	DOWN	-	Fraction of downtime for a unit of AGE for calibration requirements. (C)
7.	DUR	-	Depot utilization rate. (C)
8.	XAGE	-	AGE identification. (G)

LSC MODEL EQUATIONS

C_1 = Initial and Replacement LRU Spares Cost

$$= \sum_{i=1}^{N} (STK_i)(UC_i)(M) + \sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(1-RIP_i)(UC_i)}{MFTBMA_i} \left[(DRCT_i)(MRTS_i)\right]$$

$$+ \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(1-RIP_i)(UC_i)}{MFTBMA_i} (COND_i)$$

where

M	=	Number of operating base locations.
N	=	Number of LRUs in the subsystem.
PFFH	=	Expected peak force flying hours per month.
TFFH	=	Expected total force flying hours over the Program Inventory Usage Period.
$MFTBMA_i$	=	Mean flying time between maintenance actions for the i^{th} LRU in the mature system.
QPA_i	=	Quantity of the i^{th} LRU contained in the subsystem.
UC_i	=	Expected unit cost of the i^{th} LRU; i.e., the cost expected to be exhibited at the time of initial provisioning for the i^{th} LRU.
RIP_i	=	Fraction of operational failures of the i^{th} LRU which can be repaired in place.
$BRCT_i$	=	Average base repair cycle time in months for the i^{th} LRU.
$DRCT_i$	=	Average depot repair cycle time in months for the i^{th} LRU.
RTS_i	=	Fraction of removals of the i^{th} LRU expected to be repaired at the base
$NRTS_i$	=	Fraction of removals of the i^{th} LRU expected to be returned to the depot for repair.
$COND_i$	=	Fraction of removals of the i^{th} LRU expected to result in condemnation at base level.

STK_i = Base stock level for the i^{th} LRU which includes a safety stock level. The computation of STK_i considers the mean demand rate for the i^{th} LRU (λt) and EBO, the established standard for expected backorders for the applicable subsystem.

$$\lambda t = \frac{(PFFH)(QPA_i)(1-PIP_i)}{(MFTBMA_i)(M)} \left\{ RTS_i(BRCT_i) + NRTS_i \left[OSTCON(1-OS) + OSTOS(OS) \right] \right\}$$

where

OSTCON = Average order and shipping time within the CONUS.

OSTOS = Average order and shipping time to overseas locations.

OS = Fraction of the total force deployed to overseas locations.

then, find the minimum value of STK_i such that

$$\sum_{X>STK_i} (X - STK_i)p(X|\lambda t) \leq EBO, \text{ where } p(X|\lambda t) \text{ is Poisson.}$$

C_2 = On-Equipment Maintenance Cost

$$= \sum_{i=1}^{N} \left[\frac{(TFFH)(QPA_i)(BLR)}{MFTBMA_i} \right] \left[(RIP_i)(IMH_i) + (1-RIP_i)(RMH_i) \right]$$

$$+ \frac{(TFFH)(SMH)(BLR)}{(SMI)}$$

where

BLR	=	Average base-level labor rate in dollars/manhour.
IMH_i	=	Average manhours to perform corrective maintenance in place for the i^{th} LRU.
RMH_i	=	Average manhours to remove and replace the i^{th} LRU.
SMH	=	Average manhours to perform scheduled maintenance (including preventive maintenance, preflight, postflight and periodic inspections of the subsystem).
SMI	=	Scheduled maintenance interval in flying hours for the subsystem.

C_3 = Off-Equipment Maintenance Cost

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(1\text{-}RIP_i)}{MFTBMA_i} \left\{ RTS_i \left[(BMC_i)(UC_i) + (BMH_i)(BLR) \right] \right.$$

$$+ NRTS_i \left[(DMC_i)(UC_i) + (DMH_i)(DLR) \right]$$

$$\left. + \left[(1\text{-}OS)(PSC) + (OS)(PSO) \right] (1.25W_i) \left[2(NRTS_i) + (COND_i) \right] \right\}$$

where

BMC_i = Average material cost per base maintenance action expressed as a fraction of the unit cost (UC_i) of the i^{th} LRU. The material cost includes the mean dollar value of the consumables utilized in repairing the i^{th} LRU and any subordinate reparables of the LRU.

DMC_i = Same as BMC except refers to depot maintenance actions.

BMH_i = Average manhours at base level to diagnose, repair or attempt to repair the i^{th} LRU.

DMH_i = Same as BMH except refers to depot manhours.

DLR = Average depot labor rate in dollars/manhour.

W_i = Weight in pounds of the i^{th} LRU.

PSC = Average packing and shipping cost in dollars/pound for CONUS locations.

PSO = Average packing and shipping cost in dollars/pound for overseas locations.

C_4 = Inventory Entry and Supply Management Cost

$$= \left[IAC + (PIUP-1(RAC)\right] \sum_{i=1}^{N} (PA_i+1) + \left[IPC + (PIUP-1)(RPC)\right] \sum_{i=1}^{N} (PP_i)$$

$$+ (M)(SA)(PIUP) \left[N + \sum_{i=1}^{N} (PA_i + PP_i + SP_i) \right]^*$$

where

PIUP	=	Operational service life of the system in years.
IAC	=	Initial inventory management cost to introduce a new "P" coded reparable assembly into the Air Force inventory.
IPC	=	Same as IAC except refers to consumable items.
RAC	=	Recurring inventory management cost to maintain a reparable assembly in the wholesale system (expressed in dollars/item/year).
RPC	=	Same as RAC except refers to consumable items.
SA	=	Annual base supply inventory management cost in dollars/item/year.
PA_i	=	Number of new "P" coded reparable assemblies within the i^{th} LRU.
PP_i	=	Number of new "P" coded consumables within the i^{th} LRU.
SP_i	=	Number of standard (already stock-listed) parts within the i^{th} LRU.

*NOTE: If $RTS_i = 0$, this last term becomes

$$(M)(SA)(PIUP)(N)$$

C_5 = Cost of Support Equipment (AGE)

$$= \sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(1\text{-}RIP_i)}{MFTBMA_i} \sum_{j=1}^{K} \left\{ \frac{(RTS_i)(BMH_i)}{(BUR_j)(1\text{-}DOWN_j)(BAA)} \left[(CAB_j) \right. \right.$$

$$\left. + (PIUP)(COB_j) \right] + \frac{(NRTS_i)(DMH_i)}{(DUR_j)(1\text{-}DOWN_j)(DAA)} \left[(CAD_j) + (PIUP)(COD_j) \right] \Bigg\}$$

$$+ FLA + BA + DA + CS\ IH$$

where

BUR_j = Base-level utilization rate for AGE end item j; $0 < BUR_j \leq 1$.

DUR_j = Depot utilization rate for AGE end item j; $0 < DUR_j \leq 1$.

BAA = Total active work time in the base shop per month. (e.g., if there are two eight-hour shifts per day and 20 work days per month, BAA = (16)(20) = 320 hours/month).

DAA = Total active work time in the depot per month. See BAA.

CAB_j = Cost per unit of peculiar base AGE end item j.

CAD_j = Same as CAB_j except relates to depot AGE.

COB_j = Cost per year per unit of operating peculiar base AGE end item j.

COD_j = Same as COB_j except relates to depot AGE.

$DOWN_j$ = Fraction of downtime for AGE end item j for calibration requirements; $0 \leq DOWN_j < 1$.

K = Number of line items of peculiar AGE used in repair of the i^{th} LRU.

FLA = Cost of additional common or peculiar flight-line AGE to support the subsystem.

DA = Apportioned cost of additional common depot support equipment.

BA = Apportioned cost of additional common base shop support equipment.

CS = Cost of software to utilize existing Automatic Test Equipment.

IH = Cost of interconnecting hardware to utilize existing Automatic Test Equipment.

NOTE: In order to compute AGE costs realistically, integer quantities should be considered. The quantity

$$\frac{(PFFH)(QPA_i)(1-RIP_i)}{(MFTBMA_i)} \left[\frac{(RTS_i)(BMH_i)}{(BUR_j)(1-DOWN_j)(BAA)}\right]$$

represents the fractional requirement for the j^{th} item of AGE for the i^{th} LRU. All such fractional requirements for AGE item j can be accumulated for all LRUs in the system and the result rounded up to a whole number divisible by M to give the total base-level requirement for AGE item j. The total requirement multiplied by the term

$$\left[CAB_j + COB_j(PIUP)\right]$$

gives the total support cost for AGE item j. A similar exercise applies to the computation of depot AGE costs.

C_6 = Cost of Personnel Training and Training Equipment

$$= (TCB)\left[1 + (PIUP-1)(TRB)\right]\left\{\frac{(TFFH)(SMH)}{(PIUP)(PMB)(SMI)}\right.$$

$$\left. + \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)}{(PIUP)(MFTBMA_i)} \left[\frac{(RIP_i)(IMH_i)+(1-RIP_i)\left[(RMH_i)+(RTS_i)(BMH_i)\right]}{(PMB)}\right]\right\}$$

$$+ (TCD)\left[1+(PIUP-1)(TRD)\right] \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)}{(PIUP)(MFTBMA_i)} \left[\frac{(1-RIP_i)(NRTS_i)(DMH_i)}{(PMD)}\right]$$

$$+ TE$$

where

TCB	=	Cost of peculiar training per man at base level (including instruction and training materials).
TCD	=	Same as TCB except relates to depot training.
TRB	=	Annual turnover rate for base personnel.
TRD	=	Annual turnover rate for depot personnel.
PMB	=	Direct productive manhours/man/year at base level (includes "touch time", transportation time and set-up time).
PMD	=	Same as PMB except relates to depot manhours.
TE	=	Cost of peculiar training equipment required for the subsystem.

C_7 = Cost of Management and Technical Data

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(BLR)}{MFTBMA_i} \left[(MRO) + (1\text{-}RIP_i)(MRF + SR + TR)\right]$$

$$+ \frac{(TFFH)}{(SMI)} (BLR) \left[MRO + (0.1)SR + (0.1)TR\right] + TD(JJ + H)$$

where

MRO	=	Average manhours per maintenance action to complete on-equipment maintenance records.
MRF	=	Average manhours per maintenance action to complete off-equipment maintenance records.
SR	=	Average manhours per maintenance action to complete supply transaction records.
TR	=	Average manhours per maintenance action to complete transportation forms.
TD	=	Cost per original page of technical documentation.
JJ	=	Number of pages of organizational and intermediate level T.O.s.
H	=	Number of pages of depot level T.O.s and special repair instructions.

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