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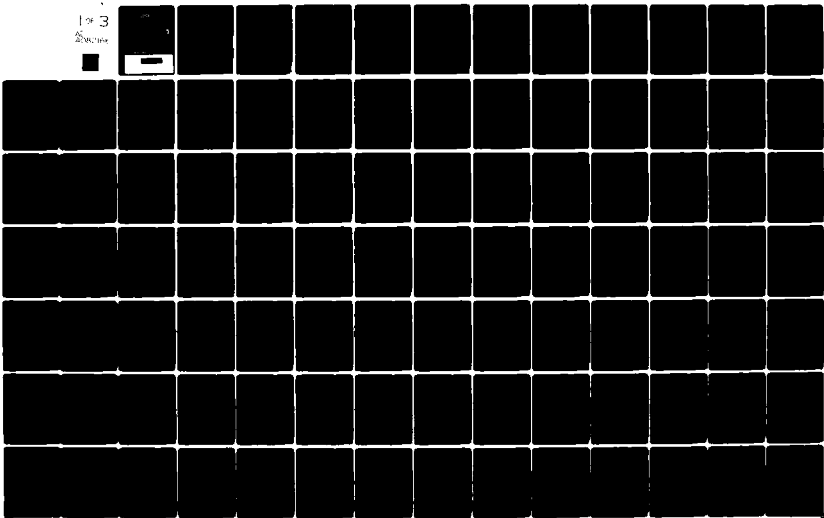

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Prepared for
AERONAUTICAL SYSTEMS DIVISION
(ASD/XRE)
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AFB, OHIO
under Contract F33657-79-C-0717

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This is the final report on a study concerning the development of an avionics packaging, mounting, and environmental (PME) standard and an associated cost-benefit analysis, performed by ARINC Research Corporation for Air Force Systems ~~Command,~~ Aeronautical Systems Division, Wright-Patterson AFB, Ohio. The report compares military and commercial airlines avionics generic standards to determine their technical and procedural differences and identifies the changes and waivers required when equipment built to the commercial airlines standards are procured by the USAF. It

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The opinions of aircraft and avionics manufacturers concerning a military avionics PME standard and their suggestions as to what the standard's scope and applicability should be, are reported. Alternative avionics cooling procedures and technologies and the concept of employing a separate environmental control system dedicated to avionics cooling are reviewed.

A life-cycle cost payback model that addresses the impact of PME standardization on the cost of avionics systems in USAF aircraft is described. The results of exercising the model are reported.

The significant tasks and scheduling for the next phases of avionics PME development, leading to the definition and acceptance of a military avionics PME standard, are presented.

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FOREWORD

Under Contract F33657-79-C-0717, ARINC Research Corporation conducted a study of the development of an avionics packaging, mounting, and environmental (PME) standard. This effort, performed for the Air Force Systems Command, included a cost-benefit analysis of PME standardization.

ARINC Research acknowledges the valuable contributions to this study provided by the Aeronautical Systems Division engineering staff (ASD/EN). We also are grateful for the cooperation extended by representatives of the aircraft and avionics industries in their written responses to our questionnaires and follow-up conversations with us.

ABSTRACT

This is the final report on a study concerning the development of an avionics packaging, mounting, and environmental (PME) standard and an associated cost-benefit analysis performed by ARINC Research Corporation for Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson AFB, Ohio. The report compares military and commercial airlines avionics generic standards to determine their technical and procedural differences and identifies the changes and waivers required when equipment built to the commercial airlines standards are procured by the USAF. It also compares the functional and physical characteristics of certain military and commercial avionics equipments and assesses the degree of utility of current commercial equipments for use in USAF aircraft.

The opinions of aircraft and avionics manufacturers concerning a military avionics PME standard and their suggestions as to what the standard's scope and applicability should be are reported. Alternative avionics cooling procedures and technologies and the concept of employing a separate environmental control system dedicated to avionics cooling are reviewed.

A life-cycle-cost payback model that addresses the impact of PME standardization on the cost of avionics systems in USAF aircraft is described. The results of exercising the model are reported.

The significant tasks and scheduling for the next phases of avionics PME development, leading to the definition and acceptance of a military avionics PME standard, are presented.

EXECUTIVE SUMMARY

1. INTRODUCTION

This report concerns the standard avionics packaging, mounting, and cooling (PMC) concepts used by the United States commercial airlines and their applicability to United States Air Force (USAF) avionics. The study it culminates investigated (1) the extent to which avionics subsystems built to commercial form, fit, and function (F^3) standards might be used in USAF aircraft; (2) aspects of equipment packaging, equipment thermal performance, aircraft environmental control, and aircraft electromechanical interfaces to which a USAF PME (Packaging, Mounting, Environment)* standard might be applied successfully; and (3) the cost-benefit relationships associated with various approaches to implementing the elements of a USAF PME standard. Also, a plan for developing and applying a USAF PME standard was completed as part of the study.

The contract's Statement of Work identifies the following subjects for study:

- Task 1: Potential USAF Use of Commercial Avionics
- Task 2: Cost-Benefit Relationships Associated with USAF PME Standardization in Avionics
- Task 3: Development Plan for an Avionics PME Standard

The first work of Task 1 was the identification of generic differences between the Military Specifications and Standards applicable to USAF avionics procurement and the ARINC Characteristics and Specifications. A corollary to this work was the identification of general exemptions to the Military Specifications and Standards that will be required if commercially developed avionics are to be used.

The second part of Task 1 was a review of specific avionics equipments, specifications, or functional requirements associated with several USAF aircraft types to determine the applicability of commercial equipment defined by ARINC 500 series Characteristics ("Current Commercial Avionics") and the ARINC 700 series Characteristics ("Future Commercial Avionics").

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*For purposes of this study, the term "PME" is used interchangeably with "PMC", since the major environmental impact under discussion is cooling or the thermal environment.

Task 2 started with the development of a systematic methodology for cost-benefit analysis for such factors as the following:

- Retrofit versus new (future installations)
- Small aircraft versus large aircraft
- Life-cycle-cost impacts
- Reliability/maintainability impacts
- Impact on common avionics versus mission-unique avionics

The second stage of Task 2 was the development of preliminary cost-benefit figures for the following standardization alternatives:

- Avionics line-replaceable unit (LRU) packaging standard
- Avionics rack/mounting/interface standard
- Avionics environment standard
- Avionics common power standard
- All of the above as a full PME standard

In support of this cost-benefit analysis, industry opinion was solicited on the potential benefits and cost implications of a military avionics PME standard. The impact of new avionics cooling technologies on PME standardization alternatives was also addressed.

In Task 3 a likely scenario for implementing a USAF PME standard was developed. It suggests that the effort needed to develop alternative PME standards should be scheduled over the next 1-1/2 to 2 years, and the task descriptions for each work package carefully defined.

A plan was formulated for developing the PME standard by open-forum discussions of "strawman" standards in meetings attended by user command and industry representatives.

Our general findings in each of these task areas are summarized in the following sections.

2. COMPARISON OF MILITARY AND AIRLINES STANDARDS

Because of their different origins and objectives, there is considerable divergence between the military standards and specifications that govern USAF avionics procurement and those that serve a parallel function for civil aviation -- FAA, RTCA, ICAO performance standards and commercial airlines (ARINC) form, fit, and function (F^3) characteristics. During this study, we reviewed a large number of both military and commercial specifications and standards in attempting to determine some of the major differences between them in both purpose and use. As a result of this review, in conjunction with ASD personnel, we developed generic classes of differences and specific waiver exemptions we feel would be applicable to use purely commercial standards for military applications. We concluded that there were three generic classes of differences:

- Physical and Performance Differences - Airlines units may be too big for space-premium USAF aircraft, may not withstand the physical environment of these aircraft, or may not provide the performance characteristics required by these aircraft. In some cases, accommodations may be made, but generally this class of differences dissuades the use of commercial equipments.
- Electrical and Mechanical Interface Differences - These encompass differences in connectors, data formats, cooling-air needs, etc., which result from differences in military and commercial practices. Minor modifications or waiver of military requirements can make commercial avionics acceptable for military use.
- Procurement Documentation Differences - ARINC Characteristics specify form, fit, and function (F^3) interfaces and do not detail design features or specify piece-parts and processes. MIL Specifications detail design and construction as well as performance required. Also, differences occur in application of quality control, vendor participation, and acquisition practices. These differences do not affect the functional adequacy of commercial equipments, but they do raise concerns in military acquisition and logistics circles.

3. POTENTIAL USE OF COMMERCIAL AVIONICS

Commercial airlines flight-essential avionics are designed, manufactured, tested, and certified to a well defined and documented set of standards, which correlate qualitatively, and sometimes quantitatively, with equivalent military specifications and standards. The key specification that has been in use in the commercial airlines since 1956 is ARINC Specification 404: Air Transport Equipment Boxes and Racking. Avionics equipments defined by current ARINC Characteristics (the "500 series") comply with ARINC 404A and provide a high degree of interchangeability between like units supplied by different avionics manufacturers. The airlines have developed and implemented a new-generation racking specification -- ARINC Specification 600. The principal advance of ARINC 600 over ARINC 404A is in ensuring the availability of improved cooling by limiting the avionics thermal dissipation according to the LRU case size, and by requiring adequate quantities of clean cooling air to be furnished to it. Other changes redefine the allowed avionics case sizes and introduce a new style "low insertion force" rear connector and revised box hold-down arrangements. Avionics equipments conforming to ARINC 600 are defined by ARINC Characteristics in the "700 series." The ARINC 700 series Characteristics also standardize data input and output to the digital formats of ARINC Specification 429, Digital Information Transfer System (DITS) and, where appropriate, to ARINC Specification 453, Very High Speed Data Bus. On the basis of our review of selected commercial standards and their applications to specified USAF aircraft, we make the following conclusions:

- Existing commercial avionics are broadly applicable to use in military transport aircraft; only relatively simple racking and interface changes are required in aircraft not originally designed for commercial avionics.
- Existing commercial avionics can be used in bombers and other penetration aircraft if racking and interface modifications are made in the aircraft and if the aircraft and/or avionics are modified to provide required interfaces with mission equipment, to prevent EMI, and to provide for EMP and nuclear hardening.
- Existing commercial avionics generally will not be applicable to high-performance aircraft because of space, environment, or performance constraints; in some cases, however, available space may permit installation of selected avionics and necessary interfaces.
- Use of future commercial avionics will require adaptive work in USAF aircraft. In addition, because they accept only digital inputs and provide only digital outputs (both to the ARINC 429 format), future commercial avionics will require additional interface equipment to make them compatible with existing analog inputs and/or with the MIL-STD-1553 data bus.
- The cost-benefit relationships associated with the USAF's using commercial avionics are difficult to articulate. The use of commercial avionics can circumvent the development time and cost of military procurement in circumstances where military equipment is not readily available. The acquisition cost of commercial avionics is comparable to large-lot GFE procurements for similar functional systems. The greater maturity and higher reliability in commercial avionics, generally due to higher flying-hour experience and continuing vendor involvement, tend to offset higher logistics cost that may be introduced by non-standard parts. Each procurement should continue to be evaluated on a case-by-case basis.

Table S-1 lists our findings on the degree of applicability of ARINC 500-series equipments in selected military aircraft.

4. STUDIES SUPPORTING COST-BENEFIT ANALYSIS

As part of the cost-benefit analysis of Task 2, we were asked to perform two special supporting studies: (1) an industry survey to solicit opinions and data on the merits of a USAF avionics PME standard and (2) a review of "new" cooling technologies, to assess the potential effects of such technologies on future PME standardization.

Table S-1. APPLICABILITY OF ARINC 500 SERIES AVIONICS TO CURRENT USAF AIRCRAFT

Avionics Function	Already Installed or Planned	Requires Feasible Changes to Avionics	Requires Changes to "A" Kit	Requires Additional Space
HF Radio ARINC 533A* or ARINC 559A	C-130, C-141	B-52, KC-135, C-5, F/FB-111, A-10, B-52	B-52, KC-135, C-5, F/FB-111, A-10, B-52	B-52, KC-135 C-5, F/FB-111
Radar Altimeter ARINC 552A	E-3	F-111, F-4, A-7, C-5, C-141, KC-135, HH-53	CH-3, F-111, C-130, F-4, A-7, C-5, C-141, KC-135, HH-53	CH-3, F-4, A-7, KC-135, C-141, C-5, HH-3
Weather Radar ARINC 564	KC-10, E-3, KC-135	C-5, C-130, C-141, E-3	C-130	-
Crash Recorder ARINC 573	E-4, C-9, C-141, VC-137	-	-	-
GPWS ARINC 594	C-5, C-141, T-43, KC-10	-	-	-
ADC ARINC 565 or ARINC 565	E-3, E-4, C-5, KC-10	C-141	C-141	-
INS ARINC 561-11	C-5, C-141, C-130, E-3, KC-135	F-4, F-111	F-4, F-111, F-16	-

*ARINC 533A has a 1 ATR long form factor but includes most military needs. Collins 618(T) is an ARINC 533A unit.

4.1 Industry Survey

Industry inputs were solicited by a mailed questionnaire. Follow-up visits were made to General Dynamics at Ft. Worth, Rockwell International (Collins Radio) at Cedar Rapids, and Bendix Avionics at Ft. Lauderdale. We conferred with personnel of Boeing Aerospace at Seattle by telephone. These direct contacts reinforced the written responses and provided first-hand information on current military and commercial avionics integration constraints in high-performance aircraft. The survey revealed an almost unanimous opinion that the military should establish an avionics PME standard along the lines of the AEEC/ARINC concept; there would need to be differences, it was generally conceded, because of the different sizes and environmental constraints of military aircraft and the sometimes more stringent performance requirements. There was an equally emphatic opinion among both aircraft and avionics manufacturers that military environmental test requirements were frequently much more demanding than the actual aircraft environment warranted. The avionics manufacturers felt that this over-specification, together with military-qualified-parts requirements, represents a cost element in military procurement that is not justified by any demonstrated superiority of the military product over its commercial counterpart.

The consensus was that a USAF avionics PME standard, based on the ARINC 600 concept, is probably viable and could be broadly beneficial for certain classes of aircraft in the proper context. The standard would need to be divided into subsets or sections to avoid "worst case" over-specification on the one hand, or excessive numbers of exceptions (needed by high-performance military aircraft) from a standard primarily directed at the transport aircraft environment, on the other hand.

While it would be desirable to apply a PME standard to all remotely mounted avionics, respondents felt that it might be more practical to restrict application of the standard to "common functions", excluding mission avionics completely. They also agreed that the primary application should be to new aircraft.

4.2 Review of Avionics Cooling Technology

Alternative avionics cooling technologies were reviewed to determine what potential impact they might have on USAF avionics standardization.

The requirement to transfer increasingly greater amounts of heat from components or chips to the outside of the package will put more emphasis on the use of conductive heat transfer rather than transfer by natural convection, internal fans, or forced air. Heat transfer from the package to the final heat sink (outside air or fuel) may rely on circulating air, vapor, or liquid, or may also be entirely conductive. Technology is now available to implement such a shift from the almost routinely used blow-through air-cooling systems to self-contained closed-cycle cooling systems or, in some circumstances, to thermoelectric heat transfer. Advantages of such a change include:

- Improved operation at high altitude
- Exclusion of contaminants (water, dust, nuclear debris)
- Less power drawn from the aircraft's propulsion system

These design trends emphasize the need to plan for a new USAF avionics PME standard, as well as making optimum use of commercial transport avionics where these will adequately perform the required function.

5. COST-BENEFIT ANALYSIS

During this preliminary study of PME standardization, two of the principal activities were (1) to develop a methodology for evaluating the potential effects of an avionics PME standard on the costs associated with the avionics in a fleet of aircraft through its life cycle, and (2) to develop and exercise a computer program in support of the evaluation; the program had to be capable of analyzing the effects of the five alternative standards under consideration:

- Avionics line-replaceable unit (LRU) packaging standard
- Avionics rack/mounting/interface standard
- Avionics environment standard
- Avionics common power standard
- Avionics PME standard (combination of the above)

The scenario that we used to perform the PME cost-benefit analysis included a mix of three types of aircraft that are currently in the USAF's projected force structure: (1) high-performance tactical, (2) tactical attack/observation, and (3) cargo/transport. This force subset is proportionally representative of the total USAF current inventory.

Avionics costs were separated into two groups: (1) communication and radio-navigation equipments (e.g., UHF Radio, TACAN), and (2) mission or aircraft-unique equipments, (e.g., EW, radar). A third cost group was added to account for the cost of environmental control when included in the standard being analyzed.

The sensitivity of potential saving to input assumptions was also determined; this provided significant insight into the relative attractiveness of each standardization concept.

Results of the cost-benefit analysis are depicted in Figure S-1.

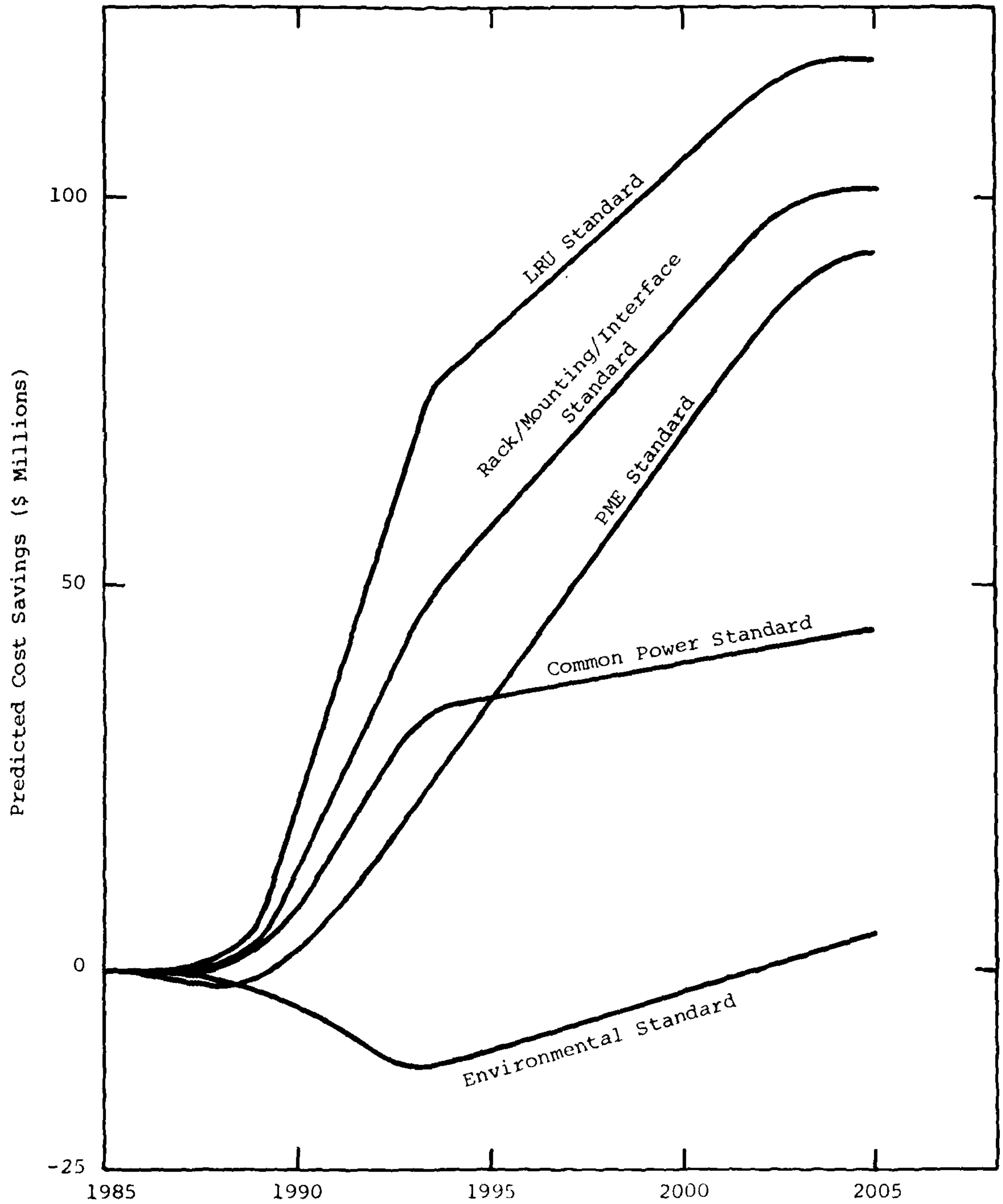

Figure S-1. PREDICTED CUMULATIVE COST SAVINGS IN AVIONICS/ AIRCRAFT INTEGRATION, OPERATION SUPPORT, AND MODIFICATION

Future cost paybacks will stem primarily from cost saving on LRU acquisitions and avionics-update modifications. We expect that the principal expenditure will be for implementing the environmental control system standard. Because of this, the new cost saving will be significantly limited for the two standardization alternatives that include an environmental standard (avionics environmental standard and full avionics PME standard). The largest payback potential resides in applying standardization to aircraft or mission-unique avionics, simply because this group incurs the greatest avionics cost and occurs in the most numerous aircraft, the tactical fighters.

If the scenario used to perform the cost-benefit analysis had not been limited to avionics used only in future aircraft, larger returns in the aggregate might have been shown. However, it was not possible to determine realistically the extent to which the PME standardization alternatives could be implemented in an existing aircraft architecture or at what cost they could be implemented. This inability stemmed principally from the wide variations in retrofit needs.

The following are key conclusions that provide good direction for future work:

- Aircraft not yet designed appear to be the best candidates for implementation of the USAF PME standard. For these aircraft, our analysis showed that economic advantages would accrue through the PME standardization alternatives in the following order of merit: (1) LRU packaging standard, (2) rack/mounting/interface standard, (3) full PME standard, (4) common power standard, and (5) environmental standard. Payback periods varied from 5 to 15 years depending on investment required and benefits gained.
- Fighter-type aircraft comprise the largest component of the USAF projected force and the largest component of the representative force addressed in this analysis. Even small cost changes associated with this class of aircraft will derive large changes in total USAF avionics life-cycle cost.
- Radar, weapon-delivery, and electronic-warfare avionics costs dominate the avionics suite LCC and, consequently, have the biggest potential quantitative payback for PME standardization.
- The "common" group of avionics, which is the most amenable to the use of commercial or similar standards, represents only a minor part of the total cost of the avionics for a combat aircraft; however, one must remember that operational benefits stem from any availability improvements in flight essential functions.
- Installation of new PME standard equipments (racks, mounting provisions, connectors and cables, environmental control, etc.) in older aircraft would cost at least as much as installation in new production-line aircraft, and most likely a great deal more. Any saving attributable to upgrading older aircraft with PME standards

would necessarily be less than that for new aircraft by the increased cost of installation. Thus the payback time would be longer, but there would be less opportunity to secure the possible benefits because of the age of the aircraft at the outset. If a PME standard is implemented, the value of installing PME equipments on older aircraft would need to be evaluated by trade-off studies on a case-by-case basis as hard PME cost data were developed.

- Environmental improvement implemented in conjunction with PME standardization would have a much more significant payback potential than environmental improvement implemented alone.
- The common power standard can be implemented on a stand-alone basis. The implementation cost necessary to provide better regulation, voltage spike protection, and outage prevention are much less than those for the improved cooling system. Currently, this protection must be provided within each LRU. The payback starts by removing this cost from the LRU (acquisition saving) and continues with improved reliability (O&S saving).
- The standardization choices are not mutually exclusive; for example, continued use of commercial standards for transport-type aircraft and adaptation of the ARINC standards for other applications could be approached simultaneously; or an LRU packaging standard developed initially could later be included as part of a full PME standard.

6. SELECTED TECHNICAL ASPECTS OF PME STANDARDIZATION

ARINC 500 and 700 series avionics equipments have different degrees of direct usability in USAF aircraft. Except where space, environment, or performance prohibit it, adaptability can be achieved through interface accommodation, waiver of standards, and changes in the procurement process. These requirements often cannot be accommodated within the authority of the military procuring agency, with the result that frequently a decision is made to pursue a military development. In many cases, this spawns another new and individualistic piece of USAF equipment. A PME standard that has attributes similar to ARINC standards can remove many of these superficial obstacles to the use of commercial equipments. Among the industry representatives we surveyed, there is a consensus that applying a USAF PME standard is a suitable way to gain many standardization benefits attributed to commercial practices, even if commercial avionics themselves are not employed. This notion complements the current USAF standardization thrust, by providing cross-system advantages of standardization as well as those gained by the GFE approach. The PME concept can extend from standard boxes, racks, plugs, wiring, test equipment, installation design, and modification process to power sources, environmental control sources, ducting, and porting. In addition, it introduces a high potential for commonality in many other aspects across multiple platforms.

We make the following specific conclusions:

- Sizing is the main point of contention associated with a PME standard. ARINC 404A and 600 Standards are considered "frequently too large," especially for space-constrained fighter-type aircraft. Sizing in a PME standard should accommodate generalized USAF needs; while a single standard would be preferable, multiple standards may be necessary to serve the full range of USAF needs economically. Perhaps some combination(s) of USAF and commercial sizing would be possible, to permit cross-fit of equipments. Size concerns appear to loom in the following order of priority: first, height; second, length. Width is not mentioned as a concern.

- The next most severe contention centers around environmental control, which would require design to maximize long-term benefits of current and future techniques. If designed and implemented carefully, an environmental standard could benefit not only the prime users (such as the F-16 and F-111) but also those who would achieve environmental control as a bonus. While good environmental design parameters certainly do not lower design and acquisition costs, they do provide lower peak operating temperatures, which, in turn, reduces equipment failure rates. This serves to reduce operating and support costs directly.

  - Convection cooling continues to serve the commercial airlines needs because of the availability of pressurized and conditioned cabin air and the acceptability of low-density avionics packaging. Military aircraft designs, too, have continued to use convection cooling for most avionics installations, in spite of the performance shortcomings that occur under some military operating conditions. At the same time, escalating performance requirements have forced avionics designers to achieve denser component packaging, pushing the state of the art of high-temperature electronic components.

  - Alternative techniques for removing excess heat from avionics components have been amply demonstrated in mission-equipment installations where forced-air cooling is not sufficiently effective. Advanced environmental studies are in process in industry today; if the results are available in time, they deserve assessment before USAF environmental standardization features are settled on.

- Vibration standards and the qualification testing relating to them need to be reconsidered in conjunction with potential shock mounting techniques. Vibration isolation for a complete avionics box-rack combination presents qualification-test problems; hard mounting is preferable, but vibration test conditions appropriate to specific aircraft and box locations should be specified. The current method of generalizing requirements frequently leads to over-specifying qualification tests and, consequently, the equipment itself. Benefits could accrue from lower costs for production and qualification testing.

- Quality control requirements on piece-parts create cost escalation for military equipments that is not necessarily incurred by commercial counterparts. In the views of several avionics manufacturers, however, the higher price of military quality control does not buy better quality. Rather, MTBF guarantees can be used to provide a positive incentive for a contractor to achieve proper design for good performance. RIW also gives the manufacturer a continuing opportunity to improve equipment performance if he chooses to -- or needs to -- to forestall an unacceptable deterioration in performance.

7. PME IMPLEMENTATION PLAN

An avionics standard for packaging, mounting, and environmental control must be applicable to a wide variety of equipments and aircraft and acceptable to the user and logistics communities. It must be managed according to a concept that stimulates and facilitates its use, primarily in new aircraft programs but also in major avionics modernization programs. Decisions must be made concerning the "depth" of the standardization to be specified, the form factors and interface parameters that are to be preferred, and the classes of aircraft to be involved. We conclude that the following specific matters should be addressed:

- Programs within the USAF, in other military services, and in industry will contribute to the formulation of basic design requirements. Study and planning will also be needed to provide design options and data from which one or more "strawman" PME standards can be developed. An AEEC-like open-forum procedure, involving representatives of the military developer, user, and logistics agencies and aircraft and avionics manufacturers, is seen as the most effective way to produce a well balanced avionics standard and obtain all-around support for its application.

- Some of the aspects of PME standardization can be implemented progressively. For example, a common power standard could be applied to the electric power supply of the next new aircraft program; existing configurations of environmental control systems could be upgraded to meet an improved cooling standard. Other aspects of PME standardization need cautious planning so that they do not conflict with technology growth (e.g., in aircraft configuration, environmental support techniques, and avionics component and device integration) or with possible subsequent higher levels of standardization.

- While the use of a PME standard generates its own advantages, expanding the concept from one of form, fit (F^2), and environment to one of form, fit, function (F^3), and environment raises the likelihood of future functional standardization, which has been widely discussed but only occasionally implemented in the Air Force. The benefits achieved through the combination of box and functional standardization are synergistic: the user and the supplier enjoy continuing competition, interchangeability, maturity, and ease of modification, and also work within the framework of a well established, recognized, and accepted discipline that encourages its own use.

- PME standardization can be applied to any class of avionics as a box standard. Function standardization should probably be added only for common and mature avionics functions -- mission avionics should be considered, at best, only if they have reached an equivalent stage of maturity. In short, F^2 can be applied to most avionics; F^3 probably should be limited to common avionics and perhaps the less complex mission avionics functions. The following is a possible sequence of events:
  - An initial "strawman" PME standard could address box size, cooling interface, rack-mounting arrangements, and connector configuration; it should be adaptable to all "avionics bay" LRU applications.
  - Individual functional standardization planning could follow for mature avionics subsystems: this would lead to "strawman" standards for "form, fit, and function" specifications applicable to future Air Force procurements with standardized interwiring.
  - As digital data bus standardization becomes more widespread, standard interwiring constraints will become less burdensome and increasing proportion of avionics LRU specifications could well be upgraded from an F^2 content to an F^3 content.

  While PME standardization techniques are appropriate for all USAF aircraft, the idea of undertaking an entire avionics-system overhaul to incorporate new avionics standards in existing aircraft does not appear reasonable. However, when entirely new avionics suites are being considered for retrofit, as in the case of the B-52, F-4G, etc., there may well be merit to a wholesale incorporation of the new standards. This would need to be evaluated on an aircraft-by-aircraft basis after basic PME acquisition and installation cost factors have been ascertained. On new aircraft, the incorporation of a PME standard would be an integral part of the design process; this appears to be the most reasonable place to initiate the concept.

8. RECOMMENDATIONS

This section presents our recommendations concerning (1) the use of commercial avionics by the USAF and (2) the development and implementation of a USAF PME standard. They are based on the results of the investigation described in this report.

Commercial airlines standard avionics, existing and future, have valid applicability to USAF aircraft. We make the following recommendations for pursuing this course:

- Procedural restraints and maintenance concepts should be reevaluated and restructured to encourage the use of these equipments wherever this course is technically and economically valid; appropriate revisions should be made to MIL-Standard directives.
- Standardized approaches to solving typical integration difficulties should be developed.

- Volumetric and environmental criteria should be established to give general guidance on the applicability to high-performance space-premium aircraft.
- Ultimately, each aircraft program decision should be the result of an individual trade-off evaluation of its common-avionics needs, interfaces, and cost constraints.
- While pursuing the development of its own PME standard, the USAF should undertake actions to foster greater commonality in avionics systems; these could include the sponsorship of a MIL-SPEC for the ARINC 600 low-insertion-force connector and mutual cooperation in the development of concepts for fiber optics data busses and software standards.

The following specific actions are recommended for establishing the USAF PME standard:

- Official USAF projections of new aircraft construction and major retrofit programs should be reviewed to determine the total market size for new rack-mounted avionics in the 1985 to 1995 period. The avionics should be categorized by type of system (radar altimeter, INS, etc.), and within each category the proportion to be installed in each class of aircraft should be determined. This process will identify the 10-year equipment universe and performance drivers for the PME standard and the extent to which retrofit applications should be considered.
- An overall management approach for the implementation and enforcement of the selected standard should be developed. The approach should consider the following particulars:
    - The roles of AFSC and AFLC in implementation and control
    - The extent of participation by industry
    - Partial versus full-up implementation approaches
    - Procurement mechanisms
- The initial "strawman" standards for consideration by the USAF and industry technical community should be developed. Following the guidance provided by the PME standardization road map, two parallel but related tasks should be undertaken: an electrical and mechanical commonality analysis and development of alternate cooling concepts.
- Candidate avionics for each candidate aircraft should be surveyed to develop a baseline of potential interface parameters, develop the permissible numerical limits of each parameter, and identify the parameters that are applicable to multiple installations.
- The result of ongoing studies of cooling techniques conducted by the military and in contractually sponsored efforts (such as the Boeing B-1 cooling studies) should be examined for application to the candidate aircraft/avionics groups.

- Agenda, issues, and procedures should be established for the open-forum meetings at which the USAF PME standard will be developed. A PME standing committee should be established, with regular members from AFSC, AFLC, and the using commands, to oversee the implementation of the open-forum process. Participants and their assigned functional responsibilities in the committee should be defined.

- During the open-forum meetings, there should be continuing evaluations of the cost/performance impacts of the changes suggested by the participants. The exact nature of the trade-offs are difficult to forecast, but it is likely that they will concern, at least, the following matters:

    - Avionics acquisition, modification/integration, and support costs
    - Avionics repackaging, redesign of aircraft mounting racks, etc., and environmental control systems
    - Reliability and maintainability
    - Mission capabilities

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

This report concerns the standard avionics packaging, mounting, and cooling (PMC) concepts used by the United States commercial airlines and their applicability to United States Air Force (USAF) avionics. The study it culminates investigated (1) the extent to which avionics subsystems built to commercial form, fit, and function (F^3) standards might be used in USAF aircraft; (2) aspects of equipment packaging, equipment thermal performance, aircraft environmental control, and aircraft electromechanical interfaces to which a USAF PME* (packaging, mounting, and environment) standard might be applied successfully; and (3) the cost-benefit relationships associated with various approaches to implementing the elements of a USAF PME standard. Also, a plan for developing and applying a USAF PME standard was completed as part of the study.

1.1 BACKGROUND

The United States commercial airlines long have used a concept of building avionics subsystems to form, fit, and fucntion (F^3) standards known to the industry as ARINC Characteristics. These documents specify operational performance characteristics that the airlines want manufacturers to adhere to in the design and manufacture of the avionics equipment they offer. Electrical inputs and outputs (interfaces) are specified in detail to ensure functional interchangeability of the equipments to achieve complete standardization, the Characteristics are complemented by a second type of standard known as ARINC Specifications. These specify equipment dimensions, mounting, electrical connections, and environmental aspects. In short, the ARINC Characteristics dictate the internal electrical parameters that must be achieved through functional design of circuitry and interwiring with other subsystems, whereas the ARINC Specification dictate the external physical parameters, including mounting, cooling, and cabling.

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*The term "packaging, mounting, and environment" (PME) is used interchangeably with PMC for the purposes of this study. Although the major environmental aspect discussed is cooling, vibration and shock are other environmental considerations. The term PME is preferred so that the broader definition is applicable.

Airframe manufacturers are involved in this standardization process too, because they must build their avionics bays with racking, mounting, cabling, and cooling provisions that comply with ARINC Specifications and ensure that the aircraft wire bundles accommodate avionics interwiring in accordance with the ARINC Characteristics.

The net result of the ARINC Specifications and Characteristics is the provision of specific directions on mechanical, electrical, and environmental interfaces that yield standard and interchangeable equipments. On the other hand, USAF avionics development and procurement practices yield equipments whose sizes, shapes, mounting provisions, connections, cabling, environmental aspects, interfacing details, and signal characteristics are tailored to their original installations. The results are non-standard equipments that have generally standard functions. This situation evolved because of the USAF's need to apply new capabilities and technology in short time frames to satisfy constantly escalating performance requirements. The resultant military procurement procedure has been successful but at the expense of standardization.

Recently, however, the USAF has been emphasizing the use of "standard" GFE avionics wherever possible. Well known examples are the AN/ARN-127 ILS, the AN/ARN-118 TACAN, and the AN/ARC-164 UHF communications system. Benefits have been derived from this policy in the form of lower acquisition cost and significantly higher MTBFs. Table 1-1 shows some primary examples of standard GFE equipments currently in use or planned for use in new-generation USAF fighter/attack aircraft (F-15, F-16, A-10), and the older F-4s and F-111s. This table makes the point that the USAF has initiated an extensive thrust to reduce the proliferation of non-standard equipments even in the difficult environmental and space constraints of fighter aircraft.

In the same vein, many of the equipments shown in Table 1-1 currently are used or will be used in less environmentally demanding aircraft types, such as bombers and cargo aircraft. Because of their multiple-aircraft applications, these equipments have truly reduced proliferation and yielded impressive economies.

Even before this new generation of standard GFE equipment was developed, the USAF had started using equipments built to ARINC Characteristics in some cargo-type aircraft similar to commercial airliners. By these occasional purchases, the USAF buys mature, reliable equipments without the expenditures that otherwise would be needed to develop a suitable military equipment. This level of standardization does provide some of the benefits that the airlines enjoy -- principally lower cost and mature design -- but the additional benefits that flow from standard box packaging, mounting, and cooling are not attainable because military aircraft normally are not built in compliance with ARINC Specifications and Characteristics.

To gain all the benefits of standardized avionics and aircraft integration, the USAF would need to allocate substantial resources to cover the cost of initial work in avionics development and modification, aircraft integration/environmental control systems, and implementation of the

Table 1-1. EXAMPLES OF AVIONICS COMMONALITY IN TACTICAL AIRCRAFT									
Aircraft Type	Equipment Nomenclature and Functions								
	ARC-164 UHF Communications	ARC-186 VHF Communications	ARN-118 TACAN	ARN-127 VOR/ILS	AGM-65 Weapon Control	APX-101 IFF Transponder	LARA Radar Altimeter (Planned)	GPS Satellite Navigation (Planned)	JTIDS Data Net (Planned)
[illegible]-16A	X	X	X	O	X	X	O	X	X
F-1[illegible]A	X	X	X	O	O	X	O	X	X
[illegible]	X	O	X	X	X	O	X	X	X
[illegible]	X	X	X	X	X	O	X	X	X
RF-[illegible]	X	O	X	X	O	X	X	X	X
A-1[illegible]A	X	X	X	O	X	X	O	X	X
F-111A [illegible]	X	X	X	O	X Except -D	O	X	X	X

X = Used

O = Not used

standardization program. Naturally, the USAF is concerned about the potential for "payback" of these expenditures in the form of increased operating effectiveness, and reduced cost to manage, install, modify, operate, and maintain the avionics. As a result of this concern, ASD/XRE selected ARINC Research Corporation to perform this study under Air Force Contract F33657-79-C-0717.

1.2 STUDY OBJECTIVES

The contract's Statement of Work identifies the following subjects for study:

1.2.1 Task 1: Potential USAF Use of Commercial Avionics

The first work of this task was the identification of generic differences between the Military Specifications and Standards applicable to USAF avionics procurement and the ARINC Characteristics and Specifications. A corollary of this work was the identification of general exemptions to the Military Specifications and Standards that are required when commercially developed avionics are used.

The second part of Task 1 was a review of specific avionics equipments, specifications, or functional requirements associated with several USAF aircraft types to determine the applicability of commercial equipment defined by the ARINC 500 series Characteristics ("Current Commercial Avionics") and the ARINC 700 series Characteristics ("Future Commercial Avionics").

The results of the work performed under Task 1 are recorded in Chapter Two of this report.

1.2.2 Task 2: Cost-Benefit Relationships Associated with the USAF Avionics PME Standardization

Task 2 started with the development of a systematic methodology for cost-benefit analysis for such factors as the following:

- Retrofit versus new (future) installations
- Small aircraft versus large aircraft
- Life-cycle-cost impacts
- Reliability/maintainability impacts
- Impact on common avionics versus mission-unique avionics

The second stage of task 2 was the development of preliminary cost-benefit figures for the following standardization alternatives:

- Avionics LRU packaging standard
- Avionics rack/mounting/interface standard

- Avionics environment standard in aircraft
- Avionics common power standard
- Combinations of the above (full PME standard)

In support of this cost-benefit analysis, industry opinion was solicited on the potential benefits and cost implications of a military avionics PME standard. The impact of new avionics cooling technologies on PME standardization alternatives was also addressed. The results of these two investigations are reported in Chapter Three, while the work on cost-benefit analysis is reported in Chapter Four.

1.2.3 Task 3: Development Plan for an Avionics PME Standard

On the basis of the work reported in Chapters Two, Three, and Four, a likely scenario for implementing a USAF PME standard was developed. It suggests that the effort needed to develop alternative PME standards should be scheduled over the next 1-1/2 to 2 years, and the task descriptions for each work package carefully defined. The scenario is presented in Chapter Five.

A plan for developing a USAF avionics PME standard by use of a "strawman" standard and using-command and industry participation in open-forum discussions is presented in Chapter Six.

Conclusions are presented in Chapter Seven; recommendations are presented in Chapter Eight.

CHAPTER TWO

POTENTIAL USAF USE OF COMMERCIAL AVIONICS

Task 3.1 of the Statement of Work concerns the study of current and future commercial airline avionics, and the determination of their potential applicability and cost-benefit relationships to existing and planned USAF aircraft. ASD/XRE provided guidance on the types of military equipment and operational aircraft that were of primary interest to the USAF and that should be used to evaluate the seven classes of avionics listed in the Statement of Work. A copy of this guidance is included as Appendix A. We also performed an additional evaluation of a VOR/ILS so as to include a military avionics equipment that was developed to have USAF-wide application to many types of aircraft. The following avionics equipments were studied, therefore:

- HF Radio
- Radar altimeter
- Weather radar
- Crash recorder
- Ground proximity warning system
- Air data computer
- Inertial navigation system
- VOR/ILS

2.1 TECHNICAL APPROACH

To evaluate the potential use of commercial airline avionics in USAF aircraft, we had to address the generic differences in civil and military procurement procedures, design specifications, and qualification-test requirements, as well as the differences in requirements and specifications for the designated avionics functions.

The USAF (AFSC/ASD/EN) provided technical comparisons between civil and military standards and information on MIL-Standards changes now under consideration. These inputs were included in our analysis and also are reproduced as Appendix B.

The generic differences in acquisition methods and standards are addressed first to identify major obstacles to the widespread use of commercial avionics in USAF aircraft and to list the exemptions from generic requirements needed if they are to be used. Then each of the designated commercial avionics equipment specifications is compared with the corresponding Air Force specification to determine the extent of its possible application in each designated aircraft. Relative costs also are compared for several equipments to provide a basis for determining potential cost advantages of the USAF's use of commercial avionics equipments.

2.2 OVERVIEW OF THE COMMERCIAL AVIONICS ACQUISITION PROCESS

In the same way that military avionics acquisition procedures, documentation, system effectiveness, and safety are governed by the application of DoD procurement directives, MIL-Standards, and MIL-Specification requirements, suppliers of avionics equipment to the airlines are governed by commercial contract, Federal regulatory agencies, and airline industry technical standards bodies and documentation. All of these are illustrated in Figure 2-1. These standards and how they are developed, approved, and used have been described in other ARINC Research reports*. A recapitulation of the process is provided here along with such aspects as the specification and characteristic development process, the airlines/FAA certification process, and associated business methodologies, in order to introduce the latest changes and provide background material for the reader unfamiliar with the process. The process is then compared with the military standards and procurement practices.

2.2.1 Airline Procurement

The high cost of developing, buying, and supporting aircraft electronic equipments was one of the major problems faced by the airlines as they were growing in the 1920s and 1930s. Each of the airlines was striving to provide safe, reliable, and on-time services to its customers, which required safe and reliable electronic systems on board the aircraft. This meant specifying new equipment and having it developed, bought, and supported each time an airline recognized a need for improvement or change. While this process frequently generated new ideas and gave impetus to the advancement of technology, it also proved to be time-consuming and expensive.

*References:
1. "Adaptability of Airline-Type Avionics Acquisition Processes to Advanced Landing System Procurement", Publication 1054-01-1-1329, October 1974.
2. "Special Report - Summary of Efforts: ASD/(RWSV) Standardization and Avionics Subsystem Interfaces", Publication 1269-01-1-1449, August 1975.
3. "Air Force Avionics Standardization: An Initial Investigation into an ASD INS Procurement Concept", Publication 1269-01-2-1497, May 1976.
4. "Air Force Avionics Standardization: An Examination of Implementation Alternatives for an Avionics F^3 Procurement Concept", Publication 1902-01-2-1599, March 1977
5. "Air Force Avionics Standardization: An Assessment of System/Subsystem Standardization Opportunities", Publication 1910-13-2-1722, March 1978

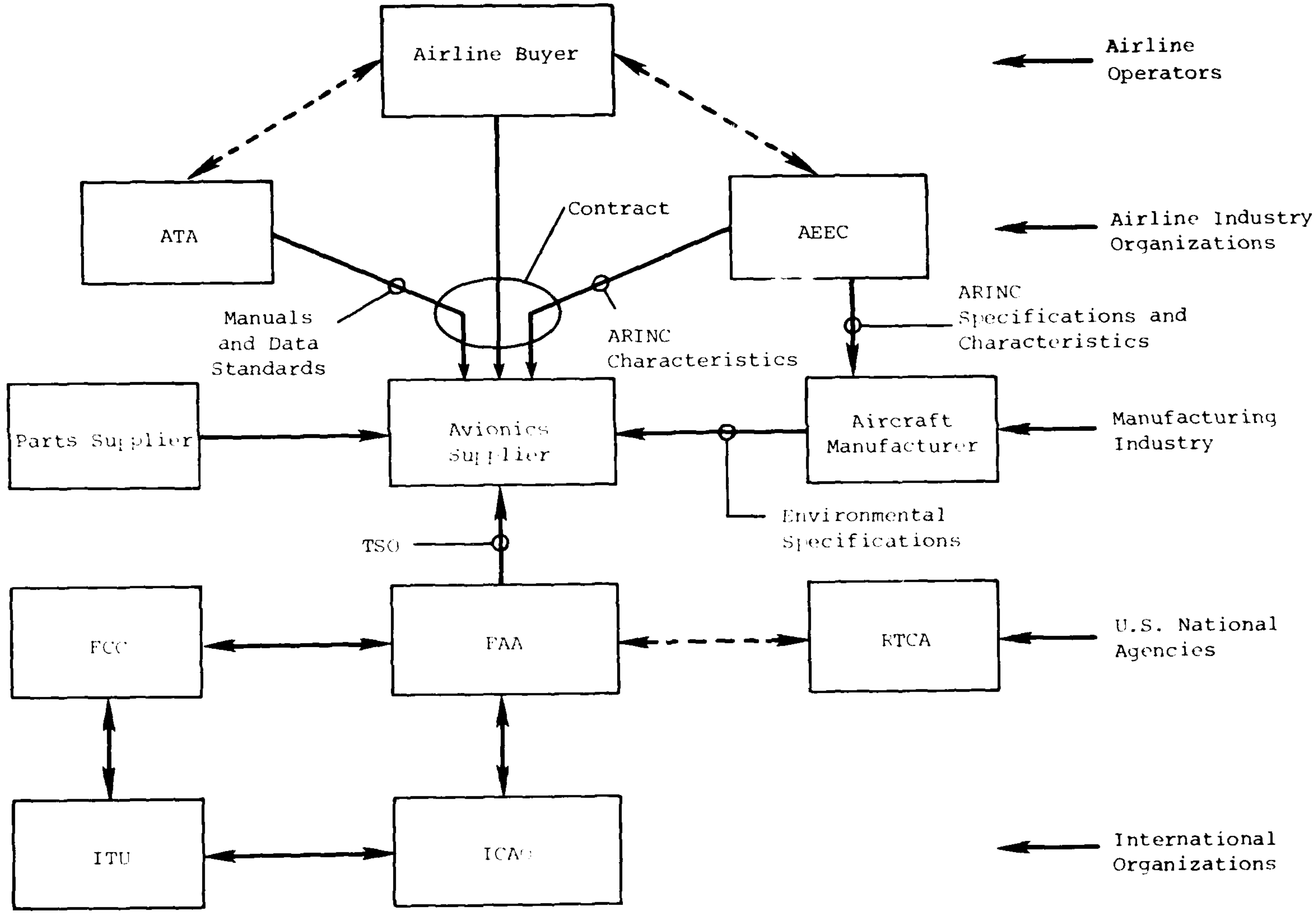


Figure 2-1. COMMERCIAL AIRLINE AVIONICS TECHNICAL STANDARDS

The inevitable growing pains associated with "getting the bugs out" of new equipments promoted expensive changes and increases in "downtime"; the equipment became obsolete in a short time, too. Also, since each airline wanted something a little different to satisfy its own operating requirements, individual airlines ended up buying small numbers of unique equipments. This process created a relatively non-competitive marketplace, because equipment manufacturers dedicated specialized equipment and services to single customers.

2.2.2 Commercial Airlines Standards

The airlines recognized these problems. In 1939, they gave the job of specification development and equipment buying to Aeronautical Radio, Inc. Over the next few years, the airlines and ARINC worked together to evolve an avionics acquisition philosophy that is simple, effective, and still in use today. It serves the needs of the airlines in buying economical, dependable avionics. The strategy: get all the potential users together to discuss their requirements openly, agree on a single common set of requirements, and then buy common equipment to serve those requirements.

The central element of this process is the ARINC Characteristic, F^3 specification. The F^3 specification defines equipment interfaces that will make it compatible with essentially all airliners in rack mounting, plug and pin connections, and the functions it performs. In turn, the equipment becomes virtually interchangeable between airframes regardless of who builds it. Basic interfaces defined in an ARINC Characteristic include mechanical (size, shape, mounting devices, and similar physical characteristics), electrical (pin assignments, load levels, signal structures, etc.), and environmental (cooling, dynamics limits, vibration, shock, etc.). The specification does not tell the manufacturer what the internal design or mechanization of the equipment must be, thereby giving him the flexibility to select his components as he feels necessary to improve performance, cost, quality, and competitiveness.

The ARINC Characteristic is developed in open-forum meetings chartered by the Airlines Electronic Engineering Committee (AEEC) and chaired by Aeronautical Radio. The meetings are attended by airlines representatives (members of the AEEC) and representatives from the electronics and airframe manufacturers. Together, the airlines and manufacturers discuss requirements and potential solutions over the course of several meetings until the most effective, common way to meet the needs of the airlines evolves. As shown in Figure 2-2, this is accomplished by taking a draft -- strawman -- specification and using it as the basis for discussion, reviewing it and updating it as the meetings proceed and as conflicts are resolved. This process typically takes about one year, but it can vary between six months and two years, depending upon the complexity of the situation. While this seems a long time, it does permit vendors to develop their product lines concurrently with the specification development. As a result, equipment prototypes are generally available shortly after the new Characteristic is approved.

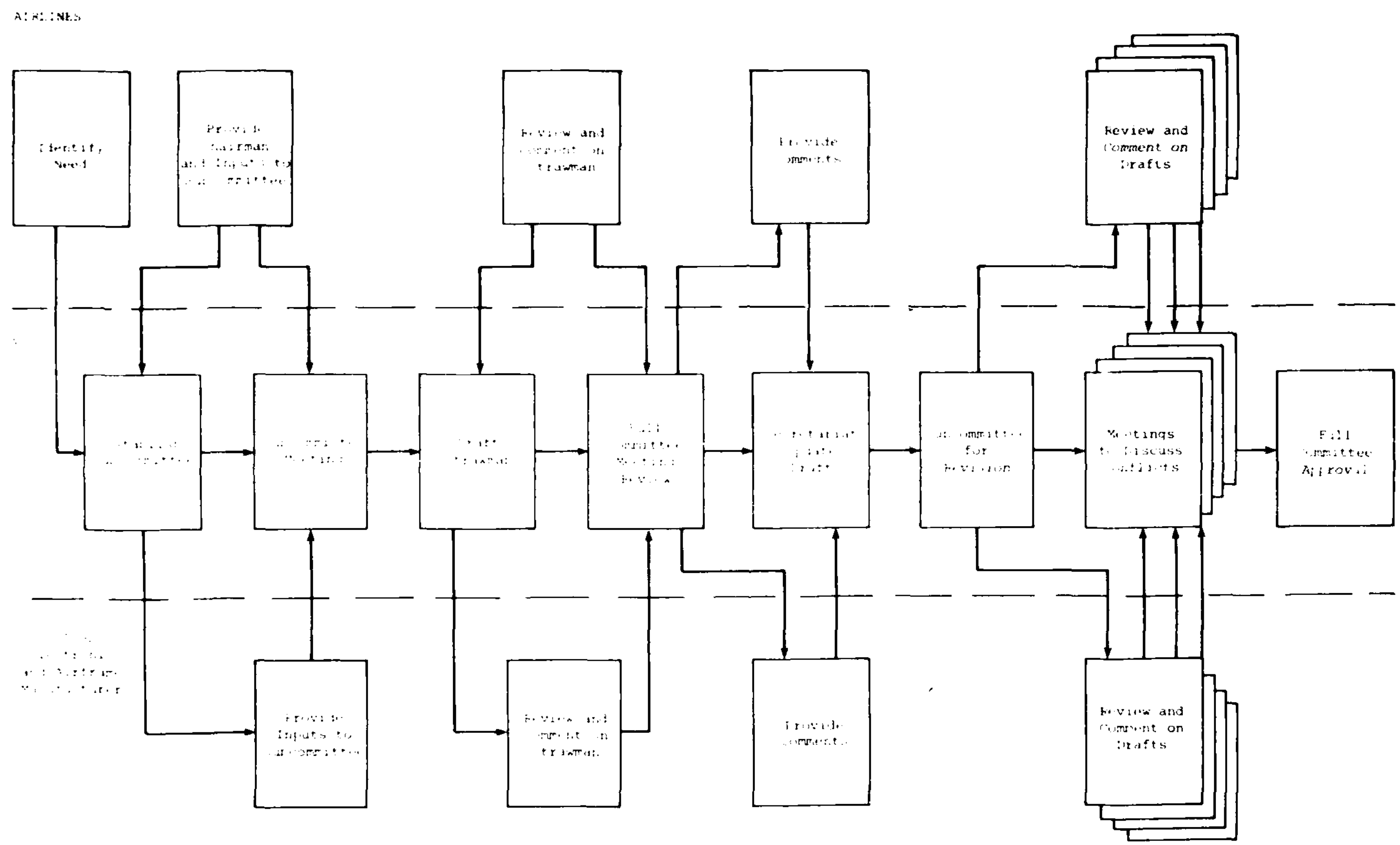


Figure 2-2. EVOLUTION OF A CHARACTERISTIC

In conjunction with the ARINC Characteristic, the airlines encourage vendor responsibility by buying equipment warranties with the equipment. A warranty is generally defined as an agreement between the parties to extend the vendor's responsibility to include maintaining his equipment in the field to a predetermined level of operational performance for a given period of time. Since warranties are bought on a fixed-price basis, they provide incentive for the vendor to reduce the number of maintenance actions he must perform as well as the cost of each repair he makes. Since lower repair cost means more profit for him, he will strive to make his equipment more reliable (fewer repairs) and more maintainable (lower cost for each repair). As a result, warranties can have the beneficial effect of improving equipment reliability and maintainability, which reduces operations and support cost to the user. They can also improve the vendor's equipment, making it more competitive for subsequent sales, and reducing the acquisition costs in the long run.

An airline's avionics purchase, made directly from the avionics supplier (or made indirectly as part of a complete airframe purchase), requires compliance with all regulatory standards, so that the FAA operator's certificate and the aircraft civil certification is not compromised. These standards are defined by an FAA Technical Standard Order (TSO) for each avionics functional system. An application for a TSO authorization has to be made by each avionics manufacturer for each model of equipment offered, in accordance with the Federal Aviation Regulations (FARs) Part 37. To conform with the FAA's TSO, the equipment design must have been shown to provide at least the minimum standard of performance defined therein (such as in TSO-C87: Airborne Low Range Radio Altimeter) or defined by reference to the applicable RTCA Minimum Performance Standard (such as DO-164 - Airborne Omega Receiving Equipment, for TSO-C94). Environmental testing requirements are similarly defined in the TSO or in RTCA DO-160. Details of the manufacturer's quality-control system (including subcontractor/parts supplier quality assurance) must be submitted, if not already on file with the FAA. TSO-authorized manufacturers must maintain data files on all equipments, must report failures, malfunctions, and defects that impact safety, and must allow FAA inspection of data files, manufacturing facilities, quality-control procedures, and the manufactured article.

The categories of environmental testing that are required to be met depend on the host aircraft type(s). These data, and details of the aircraft system interface, must be determined from the relevant aircraft manufacturer(s).

The airline's avionics purchase order will usually also require adherence to the avionics system configuration set out in the AEEC equipment Characteristics, such as ARINC Characteristic 552A - Radio Altimeter. These documents are in conformance with ARINC Specifications 404A (Racking), 406A (Standard Interwiring), and 429 (Digital Data Format), which define the aircraft/avionics interface desired by the majority of airlines. As discussed above and shown in Figure 2-2, the ARINC Characteristic is a result of coordination among the airlines industry, the avionics industry, and the principal commercial transport aircraft manufacturers; however, the negotiated contract will define any specific options or exceptions required by the purchasing airline.

Finally, data detailing installation, testing, and support procedures will be required to be provided by the avionics supplier in conformance with the operation and maintenance manual format laid down by the Air Transport Association of America (Specification for Manufacturer's Technical Data, ATA-100). This manual is written so that it lends itself to training purposes, explaining the component's functional characteristics where these are critical and/or limiting -- and why -- and pointing out any self-test or condition-monitoring features built into the component, and their capabilities. Detailed step-by-step procedures for bench/shop testing, adjusting, and troubleshooting the entire component are provided. These procedures are arranged in such a manner that they progressively isolate and identify each assembly, subassembly, or part(s), and then verify the integrity of the component after corrective action has been taken. They include visual checks, tests, and refer to applicable disassembly procedures. Testing is keyed to isolating possible troubles and indicating repairs to parts such as circuit boards, modules, etc. As faults are identified, remedial actions such as adjustments or parts replacement are given.

Equipment can be purchased "in compliance with" any applicable ARINC Characteristic even though it may contain features not required by that Characteristic. This can be done as long as the desired features are not prohibited by the Characteristic or do not require changes in the F^3 requirements. Airlines also negotiate maintenance agreements, old equipment trade-in allowances, and other considerations of value, to reduce the effective price significantly below the published price. The agreements are considered highly proprietary by both buyer and seller and are never disclosed. Because of this facet, airlines cost data that would be needed to perform conclusive cost-benefit analysis in this area are not available.

Table 2-1 summarizes the functional correspondence between military and civil standards.

As is the case with their military counterparts, civil standards are updated, amended, or superseded from time to time to take account of newly evolving operational requirements and technological capabilities and to correct observed deficiencies.

At the present time, the ARINC Specifications and Characteristics are undergoing major changes by virtue of the addition of ARINC Specification 600 (Avionics Racking/Interface/Cooling) and the ARINC 700 series of avionics systems and equipment Characteristics. Newly developed commercial airlines digital avionics equipment has been designed in response to this Specification and is being produced for the commercial market. It is, therefore, particularly timely to evaluate the degree of applicability of such a specification to USAF aircraft systems.

Table 2-1. FUNCTIONAL CORRESPONDENCE BETWEEN MILITARY AND CIVIL STANDARDS

Standard	Military Specifications	Civil Requirements
Electrical Bonding, Lightning Protector	MIL-B-5087	FAA, FAR 25.581
General Avionics Specification	MIL-STD-454 MIL-E-5400	- -
Communications Standard	MIL-STD-188	ICAO Annex 10 FCC regulations
Electromagnetic Interference	MIL-STD-461 MIL-STD-462	FAA TSOs or RTCA DO-160
Digital Data Format/Bus	MIL-STD-1553	ARINC-429 ARINC-453
Environmental Testing	MIL-STD-810	FAA TSOs or RTCA DO-160
Aircraft Electric Power	MIL-STD-704	FAA TSOs or RTCA DO-160, ARINC 413A
Form, Fit, and Function	-	ARINC 404A ARINC 600
Standard Interwiring	-	ARINC 406 (Basic, updated by bulletin)
Maintainability/ Documentation	MIL-STD-431	ATA, ATA-100

ARINC Specifications define general system interfaces and ARINC Characteristics define specific functional, operational, and performance requirements. The key specification that has been in use since 1956 is ARINC Specification 404 -- Air Transport Equipment Boxes and Racking (ATR). Avionics equipments defined by current ARINC Characteristics (the "500 series") comply with ARINC 404A and provide a high degree of interchangeability between like units supplied by different avionics manufacturers.

Following its New Installations Concept (NIC) Subcommittee activities, the AEEC has implemented ARINC Specification 600 to define the airlines' requirements for avionics equipment interfaces in new generation transport aircraft (1980 and onward) and optional retrofits. Avionics equipments conforming to ARINC Specification 600 are defined by ARINC Characteristics in the "700 series". The ARINC 700 series Characteristics also standardize data input and output to the digital formats of ARINC Specification 429, Digital Information Transfer System (DITS) and, where appropriate, to ARINC Specification 453, Very High Speed Data Bus.

The principal advance of ARINC Specification 600 over ARINC Specification 404A is in ensuring the availability of improved cooling by limiting the avionics thermal dissipation according to the LRU case size, and by requiring adequate quantities of clean cooling air to be furnished to it. Other changes redefine the allowed avionics case sizes in terms of modular concept units (MCUs) from 1 MCU to 12 MCUs in width (8 MCUs is equivalent to 1 ATR short box size; the ATR long box size is not allowed), and introduce a new style "low insertion force" rear connector and revised box hold-down arrangements.

Current USAF aircraft are more compatible with the ARINC 404A avionics integration standards and ARINC 500 series equipments. Many such installations have been made, usually in conjunction with a military procurement of a civil-certificated aircraft, but also for needed avionics modernization (replacing obsolescent MIL-SPEC equipment).

2.3 COMPARISON OF MILITARY AND AIRLINES STANDARDS

Because of their different origins and objectives, there is considerable divergence between the military standards and specifications that govern USAF avionics procurement, and those that serve a parallel function for civil aviation -- FAA, RTCA, ICAO performance standards and commercial airline (ARINC) form, fit, and function (F^3) characteristics. During this study, we reviewed a large number of both military and commercial specifications and standards in attempting to determine some of the major differences between them in both purpose and use. The following discussion documents our findings in this regard.

In seeking to limit the proliferation of unique aircraft/avionics/environmental system requirements and extend Air Force use of commercially available avionics equipment, there is concern that many of the safeguards that have been built into the MIL-STD/MIL-SPEC procurement system could be circumvented. This concern is particularly applicable to equipment that is to be used in combat-mission-oriented aircraft. Any PME standard developed by the Air Force will need to address these concerns fully, and allow for the safeguards felt necessary by the military over and above the normal flight safety hazards that are addressed equally by both military and civil/commercial regulation.

The most obvious difference between military and commercial standards is that, except for a very few F^3 specifications recently issued by the Air Force, military standards also provide extensive how-to-build-it guidance. This guidance (from MIL-E-5400 and the many MIL-standards and specifications referenced therein) covers selection of piece parts, qualified vendor tests, material specifications, workmanship specifications, safety-engineering plans, human-engineering plans, etc. The airlines depend instead on their knowledge of suppliers' products to achieve the level of quality that they require and to maximize the cost-effectiveness of the avionics equipment they purchase. This difference in procurement philosophy would require a substantial change by military buyers in the specifications they reference in governing procurement documents. In addition, some changes from typical maintenance and logistic practices could be required, unless a given equipment is procured only from a single source. However, this would eliminate the competition between suppliers and the leverage provided by that competition to control price and quality.

Other differences between military and airlines standards are outgrowths of the need for military standards to apply to a broad spectrum of aircraft types and missions, while airlines standards apply only to transport aircraft used for passenger service. In general, commercial equipment provides satisfactory service for large military transport aircraft when used in complete suites and not intermingled with military common/core equipment. Airlines avionics equipment is much less applicable to military high-performance aircraft because of differences in missions, environmental factors, aircraft operating parameters, and the space available for avionics equipment. There are circumstances, however, where commercial avionics may be directly applicable to high-performance aircraft. For example, the YF-16 prototype flew with a modified (three-channel) commercial inertial navigation system (INS) before the mission avionics suite was selected. It reportedly performed in an outstanding manner and demonstrated very high reliability; unfortunately, space criticality required a smaller unit for mission purposes. Based on this performance, the USAF initiated a program to develop first an F^3 specification and then the resulting hardware for a standard medium-accuracy INS that could fit and perform equally well in any USAF aircraft requiring a medium-accuracy INS capability. This F^3 INS is currently undergoing procurement for the A-10 aircraft.

As a result of our review of military and commercial specifications and standards in conjunction with ASD personnel, we developed both generic classes of differences and specific waiver exemptions we feel would be applicable to use of purely commercial standards for military application. Table 2-2 summarizes the types of general differences that exist between military and airline general guidance structures. The following are the major exemptions from military generic standards required when off-the-shelf airline avionics equipments are to be used:

(1) Permit use of nonstandard piece parts and changing of piece parts as desired by the manufacturer

(2) Waive requirement for MIL-STD manufacturing drawings and process specifications

(3) If nuclear and EMP hardening is required, test specific equipment design to determine ability to withstand the necessary stress

(4) Waive requirements for fault isolation by BITE below LRU level

(5) Waive requirement for inherent MIL-STD-1553 compatibility

Table 2-2. AREAS OF DIFFERENCES BETWEEN MILITARY AND AIRLINES STANDARDS AND PROCUREMENT PRACTICES

Classifications	Remarks
<u>Physical and Performance Constraints</u> Size/Form Factor Shock/Acceleration/ Vibration Performance	These problems elicit go/no-go decisions. Airlines equipments may be too big for space-premium aircraft, may not withstand the physical environment, and may not provide desired performance characteristics.
<u>Electrical and Mechanical Interface</u> Type and location of connectors Cooling air requirements Data bus format Data bus protocol BIT philosophy	These problems arise from the differences between airlines and military design practices. Airlines equipments are usable with waivers and interface modifications.
<u>Procurement Documentation Method</u> F^3 versus end-item specification Use of MIL STD piece parts Organic Maintenance versus Warranty, etc.	These problems indicate a need to change procurement and maintenance methods and policies. Differences do not change the functional adequacy of airlines equipments.

(6) Limit temperature requirements to Class 1(X) or Class 2(X) (from MIL-E-5400R) and provide for cooling-air according to ARINC 404A (for ARINC 500 series equipment) or ARINC 600 (for ARINC 700 series equipment) if this is required by the specific airline-type equipment to withstand full military ambient temperature range

(7) Permit use of rear-mounted blind-mating connectors

(8) Determine by test the ability of airline equipments to withstand vibration levels <u>as measured in the aircraft</u> at the specific location where they are to be used; use vibration isolation mounts as required for locations close to sources of high-level vibration

(9) Assess the adequacy of civil aviation electromagnetic interference (EMI) standards against the actual characteristics of mission avionics on each aircraft considered as a candidate for commercial avionics and waive (or do not reference in procurement documents) those EMI specifications that are not essential to satisfactory performance

2.4 APPLICABILITY OF DESIGNATED COMMERCIAL AVIONICS EQUIPMENT

This section discusses in detail the applicability of existing commercial avionics (ARINC 500 series Characteristics) and future commercial avionics (ARINC 700 series Characteristics) to USAF use. This section shows that:

- Existing commercial avionics are broadly applicable for use in large military transport aircraft, requiring only relatively simple racking and interface changes even in aircraft not originally designed for commercial avionics.
- Existing commercial avionics can be used in bombers and other penetration aircraft if racking and interface modifications are made in the aircraft and if the aircraft and/or avionics are modified to provide required interfaces with mission equipment to prevent EMI and to provide for EMP and nuclear hardening.
- Existing commercial avionics will not generally be applicable to high-performance aircraft, although in some cases available space may permit installation of selected avionics and necessary interfaces.
- Future commercial avionics will require similar adaptive work. In addition, because they accept only digital inputs and provide only digital outputs (both to the ARINC 429 format), they will also require additional interface equipment to make them compatible with existing analog inputs and/or with the MIL-STD-1553 data bus.

Table 2-3 lists our findings on the degree of utility of ARINC 500-series equipments in military aircraft.

2.4.1 Applicability of Commercial Radar Altimeters

ASD/XRE has requested that the considerable data gathered by ARINC Research, under contract to Warner Robins Logistic Center, in developing the specification for the low altitude radar altimeter (LARA) and high altitude radar altimeter (HARA) be used to evaluate the utilization of ARINC 552A or ARINC 707 radar altimeters in the H-3, C-130, F-4C/D/E, F/FB-111, H-53, C-130E/H, A-7D, and C-141A aircraft to replace altimeters such as the APN-150, APN-155, APN-167, and APN-171. As a result of the availability of these data, altimeters are discussed at a level of detail beyond that possible for other classes of avionics. The results of our detailed comparison between the LARA specification requirements are given

Table 2-3. DEGREE OF UTILITY OF ARINC 500-SERIES EQUIPMENTS IN MILITARY AIRCRAFT

Aircraft Type	ARINC 559A HF Radio	ARINC 552A Radar Altimeter	ARINC 564 Weather Radar	ARINC 573 Crash Recorder	ARINC 594 GPWS	ARINC 565 Air Data Computer	ARINC 561-11 INS
A-7D	0*	2,5,6	0	0	0	7	0
A-10	2,4,5,6,9	8	8	8	8	8	8
FB-111	2,4,5,6	2,5,6	0	8	8	7	0
B-52	2,4,5,6	0	0	8	0	8	8
C-5	2,4,5,6	2,5,6	5	7	1	1	1
C-9	0	0	0	1	0	0	0
C-130	2,4,5,6	5,6	5,6	0	8	8	9
C-130E/H	2,4,5,6	5,6	5,6	0	0	0	8
C-141	2,4,5,6	2,5,6	5	1	1	2,5	1
E-3A	7	1	5	7	8	1	1
E-4	0	0	0	1	0	1	0
KC-10	0	0	5	0	0	1	0
KC-135	2,4,5,6	2,5,6	0	0	0	8	1
T-43	0	0	0	0	1	0	0
VC-137	0	0	0	1	0	0	0
VC-140	0	0	0	0	1	0	0
F-4	8	2,5,6	8	8	8	7	2,6
F-16	8	8	0	8	0	7	6
F-111	2,4,5,6	2,5,6	8	8	8	7	2,6
H-3	0	3,4,5,6	0	8	0	7	8
HH-53	0	2,5,6	0	0	0	7	8

*Code:
0 - This subsystem not addressed.
1 - Commercial unit now installed.
2 - Physical/interface changes in avionics required.
3 - Group "A" changes required.
4 - ECS changes required.
5 - Features required beyond normal airline use but within ARINC functional standard.
6 - Group "A" changes beyond those required for anticipated MIL replacement.
7 - Not usable.
8 - Not currently installed.
9 - Not currently installed but space reserved.

NOTE: Airline avionics functions not listed are as follows:

- RNAV: VOR/Marker and LOC/Glideslope; Military uses LOC/Marker/Glideslope; AN/ARN-127 is becoming the de facto standard.
- DME: Military uses the full TACAN format; AN/ARN-118 is becoming the de facto standard.

in Appendix D, with direct reference to those LARA specification paragraphs to which ARINC 552A and/or ARINC 707 radio altimeters would not conform. Since the ARINC 552A and 707 altimeters are low-altitude instruments (airlines use radar altimeters only for final approach and landing), only the LARA comparison is applicable. Consequently, the feasibility of using either the ARINC 552A altimeter or the ARINC 707 altimeter is measured by its ability to meet the requirements of the LARA specification. However, the LARA specification requirements have been chosen to permit its use in all of the listed aircraft. Consequently, ARINC altimeters may be acceptable for use (instead of the LARA) in some of the listed aircraft, even though they could not be accepted for all. ARINC Characteristics permit substantial variations in equipment capabilities so long as stated minimum standards are met and the physical and electrical interfaces between the equipment and the aircraft are not affected. Consequently, special configurations that more closely approach the LARA specification requirements could be procured by the Air Force and still be in compliance with ARINC 552A (or 707).

The numerous differences between ARINC 552A and/or 707-1 and the LARA specification show clearly that the LARA could not be replaced by an equivalent commercially available equipment unless some current requirements were traded off. That is not to say that an ARINC 552A altimeter could not replace the existing radar altimeter in many of the current aircraft if the variation in physical size can be accommodated. Modifying an ARINC 552A R/T and providing a different indicator to permit operation to 5,000 feet would satisfy functional requirements of most of the aircraft types, and this is assumed in the determination of the applicability of ARINC 552A altimeters to specific aircraft types.

Table 2-4 summarizes the applicability of ARINC 552A radio altimeters to current USAF aircraft of interest, giving the currently installed radar altimeter nomenclature and describing briefly the changes in the avionics/aircraft interface that would be needed for a commercial unit to be used. The ARINC 707-1 altimeter would be similarly effective in future aircraft integration efforts where its all-digital signal format is appropriate.

2.4.2 Applicability of Commercial HF Radios

ASD/XRE suggested that the study examine the possible utilization of the ARINC 559A or ARINC 719 HF radio in the B-52, KC-135, C-5, F-111, and FB-111. This radio would replace radios such as the ARC-65, ARC-58, AT-440, ARC-123, and 618T. It was suggested that the study examine the ARC-XXX radio characteristics as defined by WR-ALC/MMIM. Military requirements that affect utilization of a commercial HF radio should be identified. Thus, if the ARC-XXX is intended to become a standard USAF HF radio to be used to replace the listed HF radios in the listed aircraft, the feasibility of substituting the ARINC 559A or ARINC 719 HF radios for the ARC-XXX for the aircraft update modification should be assessed.

Table 2-4. APPLICABILITY OF COMMERCIAL RADAR ALTIMETER

Aircraft Type	Current Radar Altimeter	Changes Needed for Use of ARINC 552A Unit
CH/HH-3-E	AN/APN-150	Larger space (vice AN/APN-150) New A-kit, rack, and connector Cooling air
C-130 A/B/E C-130 E/H/P/N	AN/APN-22 AN/APN-150 AN/APN-171	Larger space (vice AN/APN-150) New A-kit, rack, and connector Cooling air
F-4 C/D/E	AN/ARN-155	Larger space New A-kit, rack, and connector Cooling air Scale factor on analog rate output
F/FB-111	AN/APN-167	Slightly larger space New A-kit, rack, and connector Scale factor Track/no-track signal
HH-53	AN/APN-171	New A-kit, rack, and connector Scale factors Flight system coupler outputs
A-7D	AN/APN-194	Much larger space New A-kit, rack, and connector Scale factors Extra output signals
C-141	HF-9025 B/A "AWALS"	Larger space New A-kit, rack, and connector Scale factors Track/no-track signal
C-5	P/N 41003	Larger space New A-kit, rack, and connector Scale factors Extra output signals
E-3	ARINC-522 unit	None

2.4.2.1 Difference Between ARC-XXX and ARINC 559A Equipments

There are several differences that inhibit the ARINC 559A radio used by the airlines from being a direct replacement for the ARC-XXX. These are shown in Table 2-5.

Table 2-5. DIFFERENCES BETWEEN ARINC-559A AND ARC-XXX

Characteristic	ARINC 559A	ARC-XXX
Frequency Range	2.8 to 24 MHz	2.0 to 30 MHz
Sideband Selection	Upper only	Upper or lower (selectable)
Channel Spacing	1 KHz	100 Hz
Audio Baseband	350-2500 Hz (6 dB)	250-3100 Hz (1 dB)
Power Output (PEP)	200 watts (temporary expedient), 400 watts desired	400 watts
Physical Size	7.62"high x 7.5"wide x 12.52" deep (3/4 ATR Short)	7.62"high x 10.125" wide x 12.0625" deep

However, commercial HF radios can still be procured to the older ARINC Characteristic 533A. These satisfy all of the listed ARC-XXX requirements, except the audio baseband width (which can be 6 db down at 300 Hz for the ARINC 533A wide-band option) and physical size (1 ATR long instead of 1 ATR short for the ARC-XXX). A Collins radio built to ARINC 533A (the 618T) is currently used in the C-130E, HC-130 H/N/P, and the C/NC-141 aircraft. In other aircraft, ARINC 533A units are not considered because of their 7 inches of extra length, which would make them unattractive as substitutes for the ARC-XXX in most of these aircraft.

2.4.2.2 Differences Between ARC-XXX and ARINC 719 Equipments

ARINC 719 currently exists only as a first draft prepared by the ARINC staff and circulated to AEEC members for comment; until AEEC approval occurs, the draft is not a statement of airlines industry policy. It is anticipated that at least minor changes may be required when audio system minimum standards, currently being developed by RTCA Special Committee 132, are issued.

The draft ARINC 719 invokes the cooling and packaging elements of ARINC 600 and the digital control/data elements common to all ARINC 700 Characteristics. The R/T unit is not compatible with ARINC 559A control panels. Compatibility with ARINC 559A automatic antenna tuners, however, is required. A cooling-air-flow rate of 110 Kg/hr of 40° C (or cooler) air is required, and power dissipation of 500 watts maximum for continuous transmissions is specified. The R/T is specified to be 6 MCUs, which is the ARINC 600 equivalent of the 3/4 ATR size.

ARINC 719 states, "...it would be wise for the manufacturer to design the equipment for ease of modification to provide for the 100-Hz channel spacing if it were to be requested by the airlines. The manufacturer, though, should take care in keeping the additional cost for the convertibility down to an absolute minimum in order not to lose marketability of a radio which selects frequencies in 1 kHz increments only." Minimum output power (PEP) is specified as 400 watts with a commentary that, "...users will reluctantly accept, as a temporary expedient, the reduction in power output, as a manufacturer's option..." to not less than 200 watts PEP.

This will make it easier to obtain the 100-Hz channel spacing and 400 watts output in an ARINC 719 radio than in an ARINC 559A radio and, possibly, permit USAF use in place of the ARC-XXX without significant modifications from equipment procured by the airlines. The ability to select either upper or lower sidebands and to obtain an audio baseband (compatible with the ARN-XXX specification and with MIL-STD-188) would be non-standard. Modifications to achieve these capabilities may be possible within the 6 MCU ARINC 719 box size.

2.4.2.3 Feasibility of Air Force Use of ARINC 559A or ARINC 719 Equipments

It appears that ARINC 559A or ARINC 719 radios, modified as indicated above, may be used instead of ARC-XXX to replace ARC-65, ARC-58, AT-440, ARC-123, and 618T equipments. Both ARINC 719 and a version of ARINC 559A employ a data bus rather than multiple wires to transmit frequency-selection commands from the control panel to the R/T, as is required by the ARC-XXX specification. (This is not a feature of any of the units the ARC-XXX is intended to replace.)

2.4.3 Applicability of Commercial Weather Radars

We examined the possible utilization of an ARINC 564 or ARINC 708 radar in the C-141, KC-10, C-5, C-130, E-3A, and KC-135. These aircraft currently use the following radars:

Aircraft	Radar
KC-135	APN-59(B)
C-141	APN-59(B)
KC-10	RDR-1FB (modified) (ARINC 564-7)
C-5	Norden Multimode Radar
C-130	APN-59(B) Old Aircraft
C-130H	APQ-122(V)5
E-3A	AVQ-30(X) X (ARINC 564-7)

The use of a separate weather radar is not customary in other aircraft types, and in those types under consideration for installation of a new Common Multimode Radar (CMMR) (F-16, F-111, F-4E, B-52G/H, and other future applications) weather capability could be achieved by including a weather mode in the CMMR.

The Norden multimode radar in the C-5A has X-band and Ku-band subsystems, with the X-band system functionally similar to the APQ-122(V)5. AN/APN-59(E) radar is now being procured to replace the AN/APN-59(B), replacing vacuum tubes with solid-state circuitry where practicable without significant form, fit, and function changes.

The RDR-1FB (Modified) and AVQ-30(X) are ARINC 564 commercial radars with minor modifications to more closely match military needs.

The AN/APN-59(E) and APQ-122(V)5 are designed and constructed to the full MIL specification tree. They provide long-range mapping, weather detection, and beacon interrogation. In the mapping mode, maximum CEP position errors of about 1/2 nautical mile at 50 NM range are specified for the APX-122(V)5 and 1.5 miles for the APN-59(E). Interfaces with the aircraft are through synchro-signals and analog pulses. Frequency agility capability and operator adjustment of frequency within the range 9,000 to 9,500 MHz is required for the APQ-122(V)5. Primary control and display are from the navigator's station, with partial operating controls or override controls located at the pilot's and/or copilot's stations, where job assignments or flight safety considerations dictate.

2.4.3.1 Use of the Airlines Radars Built to ARINC 564

Radars built to ARINC 564 are not required to provide precise mapping or beacon-reply-reception capability. In the mapping mode, CEP position error will be about five times that allowed for the APQ-122(V)5. Scan coverage is only ±90° (±120° maximum permissible), instead of the full-circle scan or adjustable sector scan required in the APQ-122(V)5 and APN-59(E) specifications. The addition of beacon-reply reception has already been accomplished in commercial radars procured by the USAF; it may also be possible to provide the desired antenna coverage and sector scan features in an ARINC 564-7 radar.

It is unlikely that any ARINC 564-7 system can be modified to adequately replace the APQ-122(V)5 capabilities for mapping accuracy, frequency control, and frequency agility desired by the USAF.

2.4.3.2 Use of the Airlines Radars Built to ARINC 708

ARINC 708 describes an all-digital radar compatible with airlines plans for new aircraft. A radar built to this Characteristic will not accept or output analog data or controls and, thus, will not be compatible with current military aircraft, which require such analog interfaces, without the use of analog-to-digital or digital-to-analog interface equipment. For new aircraft capable of interfacing ARINC 429 low-speed and ARINC 453 high-speed digital signals, they could be adapted to provide the same level of performance as the RDR-1FB (Modified) provides for the KC-135A and the AVQ-30X(X) provides for the E-3.

2.4.4 Applicability of Commercial Crash Data Recorders

We examined the possible utilization of an ARINC 500 series or ARINC 700 series flight data recorder in the C-5, C-9, VC-137, C-141, E-3A, and E-4.

The FAA requires the recording of specified flight data and cockpit voices in such a way that the recording medium will survive a crash and the recorded information can be recovered.

2.4.4.1 Airlines Crash Recorders

Airlines separate the voice and data recordings by providing a cockpit voice recorder and an aircraft integrated data system. The integrated data system provides a data-acquisition system that receives analog and/or digital data and converts it to a form suitable for recording, and a recorder (located to ensure survivability of the recording medium) that accepts the output from the data-acquisition unit. Commercial airlines aircraft use the system defined by ARINC 573, which includes a flight data acquisition unit (FDAU), a digital flight data recorder (DFDR), an accelerometer, and an optional flight data entry panel (FDEP). The DFDR is designed to meet the FAA survivability-of-recording-medium requirement when mounted in suitable positions on the aircraft. The FDAU is designed to interface with analog data sources and with digital data sources compatible with ARINC 575/576 and to convert inputted data to a form suitable for presentation to the DFDR. Both the FDAU and the DFDR are 1/2 ATR long packages per ARINC 404A, although ARINC 573 specifically permits non-standard DFDR sizes with a free (pendant) connector terminating the aircraft wiring for cases where (foreign) civil regulations authorities require the recorder to be ejected in a major crash.

New aircraft will use the ARINC 717 flight data acquisition and recording system, which is similar to ARINC 573 equipment except:

(a) The FDAU of ARINC 573 is replaced by a digital flight data acquisition unit (DFDAU), which is compatible with ARINC 600 in all respects. Its size is 6 MCU (3/4 ATR short), and its digital inputs accept only data in ARINC 429 format. Analog data are also accepted.

(b) The DFDAU uses low-insertion-force connectors but is otherwise interchangeable with the ARINC 573 recorder.

A separate voice recorder compatible with ARINC 567 is used by the airlines. Since neither of the recorders is mounted in the avionics equipment rack, compatibility with the racking requirements of ARINC 600 is not required; therefore, no 700 series Characteristic is currently planned for either data or voice recorder.

2.4.4.2 Crash Recorders in USAF Aircraft

The E-3 aircraft uses a combined crash position indicator (CPI) beacon and flight data recorder which provides 28 channels of flight data and 3 voice channels and satisfies FAA requirements for both flight data and voice recording. Either the ARINC 573 or 717 equipments could be substituted for the flight data records section of the CPI/FDR installation with more than adequate data capacity. Neither could provide the voice capability, however, and a separate voice recorder would be required.

The E-4, C-9, C-141, and VC-137 aircraft already use commercial flight data recorders built to ARINC 573 (Lockheed 209, Fairchild 5424, Fairchild 5924, and Lockheed 109C, respectively), or others designed to the same ARINC Characteristic.

The C-5 aircraft uses a unique recorder, made by Lockheed, which provides 42 data channels and a single voice channel. Only 30 minutes of history are recorded. As with the E-3 recorder, an ARINC data recorder could be used to replace the C-5 digital recorder for data, but a separate voice recorder would be required.

2.4.5 Applicability of Commercial Ground Proximity Warning Systems (GPWS)

ASD/XRE suggested that we examine the possible utilization of an ARINC 723 GPWS in the C-5, C-141, T-43, and VC-140 aircraft. Currently all of these aircraft use the Collins CPN-622-2615-5000, which is a commercial unit built to ARINC 594. This demonstrates the ability of equipment built to ARINC 594 to serve in the listed aircraft or other transport-type aircraft requiring either Category III instrument landing capability, FAA certification for passenger service, or both. The ARINC 723 system will be applicable for such service in those new or modified aircraft that may be designed to provide ARINC 429 digital interfaces and cooling air to ARINC 600 standards.

2.4.6 Applicability of Commercial Air Data Computers

We studied the possible utilization of a commercial air data system to replace the air data computer function in the E-3A, the E-4, the KC-10, and the C-141 aircraft. The central air data computers currently used in these aircraft are:

Aircraft	Computer
E-3A	Honeywell HG-18V (standard commercial)
E-4	Bendix 100-3925-3 (standard commercial)
KC-10	Honeywell HG-280D (standard commercial)
C-141	Bendix CPU/43-A to MIL-C-38037

The first three air data computers are the same as those used in the civil aircraft that are modified to produce the E-3A, E-4, and KC-10, and are designed and constructed to ARINC 500 series Characteristics. They demonstrate the feasibility of using these commercial standards for military transport aircraft. The Bendix CPU/43-A central air data system is a fully militarized equipment built to MIL-C-38037, utilizing the full military specification tree invoked by MIL-E-5400. The CPU/43-A is similar to an ARINC 565 air data system, but has multiple-function outputs not provided by ARINC 565. Some of these are independent duplicate outputs to different loads and some have different output formats (such as a dc potentiometer output in addition to synchro outputs for altitude). In addition, eight "QC" differential pressure outputs are generated in relation to excitation signals from the automatic flight control system (AFCS), or functions derived therefrom. These are within the optional provisions of ARINC 565. An ARINC 565 air data system would have to be built to special order to provide the additional outputs of the CPU/43-A.

2.4.7 Applicability of Commercial Inertial Navigation Systems (INS)

ASD/XRE directed that the baseline INS against which airlines INS systems should be compared is the "standard" moderate-accuracy INS (SMA INS) discussed earlier in this chapter as the Air Force F^2 INS. It is described in Exhibit ENAC 77-1, "Characteristic for a Moderate Accuracy Inertial Navigation System (INS)". Airlines inertial navigation systems compatible with ARINC Characteristics 561-11 and 704 are to be considered as candidates for use in the A-10, F-16, F-111, F-4, and AMST aircraft if they can satisfy the same form, fit, and function requirements that are specified for the SMA INS.

2.4.7.1 Inertial Reference Systems Complying with ARINC Characteristic 561-11

ARINC Characteristic 561-11 describes an inertial navigation system suitable for use in airline transport aircraft and compatible with air data systems, autopilots, and other associated equipments used in airline service. It accepts sequential digital and analog inputs, and provides sequential digital and analog outputs. Its functions are substantially identical to the SMA INS. Significant differences exist between the SMA INS and the ARINC 561-11 INS for required input and output data and in the format for digital data. The 561-11-specified form factor for the inertial navigation unit (INU) is 1 ATR, while the SMA INS-specified size is equivalent to 3/4 ATR with some 3 inches of front projection allowed beyond the mounting base. Digital inputs and outputs for the SMA INS are required to be compatible with MIL-STD-1553, while digital inputs and outputs for an ARINC 561-11 unit are required to be in ARINC 419, Group C, format. The two formats are not compatible, and an active interface unit would be required for the ARINC 561-11 INS in a military aircraft using MIL-STD-1553. Positional accuracy is not specified in ARINC 561-11, although the accuracy "... deemed appropriate for use over the North Atlantic ... for flights of typical durations ..." is the same as that specified for the SMA INS for flights of over 10 hours duration. The SMA INS specification references the complete military specification tree.

The CAROUSEL IV E INS used in the C-5 and in the C/NC-141 transport aircraft is an ARINC 561-11 unit with the customer option for vertical acceleration output exercised. For combat aircraft applications, where the larger size of the 561-11 or its adherence to ARINC 419 digital format instead of MIL-STD-1553 violate USAF requirements, an ARINC 561-11 INS is not an adequate substitute for the SMA INS.

2.4.7.2 Inertial Reference System (IRS) Complying with ARINC 704

The ARINC 704 inertial reference system differs from the ARINC 561-11 inertial navigation system in that no steering outputs nor any form of waypoint navigation is provided. The 702 IRS provides sensor information that can be used by another subsystem (the ARINC 702 flight management computer system) to compute and output steering signals. Consequently, the 704 IRS could be used only if another computer subsystem is available to provide waypoint navigation and steering signals, or if waypoint navigation and steering signals are not considered to be mission-essential.

A further difference between the 704 IRS and previous airline inertial systems is that no analog inputs are accepted and all outputs (including pitch, bank, angle, and heading) are in digital form. Thus, an ARINC 704 system cannot replace any INS or IRS that uses analog inputs or outputs for any function, without the aid of digital-to-analog and/or analog-to-digital converters. This could make use of the 704 IRS difficult for retrofit purposes, whereas it would be satisfactory for those new installations where compatible digital interfaces can be provided.

2.4.8 Applicability of Commercial VOR/ILS Navigation Receiver Systems

An additional common functional equipment for both commercial and military flight operations is the VHF/UHF instrument landing system. The commercial airline requirements have evolved through a succession of Characteristics, such as the following:

Characteristic	Equipment Type
(unnumbered)	VHF Navigation and Communications
ARINC 519	Glide Slope Receiver
ARINC 547	VHF NAV (LOC/VOR with integral glide slope receiver optional)
ARINC 551	Glide Slope Receiver - Mk 2
ARINC 578-3	ILS (LOC/GS only)
ARINC 710	ILS (LOC/GS only)

Although used in ARINC 404A configuration, the marker beacon receiver had no ARINC Characteristic reference until it was included in the ARINC 711-VOR receiver requirements.

Because the ILS/VOR market includes a large part of the general aviation and commuter activities, commercial avionics suppliers offer many combinations of VOR/LOC/GS and marker beacon receiving equipment, many of them following the ARINC 404A rack mounting and standardized interconnections requirements. For the airlines, the preferred configuration includes localizer and glide slope functions in one receiver, and VOR and marker beacon in a separate receiver.

In an independent development, AFLC sponsored a supplier to repackage all four functions in one unit and qualify this for Air Force use as the AN/ARN-127.

The AN/ARN-127 has been purchased for retrofit into F-4E/G and RF-4C aircraft and is intended by AFLC to become the USAF standard modernization VOR/ILS until ILS is replaced by MLS and/or GPS in the 1990s.

New transport aircraft are being purchased by the Air Force with commercial VOR, localizer, glide slope, and marker beacon equipment already installed (VC-137, C-141, C-9, C-12, E-3A, E-4, KC-10, and possible future procurements). For aircraft currently having no ILS/VOR and for those now using obsolete military equipment, the AN/ARN-127 is the modernization equipment selected by the USAF.

2.5 COST-BENEFIT CONSIDERATION IN THE USE OF COMMERCIAL AVIONICS IN USAF AIRCRAFT

We addressed the evaluation of commercial avionics quantitatively and qualitatively. From both points of view we found that the cost-benefit decision has to be based on the circumstances surrounding each aircraft program. A major factor is the type of aircraft and its mission. There is a very persuasive argument that the environment of the cargo/tanker/transport and training-mission aircraft closely parallels that of commercial aircraft and consequently such aircraft can be served by commercial avionics. Procurements of these aircraft are often made from commercial transport designs and production facilities, in which case it would appear cost-effective to retain the commercially developed flight operations avionics suite and add the necessary military communications, identification, and other mission avionics from GFE sources. For other types of aircraft, constraints introduced by space availability and environment may prevent (or discourage) the use of commercial avionics. In this situation, we found no clear cost advantage to using commercial equipments. Table 2-6 lists the major qualitative benefits and "cost" penalties of using commercial avionics.

2.5.1 Relative Cost

The way in which commercial and military avionics prices are stated prevent direct comparisons. Commercial prices are quoted as a "net" and and sometimes also as a "list" or "selling" price marked up 33 percent.

Table 2-6. QUALITATIVE ASPECTS OF USING COMMERCIAL AVIONICS IN USAF AIRCRAFT

"Cost" Penalties	Benefits
• Performance Compromises •• Weapon delivery accuracy is not provided •• Operating range frequencies and altitudes optimized for commercial needs • Design Flexibility •• Performance, size, cost trade-offs determined for commercial use •• Standard military interface not provided •• Any major change will compromise investment and availability benefits (but may still be cost-effective) • Maintenance Considerations •• Parts may not be in standard inventory •• Maintenance data is not to MIL-Standard •• Built-In-Test is at LRU "GO/NO GO" level •• Shop test equipment not standard	• Reduced Investment •• Development cost amortized •• Selling price is listed for single unit buy •• Quantity discount can be negotiated •• Minor options and exceptions can be negotiated competitively • Availability •• "Off-the-Shelf" for small quantity •• Design is mature •• Reliability is known and based on high operating time • Interchangeability •• Multiple vendors (promotes competition) •• Evolutionary product improvement •• Continuing availability of replacement spare LRUs

Major purchasers can negotiate discounts below "net" and can also negotiate specific support efforts and warranty conditions. In the competitive commercial business environment these details are not disclosed publicly. Cost data on military GFE avionics are ultimately published in the National Stock List and can be derived also from published data on supply contract price and quantities. Again, data on what the price includes in terms of support, warranty, training, spares inventory, etc., is not generally available.

In spite of the above discrepancies, it is clear that there are no inherent acquisition-cost benefits to be derived from the use of commercial avionics equipment. Functionally equivalent military and commercial avionics units in general use have similar prices (see Table 2-7). When the USAF has bought commercial avionics in quantity (such as the Carousel IVE INS), the unit price was well below the published net price. Also, when the military has bought repackaged commercial avionics (such as the AN/ARN-127 and AN/ARN-123 ILS), the unit prices were well below the equivalent commercial airlines equipment; and the AN/ARN-127 is offered commercially at a net price 25 percent above the last USAF price known to us. We conclude that for quantity buys to a mature design requirement, the military can obtain commercial avionics, modified/repackaged commercial avionics, or custom-designed military avionics at unit costs that are comparable to airlines costs. When the quantities are small, selection of a commercial design puts a ceiling (the net price) on the acquisition cost and avoids the design, development, test, and data cost that would accompany a specialized military procurement.

2.5.2 Acquisition Lead Time

Although commercial avionics suppliers do not normally carry a large inventory of airlines avionics units, they respond to perceived market opportunities by supplying units for evaluation, testing, and prototyping. Also, they will adjust production to meet any orderly build up of demand. The uncertainties and delays typical of GFE development and pre-production programs are essentially absent in this context.

2.5.3 Interchangeability

If commercial airlines (ARINC) avionics are specified early in an aircraft design or modernization program, design details to accommodate them can be finalized, yet competitive procurement can proceed without compromising the aircraft's interface details. Prototype aircraft can be outfitted off the shelf independently of the production procurement, and second-sourcing and split-buy techniques can be routinely exercised.

2.5.4 Performance

The performance of commercial avionics is attuned to ensuring that the airlines comply with U.S. and international airspace rules and the rules pertaining to operating in the Air Traffic Control environment. Many military avionics systems have no more arduous requirements to satisfy and thus are candidates for using commercial airlines avionics. However, when significant extensions in performance are needed, cost and technical considerations may preclude their use.

2.5.5 Reliability

Commercial airlines avionics must have high reliability. Operating for up to 18 hours per day, aircraft accumulate flight hours very rapidly. Delayed departures due to unscheduled maintenance are very costly, so avionics MTBFs greater than 2000 hours are essential -- 10,000 hours are desirable. There is no reason to suppose that commercial avionics would not experience the same reliability in USAF aircraft under equivalent environmental conditions.

Table 2-7. COMPARISON OF COSTS OF MILITARY AND COMMERCIAL AVIONICS				
Type of Avionics	Commercial Specifications	Airline Cost	Military Type	Military Cost
HF Radio	ARINC 533A	$15,000	618T(-)B	$15,000
	No Equivalent	-	ARC-112	$23,000
	No Equivalent	-	ARC-123	$17,000
	ARINC 559A	$13,770	No Equivalent	-
Radar Altimeter	ARINC 552 } ARINC 552A	$10,000	LARA	$9,118 (planned budgetary)
INS	ARINC 561-11 (C-IV-E)	$100,000	C-IV-E	$54,000
			SKN-2400	$75,000
VOR/ILS	ARINC 547	$4,400	ARN-127	$2,800 ($3,500 to individual buyers)

2.5.6 Design Flexibility

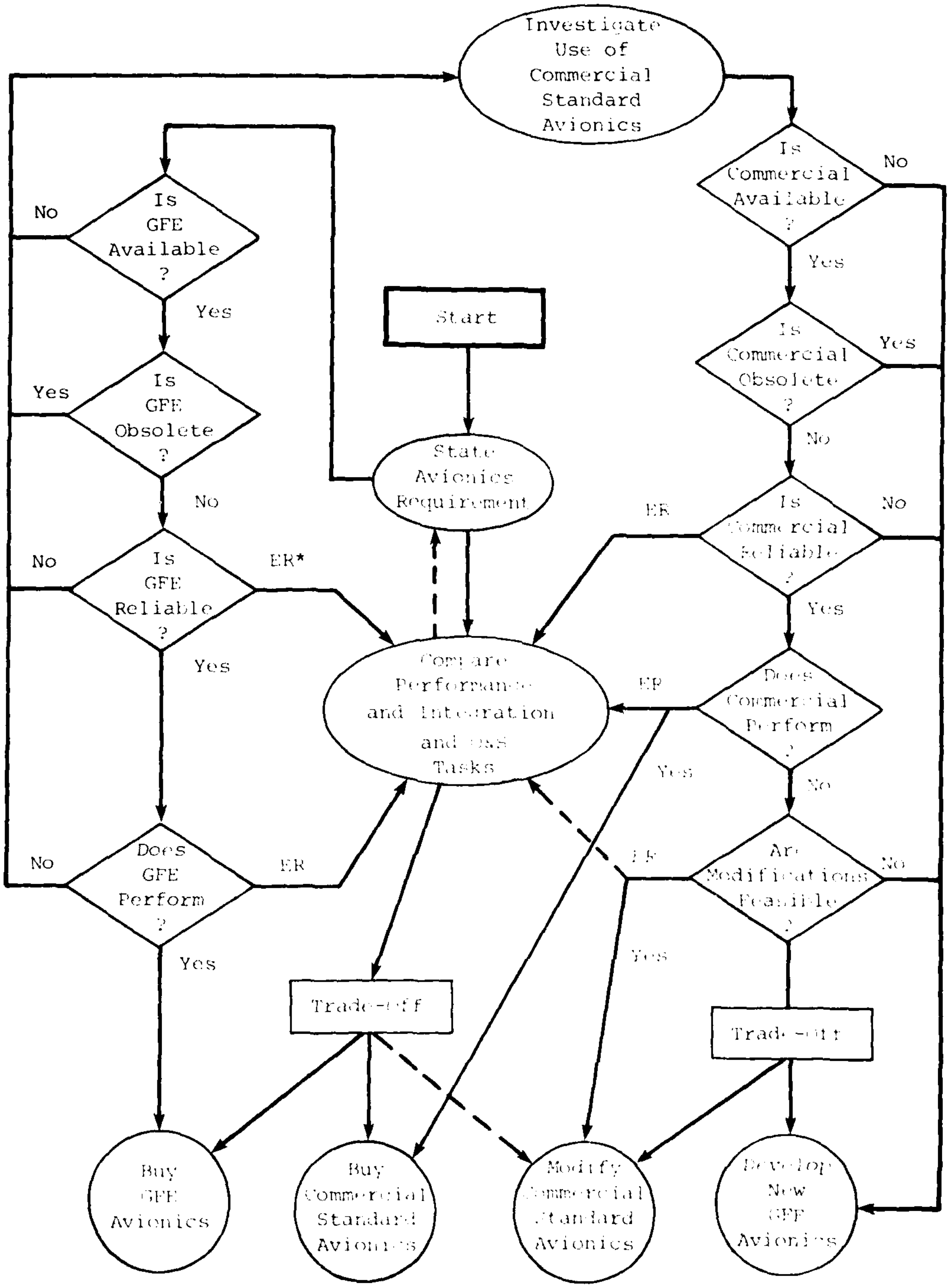
The commercial airlines have established a common avionics architectural standard. A military requirement to interface a commercial standard unit (or group of units) with a different architectural standard engenders a need to determine an effective interfacing mechanism and secure the resources to implement it.

2.5.7 Maintenance Considerations

There appears to be no reason to expect any difference between the cost of supporting commercial airlines avionics and the cost of supporting military avionics. (Cost could escalate, however, if the commercial equipment is treated as "new GFE" and MIL-STD documentation is demanded.) Commercial avionics maintenance data (in compliance with ATA 100 Specification) is complete and adequate. Service bulletins maintain currency and provide quick reaction to observed problems. The manufacturer's field service support and training are normally available on an as-needed basis, by formal contract, or under warranty terms. Automatic test equipment is generally available on a unit-by-unit basis (PSE), although some "universal" automatic test equipment is available for individual avionics manufacturers' products.

2.5.8 Cost-Benefit Decisions

Individual decisions concerning the use of existing and future commercial airlines avionics in USAF aircraft will need to be made. Figure 2-3 illustrates such a decision process. If available GFE avionics match the requirement, a clear-cut decision to use it would be made, unless there was specific direction to evaluate commercial alternatives or the aircraft was already configured for commercial avionics flight systems. If suitable GFE avionics are not available, commercial equipment, and



*ER = Evaluation required.

Figure 2-3. GFE-COMMERCIAL DECISION PROCESS feasible modifications if required, should be investigated. Where there is clearly no suitable commercial equipment available either, a program will be needed to develop new GFE. This may be "all new", a modified existing military equipment, or a repackaged commercial equipment. In many cases, the situation will not be clear-cut, and a comparison of cost, reliability, performance, acquisition integration, and support cost (life-cycle cost) will have to be made between the available alternatives.

2.6 SUMMARY AND CONCLUSIONS

Commercial airlines flight-essential avionics are designed, manufactured, tested, and certified to a well defined and documented set of standards, which correlate qualitatively, and sometimes quantitatively, with equivalent military specifications and standards.

Where military and civil functional needs run parallel, restraints on the military use of commercial standard avionics are of three kinds:

- Physical and Performance Shortcomings - which must be recognized
- Integration and Interface Difficulties - which can be overcome
- Procurement Procedures, Documentation, and Data - which can be changed or waived

2.6.1 Functional and Performance Applicability of Specific Commercial Avionics

The general performance capabilities of certain commercial airlines avionics are presented in Table 2-8.

2.6.2 Applicability of Commercial Standard Avionics to Specific Aircraft

Table 2-9 summarizes our findings concerning the applicability of existing commercial airlines avionics to specific aircraft of current interest to ASD. The avionics units listed are all ARINC-500 series; the corresponding ARINC-700 series avionics would have similar applicability, subject to evaluation of the need to transition to an all digital data transfer system and/or provide interface compatibility between the ARINC-700 units and the MIL-STD-1553 digital data bus.

2.6.3 Conclusions and Recommendations

Commercial airlines avionics, existing and future, have valid applicability to USAF aircraft. Procedural restraints and maintenance concepts should be restructured to encourage use of commercial avionics where this course is technically and economically valid. Appropriate revisions should be made to MIL-Standard directives. Standardized approaches to solving typical integration difficulties should be developed. Volumetric and

Table 2-8. CAPABILITIES OF CERTAIN COMMERCIAL AVIONICS	
Avionics Description	**Performance Capabilities**
Radio - Altimeters ARINC 522A ARINC 707	All applications for instrument and auto-coupled flight close to the ground (0 to 2,500 feet; extendable to 5,000 feet by optional changes).
HF Radio ARINC 559 ARINC 719	All applications, provided that an acceptable form factor can accommodate the optional features corresponding to Collins adaptation of the ARINC 533A HF radio to their 618T configuration for the USAF.
Weather Radar ARINC 564 ARINC 708	All applications where high resolution mapping is not also required from the same radar.
Flight Data Recorders ARINC 573	Voice recorder channel not provided; data acquisition (i.e., signal conditioning) unit interface is to ARINC 429 DITS and specific ARINC Characterized Air Data Units.
Ground Proximity Warning System ARINC 594 ARINC 723	All applications needing passenger certification and/or Category III instrument landing capability.
Air Data Computer ARINC 575-3 ARINC 576 ARINC 706	Transport aircraft applications or similar aircraft needing sophisticated instrument display and auto-pilot coupling facilities. Specialized features such as EAS auto-pilot gain adjustments are not included.
Inertial Navigation Systems ARINC 561-11 ARINC 704	All applications.
Instrument Landing System ARINC 578-3 ARINC 710	All applications, but marker beacon receiver is not included.

Table 2-9. APPLICABILITY OF ARINC 500 SERIES AVIONICS TO CURRENT USAF AIRCRAFT

Avionics Function	Already Installed or Planned	Requires Feasible Changes to Avionics	Requires Changes to "A" Kit	Requires Additional Space
HF Radio ARINC 533A* or ARINC [illegible]A	C-130, C-141	B-52, KC-135, C-5, F/FB-111, A-10, B-52	B-52, KC-135, C-5, F/FB-111, A-10, B-52	B-52, KC-135 C-5, F/FB-111
Radar Altimeter ARINC 552A	E-3	F-111, F-4, A-7, C-5, C-141, KC-135, HH-53	CH-3, F-111, C-130, F-4, A-7, C-5, C-141, KC-135, HH-53	CH-3, F-4, A-7, KC-135, C-141, C-5, HH-3
Weather Radar ARINC 564	KC-10, E-3, KC-135	C-5, C-130, C-141, E-3	C-13[illegible]	-
Crash Recorder ARINC 573	E-4, C-9, C-141, VC-137	-	-	-
GPWS ARINC [illegible]	C-5, C-141, T-43, KC-10	-	-	-
ADC ARINC 5[illegible] or ARINC 565	E-3, E-4, C-5, KC-10	C-141	C-141	-
INS ARINC 561-11	C-5, C-141, C-130, E-3, KC-135	F-4, F-111	F-4, F-111, F-16	-

*ARINC 533A has a 1 ATR long form factor but includes most military needs. Collins 618(T) is an ARINC 533A unit.

environmental criteria should be established to give general guidance concerning the non-applicability to high-performance, space-premium aircraft. Ultimately, each aircraft program decision should be the result of an individual trade-off evaluation of its common avionics needs and interfaces.

CHAPTER THREE

SUPPORTING STUDIES

As part of the cost/benefit analyses of Task 2, we were asked to perform two special supporting studies: (1) an industry survey to solicit opinions and data on the merits of an avionics PME standard and (2) a review of "new" cooling technologies, to assess the potential effects of such technologies on future PME standardization. This chapter reports the results of this work.

3.1 INDUSTRY SURVEY

In addition to collecting information from "in-house" sources, from ASD/EN study inputs, and from current and past technology reports and briefings, we sent a questionnaire to industrial firms that have substantial background in both commercial and military avionics manufacturing or in military and commercial aircraft manufacturing involving substantial avionics integration. Every effort was made to ensure that this enquiry was addressed to a responsive individual (or group) by preliminary telephone conversations. Contacts established in connection with ARINC Research's Low Altitude Radar Altimeter (LARA) specification development were also used. Where appropriate, promising responses were followed up with in-plant meetings to supplement the written replies. ASD/XRE and ENA personnel also participated in these meetings.

The questionnaire took the form of a letter requesting narrative opinion on the relevant standardization issues raised and a form designed to elicit simple, clear-cut answers to specific questions (see Figure 3-1). Twenty-five firms were solicited; of these, seven responded. The respondents included two major military aircraft manufacturers -- Boeing and General Dynamics -- and five major electronics firms -- Bendix, Emerson, Rockwell International (Collins), Singer, and Sperry. The results presented in tabular form in Table 3-1 show that the majority of respondents expressed a positive attitude toward applying packaging, mounting, cooling, and power standards to both new and old aircraft, and for both common and core avionics. One company, Emerson, expressed a minority viewpoint that favored only standardization for electric power sources. The full replies are reproduced in Appendix E.

Gentlemen:

ARINC Research Corporation is under contract to the Air Force (Contract Number F33657-79-C-0717) to evaluate and report on the possible costs/benefits of the standardization of USAF avionics packaging, mounting, environmental control requirements (PME) and to determine the extent to which such standardization, if beneficial, could utilize civil airline avionics standards. As a part of this contract, we are required to solicit inputs from aircraft and avionics manufacturers to obtain opinions and viewpoints on at least the following questions:

a. Is a military standard based on ARINC 600 concepts a viable approach to simplifying avionics installations obtaining greater equipment reliability and achieving reduced acquisition, modification, and support costs?

b. What qualitative or quantative benefits has the manufacturer previously observed in commercial practice versus military practices?

c. If the new USAF standard requires a new design of mounting racks and connectors, and an upgraded environmental control system, what are the expected areas of concerns and impacts?

1. for a new aircraft

2. for major avionics modernization programs

d. Should the USAF standard attempt to be all inclusive across all types of aircraft and core/common/mission avionics, or should it address only certain subsets of these?

We would appreciate your comments on these questions together with any related information or observations that you feel may be of benefit to our study. If possible, we would like [illegible] August [illegible] that we may expand or [illegible], if necessary, by in-plant visits and [illegible] August-September [illegible] the listed questions, [illegible] attached form [illegible] supply [illegible] summarize your [illegible]

[illegible] Should you [illegible]

Very truly yours,

[illegible]

[illegible]

INDUSTRY SURVEY: *AVIONICS PACKAGING, MOUNTING, ENVIRONMENTAL STANDARD*

RETURN TO:

ARINC Research Corporation
2551 Riva Road
Annapolis, Maryland 21401

Attention: Mr. N. Sullivan

COMPANY ______________________________

ADDRESS ______________________ CODE __________

POINT OF CONTACT ______________________________

PHONE NUMBER ______________________________

PRINCIPAL AVIATION *PRODUCT LINES*	COMMERCIAL	MILITARY

1. Organization *feels* that standards *would be beneficial*?

	Yes	No
Packaging	☐	☐
Mounting	☐	☐
Cooling	☐	☐
Power	☐	☐

2. Organization feels that standard should be:

Direct adoption of ARINC 600 ☐
Adaptation of ARINC 600 ☐
Other concept ☐

3. Standard should be made applicable to:

New design aircraft only ☐
New and older aircraft ☐

4. Standard should address:

Core avionics (e.g., computers) ☐
Common avionics (e.g., radios) ☐
Mission avionics (e.g., EW equipment) ☐

Figure 3-1. INDUSTRY QUESTIONNAIRE

Table 3-1. ANSWERS TO INDUSTRY QUESTIONNAIRE												
Company Responding	Form of Standard			Standard Should Cover				Standard Should Be Applicable To				
								Aircraft		Avionics		
	ARINC 6	Adaptation of ARINC 600	Other Spec.	Packaging	Mounting	Cooling	Power	New	New and Old	New	Former	Mixed
Bendix		X		X	X	X	X		X		X	
Boeing		X		X	X	X	X	X			X	
Collins		X		X	X	X	X		X	X	X	X
Emerson							X		X	X	X	X
General Dynamics		X		X	X	X	X		X	X	X	
Singer		X				X		X		X	X	
Sperry		X		X	X	X	X		X	X	X	X

When sufficient replies to our mailed survey questionnaire were available, follow-up visits were arranged to get personal reactions from industry people to the concept of USAF PME standardization and their opinions on the following subjects:

- Viability of ARINC 600 concepts
- Benefits, quantitative and/or qualitative
- Impacts of standard racking and connectors
- Degrees of applicability across aircraft types and equipment groups

ASD/XRE and ENA personnel took part in these visits.

Visits were made to General Dynamics Fort Worth Division (F-16), Rockwell International (Collins Radio) at Cedar Rapids, and Bendix Avionics Division, Fort Lauderdale. A visit to Boeing Aerospace Company was initiated, but, after full discussions by telephone, it was concluded by all concerned that all points had been thoroughly covered and a trip was not warranted.

3.1.1 Visit to General Dynamics, Fort Worth Division

General Dynamics, Fort Worth Division, has experience on the F-111 program and is currently working on the F-16 multi-national program. We examined the two full-scale fuselage sections (F-16A and F-16B) that are used as metal mock-ups for verifying installation of avionics hardware. Avionics equipment locations were pointed out and the environmental control system was explained. Subsequent discussions brought out the following viewpoints:

- ARINC 600 form factors would be difficult to apply to the F-16 or to fighter aircraft in general, because the uniform height and length of ARINC units makes fitting into irregularly shaped spaces difficult. For example, in the F-16, boxes of different heights are arranged to occupy curved or sloping bay contours. If a uniform height is to be selected, General Dynamics would recommend 5 inches as more appropriate for a USAF standard.
- The F-111 and the F-16 aircraft supply cooling air through a manifold on the aircraft's centerline to the rear of the avionics boxes with free exhaust from the front of each box. Boxes are installed and removed from each equipment bay through removable aircraft skin panels, as in most fighters.
- F-16 vibration is only significant aft of the engine nozzle and near the gun muzzle. Equipment mounted close to the gun (e.g., within one foot of the muzzle) is installed on shock mounts. These are effective because the gunfire vibration is confined to the narrow frequency band of 90-100 Hz and higher harmonics. Common shock-isolated equipment shelving is not practical because individual qualification-test complications would occur.

- The F-16's environmental control system is a compact arrangement of heat exchanger, expansion turbine, and water separator. The General Dynamics personnel were not aware of any overall efficiency trade-offs on cooling methods and their impact on aircraft weight and engine performance.

3.1.2 Visit to Rockwell International (Collins Radio)

The Collins engineers have experience in military and commercial avionics products. The TACAN AN/ARN-118 receiver was of particular interest. This has become a USAF standard -- 10,000 have been produced so far. The TACAN production line was visited, and AN/ARC-186 VHF AM/FM communications receiver assembly operations were seen. Subsequent discussion brought out the following viewpoints:

- Military standardization of avionics PME would be highly beneficial to all concerned. While one manufacturer might lose a favorable sole-source position in one procurement, it would have the opportunity to compete for the many other military reprocurements that would be opened up to it under an F^3 standardization policy. The USAF would also benefit from the routinely upgraded avionics design and manufacturing improvements, which otherwise could only be introduced after lengthy ECP procedures for the conventionally managed military programs.

- More than one standard (or subsets of the standard) may be necessary to encompass the needs of all aircraft classes.

- Space-premium aircraft may require modules that have less height than ARINC 600 permits. If these are produced, trade-off studies would be needed to see whether they should be used on all USAF aircraft classes.

- Collins engineers felt strongly that "MIL" vibration test requirements generally exceeded by a significant (and costly) margin the actual levels measured on equipment in the aircraft. The "MIL" vibration levels applied by powerful, rigidly coupled test equipment are much more destructive than the vibration transmitted by any typical aircraft structure, particularly at the higher test frequencies.

- Functional standardization of units should accompany PME standardization for the greatest cost benefits.

- Lowering the design operating temperature does not usually enable acquisition cost to be reduced significantly, but it does reduce failure rates considerably.

- The guaranteed MTBF clause in the AN/ARN-118 production contract gave a strong incentive for good design, with the result that guaranteed MTBF is being met or exceeded. However, the MTBF guarantee gives little opportunity for corrective action to be taken by Collins if this were not the case. A four-year reliability improvement warranty (RIW) added the opportunity for product improvement, with mutual benefit to the buyer and the seller.

- F^3 specification procedures, as employed by the commercial airlines, add further incentive for supplier support in the event of performance or reliability problems throughout the life of the equipment, because of the ability of the buyer to switch to a competing vendor for any future procurement.
- Prices of commercially supplied avionics include the overhead needed to cover vendor support (i.e., local representatives, field support, etc.). The same equipment, sold to a military buyer intending to use organic maintenance, might appear to cost less until the cost of MIL Standard documentation, initial spares, and training are added. These are usually treated as separate cost items by the government.

3.1.3 Visit to Bendix Avionics Division, Fort Lauderdale

The Bendix Avionics Division initially produced equipment only for the civil marketplace, including both general aviation and the airlines. They now produce for military customers as well, and have a mandate to develop new avionics for which they can demonstrate a competitive return on investment.

The AN/ARN-127 (Air Force) and AN/ARN-123 (Army) instrument landing system (ILS) receivers were of particular interest, having been developed from Bendix commercial standard circuitry and repackaged to meet the service requirements for an ILS/VOR/Marker-Beacon receiver in one compact box. Bendix Avionics production assembly and test areas were visited; the AN/ARN-127 temperature/vibration burn-in testing was observed in progress. All electronics products are subjected to maximum temperature "burn in" during their test cycle, mostly in simple insulating enclosures (called "rabbit boxes") vented so as to stabilize at 70°C ambient temperature.

The new ARINC 708 weather radar was seen on final test; we noted the carefully designed internal ducting that distributed cooling air from the bottom entry port to the critical power sections of the transmitter/modulator. Subsequent discussions brought out the following viewpoints:

- The MTBF penalty imposed on the AN/ARN-127 production was a highly effective incentive to good design and quality control. The program could not afford to carry any continuing penalty costs.
- Excessive batch-sample testing is costly to the government in terms of test time and production equipment diversion from delivery. AN/ARN-127 batch-test quantities appeared to be excessive; AN/ARN-123 batch-test quantities were probably insufficient.
- "Burn-in before final test" was a practical requirement, but some flexibility in the burn-in period so as to fit in with factory shift organization is a cost saver.
- Bendix experience was that MIL-reliable components were not demonstrably more reliable than the corresponding commercial version, sometimes less so, if production quantities were small. In either

case, Bendix cannot afford to let defective/unreliable parts get to the assembly area due to the cost of reworking defective assemblies. Parts are in-plant inspected and tested by the vendor; the Bendix receiving inspection and test is a second "filter" and a continuing check on the vendor's test effectiveness.

- Blow-through cooling air presents less of a contamination problem than humidity testing. Protection from both is needed and is provided by suitable coatings. Blow-through cooling is by far the cheapest way to cool avionics.

3.1.4 Telephone Conference with Boeing Aerospace

We conversed by phone with the principal contributor to Boeing's reply to the questionnaire, discussing at length the rationale for Boeing's answers and the availability of additional information. The consensus was that we had covered the areas of profitable discussion, and that, although we would be welcome, there was no justification for a visit to Seattle.

Boeing's major points were as follows:

- At least three levels of standardization will be necessary:
  - Essentially unmodified commercial standard for commercial-like equipment in planes like E-3, E-4, KC-10, and similar future aircraft.
  - Standards for difficult aircraft, like fighters with limited space or AWACS-type aircraft with large heat dissipation requirements. These standards will have to differ significantly from ARINC 600 and may require provisions for liquid or other exotic cooling.
  - Aircraft between these two extremes probably can profit from an intermediate standard. Working to such a standard would be better than trying to stretch either of the other two to fit.
- For aircraft with substantial complements of mission equipment, it now appears advantageous to separate low-power-density "logic card" circuits (with minimal cooling requirements) from higher power components or circuits requiring substantial cooling. "Logic card" assemblies probably would benefit by separate cooling and packaging standards.
- Boeing currently has USAF study contracts to investigate advanced cooling concepts but is more than a year away from a final report.

3.2 SURVEY OF COOLING TECHNOLOGIES

3.2.1 Background

This section addresses the tasks listed in 3.2.4 of the Statement of Work. It provides a composite evaluation of cooling technologies, separated or dedicated environmental control systems, and the cooling of instruments and electronic components mounted on or behind the various cockpit panels. It was not considered technically beneficial to segregate such interdependent and interrelated items for individual treatment.

3.2.2 Review of Existing Avionics Cooling

With only the most minor exceptions, the thermal environment in today's aircraft induces high thermal stresses in avionics equipment. In some aircraft the avionics may enjoy a favorable environment during normal flight and then be subjected to high thermal stress during ground operations. In some aircraft only a portion of the avionics is adequately cooled in flight. These conditions may be regarded as typical throughout the USAF inventory and exemplify the lack of any serious standards for cooling avionics.

Severe differences in the cooling environment cannot be associated with any particular class of aircraft or with any particular type of cooling. Even in aircraft equipped with high-capacity vapor-phase cooling systems, some of the installed avionics either have been denied access to the cooling air by their location in the aircraft, or the cool air distribution system has failed to deliver sufficient air flow to the individual boxes. The same conditions have been verified in aircraft using convection cooling (with or without blowers); it is typical for some locations to receive no cooling whatsoever. It may be assumed that some of the avionics in each aircraft type will be the victims of inadequate cooling arrangements during flight or ground operation.

3.2.3 Current Approaches to Improved Cooling and Reliability

As used in this report, the term "current approaches" represents the accumulated efforts made by military and civil users of modern avionics to initiate improvements in avionics cooling systems.

One of the earlier advancements was contained in ARINC Specification 404, published in 1956, which cited the avionics cooling deficiencies experienced since World War II. It prescribed specified openings in the equipment case and the "404 racks" for cooling air to reduce equipment operating temperatures. This concept assumed installation of the avionics in the cooled cabin area of the aircraft, with a vacuum duct below the equipment to draw the cooler cabin air through the avionics box. Specification 404 was successful where it was applied -- but it was not universally applied. As they entered the transport fleet, some new aircraft types did not incorporate the 404 cooling provisions and experienced serious heat problems in and around some RF transmitter units. This situation continued until remedial measures were agreed to through the Airlines Electronic Engineering Committee (AEEC) actions.

Today's panel-mounted instruments contain higher density electronics and generate more heat than the older mechanical instruments. With the more recent introduction of cathode ray tubes (CRTs) into the instrument panel, the resurgence of the heat problem can no longer be ignored. In

1976, ARINC Specification 408A (pertaining to air transport indicator cases and mountings) prescribed methods for calculating the cooling requirements of panel-mounted instruments and recommended the circulation of cooling air to remove the heat.

Reliability degradation due to overheating avionics was a primary reason for the AEEC's developing and publishing ARINC Specification 600 in 1977 and 600-1 in 1978. The ARINC 600 Specification represents an updated approached to avionics interfaces and specifies more completely the use of forced-air cooling in the avionics equipment racks. A companion document, ARINC Specification 601 (still in the process of final coordination), will prescribe similar cooling arrangements for the "control/display interfaces" -- i.e., the CRTs and other instruments mounted in the cockpit on the instrument panel, the pedestal, or the shelves and overhead panels. The specification also will contain guidelines for the amount of allowable heat dissipation per cubic inch. The application of these innovations to new aircraft entering the inventory should provide a much improved environment for cockpit controls and display devices. The Boeing 767 now in production will have some degree of compliance; the A300 Airbus (now being configured for several U.S. air carriers) probably will conform to the ARINC 600 specification with pressurized and filtered air for all avionics, including the cockpit devices.

The AEEC is currently working on Characteristic 728, which covers the provision of refrigerated air for the avionics during ground operation. This is due to be approved and published during 1980. In the meantime, United Airlines has equipped two DC-10 aircraft with a refrigeration system featuring filtered air for the avionics. This system is being evaluated primarily for ground operation, but it may well be prescribed for inflight operation also.

3.2.4 Avionics Cooling Technology of the Future

Almost all current approaches to avionics cooling have involved direct heat transfer to the surrounding air or to an air stream circulating through the equipment. This form of heat transfer depends on a high-density atmosphere that is capable of absorbing large quantities of heat. In those cases where the avionics are installed in the pressurized and environmentally controlled cabin areas, the air transfer can be adequate. To achieve proper cooling, the airframe and avionics specialists must recognize the many approaches to heat transfer that are available and abandon the routine concept of air circulation as the only solution.

3.2.5 Instruments and Cockpit Display Devices

The cooling of electronic instruments installed in the cockpit remains a weak link in avionics cooling. The problem has been recognized and an AEEC subcommittee on Instrument Cooling and Mounting (ICM) was formed in 1974, but agreed solutions have been slow in coming.

The instruments themselves were not designed for efficient heat transfer, and the instrument cases do not provide sufficient surface area for adequate cooling, even at ambient room temperatures. In the confined spaces behind the instrument panel, with the instruments clustered as closely as they can be fitted together, overheating results. To achieve a degree of short-term relief, some of the airlines have initiated a project to provide cooling air behind the panel by means of small pipes or ducts routed between the instrument clusters.

3.2.6 Military Avionics Unique Features

In military aircraft, some features are truly unique, and they must be considered in preparing for the proper cooling of future installations. For instance, in small high-performance aircraft, only the cockpit is pressurized and temperature conditioned. Relatively few of the avionics (beyond the controls and displays) can be fitted into the cockpit, but the cockpit exhaust air is used for cooling equipment in adjacent parts of the aircraft.

The supersonic military fleet presents a special set of environmental conditions in terms of both temperature and altitude. During supersonic flight, the skin of the aircraft may reach temperatures of several hundred degrees at flight altitudes above 70,000 feet, where the air is unable to absorb large quantities of heat. The most readily available heat sink under such conditions is the aircraft fuel system. Since the fuel must be warmed to assure proper metering prior to injection into the engines, the use of the fuel as a heat sink becomes mutually beneficial to both systems. Heat transfer devices can be introduced either into the fuel tanks or into the fuel lines feeding the engines.

Another source of possible avionics cooling is the liquid oxygen system. By necessity, the liquid oxygen must absorb a tremendous amount of heat to boil off the gaseous oxygen required for the life-support system. Through proper design, the excess heat from the avionics could be transferred to the liquid oxygen heat exchanger.

3.2.7 Coordinated Design Approach (Internal/External Considerations)

Avionics cooling must be approached as a total problem, inside and outside the box, from the point of heat generation within a single electronic component to the final transfer of that heat energy to some dissipative medium outside the avionics area, and perhaps outside the aircraft. Any approach that does not include this end-to-end treatment of the heat-removal problem should be regarded as incomplete. The progressive transfer of heat from the component where the heat is generated to some point outside the avionics box or assembly may include several steps with each step representing an identifiable heat transfer operation. Using a single component as the starting point, the heat may be conductively transferred to the ground plane of a printed circuit board, conductively transferred to a heat pipe located internally within the box, and conductively transferred from the heat pipe to the outer wall of the unit. From the outer wall it may be conducted to a finned area for direct dissipation -- or perhaps to another heat exchanger, with air, liquid, or vapor used as the transfer medium. This totally integrated approach, inside and outside the avionics box, appears to be the key to providing improved cooling to the electronic components, which is the most important factor in achieving more favorable operating temperatures and the greater reliability needed by both the military and civil users of complex avionics. The following review of the individual heat transfer techniques may be useful.

3.2.7.1 Convection Cooling Technology

Two types of convection cooling are of interest here: (1) free convection, where the air motion results only from the convection currents formed by the hot air rising from the heat source and (2) forced convection, where the air motion is primarily controlled by a fan or blower.

The primary problem associated with either type of convection cooling is the reduced air density that occurs with increasing altitude, causing the atmosphere to become a less efficient heat transfer medium by factors of 3 at 30,000 feet, 6 at 50,000 feet, and 12 at 70,000 feet. A commercial airliner's cabin and avionics bay is held to a pressure altitude of 5,000 to 8,000 feet, providing a heat-transfer capacity that is still approximately 80 percent of its sea-level value. Convection cooling is, therefore, appropriate to commercial transport aircraft and, by analogy, to military transports also.

In the high-performance military aircraft environment, the circulation of cooling air through an avionics assembly does not represent the best approach to system cooling. Even under ideal conditions, the cooling air will contain some degree of contamination, and, over a period of time, the contaminants will become lodged or deposited on the circuit components. This condition will reduce the effectiveness of the cooling system and may also produce a malfunction or a failure. If the weapon system should be exposed to radioactive particles suspended in the atmosphere, the direct ingestion of these particles into the avionics circuitry could induce a wide variety of malfunctions and failures. The best assurance of internal cleanliness and adequate cooling for all electronic components is achieved through designs that provide conductive cooling throughout the electronic assembly and internal heat transfer to the walls of the enclosure. This approach requires no holes or ventilation ports in the electronics enclosure. With all of the internal heat transferred to the walls, a variety of available heat-exchange techniques may be employed to cool the box.

3.2.7.2 Conductive Cooling Technology

Conductive cooling of electronic components and assemblies encompasses many techniques. To be effective, conductive cooling philosophy must be applied concurrently with circuit design, circuit layout, component selection, manufacturing methods, and system packaging.

If the metallic surface of a printed circuit board is to be used as a conductive heat-transfer device, the layout of the board is critical to its thermal transfer efficiency.

Use of a thermal shunt or a conductive cold plate is an effective technique. Usually it is a copper or aluminum part that provides an efficient heat-transfer path, cooling the heat sources while also leveling the heat distribution through the electronic assembly. A good alternative is to cover the entire printed circuit board with a thermally conductive (dielectric) material. Typically, these new materials consist of silicone rubber heavily filled with aluminum oxide or beryllium oxide. They cure at room temperature, thus applying no thermal stresses to the electronic components. For replacement of failed parts, the rubber material can be cut away and subsequently refilled without disturbing the remainder of the board. This technique provides a good heat transfer path in all directions across the circuit board and achieves an effective integral thermal mass.

A castable epoxy compound with high thermal conductivity, which cures into a hard mass, is used primarily for potting large heat-producing components rather than for coating circuit boards.

A heat pipe is a thermal shunt that includes technology for improving thermal transfer efficiency, such as a liquid-to-vapor-to-liquid evaporation/condensation cycle within its internal structure. This device must be designed, configured, and fabricated for each specific application. Heat pipes are certain to play an increasingly important role in the future.

Improvements have also been made in the quality and thermal conductivity of the silicone greases used for the thermal interfacing of flat surfaces. The best materials do not drip or run at any elevated operating temperatures and do not dry out or deteriorate during prolonged exposure to a heated environment.

Components also found to be useful are thermally conductive card guides that will ensure efficient heat transfer from printed circuit boards to the sides of an enclosure, and gaskets made of thermally conductive materials that can be fitted to bridge gaps between poorly mating surfaces. The proper materials, properly applied, with intelligent layout and parts positioning will ensure efficient heat transfer. New-generation avionics development should utilize the best techniques and the best materials available for the efficient cooling of the equipment.

3.2.7.3 Thermo-Electric Cooling

Thermo-electric cooling devices exploit the Peltier effect to remove heat from a thermo-electric junction that is in thermal contact with the device to be cooled. The passage of a (relatively large) electric current through this junction causes a corresponding Peltier heat to be developed simultaneously at another junction needed to complete the electric circuit. The device is, in effect, a heat pump. Thermo-electric devices are available (off the shelf) from approximately 1/2 watt to approximately 500 watts of dissipation capacity. They have no moving parts, they are not fragile, and their life expectancy should be in excess of 100,000 hours if properly installed and properly controlled. However, the efficiency of such devices is inherently low, and the cost has remained high. From a practical point of view, thermo-electric cooling appears best suited to small heat sources, and, even then, it should be limited to some intermediate function in a complete heat-transfer chain.

3.2.8 Opportunities for Standardization

3.2.8.1 Standard LRU Conductive Cooling Interfaces

If good thermal design can ensure that an avionics unit is effectively a uniform thermal mass, then the cooling interface can be any sufficiently large area on any of its surfaces. With good thermal contact to this area, the outward heat flow can be continued by conduction into the next segment of its overall path. There are many options for this segment: in cases where the avionics box is generating a large amount of heat, an external heat exchanger can be provided. Typically, the heat exchanger would be a double-walled structure, one wall of which could be one or more surfaces of the avionics box. The heat exchanger may contain a flow of cooled air, or it may contain a circulating liquid. If the surface of the avionics enclosure is not one of the heat exchanger walls, the flat surface of the heat exchanger would interface with the flat surface of the avionics box to provide close contact. A good quality, thermally conductive silicone grease can be used to eliminate any voids between the two surfaces. In cases where less heat is being dissipated, the heat exchanger may be a finned structure, itself cooled by convection.

In all of the cases discussed above, the avionics box can be the same identical assembly (therefore lending itself to complete standardization), while the variables are a part of the aircraft interface and normally remain fixed to the aircraft. This approach permits avionics standardization, while accommodating several variations of air cooling, convection cooling, liquid cooling, heat pipes, or thermo-electric cooling.

Potential candidates for this type of interchangeable heat exchanger configuration are the new console-mounted communications transceivers (AN/ARC-164, AN/ARC-186). These units also have optional rack mounting configurations. To fit within the standard console rail, these transceivers are built up from a series of sandwich sections, five inches square (nominal). Each section has conductive heat transfer out to its periphery. In current installations, this periphery is cooled by convection -- by air blown over the case -- but the configuration is readily adaptable to a conduction-cooled interface if this were to be provided in the aircraft. This interface could be in the form of an instrument bay rack mounting, an actively cooled console mounting, or an actively cooled main instrument panel mounting for a five-inch-square display instrument. Other standaridzed unit sizes could follow the same concept.

3.2.8.2 Cooling Standardization for the High-Performance Aircraft

An effective avionics PME standard must address the problem of the high-performance aircraft. It can do so by developing a practical definition of a mutually acceptable thermal interface. In this way, the avionics designer is tasked with delivering no more than X watts per unit area when the heat-transfer interface is at Y degrees of temperature, and the aircraft environmental system designer is tasked with maintaining the heat transfer interface at no more than Y' degrees of temperature while it is emitting no less than X' watts per unit area. The differences (X'-X) and (Y-Y') represent operating margins and testing tolerances. The form and fit definitions for the avionics/aircraft interface must then provide sufficient interface area for the necessary power dissipation for each unit, and good thermal contact to both sides of the interface. MIL-HDBK-251, and research and investigation into the relationships between the reliability and the operating temperature of avionics components provide the basis for a logical determination of the interface parameters and supporting trade-off analyses.

3.3 U.S. NAVY PME PROGRAM

As a part of our review of the state of the art in PME interface concepts, we reviewed the U.S. Navy Modular Avionics Packaging (MAP) Program. This program is an integrated effort to satisfy requirements of future avionics systems from the component/device level through the interface of the avionics with the aircraft and its integral systems. The intent is to evaluate alternative concepts and develop standard mechanical, electrical, and thermal interfaces for modules, integrated racks, and other avionics enclosures. The program began in FY 1977 and is scheduled for flight testing of developed hardware in FY 1982. The Standard Avionic Module (SAM) concept is an integral part of the MAP Program.

Current planning has selected the Improved Standard Electronic Module (ISEM) 2A as a primary candidate. The size of this module is 1.68"H × 5.74"W × 0.29"D (0.4" permitted where required). Racking is to be 36"H × 28"W having multiple subsystems implemented by the ISEM 2A packages. Direct air-impingement cooling of the ISEM 2A modules will be used with 85°C junction temperature and 20 watts per module as a goal. Zero Insertion Force (ZIF) and Low Insertion Force (LIF) connectors have been investigated, with the LIF connector currently considered more advantageous because of the excessive contact resistance and lack of cleaning action in the ZIF connectors. Data interfaces will be by high-speed (10 MB/S to 200 MB/S) multiplex busses. The principal problem experienced to date is in achieving the desired 50 percent weight and volume reduction while using standard modules and racking.

Our review of the MAP program indicates that, even though the objectives are similar to those of the USAF and civil PME standardization programs, the methods selected for implementing the concept are not compatible either with USAF architectural concepts or with ARINC 600. The major cause for incompatibility is the importance given to the ISEM program and the use of the

ISEM 2A module as the building block of the Navy program. ARINC 600 requirements standardize at the avionics subsystem level, with the smallest module (or increment between successive sizes of modules) sufficient to house 30 or more ISEM 2A modules. The MAP approach selected by the Navy is targeted to minimize the unique logistic and maintenance problems associated with avionics for carrier or other shipborne aircraft. While this is an important objective for the Navy, the problems are not shared by all users of avionics. Thus, while some of the technologies addressing cooling, connectors, and other mechanical aspects of the PME concept may be shared, there does not seem to be a case for a direct application of MAP for USAF use. Earlier USAF studies found that the use of standard electronic modules is economically attractive only in limited cases (e.g., ground support equipment and selected aircraft applications). It limits the avionics designer's flexibility in his pursuit of optimization. Another drawback to MAP in its current status is that it fixes rack size and allows no installation flexibility for the airframe manufacturer.

3.4 OVERVIEW OF THE FINDINGS OF THE SUPPORTING STUDIES

On the basis of the preceding discussions and the results of the industry survey, we can draw several conclusions concerning both technical and business aspects of a USAF PME standard. The subject of cost-benefit relationships will be dealt with in Chapter Four.

As we explained in Chapter Two, ARINC 500 and 700 series avionics equipments have different degrees of direct usability in USAF aircraft. In most cases (except where space, environment, or performance prohibit it), adaptability can be achieved through modification, interface accommodation, waiver of standards, or changes in the procurement process. These caveats can be burdensome and frequently lead to a decision to pursue a military solution unless there is a clear and convincing cost argument to the contrary. Unfortunately, this usually creates a new and individualized piece of USAF equipment. A USAF PME standard similar to the ARINC standards could be the prime solution to this problem.

The consensus among industry members surveyed is that a USAF PME standard is an acceptable way to gain many of the standardization benefits associated with the ARINC standards, without being dependent on adaptations of airlines avionics. This approach also appears to enhance the current USAF standardization thrust by providing for cross-system standardization as well as standardization for a single system. The concept extends from boxes, racks, plugs, test equipment and procedures, to training and maintenance practices, installation design, modification processes, and specified items. It also enhances the potential for commonality in many other areas across multiple platforms: power sources, environmental control sources, ducting, porting, space efficiency, wiring design, and similar avionics peripherals.

Specific conclusions are as follows:

1. Sizing is the main point of contention associated with a PME standard. ARINC 404A and 600 Standards are considered "frequently too large," especially for space-constrained fighter-type aircraft. Sizing in a USAF PME standard should accommodate generalized needs. While a single standard would be economically preferable, multiple standards may be necessary to service the full range USAF needs. Perhaps some combination(s) of USAF and commercial sizing would be possible to permit cross-fit of equipments. The order of priority in size concern appears to be: first, height; second, length. Width was not mentioned as a concern.

2. The next most severe contention centers around environmental control, which would require design to maximize long-term benefits of current and future techniques. If designed and implemented carefully, an environmental standard could benefit not only the prime users (such as the F-16 and F-111) but also those who would achieve environmental control as a bonus. While good environmental design parameters certainly do not lower design and acquisition costs, they do provide lower peak operating temperatures, which, in turn, reduce equipment failure rates and hence operating and support costs.

3. While the use of a PME standard generates significant advantages, expanding the concept from one of form, fit (F^2), and environment to one of form, fit, function (F^3), and environment introduces the notion of functional standardization, which has been widely discussed but only occasionally implemented in the USAF. The benefits achieved through the combination of box and functional standardization are synergistic: both the user and the avionics industry enjoy not only continuing competition, interchangeability, maturity, and ease of modification, but also the convenience of a well established, recognized, and accepted discipline that encourages its own use.

4. PME standardization can be applied to any class of avionics as a "box" standard. Functional standardization should probably be limited to common mature avionics functions; it should be extended to mission avionics only when an equivalent stage of maturity is reached. In short, F^2 can be applied to all avionics; F^3 should probably be limited to common functions and less complex mission avionics.

5. While PME standardization techniques are appropriate for all USAF aircraft, the concept of an entire avionics system overhaul just to incorporate new standards in existing aircraft does not seem to be reasonable. Where entirely new avionics suites are being considered for retrofit, as in the case of the B-52 or the F-4G, benefits may be derived from applying PME standardization. This would need to be determined on an aircraft-by-aircraft basis after the basic PME acquisition and installation cost has been ascertained. For new aircraft, use of PME standards would be an integral part of the design process; this appears to be a reasonable place to initiate the concept.

6. Convection cooling continues to serve the commercial airlines needs because of the availability of pressurized and conditioned cabin air and the acceptability of low-density avionics packaging. Military aircraft designs have continued to use convection cooling for most avionics installations in spite of the performance shortcomings that occur under some military operating conditions and the dense component packaging. Alternative techniques for removing excess heat from avionics components have been amply demonstrated in mission-equipment installations where forced-air cooling is not sufficiently effective. Advanced environmental studies are in process in the industry. If results are available in time, they deserve assessment before decisions are made on USAF PME environmental control features.

7. Vibration standards and the qualification testing relating to them need to be reconsidered in conjunction with potential shock-mounting techniques. Vibration isolation for a complete avionics box/rack combination presents qualification-test problems; hard mounting is preferable, but vibration test conditions appropriate to specific aircraft and box locations should be specified. The current method of generalizing requirements frequently leads to over-specifying qualification tests and, consequently, the equipment itself. Benefits could be achieved in the form of lower cost for production and qualification tests.

8. Quality control requirements for piece-parts create cost conditions for military equipments that are not necessarily incurred in the commercial process. The higher price of military quality control does not necessarily lead to better quality, however.

9. MTBF guarantees prove to be an excellent incentive for a contractor to achieve proper design for good performance. However, an RIW goes further, giving the manufacturer a continuing opportunity to improve equipment performance if he chooses to -- or needs to -- to forestall a degradation of his equipment. In short, he has the latitude under RIW to improve equipment performance as needed or desired.

10. Purchase cost comparisons between military and commercial equipments are generally not valid because of difficulties encountered in identifying comparable prices. The basis of price for commercial units may include indirectly allocated overhead functions, for example, while military costs may include inventory, training, data, and other support functions of a totally different nature. Under these circumstances, direct cost comparisons are unreliable.

CHAPTER FOUR

COST-BENEFIT ANALYSIS

4.1 INTRODUCTION

This chapter outlines the methodology and preliminary findings of our examination of the economic and other benefits associated with standardization of avionics equipment packaging, electromechanical interfaces, and environment control. The basic quantitative trade-off is between the cost and the benefits of implementing such standards. The benefits would be in terms of reduced operating and support (O&S) costs brought about by improved equipment availability, reduced acquisition cost, and reduced modification cost achieved by exploiting the interchangeability capability in successive equipment generations and replications.

4.2 APPROACH

We reviewed several avionics life-cycle-cost (LCC) models used by or for the USAF. It was readily apparent that the level of input detail that each of these models required far exceeded the data available for this analysis. Further, the models were not structured to permit parametric analysis of specific key variables. It was, therefore, more expedient to create a specialized model for our purpose rather than modify an existing one.

A proposed avionics packaging, mounting, and environment standardization policy must be evaluated for a wide cross-section of equipment and aircraft types. Typical avionics LCC models detail the buildup of costs through the development, test, and operational life of a system. Our avionics PME standardization cost-benefit model addresses the cost elements that are related to the avionics subsystem in many aircraft types, including their successive modifications. The potential cost saving is the difference between the payback elements, such as lower acquisition, O&S, and modification costs, and the added costs for initial design, engineering, testing, avionics bay structure elements, etc. To hold the work of developing these inputs to a level of effort commensurate with the resources of this study, we established plausible boundaries within which a given input could vary. Sensitivity analyses then were used to determine if that cost element was significant to the overall LCC, and thus whether data collection would be worthwhile.

In understanding our approach, it is important to recognize the fundamental difference between the potential benefits of PME standardization and those obtained by the prevalent form of standardization in the military, i.e., the use of standard (GFE) avionics. Many of the benefits of standardization can be achieved independently of a PME standard, as Figure 4-1 shows. For example, use of an existing military equipment as GFE for multiple aircraft types will reduce development cost, improve the cost-quantity discount received, decrease the spares sufficiency levels required, allow use of common support equipment, and achieve other economic benefits that can be estimated by the use of conventional LCC techniques. While a PME standard would make wider application of GFE technically much easier, it is not a prerequisite to the use of GFE for standardization purposes. Obviously, if GFE standardization were to spread across equipments to the extent that common boxes, connectors, hold downs, etc., were used, it would in itself result in a form of PME standardization. To date, however, the GFE standardization approach has achieved intra-system standardization and not the inter-system standardization that would come from the PME approach. Our analysis task was to isolate those additional benefits that would accrue if one or more of the PME standardization alternatives were implemented and to determine if it would be worthwhile for the USAF to take steps to spread such standardization concepts across both systems and aircraft.

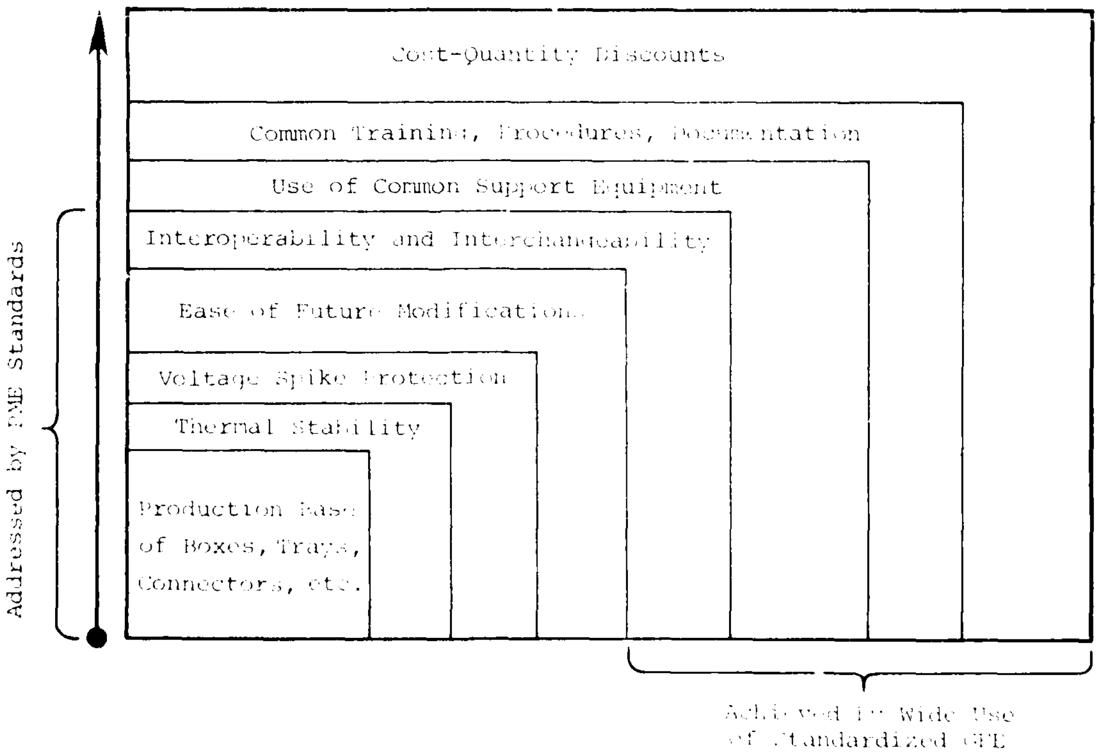


Figure 4-1. OBJECTIVES OF STANDARDIZATION

We have focused our analysis on implementation opportunities in new installations, i.e., in a new production lot for an existing airframe or as the architectural approach for an aircraft currently in the conceptual stage. While retrofit applications represent a much larger set of requirements, they also would be more costly to implement. Some inferences on the retrofit cases are discussed later in this chapter. We assumed that the earliest date of implementation for any of the PME standardization alternatives would be 1985.

4.2.1 Methodology

We first established a disciplined framework for examining quantitatively and qualitatively the benefits associated with each of the standardization alternatives. A general purpose computer was used to establish a systematic computational scheme, as indicated in Figure 4-2. The PME cost-benefit model uses three primary data bases and a set of control inputs for parametric analyses. The model computes delta costs -- that is, the difference between the cost of conventional acquisition and support of military avionics equipment and that cost if the PME standardization alternatives selected for this study were being applied. These alternatives are:

- Avionics LRU Packaging Standard

  This standard would:

  a. define a set of preferred dimensions, and multiples thereof, to be used interchangeably as the height, width, or depth of each LRU, with no constraint on the mounting attitude

  b. limit the permitted power dissipation per unit volume of the LRU to a level that is compatible with readily achievable cooling-air temperatures and flow rates

- Aircraft Rack/Mounting/Interface Standard for Avionics

  This standard would:

  a. define a required LRU rack/mounting attachment method

  b. define a set of required rack/mounting attachment interface dimensions and tolerances to ensure mechanical interchangeability with all other like-sized avionics LRUs

  c. define an electrical interface standard (i.e., connector size and style and specific pin voltage and signal standards) for each common avionics function

- Avionics Environment Standard in Aircraft

  This standard would define the efficiency of avionics cooling (and possibly other critical avionics environmental parameters) required to be achieved by any aircraft environmental system qualified for USAF acceptance. Cooling air inlet temperatures and flow rates would be specified as functions of the design electrical (heat) load, design margin, and growth factor allowance.

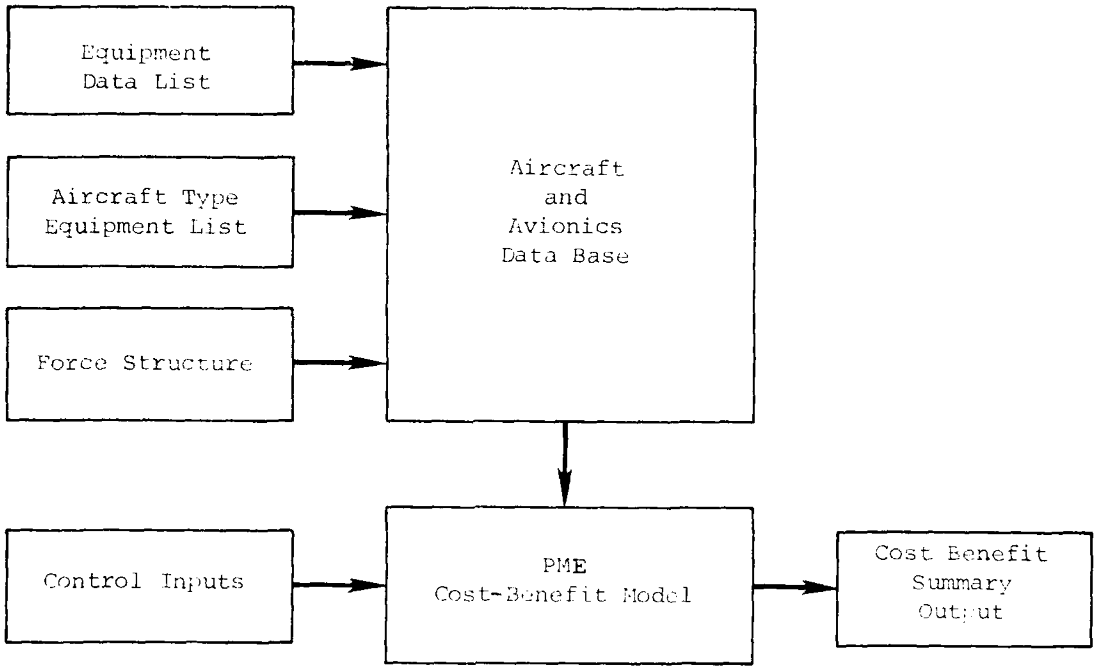


Figure 4-2. FLOW DIAGRAM OF PME COST-BENEFIT MODEL

- Avionics Common Power Standard

  This standard would define a standard of electrical power supply and electrical power regulation specifically adapted for avionics service. First-line protection of avionics circuits from over-voltages, sustained outages, noise, and high-voltage spikes would be the responsibility of the electric power system design.

- Avionics Packaging, Mounting, and Environment (PME) Standard

  This standard would define a composite of all of the above standards: LRU packaging, rack/mounting/interface, environment, and common power.

The model performs LCC payback computations for each of the standardization alternatives and for each class of aircraft. The following basic LCC elements were considered:

a. Initial cost -- engineering, model manufacture, contractor drawing and documentation, installation, test and evaluation, acquisition

b. Operation and support cost -- replenishment spares, labor, material, other

c. Modification cost -- interface analysis, design, data, installation labor and material

LCC results or Cost-Estimating Relationships documented in other studies performed for the USAF were used to establish baseline costs for each of these categories. Weighting factors then were applied to describe the estimated change in cost that would occur if each of the standardization alternatives were implemented.

Output from the model provides payback estimates on a yearly basis and on an aircraft lifetime basis and discounted values for these estimates. It should be kept in mind, however, that it is the relative ranking of the standardization alternatives, rather than absolute values, that is meaningful.

4.2.2 Aircraft Applications

First we reviewed the USAF Avionics Planning Baseline (September 1979) document to determine a reasonable implementation scenario for the standardization alternatives. On the assumption that the development and adoption of any standard having a widespread impact would take several years and that production lead times require an equal amount of time for implementation, we selected 1985 as the initial implementation date. Potential applications of PME standardization to new aircraft that are planned for introduction beyond that date are shown in Figure 4-3. It may be seen that such applications total just under 1,200 through 1994 (the limit to which planning data are available). This is less than 15 percent of the total active inventory (force) that the USAF has maintained over the past few years; however, these aircraft represent attractive initial targets, as their avionics configurations have not been finalized. Further, these aircraft form a threshold case for payback analysis -- the per-aircraft benefits should be roughly equivalent to those that would be obtained for the current inventory aircraft, while the investment-cost increment should be less.

For analysis purposes, we have grouped these aircraft into the following three generic classes according to performance characteristics:

- High-Performance Tactical - The only member of this class identified in future plans for aircraft is the Advanced Tactical Reconnaissance System (ATRS). There is no firm decision on the configuration of this system, which is a replacement for the aging RF-4C. There is still a possibility that an unmanned aircraft may fill this role. However, there are other future high-performance tactical aircraft that are likely to create applications of this order of magnitude (e.g., an advanced tactical fighter or interceptor), but they have undefined quantities.
- Tactical Attack/Observation - The FAC-X represents the largest potential application in this category. The manifestation of this concept could range from the current A-10 or similar aircraft to a light aircraft similar to the current OV-10. We have grouped in this class also the HH-X, a replacement for the current rescue helicopters, as its avionics and operational environments are similar even though its airframe is different.

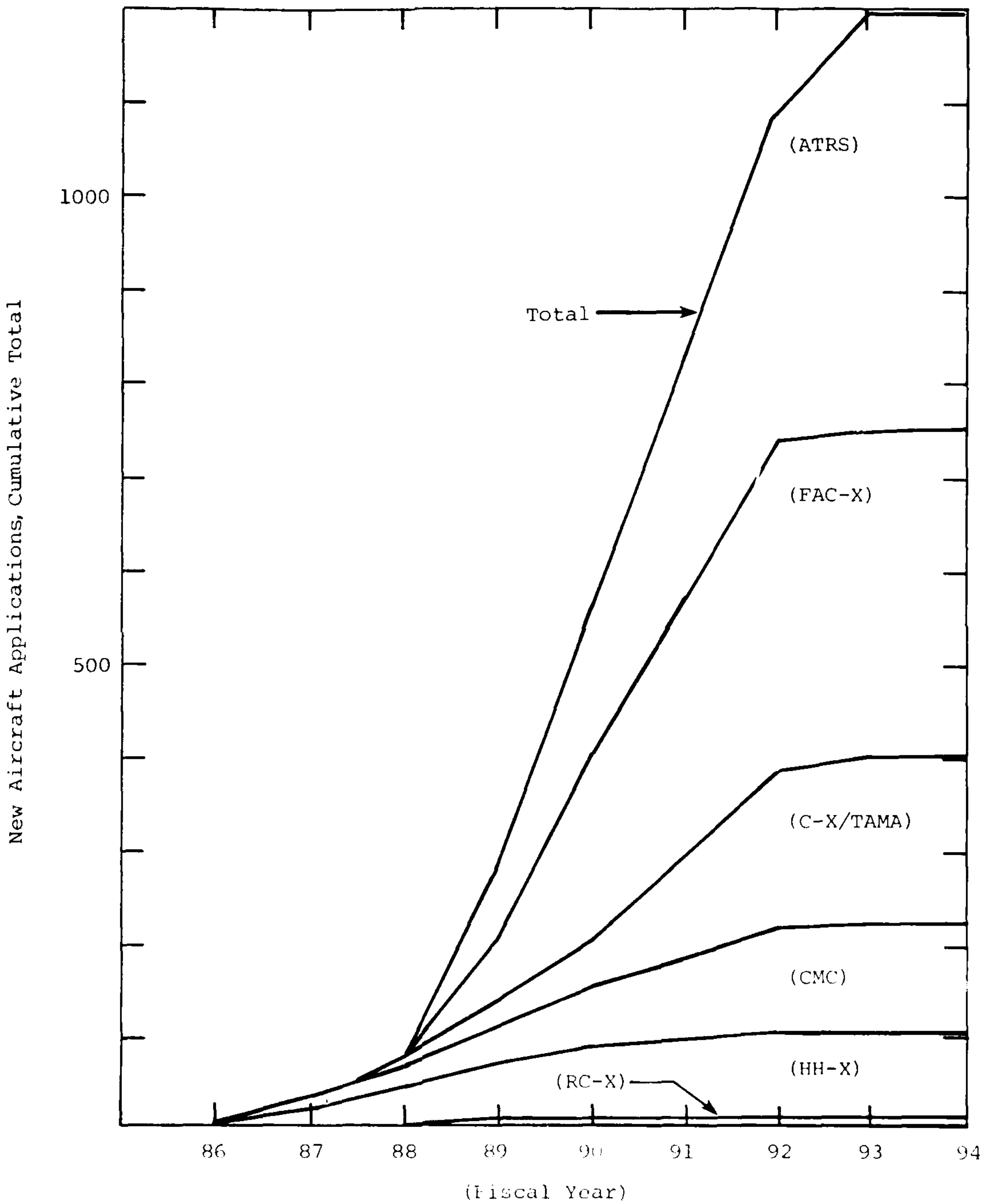


Figure 4-3. POTENTIAL NEW AIRCRAFT PME APPLICATIONS

- Cargo/Transport - Military aircraft in this category are frequently derived from commercial passenger-carrying airframes. Even if not, they offer much more liberal tolerances for installation of avionics than do the aircraft in the previous two categories. We have grouped together for analysis purposes the CX/TAMA, the RC-X, (replacement for the RC-135), and the Cruise Missile Carrier (CMC).

4.2.3 Representative Avionics and Costs

The avionics equipments for the aircraft types listed above are not defined. It is possible, however, to make reasonable inferences on the basis of the equipment types installed on the aircraft they are intended to replace. We synthesized representative current-technology avionics suites and costs for the three generic classes of aircraft. Most of our acquisition and O&S data were derived from a recent LSC analysis of the F-16 avionics.* Our modification and installation costs were estimated by the use of AVSTALL methodology developed by ARINC Research for the NAVSTAR GPS Joint Program Office.** Other estimates were either scaled from these values or taken from published commercial or government price lists.

The avionics suites that we used as baseline cases are shown in Table 4-1; only systems that would be affected by PME standardization were included. For example, we did not address antennas, displays, controls, and similar non-racked equipment. The three categories of equipments shown in Table 4-1 are explained as follows:

- Communications and Radio Navigation Systems - These systems are common to most aircraft, although the mix differs slightly depending on the aircraft's operational use. These avionics are characterized by relatively low cost and mature technology.
- Mission- or Aircraft-Unique Systems - These systems are typically high-cost and vary extensively from aircraft to aircraft. There is significant architectural interdependence; i.e., the use of outputs from one subsystem are used as inputs to another. Therefore, when modifications are made to one LRU, several others are often affected.
- Environmental Control System - This was considered as a separate cost element since it figures centrally in two of the standardization alternatives.

The costs we developed as input values to the PME standardization model for the representative aircraft and avionics suites are shown in Table 4-2. It should be noted that costs in the area of mission- or aircraft-unique systems predominate. This suggests that to have a significant impact on overall avionics LCC cost, future PME standards cannot be confined to those

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**F-16 Logistics Support Cost Status Report* (UL 76A2), 12 March 1979, General Dynamics.

***Avionics Installation (AVSTALL) Cost Model for User Equipment of NAVSTAR GPS*, ARINC Research Publication 1727-04-0959, June 1979.

Table 4-1. BASELINE AVIONICS SUITES		
Aircraft Type	System	Component
High-Performance Tactical Aircraft	Communications and Radio Navigation Systems	VHF R/T UHF R/T Interphone IFF R/T TACAN R/T ILS RX
	Mission-Unique or Aircraft-Unique Systems	Radar Video Receiver Heads-Up Display Fire Control Computer Inertial Navigation Blanker ECM RX Signal Processor
	Environmental Control Systems	Entire System
Observation/Attack Aircraft	Communications and Radio Navigation System	VHF AM/FM (2) UHF R/T HF Radio Interphone IFF R/T TACAN R/T ILS RX
	Mission-Unique Systems	ECM RX Blanker
	Environmental Control Systems	Entire System
Cargo/Transport Aircraft	Communications and Radio Navigation System	VHF AM/FM (2) UHF R/T HF Radio (2) Interphone IFF R/T TACAN R/T ILS RX (2)
	Mission-Unique or Aircraft-Unique Systems	Weather Radar Radio Altimeter (2) Ground Proximity INS (2)
	Environmental Control System	Entire System

Table 4-2. REPRESENTATIVE AVIONICS SUITES AND COSTS (DOLLARS)

System	Cost per Type: Integration Engineering Test and Data	Cost per Aircraft: LRU Procurement (Group B)	Cost per Aircraft: Installation Labor	Cost per Aircraft: Installation Material	Ten-Year Cost per Aircraft: Operation and Support	Ten-Year Cost per Aircraft: Avionics Update Modifications
High-Performance Tactical Aircraft						
Communications and Radio Navigation						
VHF Receiver/Transmitter	96,000	3,650	2,400	640	1,660	7,000
UHF Receiver/Transmitter	107,000	3,550	2,700	720	4,360	7,500
Interphone	60,000	650	1,700	450	100	6,000
IFF Receiver/Transmitter	107,000	1[illegible],700	3,400	920	8,480	8,500
TACAN Receiver/Transmitter	272,000	8,950	5,900	1,750	4,840	12,500
ILS Receiver	84,000	8,500	2,400	620	1,460	7,[illegible]
Total	726,000	41,000	18,400	5,100	21,000	48,500
Mission-Unique or Aircraft-Unique						
Radar	1,65[illegible],000	326,000	32,400	[illegible],700	75,200	46,300
Video Receiver	175,000	2,000	4,500	1,270	3[illegible]	10,130
Heads-Up Display	312,000	32,[illegible]	4,300	1,200	3,400	10,1[illegible]
Fire Control Computer	355,000	[illegible]	5,100	1,5[illegible]	7,600	11,70[illegible]
Inertial Navigation	43[illegible]	[illegible]	5,7[illegible]	1,7[illegible]	25,600	12,800
Blanker	100,000	6,[illegible]	[illegible]	[illegible]	[illegible]	7,[illegible]
ECM Receiver	11[illegible],000	[illegible]	2,[illegible]	[illegible]	1,[illegible]	7,3[illegible]
Signal Processor	230,000	[illegible]	4,3[illegible]	1,230	[illegible]	17,2[illegible]
Total	3,367,000	[illegible]	[illegible]	14,[illegible]	[illegible]	113,500
Environmental Control	3,6[illegible]	[illegible]	[illegible]	8,[illegible]	[illegible]	--
Observation Attack Aircraft						
Communications and Radio Navigation						
VHF AM/FM (2)	[illegible]	[illegible]	1,[illegible]	[illegible]	4,3[illegible]	[illegible],000
UHF Receiver/Transmitter	74,000	3,[illegible]	1,[illegible]	4[illegible]	4,36[illegible]	4,3[illegible]
HF Radio	17[illegible]	[illegible]	[illegible]	[illegible]	[illegible],43[illegible]	7,5[illegible]
Interphone	46,[illegible]	[illegible]	[illegible]7[illegible]	[illegible]	[illegible]	[illegible],3[illegible]
IFF Receiver/Transmitter	114,[illegible]	[illegible],7[illegible]	1,7[illegible]	[illegible]	[illegible]	[illegible]
TACAN Receiver/Transmitter	163,000	[illegible]	3,[illegible]	[illegible]	4,84[illegible]	[illegible]
ILS Receiver	78,000	[illegible]	1,[illegible]	4[illegible]	1,4[illegible]	4,[illegible]
Total	743,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mission-Unique						
ECM Receiver	82,000	[illegible]	1,[illegible]	4[illegible]	1,[illegible]	4,[illegible]
Blanker	7[illegible]	[illegible]	1,[illegible]	4[illegible]	[illegible]	4,1[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Environmental Control	48[illegible]	[illegible]	4,[illegible]	4[illegible]	4,[illegible]	[illegible]
Cargo/Transport Aircraft						
Communications and Radio Navigation						
VHF AM/FM (2)	14[illegible]	[illegible]	[illegible]	1,[illegible]	4,33[illegible]	[illegible]
UHF Receiver/Transmitter	12[illegible]	3,[illegible]	[illegible]	1,4[illegible]	4,36[illegible]	[illegible]
HF Radio (2)	44[illegible]	31,[illegible]	[illegible]	3,[illegible]	[illegible]	[illegible]
Interphone	[illegible]	1,[illegible]	[illegible]	1,1[illegible]	[illegible]	[illegible]
IFF Receiver/Transmitter	[illegible]	[illegible]	[illegible]	1,[illegible]	8,4[illegible]	8,[illegible]
TACAN Receiver/Transmitter	[illegible]	[illegible]	[illegible]	[illegible]	4,84[illegible]	[illegible]
ILS Receiver (2)	[illegible]	[illegible]	[illegible]	1,[illegible]	[illegible]	[illegible]
Total	1,38[illegible]	[illegible]	[illegible]	13,[illegible]	[illegible]	[illegible],8[illegible]
Mission-Unique or Aircraft-Unique						
Weather Radar	41[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible],4[illegible]
Radio Altimeter (2)	1[illegible],000	1[illegible]	[illegible]	1,[illegible]	8,[illegible]	2,8[illegible]
Ground Proximity	11[illegible],000	4,[illegible]	1,7[illegible]	[illegible]	[illegible]	1,[illegible]
INS (2)	[illegible]5,000	11[illegible]	[illegible]	4,[illegible]	[illegible]	17,[illegible]
Total	1,664,0[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]	3[illegible],800
Environmental Control	1,432,000	1[illegible],4[illegible]	1,[illegible]	3,[illegible]	1[illegible]	--

equipments that are common to all classes of aircraft; rather, they must include, at least to some degree, mission avionics. Also, the environmental control system, which has a significant impact on the reliability performance of the avionics, requires a substantial investment contribution to the acquisition and O&S cost, although, as shown later, its payback has good potential when associated with a full PME standard.

4.2.4 Modification Scenario

Schedules for similar type aircraft in the Avionics Planning Baseline and costs determined by the AVSTALL model were used to synthesize modification scenarios for each of the aircraft types. Basically, our scenario introduces modifications to the aircraft on a box-by-box basis starting five years after the aircraft's initial operational capability and continuing until five years before its complete phase-out. The scenario postulates the eventual complete exchange of avionics once within the lifetime of the aircraft; variations on this rate are explored in later sensitivity analyses.

The cost of modification has many commonalities with initial installation: integration, purchase of the avionics units, initial spares, support, equipment, etc. There are also differences, e.g., removing or relocating LRUs, modifying racks, installing new cable runs, etc. The method of computing these differences is described, for an illustrative case, in Section 4.4.

4.3 WEIGHTING FACTORS

The weighting factors are values applied to the baseline values to indicate the extent of increase or decrease in cost resulting from a standardization action. Examples of the weighting factors are shown in Table 4-3; these are the factors used for the common avionics in high-performance tactical aircraft. If no change from present procedures is indicated, the value of the weighting factor is unity.

Most of the weighting factors are based on engineering judgment; some were developed, or influenced to some extent, by the comments of the airframe and avionics manufacturers whose opinions were discussed in Chapter Three. A tabulation of the weighting factors for each of the cases explored is presented in Appendix E. As their quantification was highly subjective, little purpose would be served by providing detailed rationales for all the factors. We did perform a sensitivity analysis on them to determine their influence on results. This is covered in Section 4.5.1. As defined standardization plans are developed, these estimated weighting factors should be replaced by values that command higher confidence.

4.3.1 LRU Packaging Standard

We anticipate that the existence of an LRU-packaging standard would cause the design and acquisition cost to decrease. This would result from the easier prediction of the avionics bay's configuration, particularly

Table 4-3. WEIGHTING FACTORS FOR COMMUNICATIONS/RADIO-NAVIGATION LRUs IN HIGH-PERFORMANCE FIGHTER AIRCRAFT

Standard	Current	Engineering, Testing, and Data	Installation Materials (Group-A)	Avionics Units Procurement (Group-B)	Installation Labor	Operation and Support (O&S)	Avionics Update Modification
Full PME	1.0	1.2	1.1	0.9	1.0	0.8	0.4
LRU Packaging	1.0	0.8	0.6	0.8	1.0	1.0	0.5
E/M/I	1.0	0.8	0.6	0.8	1.0	1.0	0.4
Environmental	1.0	1.2	1.1	1.0	1.0	0.8	1.0
Common Power	1.0	1.1	1.0	0.9	1.0	0.9	1.0

with respect to the establishment of installation methods and materials (Group-A provisions) because of the existence of a standard form factor. The impact would also be reflected in the avionics units because suppliers of the boxes and other mechanical components would achieve larger production economies and be subject to greater competition.

We were unable to identify any significant impact on reliability stemming from application of a packaging standard that was not accompanied by concurrent environmental system improvements. Therefore, we show no change over present O&S cost factors for this standard. However, there would be a salutory benefit on avionics update modification cost, because space would be more efficiently used within the avionics bay and rearrangement could probably be implemented more methodically with unit or modular sizing.

4.3.2 Rack/Mounting/Interface Standard

The rack/mounting/interface standard alternative requires LRU dimensional standardization as a prerequisite. All the benefits described above for the LRU packaging standard also apply to the racking/mounting/interface standard. The costs of future modifications would be reduced to a greater extent with the existence of racks adaptable to LRU size multiples. The requirement for adapter trays would be virtually eliminated and the likelihood of major equipment relocations within the aircraft in its later life would be reduced. The continuing trend toward miniaturization of avionics made possible with VLSI and similar technologies makes this an important consideration.

4.3.3 Environmental Standard

The provision of a more effective environmental control system (ECS) by adherence to a stringent standard would be expected to require some additional "up front" cost in integration engineering and testing and to a lesser degree, in the corresponding installation materials. These costs, of course, would be in addition to current costs and could vary considerably depending on the aircraft avionics environmental philosophy. For example, an aircraft designed today without an ECS might be a suitable candidate for one if standard environmental systems were more routinely implementable and performance improvements promised cost paybacks. In this example, the difference (delta) would be the full initial investment cost of the ECS. On the other hand, an aircraft normally designed with an ECS would probably experience a smaller delta -- the difference between the cost of the current system and the cost of meeting a more stringent environmental standard. In this example, payback would doubtless occur in a shorter time than in the first example.

According to the avionics manufacturers contacted in our survey, the provisions of better cooling would not cause them to use less expensive components in their equipments; rather, they would continue to employ currently selected components, reaping the benefit of the higher reliability attained in the cooler environment. Accordingly, we allocated the benefits of environmental standardization entirely to O&S -- better reliability through better thermal control, as described in Subsection 4.2.4.

4.3.4 Full PME Standard

The full PME standard incorporates all the concepts explained in Subsections 4.3.1, 4.3.2, and 4.3.3, and likewise reaps all the benefits mentioned therein. We have conservatively assumed the implementation cost to be driven by the environmental provisions and, therefore, used the weighting factors for engineering, testing, and data, for installation materials, and for installation labor that we used for the environmental standard alternative.

4.3.5 Common Power Standard

The advent of all-digital avionics has increased the requirement for "clean" power. The application of a common electrical power standard would generate only nominal cost for initial integration engineering and testing, because the technology is well understood. Our survey gave reason to expect nominal reduction in the avionics unit design and acquisition cost, because of reduced internal requirements for power conditioning. The less stressful electrical environment should also improve reliability, which would reduce O&S cost, although not to the extent that we associated with better cooling. We could find no reason to expect a change in the cost of avionics-update modification or of installation materials or labor.

4.4 ESTIMATION OF WEIGHTING FACTORS

An area of key interest is the impact of standardization on O&S cost, particularly the impact produced by improvements to the environmental control system. This is a treacherous area for prediction because solid-state electronics have achieved great improvements in reliability even within the current military thermal environments. We selected as our illustrative case an advanced technology CNI equipment -- the Joint Tactical Information Distribution System (JTIDS) Class II terminal. Figure 4-4 describes the relationship between MTBF and O&S cost for this equipment when installed in tactical aircraft. This graph was developed in a recent LCC exercise performed for the JTIDS Joint Program Office. In the insert are results of USAF tests performed on an improved version of the F-15 environmental control system. In this example, the combined MTBF of the three units cited (whose combined complexity is roughly equivalent to JTIDS) was found to increase from 170 hours to 276 hours because of the improved cooling. Translated into O&S cost, this represents a reduction from $1,310 to $1,080 per year, a ratio of approximately 0.8. We employed this value in our input set. The plausible range established for this factor was from 0.9 to 0.6. A parallel analysis by methods documented in MIL-HDBK-217C indicated that improvements up to 300 percent theoretically could be achieved.

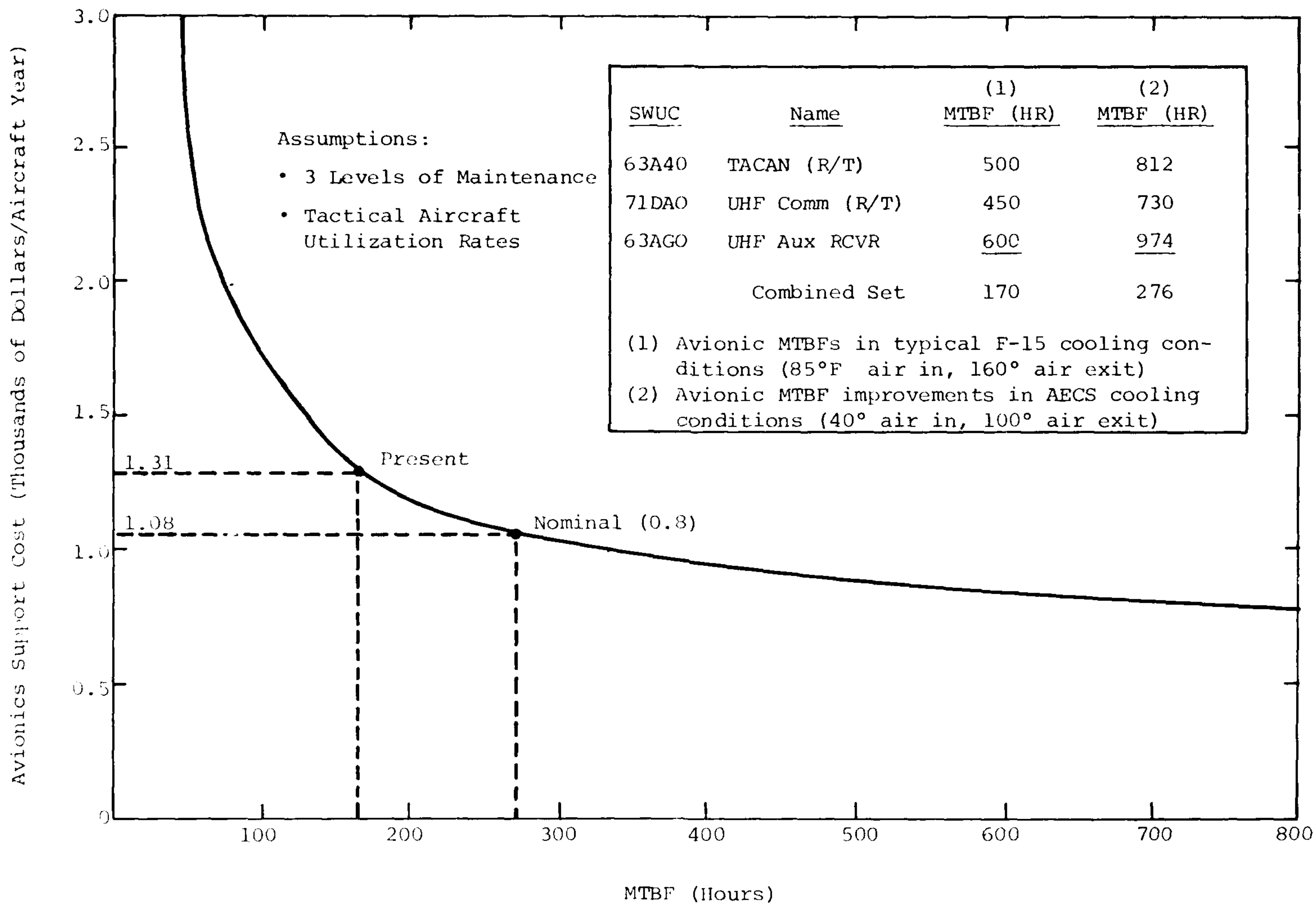

Figure 4-4. SUPPORT COST WEIGHTING FACTOR

The impact of PME standardization on modification cost is examined in more detail, because this is considered to be the area that will yield the most significant benefit. To estimate the differences in modification costs for the standardization alternatives, we used the AVSTALL model, which provides CERs for installation or modification activities such as modifying mounting shelves, relocating LRUs, and replacing major cable runs. Reducing or eliminating the need for such actions when avionics updates are made is one of the benefits of designing to a PME standard. The extent to which PME standardization will affect total modification cost is, therefore, of particular interest.

The postulated impact of each standardization alternative on modification cost is shown in Table 4-4 in qualitative terms.

Table 4-4. POSTULATED IMPACT OF STANDARDIZATION ALTERNATIVES ON MODIFICATION COSTS

Modification Cost Element	Cost Impact After Standard Is Implemented				
	Full PME	Rack/ Mounting/ Interface	LRU Packaging	Environmental	Common Power
Engineering/Design	Less	Less	Less	Same	Same
Test and Evaluation	Same	Same	Same	Same	Same
A-Kit and Labor					
Shelf	Less	Less	Same	Same	Same
Mounting	Less	Less	Less	Same	Same
Cable Run	Less	Less	Same	Same	Same
Cockpit Panel	Same	Same	Same	Same	Same
Antenna	Same	Same	Same	Same	Same
B-Kit	Less	Less	Less	Same	Less
Support Equipment	Same	Same	Same	Same	Same
Documentation	Less	Less	Same	Same	Same

We used the AVSTALL CERs to translate this tabulation into quantitative terms, using the TACAN as a representative unit. Our computations for this case are described below.

The AVSTALL cost model estimates the unit cost of modifying an aircraft to install or replace an avionics subsystem or component. This cost-estimating relationship is characterized as:

$$C = C_A + C_B + C_L + (C_D + C_E + C_F + C_T) \times \frac{1}{n}$$

where

C is the unit modification cost that is to be estimated

C_A is the cost of the A-Kit, aircraft-peculiar mounting, and cabling

C_B is the cost of the avionics LRUs supplied

C_L is the cost of the labor to install

C_E is the cost of engineering/design

C_D is the cost of documentation

C_P is the cost of the prototype installation

C_T is the cost of test and evaluation of the installation

n is the number of aircraft modified

The value of each cost element is governed by the description of the actions required to implement the modification. The descriptors selected by the AVSTALL model are as follows:

Items

- Mounting shelf, rack
- LRU
- Major cable run

Actions

- Install
- Remove
- Replace
- Relocate
- Modify

Cost Areas

- Aircraft modification
- Trainer modification
- Peculiar support equipment
- Spares

Aircraft Types

- Fighter and fighter/bomber
- Heavy attack
- Light/attack and observation/attack
- Bomber
- Medium-large transport
- Small transport
- Helicopter

The cost elements that contribute to C_A and C_L for a typical case of installing a single LRU in a fighter aircraft are shown in Table 4-5.

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STANDARD AVIONICS PACKAGING, MOUNTING, AND COOLING BASELINE STU--ETC(U)
JAN 80 S BAILY, A JACKSON, J RUSSELL F33657-79-C-0717
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Table 4-5. AVSTALL COSTS FOR TYPICAL LRU INSTALLATION ACTIONS (DOLLARS)						
Action	Constant Term	Modify Shelf	Relocate an LRU	Replace a Cable	Install a Cable	Install the LRU
C_A	200	50	200	150	150	$40W_B$
C_L	0	365	1,750	875	1,050	$280W_B^{0.8}$*

$C_D = 6.033\ (C_A)^{1.09}$

$C_E = 100\ (C_A)$

$C_P = C_A + C_B + C_L$

$C_T = 4(C_B)^{0.4}(C_A)^{0.8}$

*Where W_B = weight of the LRU in pounds.

NOTE: Labor at $35 per hour assumed.

For TACAN (AN/ARN-118), W_B is 35 pounds, thus $40W_B$ = $280, and $280W_B{}^{0.8}$ is $4,813. Thus, C_A = $2,150 and C_L is $8,853. The unit cost of the TACAN Receiver/Transmitter unit is given as $8,925.

From these data, we calculated the modification cost for the present case, for a case where an LRU packaging standard was applied (so that shelf modification and LRU relocation would not be required), and for a case where a rack/mounting/interface or full PME standard was applied (so that mounting adapter hardware would be standard and cabling changes minimal). The resulting CERs for these cases are shown in Table 4-6, where they may be compared. In the special case where the TACAN LRU to be installed is a direct F^3 replacement for one being removed, the AVSTALL CER gives a cost of $305 recurring and $23,721 non-recurring, yielding a unit modification cost of $400 each for 250 aircraft. This special case was not used in our relative-cost calculations, but it does underscore the ready second-source replacement flexibility that is provided by a fully defined interface standard.

Unit modification costs were derived in the same way for the remaining LRUs in each avionics suite. Table 4-7 shows these costs for the communications/radio-navigation avionics for the high-performance fighter, and gives the combined weighting factors used for that section of our cost model. Similar calculations were performed for the other two classes of aircraft; they are reflected in the weighting factors contained in Appendix E.

Table 4-6. PREDICTED UNIT MODIFICATION COSTS (QUANTITY OF 250) FOR TACAN LRU INTEGRATION			
CER Factor	Present Practice	LRU Packaging Standard	Rack/Mounting/ Interface Standard
Recurring Costs			
C_A	$ 2,150	$ 1,750	$ 1,600
C_L	8,853	5,863	4,813
Total Recurring	$ 11,003	$ 7,613	$ 6,413
Nonrecurring Costs			
C_D	$ 25,878	$ 20,675	$ 18,751
C_E	215,000	175,000	160,000
C_P	19,928	16,538	15,338
C_T	70,505	59,798	55,661
Total Nonrecurring	$331,311	$272,011	$249,750
Unit Cost for Quantity of 250	$ 12,328	$ 8,701	$ 7,412
Cost Ratio	1.000	0.706	0.601

Table 4-7. MODIFICATION COST FOR COMMUNICATIONS/RADIO-NAVIGATION AVIONICS LRUs (HIGH-PERFORMANCE FIGHTER AIRCRAFT)			
LRU Function	Present Practice	LRU Packaging Standard	Rack/Mounting/ Interface Standard
VHF Communications	$ 7,408	$ 3,430	$ 2,144
UHF Communications	7,475	3,858	2,572
Interphone	5,946	2,345	1,065
IFF Receiver/ Transmitter	8,636	4,661	3,697
TACAN Receiver/ Transmitter	12,328	8,701	7,412
ILS Receiver	7,070	3,437	2,145
Total	$48,503	$26,432	$19,035
Ratio	1.00	0.54	0.39

4.5 PAYBACK ANALYSIS

Payback, in terms of military expenditures, may be interpreted as a cost avoidance value. All payback values shown in this and succeeding sections are displayed in the same dollar values as the input, i.e., FY 1975. As discussed in the introduction to this chapter, however, it is the relative rankings rather than absolute values that are meaningful.

The principal significance of a payback analysis is the insight it provides on the recovery of investment. In this period of tight money and high interest rates, economic institutions place great emphasis on rapid payback. We conducted a payback analysis and plotted the results on a year-by-year basis. The payback cost streams are shown in Figure 4-5. Standard alternatives that have smaller "up front" cost and that principally reduce acquisition cost, produce quicker and larger paybacks, and are favored over those that require substantial investment and principally influence long-term logistics cost. The LRU packaging standard looks particularly attractive from an early-payback point of view. The environmental standard is not cost-competitive because its payback occurs as reduced O&S cost, which represents only a small part of the total LCC and accrues slowly. It also requires significant initial investment and does not impact future modification cost.

The slopes of curves in Figure 4-5 are driven by the USAF installation and modification assumptions used as input. In this subset of the planned USAF force of the late 1980s, there are high payoffs for standardization alternatives that reduce future modification cost. The results shown graphically in Figure 4-5 are also depicted in tabular form in Table 4-8.

4.6 SENSITIVITY ANALYSIS

After exercising the model for the three-aircraft-class scenario, we explored the sensitivity of the LCC relationships to the weighting factors assumed and to the frequency of avionics-update modifications assumed.

4.6.1 Sensitivity to Weighting Factor Values Assumed

The results of the analysis of weighting factor sensitivity are displayed in Figure 4-6. This figure shows the net economic benefits of implementing each of the standardization alternatives over the projected force lifetime. Plotted on the chart are the results obtained when the nominal, most optimistic, and most pessimistic values of weighting factors were used. Table 4-9 shows the ranges of the values used. Within the range of variance explored, the LRU packaging standard, the rack/mounting/interface standard, and the full PME standard are competitive and attractive from an economic standpoint.

The environmental standard and common power standard provide paybacks, but not on the same order as the other standardization concepts. This occurs primarily because these two concepts have a lesser cost-reduction impact on future modification cost than do the other three alternatives.

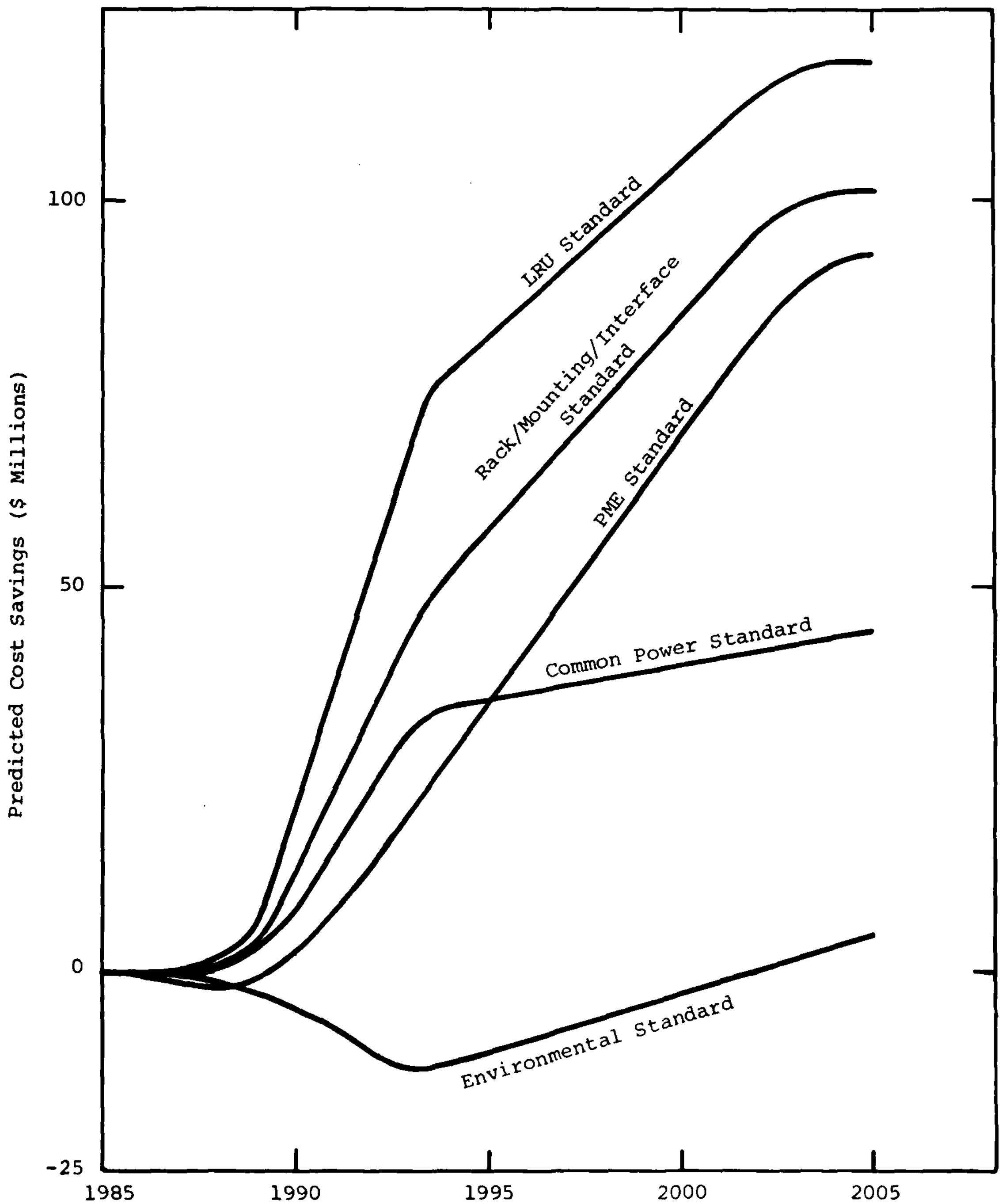

Figure 4-5. PREDICTED CUMULATIVE COST SAVINGS IN AVIONICS/ AIRCRAFT INTEGRATION, OPERATION SUPPORT, AND MODIFICATION

Table 4-8. PREDICTED ANNUAL COST SAVINGS IN AVIONICS/AIRCRAFT INTEGRATION, OPERATION, SUPPORT AND MODIFICATION (*THOUSANDS OF DOLLARS*)

Year	LRU Packaging Standard	Rack/Mounting/ Interface Standard	Full PME Standard	Common Power Standard	Environmental Standard
1985	0	0	0	0	0
1986	0	0	0	0	0
1987	1,068	1,019	-328	37	-581
1988	682	642	271	309	-14
1989	12,527	7,800	1,383	5,123	-3,979
1990	15,316	9,719	4,630	7,369	-2,375
1991	15,470	9,732	4,922	7,598	-2,121
1992	17,018	11,744	7,351	7,680	-1,762
1993	14,248	9,121	6,707	6,664	-1,313
1994	4,454	5,592	7,115	878	1,522
1995	4,454	5,592	7,115	878	1,522
1996	4,454	5,592	7,115	878	1,522
1997	4,454	5,592	7,115	878	1,522
1998	4,454	5,592	7,115	878	1,522
1999	4,454	5,592	7,115	878	1,522
2000	4,454	5,592	7,115	878	1,522
2001	4,454	5,592	7,115	878	1,522
2002	2,627	3,358	4,881	878	1,522
2003	2,627	3,358	4,881	878	1,522
2004	0	0	1,522	878	1,522
Sum	117,211	101,231	93,137	44,434	4,602

4.6.2 Sensitivity to the Modification Scenario Assumed

Our modification scenario was based on an ASD/AX estimate that each military aircraft experiences a full swap-out of avionics over a 20-year period (although the swap-out is done incrementally on a system-by-system basis).

Since the modification scenario is a critical factor in ranking the standardization alternatives, we varied the rate of avionics updates from zero (no changes over the lifetime) to a complete change of avionics every

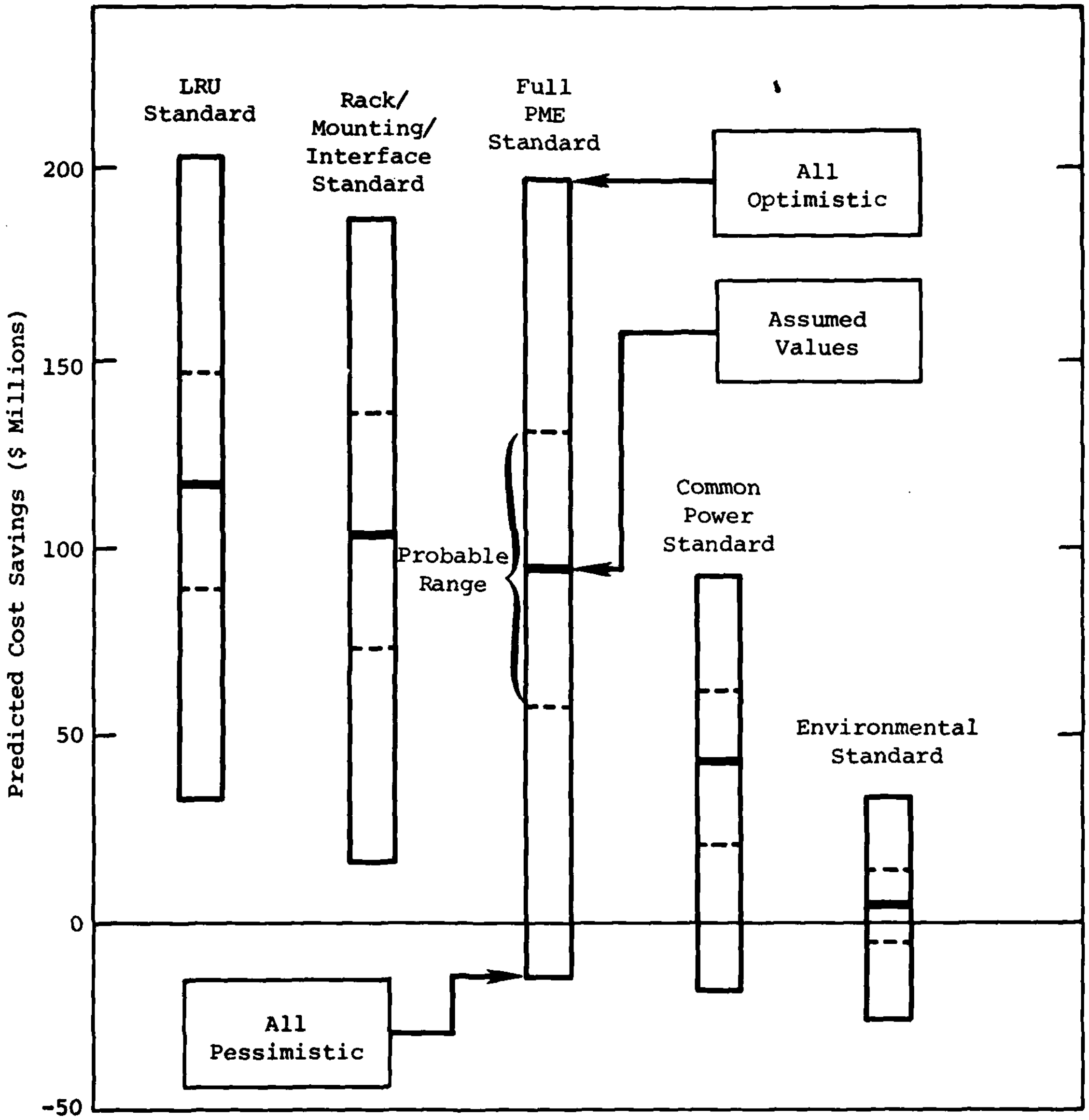

Figure 4-6. SENSITIVITY OF COST-SAVING PREDICTION TO THE COST-SAVING WEIGHTING FACTORS THAT ARE ASSUMED

Table 4-9. RANGE OF WEIGHTING FACTORS					
Standardization Alternative	Integration Data and Test	Group-A Hardware	Group-B Hardware	Operation and Support	Modification/ Update
Communications and Radio Navigation					
Packaging, Mounting, and Environmental Standard	1.0-1.4	1.0-1.2	0.8-1.0	0.7-0.9	0.2-0.7
LRU Standard	0.7-0.9	0.4-0.8	0.7-0.9	1.0	0.3-0.8
Rack/Mounting/ Interface Standard	0.7-0.8	0.4-0.8	0.7-0.9	1.0	0.2-0.7
Environmental Standard	1.0-1.4	1.0-1.2	1.0	0.7-0.9	1.0
Common Power Standard	1.0-1.2	1.0	0.8-1.0	0.8-1.0	1.0
Mission-Unique or Aircraft-Unique					
Packaging, Mounting, and Environmental Standard	1.1-1.3	0.9-1.3	0.7-1.1	0.7-0.9	0.5-0.7
LRU Standard	0.6-1.0	0.4-0.8	0.6-1.0	1.0	0.5-0.9
Rack/Mounting/ Interface Standard	0.7-1.1	0.7-0.9	0.7-1.1	1.0	0.6-0.8
Environmental Standard	1.0-1.4	1.0-1.2	1.0	0.7-0.9	1.0
Common Power Standard	1.0-1.2	1.0	0.8-1.0	0.8-1.0	1.0
Environmental Control System					
Environmental and PME Standard	1.0-1.6	1.0-1.4	1.0-2.0	1.0-1.2	--

five years on the average. The results of this exercise are shown in Figure 4-7. It may be seen in the figure that the common-power standard is competitive when the avionics suite is not exchanged. The environmental standard does show some savings, but tends not to be persuasive.

4.6.3 Sensitivity to Mission Avionics O&S Cost Assumption

We noticed that the O&S cost for the mission-unique avionics, as derived from our source (the F-16 logistic support cost estimate), were approximately 2 percent of the LRU acquisition cost per year. This is very low for such sophisticated equipment, even considering its wide use of solid-state components. Current RIW manufacturer-support contracts are approximately at 5 percent per year of the LRU cost, and organizational maintenance is even more costly. We, therefore, made runs with mission-unique cost adjusted up to 5 percent. Figure 4-8 shows the sensitivity of the total force life-cycle cost to this change. Notice that the relative attractiveness of the environmental standard, the common power standard, and the full PME standard are substantially improved. The merits of the LRU packaging standard and the rack/mounting/interface standard are relatively unchanged, as they are postulated to influence initial acquisition and modification costs rather than O&S cost.

4.7 SUMMARY OBSERVATIONS

The subset of the USAF force examined is proportionally representative of the total USAF current inventory, which is comprised of approximately 60 percent one- or two-seater aircraft and 40 percent wide-bodied or bomber aircraft. If these applications were included in the analysis, a larger return in the aggregate might be shown. It was not possible, however, to determine realistically the extent to which the PME standardization alternatives might be implemented in an existing aircraft architecture and at what cost. It seems reasonable to assume that installation of new PME-standard equipments in older aircraft (racks, mounting provisions, connectors and cables, ECS, etc.) would cost at least as much as installation in production-line aircraft, and most likely a great deal more. The uncertainties of these costs did not permit us to evaluate, or even estimate, their magnitude. Any saving attributable to upgrading older aircraft with PME standards would necessarily be less than that for new aircraft by the amount of the increased cost of installation. Accordingly, the payback time would be longer. This implies a lessened opportunity to secure the possible benefits because of the age of the aircraft at the outset and the lesser life expectancy and lessened potential for needing to exchange avionics suites as on new aircraft. If a PME standard is implemented, and hard PME cost data are developed (rack costs, installation times, etc.), the value of installing PME equipments on older aircraft would then need to be evaluated on a case-by-case basis through detailed cost trade-off studies. As was pointed out earlier, the largest contributors to acquisition and O&S costs are the avionics that are not common across the force. Thus, it is difficult to establish a PME "block" for

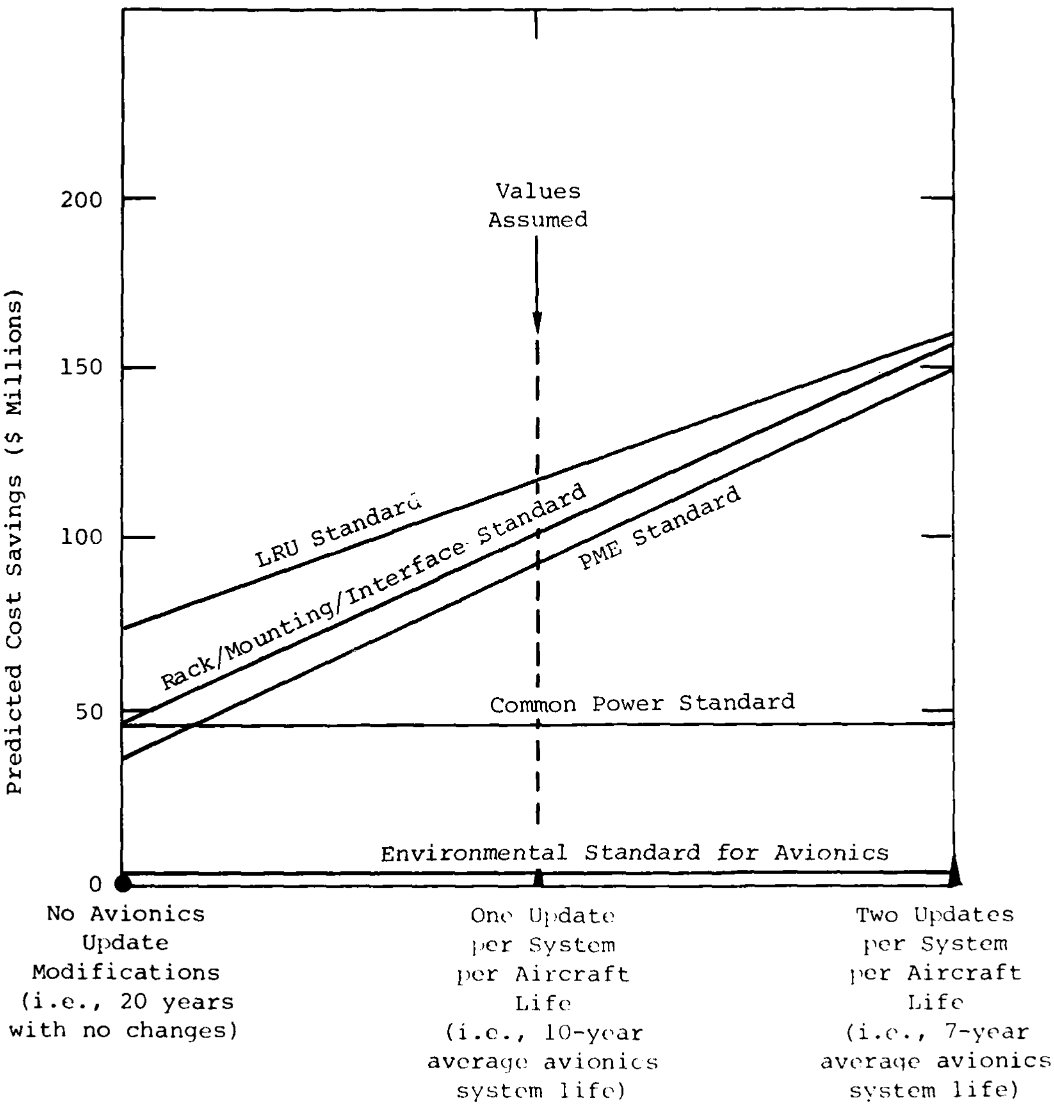

Figure 4-7. SENSITIVITY OF THE COST-SAVING PREDICTIONS TO THE FREQUENCY OF AVIONICS UPDATE MODIFICATION THAT IS ASSUMED

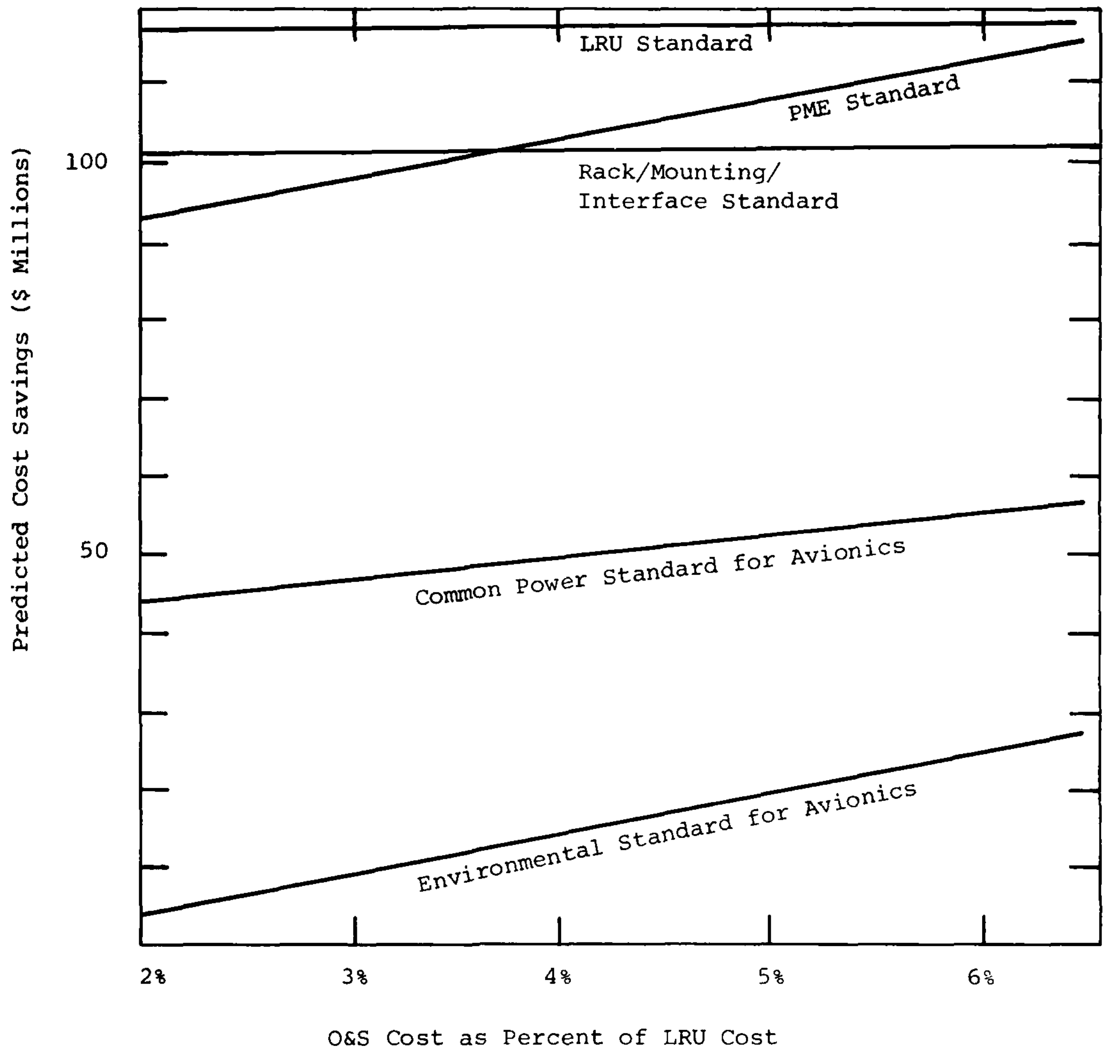

Figure 4-8. SENSITIVITY OF COST-SAVING PREDICTION TO MISSION AVIONICS OPERATION AND SUPPORT COST

installation during the periodic retrofits for these aircraft. This concept will require further development before economic analysis can be made. It is fair to conclude, however, that PME standardization does have economic benefit if used for installations in new aircraft.

The magnitude of the predicted saving associated with PME standardization appears small when viewed in the context of the USAF's current spending level of approximately $2 billion per year on avionics acquisition. However, we have considered only a small fraction (15 percent) of the total applications. Further, the difficult-to-quantify aspects of PME standardization as a building block for wide employment of GFE avionics, as discussed in Section 4.2, have not yet been included.

The results of this analysis, while preliminary and of first-order approximation, indicate that there is significant potential for achieving payback from PME standardization. The LRU packaging standard and rack/mounting/interface standard appear attractive, with lower investment requirements than were assumed for the full PME standardization. However, these results consider the quantifiable costs alone. Operational benefits of improved avionics reliability, such as reduced mission aborts or mission curtailments, are difficult to quantify in terms of cost saving, since the avionics system is only one of many potential mission availability problems. One conclusion that can be drawn is that environmental improvement plus PME standardization can have a much more significant payback potential than environmental improvement implemented alone.

The common power standard can stand alone. The implementation cost necessary to provide better regulation, voltage-spike protection, and outage prevention are much less than those for the improved cooling systems. Currently, this protection must be provided within each LRU. The payback starts by removing this cost from the LRU (acquisition saving) and continues with improved reliability (O&S saving).

It should be kept in mind that the standardization choices are not mutually exclusive. For example, continued use of commercial standards for wide-bodied aircraft and adaptation of the commercial PME standard for other military applications could be approached simultaneously; an LRU packaging standard developed initially could later be established as a part of a full PME standard. Our review of the key technical issues that governed the inputs to the analysis produced further insight into the attractiveness of the alternatives that cannot be displayed as direct model outputs, i.e.:

- Fighter-type aircraft comprise the largest component of the representative force addressed in this analysis; they also represent the largest component of the USAF's projected force. Even small cost payback changes in this class of aircraft will derive large absolute changes in total USAF avionics life-cycle costs.
- The "common" group of avionics, which is the most amenable to the use of commercial or similar standards, represents a minor part of the total cost of the avionics for a combat aircraft; however,

associated with flight-essential functions there are high operational benefits associated with availability improvements. Integration cost for radar, weapon-delivery, and electronic-warfare avionics dominates the avionics-suite LCC and, therefore, has the biggest potential quantitative payback for PME standardization.

- Where cost has been a principal design factor (e.g., for AN/ARN-118 and AN/ARN-127), military avionics prices are fully competitive with commercial avionics prices.

4.8 RECOMMENDATIONS

The PME model developed for this analysis is a powerful tool for examining the impact of standardization alternatives on life-cycle costs in a multiple-aircraft implementation scenario. It will require, however, a significant additional planning and costing effort to provide the data on input-cost elements needed for an absolute set of values. To obtain a better confidence in the relative attractiveness of the five standardization alternatives, the performance of the following tasks is required:

1. Obtain both planning and projected cost data on a larger group of aircraft selected as viable candidates for PME standardization
2. Define specific types of avionics in the aircraft of interest
3. Construct scenarios describing in detail implementation plans for candidate PME standardization alternatives
4. Obtain more detailed data, particularly for the modification cost
5. Perform an analysis on what the planned implementation -- ECS systems, power distribution systems, etc. -- would cost for the various standardization alternatives

At this stage in planning for a PME standard, there is some doubt that such an extensive effort would be warranted. Of the tasks outlined above, the fifth (implementation cost) is the most critical. However, before this can be analyzed in any significant detail, a set of "strawman" approaches must be defined: sizing, cooling method, etc. One scenario is described in Chapter Five to demonstrate what we feel is a practical approach to implementing PME standardization in the USAF. The steps required to establish other activities are described in the PME standardization plan in Chapter Six.

CHAPTER FIVE

SCENARIO FOR IMPLEMENTING USAF PME CONCEPT

This chapter describes a single scenario for implementing a USAF PME concept. It takes the approach that avionics boxes, racks, mounting devices, connectors, power systems, and environmental-control systems will all be incorporated into the PME standards, either concurrently or sequentially. It postulates that functional standardization to achieve complete LRU interchangeability can be incorporated either initially or after implementation of the PME standardization. This scenario offers many technical and institutional benefits but it should be recognized as being just one of several. The cost analysis process should be applied to other scenarios similarly postulated to determine an optimized approach for implementing PME standardization.

5.1 THE CHARACTER OF A USAF PME STANDARD

5.1.1 Sizing

Our discussions with USAF engineers and manufacturers of aircraft and avionics revealed that, while many commercial avionics have applicability to military cargo aircraft and other similar large-bodied aircraft, a PME approach unique to the military will be required for smaller, high-performance aircraft. It is possible that the military PME standard might be an adaptation of ARINC 600, retaining sufficient common features to allow interchangeability of functionally equivalent LRUs. For example, if the USAF PME standard embodied the ARINC 600 Modular Concept Unit (MCU) approach, it is conceivable that an Air Force MCU could be differently defined in terms of dimensions, watt-dissipation factors, and hold-down devices, yet be adaptable to ARINC 600 racks and accept ARINC 700 series equipments. While the notion of military/commercial cross-fit is certainly not essential, obvious benefits could stem from it: common designs, shared specification development, cross-community procurements, etc. If there were cross-fit compatibility between the USAF PME standard and ARINC 600 standards, the USAF would in effect enjoy the benefit of a single standard across its entire force: it could use ARINC 700 equipment in its larger commercial-like aircraft and USAF equipments in smaller configurations for its space-constrained aircraft. On the other hand, the absence of cross-fit compatibility would present two alternatives: first, commercial equipment would be used in the larger aircraft, as is the custom now, and a unique USAF PME standard would be applied to smaller or specialized and high-performance aircraft; or, second, the unique USAF PME standard and its associated smaller equipment would be used for all USAF aircraft. The latter notion is acceptable because the avionics would have been designed for high-performance or constrained situations, and consequently certainly would be suited to operation in larger aircraft and circumstances requiring lesser performance.

5.1.2 Interface

The USAF solved the interface problem posed by the need to put a common piece of avionics into a broad variety of aircraft when it developed the AN/ARN-118 TACAN. The receiver/transmitter (R/T) unit was designed to provide common functions for all aircraft it was to serve. Since each installation required a unique interface, the R/T unit and its accompanying interface box and rack were sized together to provide a direct swap-out with the previously installed TACAN. We suggest that this approach, in conjunction with the ARINC 600 MCU concept, is an ideal way to design equipments for the USAF PME standard, whether or not the resulting boxes have cross-fit compatibility with commercial units. For example, if a USAF avionics unit needs to be 3 MCUs wide to serve the common functions it performs, the interfaces might be provided in a single separate MCU connected to the 3-MCU box (see Figure 5-1).

F^2 — F^3 RELATIONSHIP

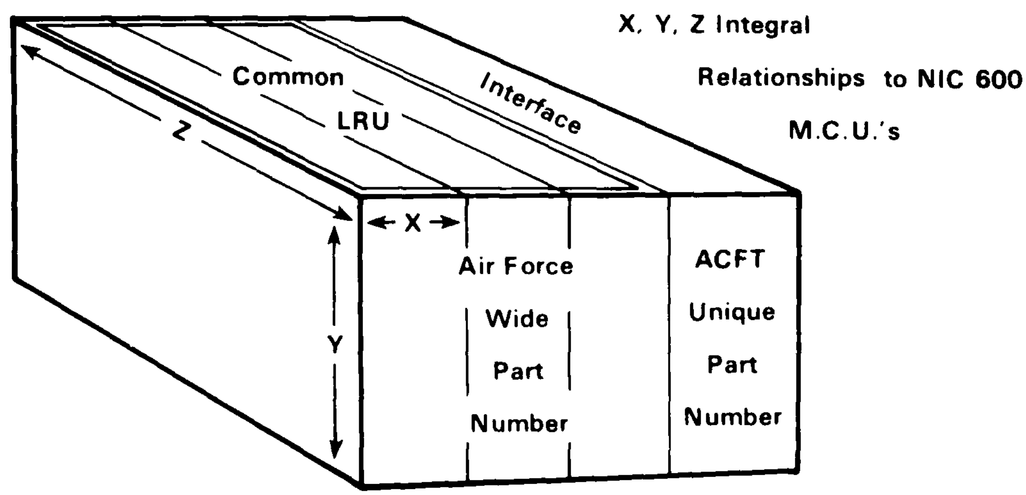

Figure 5-1. AN AIR FORCE MCU BOX CONCEPT

For logistics purposes, the 3-MCU box would be common to all aircraft it is used in; if manufactured by a single supplier in a single configuration, it would have a USAF-wide part number. The interface MCU, on the other hand, would serve only to provide adaptation to one kind of aircraft and would have an aircraft-unique part number. The functional assembly, however, would be sized as 4 MCUs for installation purposes. This same interface concept could be used to cross-fit military and commercial units that required, for example, a DITS/MIL-STD-1553B conversion.

One other concern about interfaces is the level of standardization that is incorporated. For example, in a PME standard, the notion of functional standardization need not be addressed. PME standardization can be construed as F^2E: a box, rack, connector, and environment standard. At the next level, it may define electrical interfaces dealing with power sources, control voltages, discretes, etc. At the other end of the spectrum, PME standardization can be construed as F^3E, which includes full functional interface description, as in an ARINC Characteristic, and a full aircraft-avionics interwiring scheme to provide unit interchangeability when new equipments, techniques, technologies, or manufacturers are introduced and replacements occur. The notion of moving from F^2E to F^3E is also viable if the interwiring provisions are accommodated in the F^2 phase. Because of the nature of digital signals, we believe this is not a difficult task, and suggest that early efforts should concentrate on implementing an F^2E concept initially, and then moving to F^3E after the institutional inertia of the USAF has been overcome.

5.1.3 Environmental Control System (ECS)

A PME standard should deal with an ECS from the standpoint of the aircraft that will use it and from the standpoint of the aircraft that will not. Since installing an ECS can be a costly proposition, its incorporation into an aircraft probably will depend either on a favorable cost-benefit analysis or, where payback is not expected, on its mission essentiality. Aircraft that do not meet either of these criteria probably will not have an ECS installed. The avionics must be designed to accommodate an ECS if one is installed or to operate in a free environment if one is not installed. Box provisions should be carefully considered in this regard from the outset, even if an ECS is not included at the early stages of developing a PME standard. Inclusion of an ECS at a later time would require a new box design and interface retrofit, if the original box was not designed for use with an ECS.

5.2 A SCENARIO FOR IMPLEMENTING USAF PME STANDARD

5.2.1 The Standard

Chapter Six discusses in detail a plan for developing and implementing a PME standard. One aspect of the plan is to use an open forum to develop specifications that would be broadly accepted and implementable. This scenario, depicted in Figure 5-2, begins with a developed PME standard that describes LRUs (dimensions, shapes, ECS adaptability); rack, mounting, and interfaces (rack, hold-downs, connectors, a power standard, accessory signals, and interwiring); and an environmental control system (source, medium, sinks, flows, ducting, etc.).

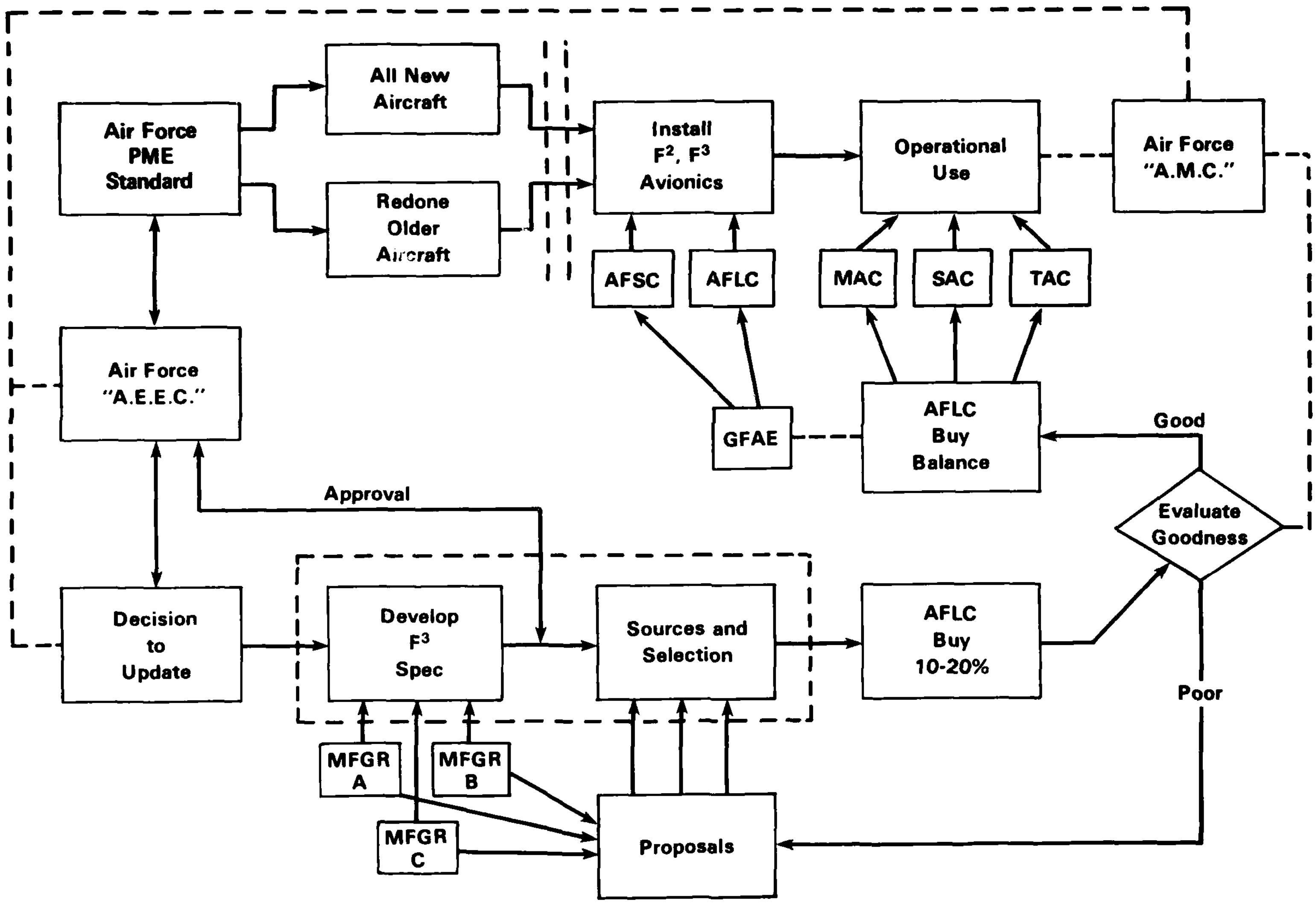

Figure 5-2. A PME STANDARD F^2 - F^3 IMPLEMENTATION SCENARIO

5.2.2 New Aircraft

Each future aircraft to be manufactured will have the PME standard incorporated to the necessary degree. At a minimum, it will have avionics bays, shelves, racks, mounting provisions, connectors, and cable runs that conform to the standard. An electrical power system standard could be implemented separately, but preferably would be included in production design. The incorporation of an ECS should be based on a cost/performance trade-off study for the specific aircraft.

5.2.3 Older Aircraft

A large portion of the USAF force will be older aircraft by the time a PME standard can be introduced. This will include current new first-line aircraft like the F-15, F-16, and A-10. These aircraft obviously will not be well suited to the incorporation of a new standard for avionics boxes, mounting, etc. Should they be retrofitted with new avionics according to the PME standard? This is a difficult question to answer from a cost viewpoint because of the wide range of variables involved. As suggested earlier, incorporation of equipments designed to PME standards into these older aircraft would cost at least as much -- and probably a great deal more -- than incorporation in a production-line aircraft designed for PME. This makes cost saving suspect, and practicality doubtful. Furthermore, since these aircraft are older, there will be less opportunity for future retrofits, which further restricts payback potential. An exception to this reasoning would be an aircraft that has been singled out for an entirely new suite of avionics, as in the case of the B-52. If a decision is made to strip out old avionics and redo them, then PME standardization may very well be a practical solution. A cost/performance trade-off study would be well advised in these circumstances to provide a convincing rationale for a decision.

5.2.4 Installed Avionics

The avionics to be packaged in the new boxes should probably be existing avionics to be greatest degree possible to minimize development cost. However, because new aircraft will be designed to satisfy demands for higher performance, it would be expected that many of the avionics that go into new PME boxes will be the outcomes of new or recent development programs; some may even be concurrent with the aircraft development. These avionics will not be good candidates for F^3 specification and should probably be MIL-specified to the best design, employing F^2 or F^2E standardization at this stage. If there is cross-fit compatibility for common functions such as communications or navigation, development cost might be avoided by using commercial units. If this is not possible, some of these avionics might lend themselves to the development of a functional specification standard. These would be avionics employing F^3 or F^3E standardization at the outset. The four situations described would include both common and mission avionics. The only avionics that would not be packaged in PME boxes would be those that were too large or that might require specialized enclosures.

5.2.5 Decision to Update

At some time in the later life of the aircraft, avionics modernization begins to take place; we are now dealing with an aircraft that has all of its avionics in PME boxes and has implemented, to varying degrees, the PME standard. As described in Subsection 5.2.4 above, there are four kinds of avionics possible:

1. Originally existing equipment, repackaged to PME standards
2. Equipment developed and MIL-specified to PME standards
3. Commercial equipments cross-fitted to serve military needs
4. Equipments built to an F^3 specification for PME standard use

Since the last two types are built to functional specifications and also fit the PME standard, they are easily replaced on a one-for-one swap-out. An F^3 procurement would be in order. The first two types, however, while built to PME standards from a form-and-fit viewpoint, employed unique functional design and are F^2 rather than F^3 in nature. It is at this point in their life cycles that their suitability for F^3 standardization should be addressed. If they make good F^3 candidates, this is probably the last good opportunity to develop an F^3 specification and buy the avionics as a USAF standard item for other aircraft as well. At this point, the equipment in question probably is well defined: it has been used for a long period in an operational environment, and its performance, cost, and maintenance data are all well known. These elements can all contribute to preparing a better specification, particularly if the specification is developed in an environment similar to the Airlines Electronic Engineering Committee (AEEC) open-forum process. Other elements that would support the suitability of the equipment as an F^3 candidate are also well known at this time in the avionics life cycle: the market size for new and retrofit aircraft, the user's current (not future) requirements, and the equipment's state of maturity. Once the specification is developed, an F^3 procurement could proceed here as well, and modification would become a relatively simple and straightforward process.

5.2.6 Sources and Selection

A novel idea can be applied to F^3 procurements to cause them to create a win-win situation for both the USAF and the contractor, and to assuage the major concern of the logistics community with respect to the F^3 concept: spares proliferation. As shown in Figure 5-2, several competitors involved in developing the F^3 specification would be expected to bid on the procurement. Since he knows that this is an update program, and he can easily calculate the market size, each competitor should be motivated to build the best, most competitive product in an attempt to be the single source selected. To ensure that the source selection process does select the best source, only a small increment of the total buy is procured initially to verify the equipment's performance. If the product proves itself in operational conditions, the balance of the procurement is bought. In this manner, the USAF assures itself of a good buy and a single spares-set logistics scenario. If the initial source selection proves to be bad, however, other sources are waiting in the wings, and the USAF has the opportunity to rectify its earlier mistake. True, there are losses on the initial procurement, but, considering the alternative, the losses are minimized, and the users do not have to settle for poor performance. At this point, additional units can be bought as GFE; these could now qualify as F^3 GFE, built to PME standards, for other new aircraft coming along.

5.3 SUMMARY

In summary, the introduction of a new PME standard will require institutional, as well as technical innovations. A comprehensive concept can be implemented in new aircraft designs; retrofit applications must be considered on an LRU-by-LRU installation basis for the older aircraft. An approach which permits both F^2 and F^3 standardization is attractive from a force-wide application standpoint. One approach has been developed in this chapter to demonstrate the pervasiveness of the elements to be considered in implementation of a PME standard. This approach would require further development; it should be evaluated against alternative approaches found acceptable to the affected organizations in AFSC and AFLC. Steps required to develop both the technical and institutional procedures are outlined in Chapter Six.

CHAPTER SIX

DEVELOPMENT PLAN FOR THE PME STANDARD

6.1 INTRODUCTION

6.1.1 Approach

This plan was prepared in response to Task 3 of the Statement of Work, which requires the development of a plan by which the USAF can pursue PME standardization activities. The plan describes the analyses, investigations, and other major tasks needed for the development and implementation of a USAF PME standard.

ARINC Research used the following source materials to develop this plan:

- Procedures for establishing military standards (DoD 4120.3-M)
- Reports of activities leading to the commercial PME standard (ARINC 600)
- Proceedings of the 1978 and 1979 Avionics Planning Conferences, which provided recommended road maps for PME interface standardization.
- Discussions with affected central organizations
- Results of preliminary PME studies as reported in this document

Our approach to the presentation of this plan is to format it as a management-oriented chapter that could be converted readily into a USAF implementation tool after review and comment. Accordingly, there is some redundancy with material presented in other sections of the report.

6.1.2 USAF PME Standardization Road Map

USAF PME standardization initiatives were begun at the 1978 Avionics Planning Conference, which reviewed opportunities available to the USAF for standardization in avionics development and aircraft installations. It identified a standard for avionics PME interfaces as a premier opportunity. The 1979 Conference participants reaffirmed this conclusion and recommended two further considerations: a possible near-term environmental standard for aircraft systems application, and coordination with the Navy and Army on future PME standards for possible DoD-wide use. The road map of activities developed by the conference participants provides the overall basis for this development plan.

The current road map for PME standardization is contained in the January 1980 Armament and Avionics Planning Guidance document, which is being routed for coordination within the USAF. The road map is reproduced in Figure 6-1. The associated descriptions of nodal points are shown in Table 6-1. As indicated at the starting point of the road map, most existing USAF avionics Line Replaceable Units (LRUs) are packaged and mounted in unique form factors dictated by the first application. Their cooling provisions are often not adequately matched with the aircraft environmental control system. The unique features of each equipment have resulted in the proliferation of hardware. Because LRU packaging, mounting, and environment standards are not available, interchangeability of avionics equipments between aircraft models is extremely limited. The introduction of new technology is impeded in many cases because of the time required to develop and package a new concept for retrofit in military aircraft.

The overall objectives of PME standardization, as shown on the right-hand side of the road map, are as follows:

1. Promote Competition - Standardized interfaces promote competition and the development of multiple vendor sources because the market is larger and easier to assess.
2. Improve Cooling and Reliability - Thermal management is a key determinant of reliability. The use of a proven thermal interface with specified flow rates and temperatures can improve reliability and reduce maintenance costs.
3. Promote LRU Interchangeability - Electrical, environmental, and mechanical interchangeability of LRUs reduces spares sufficiency levels and increases aircraft availability. It also promotes competition by providing several sources of essentially identical equipments.
4. Improve Maintainability - More orderly arrangement of avionics in the equipment bays permits easier access and swap-out of avionics for on-equipment maintenance. Training and procedures become standardized.
5. Facilitate Retrofit - Interchangeability eliminates the need to modify the aircraft racks or wiring to introduce new technology or an updated product. The interfaces maintain their integrity regardless of different manufacturers' technology, mechanization, or processes.
6. Reduce Cost - All of the above goals combine to promote overall cost reduction in development, acquisition, installation, and O&S.

Three primary paths are shown on the road map:

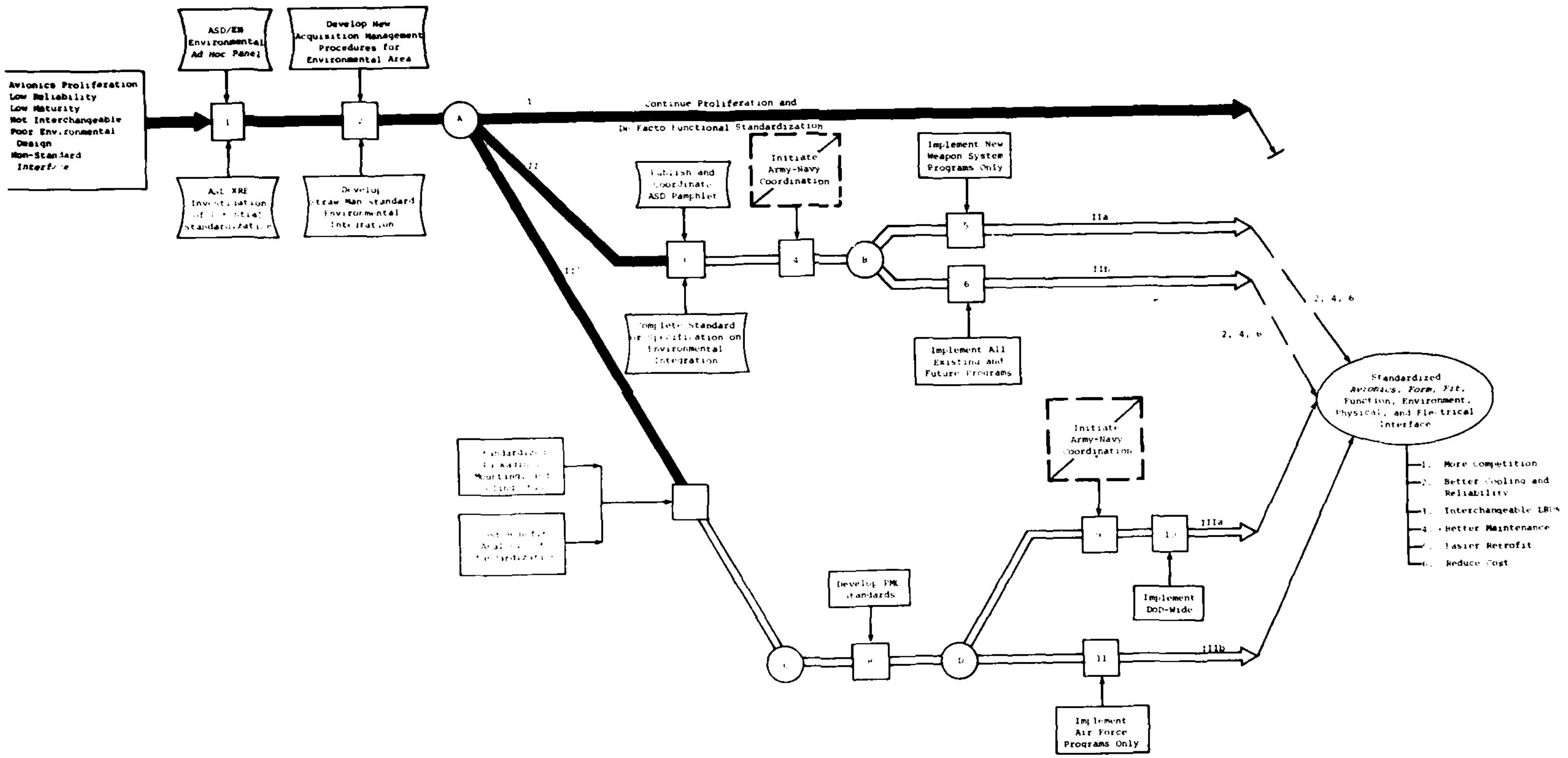

Figure 6-1. STANDARD AVIONICS PACKAGING, MOUNTING, AND COOLING INTERFACES ROAD MAP

Table 6-1. STANDARD AVIONICS PACKAGING, MOUNTING, AND COOLING INTERFACES ROAD MAP NODAL POINT DESCRIPTIONS

Path	Node	Title	Description	Status/ Suggested Action Agencies
--	1	ASD In-House Investigation of Problem	An ad hoc group within ASD/EN was established to investigate and confirm the degrading effects of aircraft environment on avionics reliability. Findings indicated that improved cooling and environmental control would provide major improvements. Also the subject of standardized form, fit, and function was investigated by ASD/XRE. Commercial form, fit, function environment (F^3E) standards (ARINC 600) were considered for a potential AF standard.	ASD/EN/XRE
--	2	Straw Man Environmental Integration and Acquisition Management Documents	A straw man document was developed covering all system and program requirements for an improved and controlled environment for avionics. Because no standard exists for this subject, an ASD pamphlet covering acquisition management procedures was also prepared.	ASD/EN
I	A	De Facto Standards without Interchangeability	In the interim, before the implementation of standards for packaging, mounting, cooling, and electrical and environmental interfaces, different equipments with unique interfaces will continue to be procured. Severe problems in reliability, poor interchangeability, and restricted competition will continue.	N/A
II	A	Decision to Continue Work on Environmental Integration Document	The high potential for increased avionics reliability through better environmental design of the equipment and better control of the environment in the aircraft justifies continued engineering effort on standards and procedures.	ASD/EN
II	3,4		Continue and complete technical and administrative documents for environmental integration. Initiate DoD coordination.	ASD/EN
II IIa IIb	B 5 6	Implementation Decision	After documents on standards for environmental integration are coordinated and approved, a decision on implementation will be required. Short-term and long-term benefits and cost effect must be evaluated. Limited benefits include better reliability, reduced ground failures during maintenance, and lower logistics costs.	ASD/AX
III	A	Decision to Initiate PMC Standard	The full potential benefits of standardization of avionics architecture cannot be realized unless standards for packaging, mounting, cooling interface, electrical interface, and environmental exposure control are employed together.	ASD/AX/XRE
III	7	Packaging, Mounting, and Cooling (PMC) Study	A study and analysis performed by a contractor evaluated alternate approaches and accompanying cost/benefits to establish AF standards for PMC. Results of this effort are scheduled to be available in December 1979.	ASD/XRE

(continued)

Table 6-1. (continued)

Path	Node	Title	Description	Status/ Suggested Action Agencies
III	C	Decision to Select PMC Standardization Approach	Alternate approaches include the following: • Develop standard applicable to all USAF aircraft • Develop standards applicable to classes of aircraft (fighter, bomber, cargo) • Develop standard with limited scope for near term application • Develop standard for totally new aircraft weapon systems (digital, etc.) • Perform all work in-house (ASD) • Use contractor support to supplement in-house effort (ASD) • Adopt commercial standards for PMC	ASD/AX/XRE
III	8	PMC Standards	PMC standards are expected to include the following: • Standards for volume and form of individual line replaceable units (LRUs) • Racking and mounting standards • Standard interface for air cooling • Standard interface for liquid cooling • Standardized connector and connector location • Standards for equipment thermal design evaluation	ASD/AX/XRE
III	D	Decision of AF Implementation -vs- DoD Implementation	A decision to implement PMC standards on selected programs is expected as an initial step to demonstrate the true benefits of standardization.	DoD/AF
IIIa	9	Initiate Army and Navy Coordination	Coordinate PMC standards through appropriate Army and Navy organizations.	
IIIa	10	Implement DoD-Wide	After service coordination, coordinate throughout DoD and implement DoD-wide.	
IIIb	11	Implement Air Force-Wide	Coordinate and implement the standards only within the Air Force.	

- Path I - This path continues the current approach, which provides very limited interface standardization. There are some design standards, such as MIL-E-5400 and MIL-STD-1553, that are generally imposed on new equipment developments. These promote standardization of certain mechanical and electrical aspects of the equipments, but they are not consistently applied and do not achieve the goals stated on the road map.
- Path II - This path develops an environmental standard for use in military aircraft. There are two options: to impose such a standard for new aircraft only or for all cases when major installations of avionics are made. This path serves only goals 2, 4, and 6.
- Path III - This path develops a new PME standard for military aircraft -- either an adaptation of the commercial standard or a completely new concept that meets all goals on the road map.

The shaded area of the road map indicates the progress made along each of these paths. In this form of road map, it is possible to proceed in parallel along multiple paths because they are complementary in purpose. A time scale is not shown on the road map, but standardization activities may be divided into three phases. The initial phase consists of studies to determine the preliminary cost-benefit relationships of PME standardization and define alternative concepts for the standards. These studies are shown as completed, leading to decision node "C." The USAF will decide on continuation with the PME standardization efforts on the basis of these preliminary studies, which include:

- First-order cost-benefit analysis of the USAF PME standards
- Initial industry survey concerning the feasibility, applicability, and expected problem areas in USAF PME standardization
- Generic areas of differences between commercial and military standards

The next phase involves efforts to determine the best approach to achieving standardization. These efforts may involve industry R&D support in developing and validating new concepts of technology to supplement USAF studies. The USAF may also decide to coordinate the developed PME standard with the Navy and Army for possible DoD-wide application.

The final phase is implementation of the standard.

The results of the preliminary studies, which are presented in other chapters of this report, lead to three conclusions concerning continuation with the PME standardization efforts:

- PME standardization appears to be a viable concept for the USAF on the basis of predicted cost-benefit relationships, expecially in the area of new-aircraft installations.

- The PME standard should include more than just thermal considerations; to achieve significant savings, form-fit (F^2) or form-fit-function (F^3) standardization should be implemented, with provisions to incorporate environmental standards where judged appropriate.
- The USAF PME standard possibly could be based on the ARINC 600 concepts; possibilities include designing the standard to accommodate cross-fit standardization with commercial equipments or using ARINC 600 directly to supplement a USAF-unique standard.

The first two conclusions reflect the results of a first-order cost-benefit analysis of applying a new USAF PME standard versus the current practice of using non-standardized PME. The analysis projected significant potential avionics life-cycle-cost saving for avionics applications in new aircraft. The third conclusion reflects the results of our industry survey on USAF PME standardization; the participants were in agreement, for the most part, that USAF PME standardization should be based on the ARINC 600 concept, with essential military requirements added and necessary exceptions made.

In summary, the development of a new USAF PME standard should follow the PME standardization road map depicted in Figure 6-1.

6.1.3 Commercial PME Standardization and the Open-Forum Process

The history of the commercial development of PME standards suggests that successful development of the USAF PME standard and its acceptance will depend greatly on the open-forum process. This process was used by the commercial airlines industry to develop ARINC 600, which is the commercial PME standard. There was no formal cost trade-off analysis performed in this development. Rather, the open forum was used to provide an arena for a full and free exchange of ideas and technical expertise among aircraft manufacturers and vendors so that they could better understand users' needs and the users could better relate trade-offs between capabilities and costs. Participants in the open forum negotiated mutually beneficial common factors and specifications, from which the standard evolved.

ARINC 600 was developed for implementation on new commercial aircraft construction (e.g., the Boeing 757, 767, and 777 series). It reflects a sharp departure from the older ARINC 404 concepts; there is very little backward compatibility with older commercial standards. It may be inferred that the USAF will be led to this same approach. The attractive features of new technology -- low or zero insertion force connectors, improved cooling standards, etc. -- are difficult to introduce in an evolutionary manner. The military standard should seek the best approach for future aircraft, then find ways for accommodating retrofit applications where it proves beneficial.

6.2 TASK OVERVIEW

This section addresses in detail the activities required to develop and implement a USAF PME standard if a favorable decision is rendered at nodal point "C." We have introduced steps indicated by our analysis or by precedents established during the development of ARINC 600.

Figure 6-2 depicts the evolution of the USAF PME standard in four phases.

Phase I, which consists of conducting preliminary studies, is now completed.

Phase II involves developing a series of requirements, applications, and architectural analyses to initiate the open-forum process in an effective manner. The analyses, to be conducted prior to the first open forum, provide initial data and identification of the issues that must be reconciled about PME standardization. Requirements and application analyses address:

- Potential PME interface parameters and associated quantitative values to be standardized
- Specific application of PME standardization to post-1985 aircraft installations and potential application for retrofit

Architectural analysis is needed to provide strawman versions of PME standards to be used as the baselines for military and industry participation in open-forum resolution of differences.

Phase III begins when open-forum activities are undertaken. The early open forums would provide agreement on the structure and quantitative values to be assigned to the standard specifications and on the number and form of USAF PME standard documents needed to be issued.

In conjunction with the open-forum process, USAF or industry development and validation efforts on the equipment itself would continue. To assure broad technical and market acceptability, the open-forum membership would review and comment on all technical contributions to PME standard specifications before the specifications took final form. It will be necessary to obtain formal USAF coordination and approval of USAF PME standards that could result from the open-forum process. MIL-STD-962 and DoD 4120.3-M provide instructions on how to do this.

Implementation of the USAF PME standard would begin in Phase IV with the establishment of a control agency to monitor the implementation and actively participate in it as required.

The following sections describe Phases II, III, and IV in task-oriented statements. A schedule for implementation of these activities is presented at the end of the discussion.

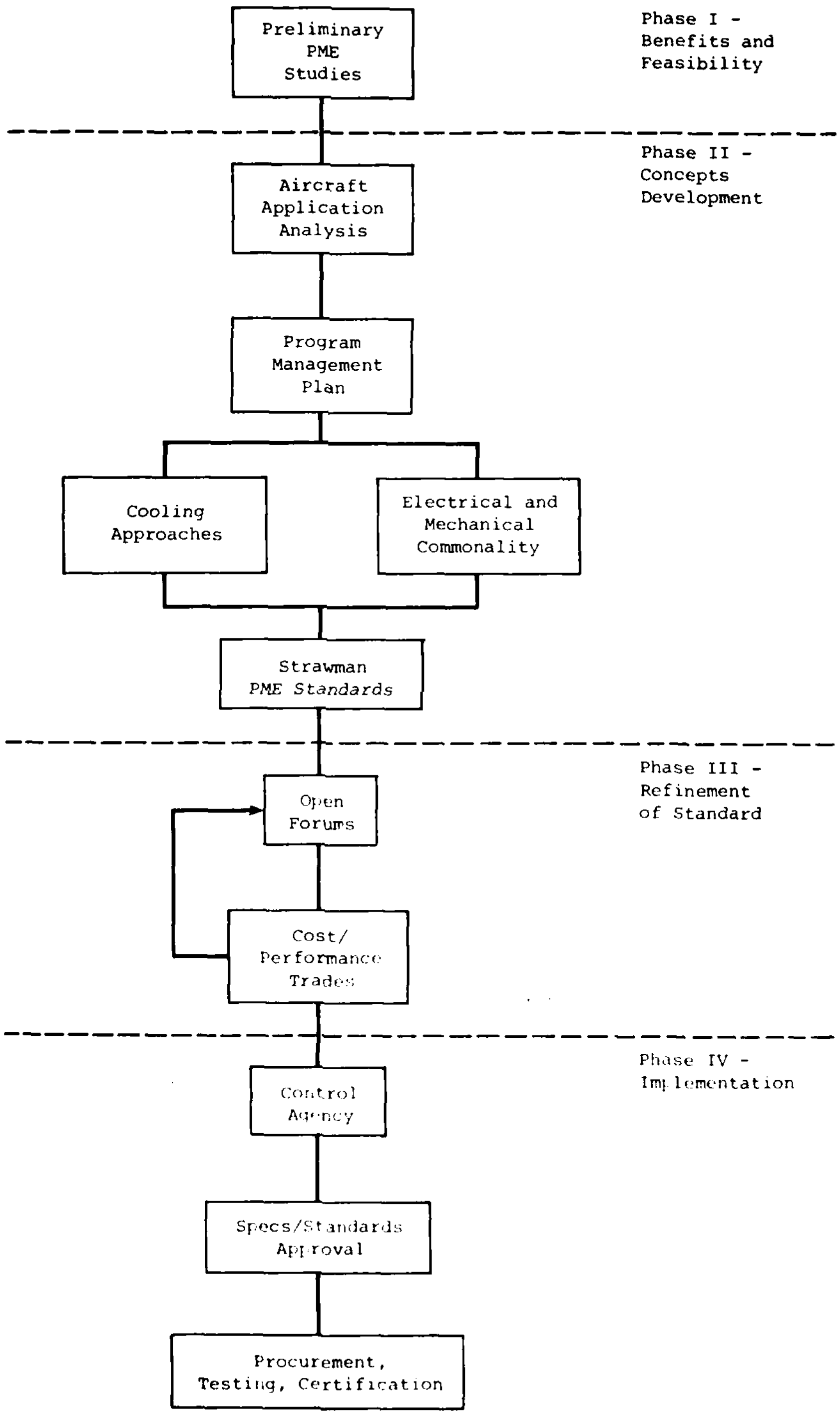

Figure 6-2. DEVELOPMENT OF A NEW USAF PME STANDARD

6.3 PME STANDARDIZATION ACTIVITIES

A proposed schedule of PME standardization activities is shown in Figure 6-3. This schedule was formulated with the objective of implementing a military PME standard in time to influence avionics retrofits occurring after 1985. Considering production lead times and procurement delays, this suggests that the testing and certification of selected equipments must be commenced by 1983. The following subsections provide details on each of the proposed activities.

6.3.1 Task 1 - Development of Implementation Concepts

This task defines the applications and management concept for implementing a PME standard. Two broad subtasks are envisioned.

6.3.1.1 Subtask 1.1 - Aircraft Applications Analysis

Official USAF projections of new aircraft construction or major retrofit programs should be reviewed to determine by category of system (e.g., radar altimeter, INS, etc.) the total market size for new rack-mounted avionics in the 1985-2000 period. Within each of these categories, the proportion to be installed within each class of aircraft should be determined. The objective of this subtask is to determine the overall sizing and performance drivers for future PME standards and the extent to which retrofit applications should be considered.

The data should be summarized by type of aircraft and class of avionics systems (e.g., INS, Transponder, GPS, MLS, etc.), and a screening process performed to determine those avionics and aircraft that may be appropriate for USAF PME standardization and those that should be exempted from it. Qualitative and quantitative criteria (technical, economical, and operational factors) that govern the appropriateness of either an aircraft type or avionics class should be used in the screening process. Examples of these factors include:

- Technological maturity of avionics
- Commonality of avionics across aircraft installations
- Unique operational requirements of aircraft or avionics
- Total number of avionics needed in or projected for the USAF inventory

6.3.1.2 Subtask 1.2 - Development of Management Approach

This subtask develops, for USAF coordination and approval, an overall management approach for the implementation and enforcement of the selected standards. The approach should consider:

- The roles of AFSC and AFLC in implementation and control
- Extent of participation by industry

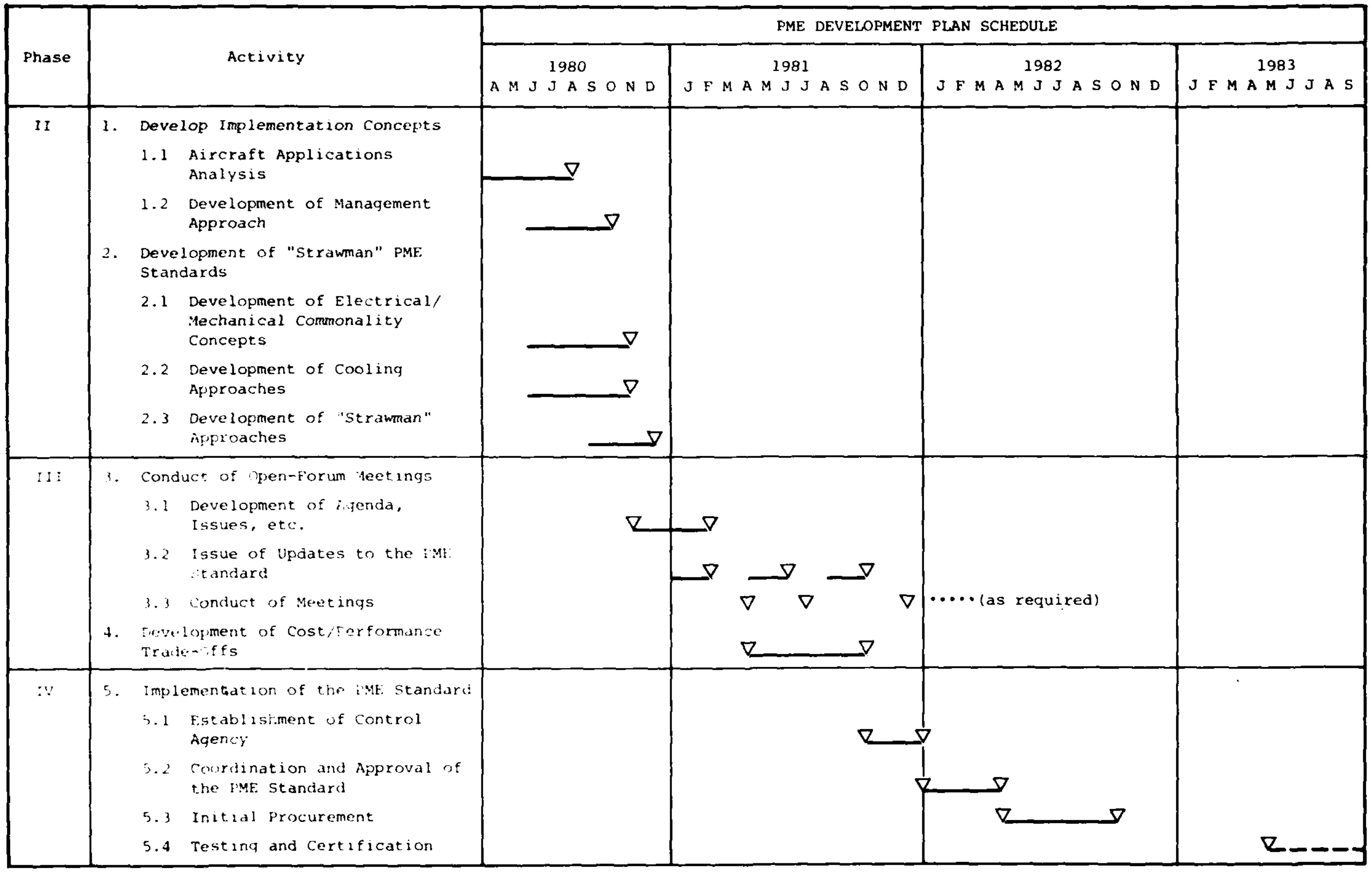

Figure 6-3. PME DEVELOPMENT PLAN SCHEDULE

- Partial versus full implementation approaches
- Procurement mechanisms

The results of the analysis should be presented in Program Management Plan (PMP) format. Included in the plan should be estimates of the total in-house resources required to develop the PME standard, the funding budgetaries, appropriate funding elements, and detailed schedules.

6.3.2 Task 2 - Development of "Strawman" PME Standards

The purpose of this task is to develop the initial "strawman" standards for consideration by the USAF and industry technical community. Following the guidance provided by the PME standardization road map, two parallel, but related, investigations are indicated: an electrical and mechanical commonality analysis and the development of alternate cooling concepts.

6.3.2.1 Subtask 2.1 - Development of Electrical/Mechanical Commonality Concepts

The preliminary results of the aircraft applications analysis conducted in Task 1.1 should be used to determine the extent of electrical and mechanical commonality to be addressed by the PME standard.

Candidate avionics for each candidate aircraft should be surveyed to identify a baseline of potential interface parameters, the permissible numerical limits of each parameter, and the parameters that are applicable to multiple installations. The following are examples of interface parameters:

- LRU case sizes
- Electrical connector types
- Signal formats (digital, analog, etc.)
- Power requirements
- Vibration, shock, and acceleration values

6.3.2.2 Subtask 2.2 - Development of Cooling Approaches

The results of ongoing studies on cooling techniques conducted in-house by the military and in contractually sponsored efforts (such as the Boeing B-1 cooling studies) should be examined for application to the candidate aircraft/avionics groups. This effort should consider (a) the direct application of the methods employed for ARINC 600, (b) advanced conduction methods, and (c) the impact of employing avionics designed to improve thermal environments in aircraft on other forms of environmental control systems.

6.3.2.3 Subtask 2.3 - Development of "Strawman" Approaches

"Strawman" approaches that address the range of interface requirements identified in Subtasks 2.1 and 2.2 should be developed. These approaches should include:

- USAF PME standard designed to interface with commercial standards (ARINC 600)
- USAF unique standards such as the following:
  - •• PME standard common to all USAF aircraft
  - •• PME standards applicable to specific classes of aircraft
  - •• Avionics environment standard
  - •• Avionics common power standard

To whatever extent possible, approaches should be considered that permit both full implementation (e.g., for new aircraft or complete avionics swap-outs) and partial implementation (e.g., for retrofit purposes).

Technical issues and problems concerning the development and application of the USAF PME standard that are to be resolved by open-forum discussion should be identified. Major USAF organizations and manufacturers of avionics systems and aircraft should be surveyed for relevant information and viewpoints. Wherever possible, information from Navy, Army, and civilian organizations involved with avionics installations should be obtained. Major areas for consideration include:

- State-of-the-art technologies (post-1985) that will drive design of PME interfaces
- Market factors -- number of suppliers, etc.
- Operational constraints
- Impact of aircraft system configuration management
- Logistics support

Possible approaches to resolving the issues and problems identified should be summarized. An outline of the key issues, problems, and possible resolutions should be provided for USAF use in planning and preparing the agenda for each open-forum meeting. The outline should also be given to the participants prior to each meeting.

6.3.3 Task 3 - Conduct of Open-Forum Meetings

This task involves wide participation of USAF organizations, other interested government agencies, and avionics and aircraft manufacturers in the refinement of the "strawman" PME standards.

6.3.3.1 Subtask 3.1 - Development of Agenda, Issues, etc.

Prior to the scheduling of the open-forum meetings, agenda, issues, and procedures should be established. A PME standing committee should be established, with regular members from AFSC, AFLC, and using commands, to oversee the implementation of the open-forum process. Participants and their assigned functional responsibilities in the committee should be defined. The guidelines in the Federal Advisory Committee Act (PL92-463, October 6, 1972) should be referred to in regard to this task.

The standing committee's responsibilities will include the following:

- Careful preparation of guidance instructions and correspondence so that all participants will clearly understand USAF intent, goals, and expected participation.
- Prior study and analysis to identify viable approaches and alternatives to the problems that have been identified before an open-forum meeting is convened.
- Allowance of sufficient time in the open-forum process for the evolution of an effective standard that is acceptable to all concerned.
- Performance of necessary trade-offs and analyses to determine the most economical form of PME standard.

6.3.3.2 Subtask 3.2 - Issue of Updates to the PME Standard

As soon as possible after each open-forum meeting is concluded, the changes to the standard suggested by the forum participants should be incorporated and the standard re-issued. Each change should be accompanied by a commentary that explains the reasons for its adoption. At least two months should be scheduled after re-issue of the specifications to permit the participating commands to analyze the impact of the changes on their requirements.

6.3.3.3 Subtask 3.3 - Conduct of Meetings

We expect that at least three meetings will be required to converge upon an acceptable standard -- more may be required. These meetings should be conducted with rigorous attention to agenda and purpose.

6.3.4 Task 4 - Development of Cost/Performance Trade-Offs

During the open-forum meetings, there should be continuing evaluations of the cost/performance impacts of the changes suggested by the participants. The exact nature of the trade-offs are difficult to forecast but it is likely that they will concern, at least, the following matters:

- Avionics acquisition, modification/integration, and support costs
- Mechanical interface requirements
- Avionics repackaging, redesign of aircraft mounting racks and environmental control systems
- Reliability and maintainability
- Mission capabilities

6.3.5 Task 5 - Implementation of the PME Standard

The PME standard developed by the preceding tasks is formalized as an approved USAF and/or DoD-wide Standard by this task.

6.3.5.1 Subtask 5.1 - Establishment of Control Agency

An agency should be designated to control the PME standard within the USAF and in other military services if applicable. Possible candidates include ASD/AEA, ASD/XRE, ASD/ENE, or the DAC.

6.3.5.2 Subtask 5.2 - Coordination and Approval of the PME Standard

Should the USAF decide to coordinate the PME standard with the Navy and Army for possible DoD-wide application, a minimum of four months will be required for a MIL-STD to be coordinated and approved. This assumes that all reviewers have participated throughout most of the development of the draft PME standard and have concurred with the draft by consensus agreement during the open-forum meetings. The process, in general, involves a 60-day review cycle for the preliminary draft standard, followed by another 60-day cycle to resolve comments and obtain coordinated approval. Activities required are:

- Preparation of PME military standard in accordance with MIL-STD-962
- Coordination of PME military standard for approval in accordance with DoD 4120.3-M
- Resolution of open actions from the coordination cycle

6.3.5.3 Subtask 5.3 - Initial Procurement

Upon approval of the PME standard as either a limited coordination (Air Force) Military Standard or as a coordinated (DoD-wide) Military Standard, the initial applications for it should be placed under procurement. Initially, it is envisioned that these would be the repackaging of existing equipments in accordance with the new Standard. This procurement should be initiated well in advance of the aircraft installation time, so that the SPO director can elect other options if testing or certification is not completed in time to mesh with production schedules.

6.3.5.4 Subtask 5.4 - Testing and Certification

Testing and certification will occur upon delivery of the preproduction items. It is difficult to forecast the amount of time required for this process because the extent of interfaces to be included in the PME standard has not been determined.

6.4 SUMMARY

We believe that the success of USAF PME standardization will depend on dedicated participation of USAF and industry personnel who are involved in avionics development or aircraft installation. These people may require assistance in understanding, planning with, and using the PME standard. The promotion of commonality between the USAF and the airlines' standards could be mutually beneficial. Further, the military's use of commercial standards whenever possible, in lieu of developing new military standards, reflects support of DoD 4120.20 guidance.

The development of a USAF PME standard will take place over a period of about three years in four phases:

Phase I (1978 to present)	-	Performance of preliminary studies to evaluate potential USAF use of commercial avionics standards and determine the potential cost-benefit relationships associated with the USAF's applying PME standardization to aircraft installations
Phase II (1980-1981)	-	Performance of a series of requirements and applications studies and analyses leading to strawman PME standards for the open-forum process.
Phase III	-	Development of the PME standard by the open-forum process. Validating the PME standard and obtaining approval for it as a MIL-STD.
Phase IV	-	Implementation of the PME standard.

Other inferences on the nature of the USAF PME standard and its implementation, which can be drawn from this plan and from the scenario examined in the previous chapter are:

- Programs within the USAF, in other military services, and in industry will contribute to the formulation of basic design requirements. Study and planning will also be needed to provide design options and data from which one or more "strawman" PME standards can be developed. An AEEC-like open-forum procedure, involving representatives of the military developer, user, and logistics agencies and aircraft and avionics manufacturers, is seen as the most effective way to produce a well balanced avionics standard and to obtain all-around support for its application.
- Some of the aspects of PME standardization can be implemented progressively. For example, a common power standard could be applied to the electric power supply of the next new aircraft program; existing configurations of environmental control systems could be upgraded to meet an improved cooling standard. Other aspects of PME standardization need cautious planning so that they do not conflict with technology growth (e.g., in aircraft configuration, environmental support techniques, and avionics component and device integration) or with possible subsequent higher levels of standardization.

- While the use of a PME standard generates its own advantages, expanding the concept from one of form, fit (F^2), and environment to one of form, fit, function (F^3), and environment raises the likelihood of future functional standardization, which has been widely discussed but only occasionally implemented in the Air Force. The benefits achieved through the combination of box and functional standardization are synergistic: the user and the supplier enjoy continuing competition, interchangeability, maturity, and ease of modification, and also work within the framework of a well established, recognized, and accepted discipline that encourages its own use.

- PME standardization can be applied to any class of avionics as a box standard. Functional standardization should probably be added only for common and mature avionics functions -- mission avionics should be considered, at best, only if they have reached an equivalent stage of maturity. In short, F^2 can be applied to most avionics; F^3 probably should be limited to common avionics and perhaps the less complex mission avionics functions. The following is a possible sequence of events:

  - An initial "strawman" PME standard could address box size, cooling interface, rack-mounting arrangements, and connector configuration; it should be adaptable to all "avionics bay" LRU applications.

  - Individual functional standardization planning could follow for mature avionics subsystems: this would lead to "strawman" standards for "form, fit, and function" specifications applicable to future Air Force procurements with standardized interwiring.

  - As digital data bus standardization becomes more widespread, standard interwiring constraints will become less burdensome and an increasing proportion of avionics LRU specifications could well be upgraded from an F^2 content to an F^3 content.

- While PME standardization techniques are appropriate for all USAF aircraft, the idea of undertaking an entire avionics-system overhaul to incorporate new avionics standards in existing aircraft does not appear reasonable. However, when entirely new avionics suites are being considered for retrofit, as in the case of the B-52, F-4G, etc., there may well be merit to a wholesale incorporation of the new standards. This would need to be evaluated on an aircraft-by-aircraft basis after basic PME acquisition and installation cost factors have been ascertained. On new aircraft, the incorporation of a PME standard would be an integral part of the design process; this appears to be the most reasonable place to initiate the concept.

CHAPTER SEVEN

CONCLUSIONS

This chapter summarizes our conclusions in each of the areas addressed in the study. We have organized these conclusions into five areas, corresponding to the emphasis areas delineated in the Statement of Work: (1) A comparison of military and airlines standards, (2) potential use of commercial avionics, (3) cost-benefit relationships associated with the PME standard, (4) examination of selected technical aspects of the PME standard, and (5) an implementation plan.

7.1 COMPARISON OF MILITARY AND AIRLINES STANDARDS

Because of their different origins and objectives, there is considerable divergence between the standards and specifications that govern USAF avionics procurement and those that serve a parallel function for civil aviation -- FAA, RTCA, and ICAO performance standards and commercial airlines (ARINC) form, fit, function (F^3) standardization characteristics. We concluded that these fall into three generic classifications:

- Physical and Performance Differences - Airlines units may be too big for space-premium USAF aircraft, may not withstand the physical environment of these aircraft, or may not provide the performance characteristics required by these aircraft. In some cases, accommodations may be made, but generally this class of differences dissuades the use of commercial equipments.
- Electrical and Mechanical Interface Differences - These encompass differences in connectors, data formats, cooling-air needs, etc., which result from differences in military and commercial practices. Minor modifications or waiver of military requirements can make commercial avionics acceptable for military use. *Nine specific* areas of waiver or exemption are identified in Chapter Two.
- Procurement Documentation Differences - ARINC Characteristics specify form, fit, and function (F^3) interfaces and do not detail design features or specify piece-parts and processes. MIL Specifications detail design and construction as well as performance required. Also, differences occur in application of quality control, vendor participation, and acquisition practices. These differences do not affect the functional adequacy of commercial equipments, but they do raise concerns in military acquisition and logistics circles.

7.2 POTENTIAL USE OF COMMERCIAL AVIONICS

Commercial airlines flight-essential avionics are designed, manufactured, tested, and certified to a well defined and documented set of standards, which correlate qualitatively, and sometimes quantitatively, with equivalent military specifications and standards. The key specification that has been in use in the commercial airlines since 1956 is ARINC Specification 404: Air Transport Equipment Boxes and Racking. Avionics equipments defined by current ARINC Characteristics (the "500 series") comply with ARINC 404A and provide a high degree of interchangeability between like units supplied by different avionics manufacturers. The airlines have developed and implemented a new-generation racking specification -- ARINC Specification 600. The principal advance of ARINC 600 over ARINC 404A is in its ensuring the availability of improved cooling by limiting the avionics thermal dissipation according to the LRU case size and by requiring adequate quantities of clean cooling air to be furnished to it. Other changes redefine the allowed avionics case sizes and introduce a new style "low insertion force" rear connector and revised box hold-down arrangements. Avionics equipments conforming to ARINC 600 are defined by ARINC Characteristics in the "700 series." The ARINC 700 series Characteristics also standardize data input and output to the digital formats of ARINC Specification 429, Digital Information Transfer System (DITS) and, where appropriate, to ARINC Specification 453, Very High Speed Data Bus. On the basis of our review of selected commercial standards and their applications to specified USAF aircraft, we make the following conclusions:

- Existing commercial avionics are broadly applicable to use in military transport aircraft; only relatively simple racking and interface changes are required in aircraft not originally designed for commercial avionics.
- Existing commercial avionics can be used in bombers and other penetration aircraft if racking and interface modifications are made in the aircraft and if the aircraft and/or avionics are modified to provide required interfaces with mission equipment, to prevent EMI, and to provide for EMP and nuclear hardening
- Existing commercial avionics generally will not be applicable to high-performance aircraft because of space, environment, or performance constraints; in some cases, however, available space may permit installation of selected avionics and necessary interfaces.
- Use of future commercial avionics will require adaptive work in USAF aircraft. In addition, because they accept only digital inputs and provide only digital outputs (both to the ARINC 429 format), future commercial avionics will require additional interface equipment to make them compatible with existing analog inputs and/or with the MIL-STD-1553 data bus.
- The cost-benefit relationships associated with the USAF's use of commercial avionics are difficult to articulate. The use of commercial avionics can circumvent the development time and cost of military procurement in circumstances where military equipment is

not readily available. The acquisition cost of commercial avionics is comparable to large-lot GFE procurements for similar functional systems. The greater maturity and higher reliability in commercial avionics, generally due to higher flying-hour experience and continuing vendor involvement, tend to offset higher logistics cost that may be introduced by non-standard parts. Each procurement should continue to be evaluated on a case-by-case basis.

7.3 COST-BENEFIT PME RELATIONSHIPS ASSOCIATED WITH THE STANDARD

The scenario that we used to perform the PME cost-benefit analysis included a mix of three types of aircraft that are currently in the USAF's projected force structure: (1) high-performance tactical, (2) tactical attack/observation, and (3) cargo/transport; it also included two groupings of appropriate avionics: (1) common equipments and (2) mission equipments. This subset of the force is proportionally representative of the total USAF current inventory (60 percent of the aircraft are of the one- or two seater type). If all applications were included in the analysis, larger returns in the aggregate might be shown. However, it was not possible to determine realistically the extent to which the PME standardization alternatives might be implemented in an existing aircraft architecture, because such modifications are currently performed on an equipment-by-equipment basis. Implementation of a PME standard would appear feasible only if the modifications were grouped for major swap-outs, as is the case in the current B-52 update program.

The following are key conclusions that provide good direction for future work:

- Aircraft not yet designed appear to be the best candidates for implementation of the USAF PME standard. For these aircraft, our analysis showed that economic advantages would accrue through the PME standardization alternatives in the following order of merit: (1) LRU standard, (2) rack/mounting/interface standard, (3) full PME standard, (4) common power standard, and (5) environmental standard. Payback periods varied from 5 to 15 years depending on investment required and benefits gained.
- Fighter-type aircraft comprise the largest component of the USAF projected force and the largest component of the representative force addressed in this analysis. Even small cost payback changes associated with this class of aircraft will derive large changes in total USAF avionics life-cycle cost.
- Radar, weapon-delivery, and electronic-warfare avionics costs dominate the avionics suite LCC and, consequently, have the biggest potential quantitative payback for PME standardization.

- The "common" group of avionics, which is the most amenable to the use of commercial or similar standards, represents only a minor part of the total cost of the avionics for a combat aircraft; however, one must remember that operational benefits stem from any availability improvements in flight essential functions.
- Installation of new PME standard equipments (racks, mounting provisions, connectors and cables, environmental control, etc.) in older aircraft would cost at least as much as installation in new production-line aircraft, and most likely a great deal more. Any saving attributable to upgrading older aircraft with PME standards would necessarily be less than that for new aircraft by the increased cost of installation. Since the payback time would be longer, there would be less opportunity to secure the possible benefits because of the age of the aircraft at the outset. If a PME standard is implemented, the value of installing PME equipments on older aircraft would need to be evaluated by trade-off studies on a case-by-case basis as hard PME cost data were developed.
- Environmental improvement implemented in conjunction with PME standardization would have a much more significant payback potential than environmental improvement implemented alone.
- The common power standard can be implemented on a stand-alone basis. The implementation cost necessary to provide better regulation, voltage spike protection, and outage prevention is much less than that for the improved cooling system. Currently, this protection must be provided within each LRU. The payback starts by removing this cost from the LRU (acquisition saving) and continues with improved reliability (O&S saving).
- The standardization choices are not mutually exclusive; for example, continued use of commercial standards for transport-type aircraft and adaptation of the ARINC standards for other applications could be approached simultaneously; or an LRU packaging standard developed initially could later be included as part of a full PME standard.

7.4 SELECTED TECHNICAL ASPECTS OF PME STANDARDIZATION

ARINC 500 and 700 series avionics equipments have different degrees of direct usability in USAF aircraft. Except where space, environment, or performance prohibit it, adaptability can be achieved through interface accommodation, waiver of standards, and changes in the procurement process. These requirements often cannot be accommodated within the authority of the military procuring agency, with the result that frequently a decision is made to pursue a military development. In many uses, this spawns another new and individualistic piece of USAF equipment. A PME standard that has attributes similar to ARINC standards can remove many of these superficial obstacles to the use of commercial equipments. Among the industry representatives we surveyed, there is a consensus that applying a USAF PME standard is a suitable way to gain many standardization benefits attributed to commercial practices, even if commercial avionics themselves are not employed. This notion complements the current USAF standardization thrust, by providing cross-system benefits of standardization as well as those gained by the GFE approach. The PME concept can extend from standard boxes, racks, plugs, wiring, test equipment, installation design, and modification process to power sources, environmental control sources, ducting, and porting. In addition, it introduces a high potential for commonality in many other aspects across multiple platforms.

We make the following specific conclusions:

- Sizing is the main point of contention associated with a PME standard. ARINC 404A and 600 standards are considered "frequently too large," especially for space-constrained fighter-type aircraft. Sizing in a PME standard should accommodate generalized USAF needs; while a single standard would be preferable, multiple standards may be necessary to serve the full range of USAF needs economically. Perhaps some combination(s) of USAF and commercial sizing would be possible, to permit cross-fit of equipments. The order of priority in size concerns appears to be: first, height; second, length. Width is not mentioned as a concern.

- The next most severe contention centers around environmental control, which would require design to maximize long-term benefits of current and future techniques. If designed and implemented carefully, an environmental standard could benefit not only the prime users (such as the F-16 and F-111) but also those who would achieve environmental control as a bonus. While good environmental design parameters certainly do not lower design and acquisition costs, they do provide lower peak operating temperatures, which, in turn, reduce equipment failure rates and hence operating and support cost.

  - Convection cooling continues to serve the commercial airlines needs because of the availability of pressurized and conditioned cabin air and the acceptability of low-density avionics packaging. Military aircraft designs, too, have continued to use convection cooling for most avionics installations, in spite of the performance shortcomings that occur under some military operating conditions. At the same time, escalating performance requirements have forced avionics designers to achieve denser component packaging, pushing the state of the art of high-temperature electronic components.

  - Alternative techniques for removing excess heat from avionics components have been amply demonstrated in mission-equipment installations where forced-air cooling is not sufficiently effective. Advanced environmental studies are in process in industry today; if the results are available in time, they deserve assessment before USAF environmental standardization features are settled on.

- Vibration standards and the qualification testing relating to them need to be reconsidered in conjunction with potential shock mounting techniques. Vibration isolation for a complete avionics box-rack combination presents qualification-test problems; hard mounting is preferable, but vibration test conditions appropriate to specific aircraft and box locations should be specified. The current method of generalizing requirements frequently leads to over-specifying qualification tests and, consequently, the equipment itself. Benefits could accrue from lower cost for production and qualification testing.

- Quality control requirements on piece-parts create cost escalation for military equipments that is not necessarily incurred by commercial counterparts. In the views of several avionics manufacturers, however, the higher price of military quality control does not buy better quality. Rather, MTBF guarantees can be used to provide a positive incentive for a contractor to achieve proper design for good performance. RIW also gives the manufacturer a continuing opportunity to improve equipment performance if he chooses to -- or needs to -- to forestall an unacceptable deterioration in performance.

7.5 PME IMPLEMENTATION PLAN

An avionics standard for packaging, mounting, and environmental control must be applicable to a wide variety of equipments and aircraft and acceptable to the user and logistics communities. It must be managed according to a concept that stimulates and facilitates its use, primarily in new aircraft programs but also in major avionics modernization programs. Decisions must be made concerning the "depth" of the standardization to be specified, the form factors and interface parameters that are to be preferred, and the classes of aircraft to be involved. We conclude that the following specific matters should be addressed:

- Programs within the USAF, in other military services, and in industry will contribute to the formulation of basic design requirements. Study and planning will also be needed to provide design options and data from which one or more "strawman" PME standards can be developed. An AEEC-like open-forum procedure, involving representatives of the military developer, user, logistics agencies, and aircraft and avionics manufacturers, is seen as the most effective way to produce a well balanced avionics standard and obtain all-around support for its application.
- Some of the aspects of PME standardization can be implemented progressively. For example, a common power standard could be applied to the electric power supply of the next new aircraft program; existing configurations of environmental control systems could be upgraded to meet an improved cooling standard. Other aspects of PME standardization need cautious planning so that they do not conflict with technology growth (e.g., in aircraft configuration, environmental support techniques, and avionics component and device integration) or with possible subsequent higher levels of standardization.
- While the use of a PME standard generates its own advantages, expanding the concept from one of form, fit (F^2), and environment to one

of form, fit, function (F^3), and environment raises the likelihood of future functional standardization, which has been widely discussed but only occasionally implemented in the Air Force. The benefits achieved through the combination of box and functional standardization are synergistic: the user and the supplier enjoy continuing competition, interchangeability, maturity, and ease of modification, and also work within the framework of a well established, recognized, and accepted discipline that encourages its own use.

- PME standardization can be applied to any class of avionics as a box standard. Function standardization should probably be added only for common and mature avionics functions -- mission avionics should be considered, at best, only if they have reached an equivalent stage of maturity. In short, F^2 can be applied to most avionics; F^3 probably should be limited to common avionics and perhaps the less complex mission avionics functions. The following is a possible sequence of events:

  - An initial "strawman" PME standard could address box size, cooling interface, rack-mounting arrangements, and connector configuration; it should be adaptable to all "avionics bay" LRU applications.

  - Individual functional standardization planning could follow for mature avionics subsystems; this would lead to "strawman" standards for "form, fit, and function" specifications applicable to future Air Force procurements with standardized interwiring.

  - As digital data bus standardization becomes more widespread, standard interwiring constraints will become less burdensome and an increasing proportion of avionics LRU specifications could well be upgraded from an F^2 content to an F^3 content.

While PME standardization techniques are appropriate for all USAF aircraft, the idea of undertaking an entire avionics-system overhaul to incorporate new avionics standards in existing aircraft does not appear reasonable. However, when entirely new avionics suites are being considered for retrofit, as in the case of the B-52, F-4G, etc., there may well be merit to a wholesale incorporation of the new standards. This would need to be evaluated on an aircraft-by-aircraft basis after basic PME acquisition and installation cost factors have been ascertained. On new aircraft, the incorporation of a PME standard would be an integral part of the design process; this appears to be the most reasonable place to initiate the concept.

CHAPTER EIGHT

RECOMMENDATIONS

Commercial airlines standard avionics, existing and future, have valid applicability to USAF aircraft. We make the following recommendations for pursuing this course:

- Procedural restraints and maintenance concepts should be reevaluated and restructured to encourage the use of these equipments wherever this course is technically and economically valid; appropriate revisions should be made to MIL-Standard directives.
- Standardized approaches to solving typical integration difficulties should be developed.
- Volumetric and environmental criteria should be established to give general guidance on the applicability to high-performance space-premium aircraft.
- Ultimately, each aircraft program decision should be the result of an individual trade-off evaluation of its common-avionics needs interfaces, and cost constraints.
- While pursuing the development of its own PME standard, the USAF should undertake actions to foster greater commonality in avionics systems; these could include the sponsorship of a MIL-SPEC for the ARINC 600 low-insertion-force connector and mutual cooperation in the development of concepts for fiber optics data busses and software standards.

The following specific actions are recommended for establishing the USAF PME standard:

- Official USAF projections of new aircraft contruction and major retrofit programs should be reviewed to determine the total market size for new rack-mounted avionics in the 1985 to 1995 period. The avionics should be categorized by type of system (radar altimeter, INS, etc.), and within each category the proportion to be installed within each class of aircraft should be determined. This process will identify the 10-year equipment universe and performance drivers for the PME standard and the extent to which retrofit applications should be considered.

- An overall management approach for the implementation and enforcement of the selected standard should be developed. The approach should consider the following particulars:
  - •• The roles of AFSC and AFLC in implementation and control
  - •• The extent of participation by industry
  - •• Partial versus full-up implementation approaches
  - •• Procurement mechanisms
- The initial "strawman" standards for consideration by the USAF and industry technical community should be developed. Following the quidance provided by the PME standardization road map, two parallel but related tasks should be undertaken: an electrical and mechnical commonality analysis and development of alternate cooling concepts.
- Candidate avionics for each candidate aircraft should be surveyed to develop a baseline of potential interface parameters, develop the permissible numerical limits of each parameter, and identify the parameters that are applicable to multiple installations.
- The result of ongoing studies of cooling techniques conducted by the military and in contractually sponsored efforts (such as the Boeing B-1 cooling studies) should be examined for application to the candidate aircraft/avionics groups.
- Agenda, issues, and procedures should be established for the open-forum meetings at which the USAF PME standard will be developed. A PME standing committee should be established, with regular members from AFSC, AFLC, and using commands, to oversee the implementation of the open-forum process. Participants and their assigned functional responsibilities in the committe should be defined.
- During the open-forum meetings, there should be continuing evaluations of the cost/performance impacts of the changes suggested by the participants. The exact nature of the trade-offs are difficult to forecast, but it is likely that they will concern, at least, the following matters:
  - •• Avionics acquisition, modification/integration, and support costs
  - •• Avionics repackaging, redesign of aircraft mounting racks, etc., and environmental control systems
  - •• Reliability and maintainability
  - •• Mission capabilities

APPENDIX A

ASD/XRE GUIDANCE

Information and guidance provided by the U.S. Air Force, Directorate of Avionics Planning, in identifying avionics equipment and functions of primary interest for analysis under Task 1 is reproduced in this appendix.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: ASD/XRE

27 Jul 79

SUBJECT: Standard Packaging, Mounting, and Cooling Baseline Study - Contract No. F33657-79-C-0717

TO: ARINC Research Corp. (Mr James Russell)
2551 Riva Road
Annapolis, MD 21401

The following information is provided to assist you in Task 3.1.2 of the subject contract:

a. HF Radio-

The study should examine the possible utilization of an ARINC 559A or ARINC 719 HF radio in the B-52, KC-135, C-5, F-111, and FB-111. The radio would replace radios such as the ARC-65, ARC-58, AT-440, ARC-123, or 618T. The study should examine the ARC-XXX radio characteristics as defined by WR-ALC/MMIM. Military requirements which affect utilization of a commercial HF radio should be identified.

Attachment 1 is descriptive information for the Collins Model 728U radio which is being procured for the ARC-XXX (ARC-65 replacement). The WR-ALC specification for the ARC-XXX will be forwarded to you as soon as received by this office.

b. Radar Altimeter-

The study should examine the possible utilization of an ARINC 552A or ARINC 707 radar altimeter in the H-3, C-130, F-4 C/D/E, F/FB-111, H053, C-130 E/H, A-70, and C-141A. The altimeter would replace altimeters such as the APN-150, APN-155, APN-167, APN-171, APN-194, or AWLS. Military requirements which affect utilization of a commercial radar altimeter should be identified.

It is expected that ARINC can use in-house data gathered during the LARA/HARA specification formulation to examine the above applications. In addition, Attachments 2, 3, and 4 provide USAF comments to the ARINC LARA/HARA specifications which may be of use to you during this study.

c. Weather Radar-

The study should examine the possible utilization of an ARINC 564 or ARINC 708 radar in the C-141, KC-10, C-5, C-130, E-3A, and KC-135. The radar would replace radars such as the RDR-1FB, AVQ-30X(X), APQ-122(V)5, or APN-59(E). Military requirements which affect the utilization of a commercial radar should be identified.

Contact Mr Robert Bellflower, WRALC/MMIRCR (telephone 912-926-5091) for specification data on the APN-59(E) and RDR-IRB. Attachment 5, CEI Specification CP 681895 for Radar Set APQ-122(V)5 which is representative of the weather radar in new production C-130 aircraft is provided. Attachment 6 AVQ-30X(X) specification 1712990 covering the weather radar being used in the E-3A including recent changes is also included. Attachment 7 covers additional information on the modified Bendix RDR-1FB radar to be used in the KC-10A. This data is preliminary since this is a contractor furnished item. Specification MIL-R-5582 covering the radar beacon function of all weather radars is supplied as Attachment 8.

d. <u>Crash Data Recorder-</u>

The study should examine the possible utilization of an ARINC 500-series or ARINC 700-series flight data recorder in the C-5, C-9, VC-137, C-141, E-3A, and E-4.

e. <u>Ground Proximity Warning System-</u>

The study should examine the possible utilization of an ARINC 594 or ARINC 723 GPWS in the C-5, C-141, T-43, and VC-140.

f. <u>Air Data Computer-</u>

The study should examine the possible utilization of a commercial air data system to replace the air data computer function in the E-3A, E-4, KC-10, and C-141.

g. <u>Inertial Navigation System-</u>

The study should examine the possible utilization of an ARINC 561-11 or ARINC 704 INS in the A-10, F-16, F-111, F-4, and AMST.

We have previously supplied you with the specification for the Standard Medium Accuracy Navigation (F^3INS). This document should be useful for comparing commercial requirements to military requirements.

GERALD J. SCHOPF, Major, USAF
Project Manager
Directorate of Avionics Planning
Deputy for Development Planning

8 ATCH
1. Tech Data Sheet Collins 728U Radio
2. ASD/EN AMD Memo 14 May 79
3. ASD/RA Ltr, 21 May 79
4. ASD/EN AMD Comments
5. Texas Instruments CEI Spec
6. RCA Avionic System Rpt AVQ-30X(X)
7. Memorandum, 20 Jun 79
8. Mil Spec MIL-R-5582, 19 Nov 48

APPENDIX B

REVIEW OF MILITARY STANDARDS AND SPECIFICATIONS AND ASD/EN STUDY INPUTS

This appendix provides a summary and evaluation of the generic differences between the military and commercial standards and specifications pertinent to the USAF's use of commercial airlines standard avionics. The following documents were listed in the Statement of Work as being of primary interest:

Document	Title
MIL-B-5087	Bonding, Electrical and Lighting Protection for Aerospace Systems
MIL-E-5400	Electronic Equipment, Aircraft, General Specification for
MIL-E-6051	Electromagnetic Compatibility Requirements, Systems
MIL-I-8500	Physical Interchangeability and Replaceability of Component Parts for Aircraft
MIL-STD-188	Military Communication Standard
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-471	Maintainability Verification, Demonstration, Evaluation
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of
MIL-STD-810	Environmental Test Methods
MIL-STD-1553	Aircraft Internal Time Division Command/Response Multiplex Data Bus
RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments
ARINC Report 423	Guidance for the Design and Use of BITE
ARINC Report 416	Abbreviated Test Language for Avionics System (ATLAS)

ARINC Report 413A	Guidance for Aircraft Electrical Power Utilization and Transient Protection
ARINC Specification 600	Air Transport Avionics Equipment Interfaces
ARINC Specification 429	Digital Information Transfer System
ARINC Specification 404A	Air Transport Equipment Cases and Racking

Section 1 summarizes our review of the purpose of the referenced MIL-specifications and standards and the areas where they differ from commercial practice. Table B-1 shows the functional correspondence between military and civil requirements documents.

Table B-1. FUNCTIONAL CORRESPONDENCE BETWEEN MILITARY AND CIVIL STANDARDS

Standard	Military Specification	Civil Requirement
Electrical bonding, lightning protector	MIL-B-5087	FAA, FAR 25.581
General avionics specification	MIL-STD-454 MIL-E-5400	---
Communications Standard	MIL-STD-188	ICAO Annex 10 FCC regulations
Electromagnetic Interference	MIL-STD-461 MIL-STD-462	FAA TSOs or RTCA DO-160
Digital Data Format/Bus	MIL-STD-1553	ARINC-429 ARINC-453
Environmental Testing	MIL-STD-810	FAA TSOs or RTCS DO-160
Aircraft Electric Power	MIL-STD-704	FAA TSOs or RTCA DO-160, ARINC 413A
Form, Fit, and Function	---	ARINC 404A ARINC 600
Standard Interwiring	---	ARINC 406 (Basic, Updated by bulletin)
Maintainability/Documentation	MIL-STD-431	ATA, ATA-100

Sections 2 and 9 present comparisons between military and commercial airlines avionics standards in the following areas:

Section 2: Electromagnetic Compatibility Requirements

Section 3: Electrical Power Standards

Section 4: Environmental Requirements

Section 5: Built-in-Test (BITE) Requirements

Section 6: H.F. Radio Requirements

Section 7: Inertial Navigation System Requirements

Section 8: Weather Radar Requirements

Section 9: Automatic Flight Control System Requirements

This material was provided for this study by ASD/EN staff.

1. ARINC RESEARCH'S REVIEW OF MILITARY STANDARD DOCUMENTS REFERENCED IN THE STATEMENT OF WORK

MIL-B-5087B

Most of MIL-B-5087B is not applicable to avionics subsystems. It does require bonding of the enclosure of avionics LRUs to the airframe directly rather than through connectors as is specified in DO-160. Bonding straps to satisfy MIL-B-5087B could be added at the time of installation.

MIL-E-5400

MIL-E-5400 is the general specification for aircraft electronic equipment. It is, essentially, a compilation of the military specifications covering all aspects of designing and testing aircraft electronics. These referenced specifications cover selection of materials, methods of fastening, selection of piece parts, use of parts and materials from qualified sources, workmanship specifications, safety engineering specifications, human engineering specifications, and all the other how-to-build-it guidance normally imposed on manufacturers of military equipment. None of this is included in the airline form/fit/function equipment standards. These must be waived (or not referenced in the procurement documentation) if airlines equipment is to be purchased.

MIL-E-6051

MIL-E-6051 is an electronic capability specification that concerns overall systems; and it is concerned with the subsystem level only to the extent of specifying subsystem-level documents.

MIL-I-8500

MIL-I-8500 specifies interchangeability and replaceability of component parts of aerospace vehicles. None of the avionics equipment considered in evaluating PME standardization are included in the list of controlled items for which interchangeability is required by 3.3.1 of MIL-I-8500.

MIL-STD-188

MIL-STD-188 is the military communications standard and, among the avionics classes considered for standardization, is applicable only to the HF Radio. For this, the audio band pass, frequency range, channel spacing, and side band selection shown in Subsection 2.4.2 of this report as required for the ARC-XXX are requirements also of MIL-STD-188. No other requirements of MIL-STD-188 are in conflict with the commercial avionics considered.

MIL-STD-454

MIL-STD-454 gives standard general requirements for electronic equipment and is one of the key specifications referenced by MIL-E-5400. Remarks under MIL-E-5400 apply to MIL-STD-454.

MIL-STD-461

MIL-STD-461 establishes requirements for the electromagnetic interference characteristics of equipments. MIL-STD-462 specified methods of testing to verify these characteristics. Differences between the requirements of RTCA DO-160, the applicable commercial standard, and the joint requirements of MIL-STD-461 and MIL-STD-462 are primarily due to the greater power output of some mission equipment as compared with commercial equipment in the same frequency range. Applicability of specific types of airlines equipments designed to the less restrictive DO-160 requirements for use in a specific aircraft will have to be considered on a case-by-case basis. In general, where mission equipments do not impose additional restrictions, commercial equipments are compatible with each other and a complete suite of commercial avionics, as in the E-3, E-4A, and KC-10, does not produce EMI problems. Where mission equipments cannot be interconnected with the commercial equipments to provide blanking of receivers while interfering transmitters are radiating, EMI may be a problem.

MIL-STD-471

MIL-STD-471 covers maintainability verification, demonstration, and evaluation. It is equally applicable to either commercial or military avionics. Formal maintainability verification is not specified for commercial avionics, however, and no standard is available to be verified.

MIL-STD-704

MIL-STD-704 defines the permissible characteristics of aircraft primary power supplies and, therefore, establishes the range of primary power characteristics with which military avionics equipments must be compatible. In general, the similar commercial standard, ARINC 413A, is compatible with MIL-STD-704; differences do not preclude use of airline avionics in military aircraft.

MIL-STD-810

MIL-STD-810 specifies the environmental test methods to be used in demonstrating the conformance of a military equipment with its environmental specifications. RTCA-DO-160 accomplishes the same purpose for airlines equipment. Special thermal problems in military fighter aircraft will require improved environmental control systems in those aircraft.

In evaluating the differences in vibration requirements between military and commercial equipments, it should be understood that MIL-STD-810 test levels are believed by many to be unrealistic when compared to levels actually encountered by LRUs under operating conditions. According to this belief, the levels may be realistic when applied to the mounting surfaces in aircraft on which equipments are to be mounted. However, these surfaces are usually of non-rigid sheet metal. At frequencies where the LRU resonates, these non-rigid airframe structures do not couple the LRU to the vibration source sufficiently to transmit the energy necessary to generate the MIL-STD-810 levels. Consequently, the dwell times at resonance, as specified by MIL-STD-810, when rigidly coupled to a vibration table with relatively unlimited power capability, can cause failures which do not occur in operational use. Operational tests will be required to determine if a particular commercial LRU will operate reliably in a particular location in a particular aircraft, even though it is known that it cannot pass some part of the MIL-STD-810 vibration test. The use of suitable vibration mounts in locations known to produce high vibration stress will increase greatly the probability of such reliable operation. A case in point is the imported commercial video tape recorder used in some configurations of the F-16. It is only about two feet from the gun muzzle and failed immediately when hard mounted. Reliable operation was achieved by designing isolating mounts to suppress the 100 Hz fundamental frequency of vibration caused by gun fire.

MIL-STD-1553

MIL-STD-1553 defines a digital language, operating protocol, and interface characteristics for two-way time-division multiplex communication between a bus controller and remote terminals via a multiplex data bus. It is anticipated that this will become the USAF standard for data transfer although no operational aircraft currently are completely compatible with MIL-STD-1553. Currently, operational commercial avionics with digital inputs and/or outputs utilize a number of different digital data transfer standards. Future airlines avionics designed to ARINC 700 series characteristics will accept only digital inputs and generate only digital outputs with either ARINC 429 (for data rates up to 100 kilobits per second) or ARINC 453 (for data rates up to 1 megabit per second) data transfer specifications. All of the ARINC standards use data formats different from MIL-STD-1553. More importantly, the operating protocol and the philosophy behind it are radically different from MIL-STD-1553. MIL-STD-1553 uses a single multiplex data bus operated at 1 megabit per second under control of a bus controller to provide 2-way communication between the controller and connected remote terminals and (when so orderd by the controller) between remote terminals. Two or more controller/data bus systems may be used for redundancy or for increased capacity. All transmissions by remote terminals are in response to controller commands. Data sources connected to remote terminals must have a buffer storage to hold data (either internally or in the remote terminal) until each is polled by the controller. MIL-STD-1553A provides a 5-bit mode-control field internal to the command word may be used by a remote terminal to direct data to up to 31 connected subsystems. The code 00000 is reserved for special purpose. Any data required by more than one remote terminal must be repeated with a different address each transmission. Any message required by more than one subsystem connected to a remote terminal can be distributed by the remote terminal outside the 1553 system if the terminal is so designed and if terminal software or hardware is provided to implement this function.

It is relatively easy to provide a modified printed circuit card in avionics units not using the MIL-STD-1553 format to translate that unit's data into the 1553 format; but the ARINC standards also require a one-way dedicated data bus connecting each data source with the data sinks which utilize its data. The source transmits data, labeled to show the data function at time under its internal control without the need for buffer storage. Data storage, the ability to read and respond to bus controller commands, and the ability to strip function labels and replace them with addresses (or at least the bus controller address) must also be provided if the avionics unit is to function as a MIL-STD-1553 remote terminal. All of these functions can be provided in a MIL-STD-1553 remote terminal specifically designed to interface with one or more non-1553 avionics subsystems. This will permit avionics units using ARINC 429 or 453 (or 419 or 568 or 575 for older airline equipments) data standards to delegate to that terminal the provision of 1553 compatibility. This is the method currently employed in the F-16 to interface the ARINC 568 data standard used by the ARN-118 TACAN with the 1553A data bus.

Special remote terminals to interface airlines equipment with a MIL-STD-1553 data bus will not pose major problems for new aircraft. They would have to be provided in retrofit aircraft as additional Group A or Group B equipment.

2. <u>ASD/ENAMA Comments on Differences Between Commercial Standards and Military Standards</u>

RTCA DO-160	MIL-E-6051D
ARINC 600	MIL-B-5087B
	MIL-STD-461A
	MIL-STD-462

1. MIL-E-6051D requirements are generally not related to the type of requirements addressed in ARINC Document 600-1 and RTCA Document DO-160. MIL-E-6051D is concerned with electromagnetic compatibility of an overall system and treats items at the subsystem level only to the extent of specifying subsystem level documents.

2. The primary concern of MIL-B-5087B at the subsystem level is to obtain a good electrical bond (Class R) between the subsystem enclosure and aircraft structure. The intent of this specification is to obtain this bond across mating surfaces without the use of wiring through connectors. This is to insure that the bond will be effective at radio frequencies in addition to audio frequencies. MIL-B-5087B specifies the bond in terms of a dc resistance for simplicity of measurement. ARINC 600-1 addresses bonding between LRU's and the equipment rack in paragraph 3.3.1.2. The bond is obtained through connector contacts which are tied to the connector shells. This technique will not be effective at radio frequencies.

3. Electromagnetic interference (EMI) requirements in RTCA DO-160 appear to be patterned after an earlier military specification MIL-I-6181D which became obsolete in 1964. In general, the test techniques and test limits are different than those used in the present EMI standards, MIL-STD-461A and MIL-STD-462. The difference in test techniques make direct comparison of test limits for a particular class of testing difficult. However, through the use of a few assumptions, a comparison has been attempted. The most severe limits of DO-160 were used for comparisons. Generally, conducted and radiated emission limits appear to be similar in severity, however, the frequency ranges covered by DO-160 are more limited than MIL-STD-461A and MIL-STD-462. The conducted and radiated susceptibility requirements of MIL-STD-461A and MIL-STD-462 are in general more severe than DO-160 and are more extensive in frequency coverage. More extensive comparisons for types of testing are provided below.

a. Conducted emissions on power leads and signal leads. DO-160 requires testing from 150 kHz to 30 MHz. MIL-STD-461A/462 requires testing from 20 kHz to 50 MHz. Signal lead test techniques and limits are identical for both documents. For power leads, MIL-STD-461A/462 uses a 10 microfard capacitor to short circuit noise to ground and short circuit current is measured with a current probe. DO-160 provides two optional techniques. One technique is to use Line Impedance Stabilization Networks (LISN's) and to measure the voltages developed across the LISN's. By assuming a 50 ohm source impedance for the noise,

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the DO-160 limits are almost identical to MIL-STD-461A limits. However, for lower source impedances which may be encountered, MIL-STD-461A limits become more severe. The second technique of DO-160 is to measure conducted current with a current probe similar to MIL-STD-462 using identical limits to MIL-STD-461A. However, the 10 microfarad capacitors are not used to short circuit the interference resulting in the MIL-STD-461A limits being more severe.

b. Radiated emissions. DO-160 requires testing from 150 kHz to 1.215 GHz. MIL-STD-461A/462 requires testing from 14 kHz to 10 GHz. Correction factors for antenna to equipment spacings and for converting from antenna induced voltages to field strengths were used to allow comparison of limits. At low frequencies DO-160 is more severe while at higher frequencies MIL-STD-461A becomes more severe. Above 25 MHz, MIL-STD-461A requires both horizontal and vertical polarizations of signals to be measured while DO-160 requires only one polarization.

c. Conducted susceptibility on powerlines. For frequency sweeps, DO-160 requires testing from 10 Hz to 30 MHz. MIL-STD-461A/462 requires testing from 30 Hz to 400 MHz. MIL-STD-461 is significantly more severe across the entire frequency range for dc lines and is more severe over most of the frequency range for ac lines. For example, above 90 kHz DO-160 requires that 100 millivolts open circuit from a 50 ohm source be applied to the ac or dc powerline. This level represents 50 microwatts of maximum power applied. MIL-STD-461A requires 1.0 volts closed circuit applied from a source capable of 1.0 watt output. The difference between the two levels is 43 dB. For application of voltage transients onto powerlines, DO-160 requires 600 volts open circuit from a 50 ohm source while MIL-STD-461A requires 100 volts closed circuit for 115 volt ac lines and 56 volts closed circuit for dc lines from a 0.5 ohm source. For many cases, the MIL-STD-461A voltage would be expected to be higher than the voltage resulting when the 600 volt open circuit signal is applied to a low impedance load.

d. Radiated susceptibility. For magnetic induction fields, similar requirements exist at the 400 Hz power line frequency. DO-160 does not contain a requirement for a magnetic induction field due to a current spike similar to the MIL-STD-461A requirement. For radiated electric fields, MIL-STD-461A requirements are significantly more severe. Due to the wide variety and density of transmitters used on Air Force aircraft, this fact is considered particularly important. DO-160 covers the frequency range of 15 kHz to 1.215 GHz while MIL-STD-461A/462 covers 14 kHz to 10 GHz. The antenna input voltages specified in DO-160 were converted using several assumptions to equivalent field strengths at the tested equipment. DO-160 levels are on the order of 0.15 volts/meter while MIL-STD-461A requirements are 10 and 5 volts/meter.

e. MIL-STD-461A covers extensively transmitter and receiver characteristics at antenna ports for spurious outputs, front end

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rejection, intermodulation, cross-modulation, and squelch operation. DO-160 does not address these areas.

4. In summary, bonding provisions between LRU's and equipment racks may be inadequate. Due to significant differences between DO-160 and MIL-STD-461A/462 requirements, items qualified to DO-160 cannot be considered to be qualified to MIL-STD-461A/462. Retesting to MIL-STD-461A/462 would be required for general usage subsystems to avoid risks of electromagnetic compatibility problems. For subsystems intended for a particular aircraft and installation location, portions of the DO-160 testing may be accepted (particularly emission testing) on an individual equipment basis after aircraft receiving and transmitting equipment has been reviewed. However, some retesting would almost certainly be required.

3. ASD/ENACD Comparison of MIL-STD-704 with ARINC Report 413A

1. Although ARINC Report 413A and MIL-STD-704 are concerned with the same subject, aircraft electric power, they are very different in character. MIL-STD-704 is a "standard" which defines precise limits for aircraft power characteristics. This document is widely used in commercial aviation as well as by the military. ARINC Report 413A, on the other hand, is a "report" which more or less philosophically surveys the field of aircraft electric power and provides guidance to equipment and aircraft manufacturers. The Report does not levy firm requirements.

2. The two documents are basically compatible. Paragraph 1.3.2 of the Report states: "It is the intent of this document to provide coordinated industry interpretations of the existing requirements of MIL-STD-704B as they apply to airline equipment and to update these requirements with additional supplementary guidance." MIL-STD-704 (original issue), MIL-STD-704A, and MIL-STD-704B are included in Report 413A as attachments and appendices.

3. Report 413A goes beyond the scope of MIL-STD-704 by giving guidance in equipment design with regard to personnel protection, component protection, smoke prevention, and reverse polarity protection. The Report also addresses electromagnetic compatibility areas which are covered by MIL-E-6051 rather than by MIL-STD-704.

4. Since Report 413A was published, MIL-STD-704C was issued in December 1977. Furthermore, MIL-STD-704D is now being coordinated among the military services. These recent changes to MIL-STD-704 do not significantly affect its relationship with commercial practice, with one possible exception. The voltage spike susceptibility requirement against equipment which was in MIL-STD-704B has been removed from the C and D revisions. This was done to eliminate duplication with a similar requirement of MIL-STD-461. Industry members of the aircraft electric power community have vigorously opposed this action and will undoubtedly insist that the spike requirement of MIL-STD-704B be retained for their commercial equipment. This would have no detrimental effect on the compatibility of commercial equipment in military aircraft, however.

4. ASD/ENEC Comparison of Environmental Requirements

RTCA-DO-160	MIL-STD-810 MIL-STD-454 MIL-E-5400

1. INTRODUCTION

The ASD/XRE ltr. (26 July 79) included a request to compare the environmental requirements of DO-160, MIL-STD-810, MIL-STD-454, and MIL-E-5400 with regard to two viewpoints, i.e.,

a. Address the significant differences in commercial and military requirements, which may prevent DO-160 qualified equipment from being used in Air Force aircraft.

b. Can these significant differences be eliminated, by applying available technology to control the avionics environments in Air Force aircraft?

2. RELATED ISSUES

The following general comments are provided to place this response in perspective with numerous related issues:

a. Due to the short time for response, this review is very cursory in nature. Thus, it is difficult, if not impossible, to determine what are "significant" differences.

b. DO-160 and MIL-STD-810 are test documents, while MIL-STD-454 and MIL-E-5400 are design documents. MIL-E-5400 references the test procedures of MIL-STD-810 for Air Force electronics, and MIL-T-5422 for Navy electronics. The environmental design requirements in MIL-STD-454 and MIL-E-5400 are sufficiently nebulous to allow a broad range of environmental design approaches for avionics equipments, which makes the testing documents the driving design factor, for military applications. The testing requirements of MIL-E-5400 (MIL-T-5422) are essentially the same as the requirements of MIL-STD-810. Normally, when significant differences exist, the acquisition engineer, in the Program Office, selects the better of the two requirements.

c. Based on the above conditions, this review will be limited to comparing DO-160 and MIL-STD-810 requirements. MIL-STD-810C and DO-160 (14 May 79) were used for this review.

d. The test requirements in MIL-STD-810 are generally more extensive, and more detailed, than the requirements in DO-160, which is caused by their different purposes in the overall scheme of "doing business", i.e.,

(1) The commercial airlines do not need to place heavy reliance on testing for successful field operation, since they: (a) Develop competitive designs for the same avionics function, (b) Have the financial capability of rapidly addressing and correcting field problems, and (c) Have the economic leverage of buying a competitors product, when specific equipments become an economic burden.

By comparison, the military procedures heavily emphasize MIL-STD-810 tests as the environmental success criteria for satisfactory operation in the field environments.

From this viewpoint, the purpose for testing is significantly different, when viewed from the commercial airline, and the military, way of "doing business". This difference is reflected in the fact that the

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DO-160 requirements are generally just a check of equipment performance at the environmental design limits, whereas the MIL-STD-810 requirements emphasize an environmental endurance level which is equivalent to a long-term, successful operation.

(2) DO-160 is limited to avionics, while MIL-STD-810 includes requirements for all DOD equipments. In addition, the airline avionics equirements generally apply to a specif c type of aircraft and a specific operational pattern, while MIL-STD-810 covers all types of aircraft, flying different types of operational missions. Also, the most severe airline avionics environments are relatively benign, compared to the environments associated with the large majority of Air Force avionics installations.

e. The DO-160 requirements are further tailored to specific types of avionics by the use of a "Minimum Performance Standard", which is developed for each type of avionics. It is assumed that the standard is then referenced in the avionics specification.

By comparison, the MIL-STD-810 procedures are directly referenced in the avionics specification (with some tailoring by individuals, but without the group decision tailoring, as reflected in the "Minimum Performance Standard").

f. In the way that both the commercial airlines and the military do business, the real acceptability for environmental requirement rests with the procuring activities which have diverse opinions on the same issue. In addition, the environmental requirements, which are applied to contracts, are the responsibility of the procuring activity. DO-160 and MIL-STD-810 are only general guidelines. As a consequence, it is difficult to identify how MIL-STD-810 is used, for a large spectrum of avionics procurements, or to identify general acceptability levels for the results of this study.

g. With regard to avionics, the large majority of MIL-STD-810 test failures occur in the temperature-altitude, humidity, and random vibration tests.

h. MIL-STD-810 is in the process of being revised. In some instances, MIL-STD-810 misses the critical failure environments for fighter aircraft avionics, e.g.,

(1) Thermal fatigue of internally forced air cooled avionics, caused by oscillations in the cooling capacity (especially prevelent during ground operations).

(2) Corrosion of cockpit equipment caused by the combination of solar radiation and electrolytic rain.

(3) Thermal environments associated with the ground cooling system, during flight-line maintenance.

3. AVIONICS ENVIRONMENTAL TESTS

A comparison of the DO-160 and the MIL-STD-810 test environments is given in Table 1.

4. TEMPERATURE & ALTITUDE

DO-160 is essentially limited to an avionics performance check at the temperature extremes. The altitude tests are conducted separately, to simulate the effects of emergency decompression, and the effects of temporary over-pressurization by the aircraft environmental control system (ECS).

MIL-STD-810 includes a combined temperature-altitude test (which is applied

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TABLE 1. AVIONICS ENVIRONMENTAL TESTS	
DO-160	MIL-STD-810
Temperature	Temperature - Altitude
Temperature Variation	-----
Humidity	Humidity
Shock	Shock
Vibration	Vibration
Explosion (C)	Explosion (CL)
Drip Proofness (C)	Rain (CL)
Fluids Suscept (C)	-----
Sand & Dust (C)	Dust (CL)
Fungus (C)	Fungus (CM)
Salt Spray (C)	Salt Fog
	Solar Radiation (CL)
	Acceleration
	Acoustical Noise (CL)
	Temp-Humid.-Alt. (A)
	Gunfire Vibration (CL)

Conditional Application
CL-Conditional/location
CM-Conditional/materials
A-Alternate
C-Conditional

universally to avionics), with the following unique features:

a. Temperature and altitude effects are combined which affects the heat-transfer from the avionics.

b. Operational altitudes are included which affects seals, equipment "breathing" phenomena, arcing of high-powered avionics, etc.

c. Avionics operational checks are included at various temperature-altitude combinations, which cover the normal flight envelope.

d. Short-time, high-temperature, altitude conditions are included to represent fighter aircraft high-speed dash conditions, when the ECS performance is degraded, and aerodynamic heating becomes a significant thermal factor.

e. Avionics operational checks for intermittant failures are included, when the altitude is changing.

f. Avionics operational checks are included, for the frost-thaw-frost condition.

g. The test times, at the test points, are much longer than the times in DO-160.

A comparison of the differences between DO-160, and MIL-STD-810 is illustrated in Figure 1, where the DO-160, category E1 equipment (no temperature or pressure control, and operational to 70,000 ft) is compared to the MIL-STD-810, Category 6 equipment (up to 70,000 ft), which is typical for fighter aircraft avionics.

Considering all the differences between military and commercial avionics, which are alluded to in para. 2 above, the differences between DO-160 and MIL-STD-810 are generally considered significant. The combinations of temperature and altitude are important, and DO-160 does not address these combinations.

At sea level conditions, the MIL-STD-810 temperature requirements may be reduced to the requirements of DO-160, although the test-times of MIL-STD-810

(continued)

Note: MIL-STD-810: Satisfactory operation req., when equipment "on"
DO-160: Performance check req., when equipment "on"

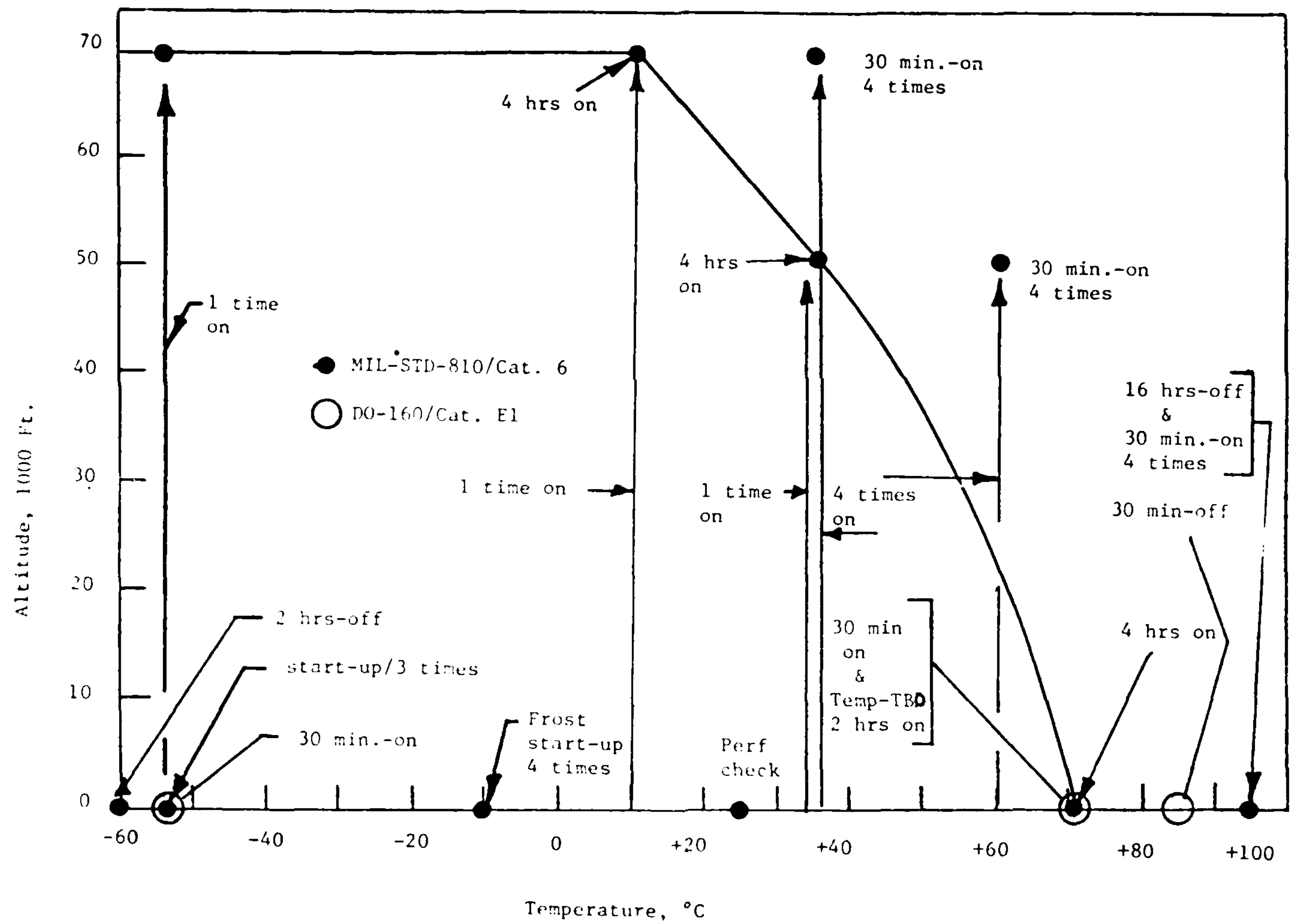

Figure 1. Comparison of Temperature - Altitude Test Requirements (continued)

should be maintained (with the exception of time spent at 95°C).

Closer evaluation of the MIL-STD-810 temperature altitude test points may increase or decrease the temperature values, as related to avionics testing. Future Air Force emphasis, on avionics environmental control, may also reduce the temperature test points at the various altitudes, but the altitude requirement will not be eliminated.

In a related issue, MIL-STD-810 is being revised to where the fixed set of temperature-altitude test points are being replaced by a variable set, depending on aircraft application. This type of tailoring has generally been done in the past, anyway, by the acquisition/contractor engineers associated with specific Programs.

A more serious limitation of DO-160 qualified equipment for military aircraft, is the thermal fatigue condition associated with internally forced air cooled equipments in fighter aircraft. This condition will be simulated in the revised MIL-STD-810. Normally, there would be no reason for DO-160 to have a thermal fatigue test, since there are minimal excursions in the cooling capacity of the cooling air in commercial airline, environmental control systems. Fighter aircraft ECS, though, have significant excursions in cooling capacity, during ground operations, and during changes in altitude. Various sources of information indicate that thermal fatigue is a more prevelant source of avionics failures, than exposure to constant temperatures. Another solution to this problem, though, is for the Air Force to emphasize the use of a fighter aircraft ECS which essentially provides constant cooling to the avionics during ground and flight conditions.

Another serious limitation, for internally forced air cooled avionics, is the differences in commercial and military cooling air capacities. These differences are not specifically addressed in DO-160 or MIL-STD-810, but the cooling air is included by reference in the test set-up procedures. The practical effect is that commercial airline avionics will be receiving 5-8 pounds/minute/KW at 30-70°C, while the military equipment will be receiving 2 pounds/minute//KW at 30-70°C, when the units are undergoing DO-160 and MIL-STD-810 tests. This effect is more serious than the differences in chamber temperatures, since the component temperatures are primarily controlled by the cooling air parameters.

Future Air Force emphasis on avionics environmental control may reduce the commercial-military differences in cooling air, or the significance of these differences may be limited to aircraft ground operations, which may be handled by modifications to the engine bleed air system for ground operations.

5. HUMIDITY

The primary DO-160 test requirement, for airline avionics, is Category A. Since this test is limited to an avionics performance check after two, twenty-four hour cycles, using a reduced temperature limit, it is considered unacceptable for Air Force applications.

On the other hand, DO-160, Category B test requirements are essentially the same as MIL-STD-810, Procedure I requirements with slight differences in the approach to checking equipment performance at the end of the test.

(continued)

There should be minimal problems with using DO-160 (Category B) requirements for Air Force applications.

In a related issue, the Humidity tests are questionable in terms of not having alternating dry and wet cycles, and in terms of not having electrolytic moisture (present tests use pure water).

6. VIBRATION

Vibration is sufficiently complicated to prevent any typical comments, since it is dependent on so many local aircraft conditions, which are generally not definable prior to the final development phase for aircraft development programs. To complicate the issue, there exists an infinite number of choices of spectra, levels, and time histories, which are dependant upon a specific installation in a specific aircraft.

Even so, there is a need to initiate some thought on the general boundaries of vibration requirements so that the use of DO-160 for Air Force equipment applications may be evaluated.

From this viewpoint, a comparison is made of the DO-160 vibration requirements and the requirements of MIL-STD-810 (as interpreted by the author).

a. General Comments. To boil-down the many choices of Vibration procedures and levels in DO-160 and MIL-STD-810, this review will cover only avionics in jet aircraft, which covers the large majority of Air Force avionics applications. In addition, this review will cover only the avionics located in the foward and center fuselage, and in the cockpit, which covers the large majority of avionics installations which may be feasible for commercial avionics.

DO-160 allows either sinusoidal or random vibration tests for avionics equipments. Avionics equipments, qualified to sinusoidal vibration tests, are considered unacceptable for Air Force applications.

MIL-STD-810 requires both a vibration Performance test level, and a vibration Endurance test level, to be applied to each equipment, in all three axes. DO-160 is written in such a manner that it requires a vibration Performance level to be conducted, in all three axes, but the vibration "Robustness" (Endurance) level (which is the "severe" vibration level) may be eliminated, according to how the avionics specification is written. Avionics equipments, qualified without the "Robustness" tests, for all three axes, are considered unacceptable for Air Force applications (Note: The actual vibration levels are not as important as the need to run some type of vibration endurance test). Gunfire vibrations are not considered important, since avionics can generally be placed outside of the gunfire vibration affected regions of most Air Force aircraft.

The following review covers a comparison of vibration levels for different classes of aircraft.

b. High-Performance Aircraft. The aircraft categories in this group include fighter, fighter-bomber, and bomber aircraft. This review is very general, of necessity, since there are always exceptions to the rule, especially in the vibration area.

A general comparison of DO-160 and MIL-STD-810 vibration level requirements, at the Performance level of vibration, is illustrated in Figure 2.

The major difference in vibration levels is in the cockpit area, where commercial airline cockpit vibration levels are far below the high-performance aircraft cockpit levels.

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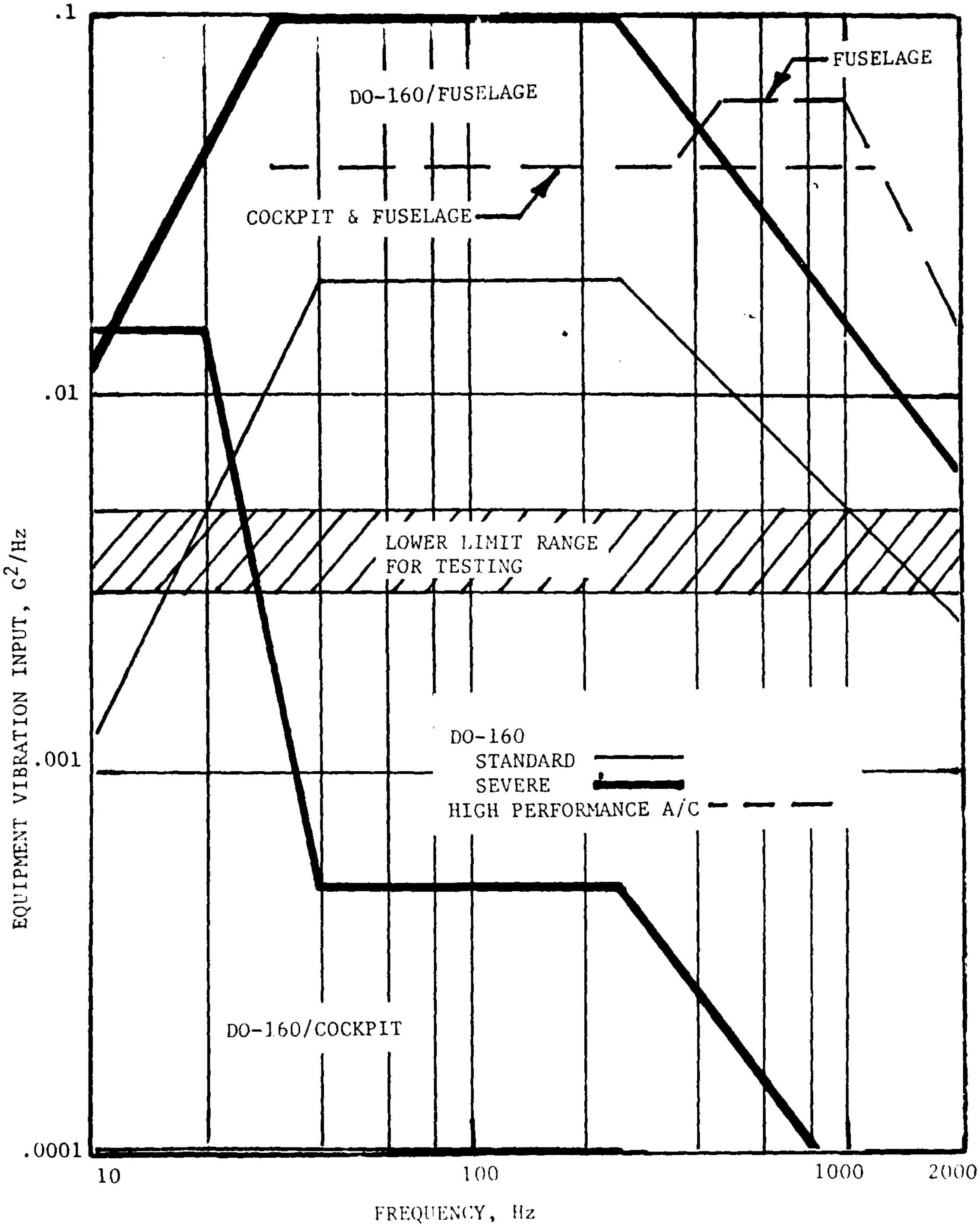

FIGURE 2. COMPARISON OF PERFORMANCE VIBRATION SPECTRA REQUIREMENTS

In terms of fuselage locations, the DO-160, "Standard" vibration spectrum is below the typical spectrum for high-performance aircraft, and it does not address the high-frequency content, in the 600-1000 Hz region (which is expected, since commercial airlines do not have to worry about aerodynamic pressure fluctuations, as a dominant source of vibration). While the "Severe" vibration spectrum is significantly above the typical spectrum for high-performance aircraft, in the lower frequency range, it also misses the high frequency content.

In terms of comparing vibration Endurance (Robustness) test levels, the spectrum for high-performance aircraft, could be moved up until the high plateau region (Fuselage) reaches 0.1 G^2/Hz. The DO-160 "Robustness" levels are the levels for the "Severe" vibration category.

As a consequence of the above, the DO-160 random vibration requirements need to be modified, in some fashion, to be readily applicable to Air Force avionics vibration requirements, for high-performance aircraft.

In terms of related issues, the 0.04 G^2/Hz level is generally established as a lower vibration test limit for high-performance aircraft equipment, to cover efficient production quality assurance vibration levels, and to cover transportation vibration levels. Also, a lower vibration range for testing is given, from a practical viewpoint, since vibration ceases to be a problem, when the levels are sufficiently low. An alternative to no testing at all, would be a minimal Performance level check.

In addition, MIL-STD-810 vibration test are being revised to replace discrete sets of vibration spectra with blanks, to be filled in as the specific avionics/aircraft application becomes known. A related handbook will be proveded, giving the user some rationale for deriving test levels.

c. Medium Size Cargo & Transport Aircraft. These requirements may be the same as the "high-performance aircraft" requirements, or slightly less.

d. Large Cargo & Transport Aircraft. These requirements may be the same as the DO-160 requirements with the following conditions:

(1) If supersonic, use "high-performance aircraft" requirements.

(2) Below the vibration level range of 0.004-0.006 G^2/Hz, the vibration test is considered inefficient anyway, so the difference between sinusoidal and random is inconsequential. Even so, if tests are required, try to use random vibration.

SALT SPRAY TEST

DO-160 includes Category X, which means that the salt-spray test is not required, and Category S, which is essentially the same as MIL-STD-810.

No hard statement can be made about the salt-spray test, since:

a. The test generally causes relatively few and minor failures.

b. The test is questionable in terms of lacking moisture - solar radiation-moisture cycles, which are typical of aircraft operations.

c. The test should be primarily limited to exposed equipment (e.g., fighter aircraft cockpit equipment).

8. ALL OTHER ENVIRONMENTAL TESTS

The remaining environmental test of Table I are generally inconsequential. The acceleration test should be limited to avionics with moving mechanisms.

The shock test normally does not generate avionics failures, and the input effects may well be covered by the random vibration tests.

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The fungus test is usually accomplished by similarity-by-analysis (i.e., equipment materials do not support fungus growth).

The explosion test is limited to areas with explosive atmospheres (e.g., engine compartments rather than avionics bays).

The solar radiation test should be limited to exposed avionics (e.g., fighter a_rcraft cockpit equipments), although it seldom causes failures by itself.

The acoustical noise tests should be limited avionics located in high noise areas (Overall level greater than 140 dB re. 0.0002 dynes/cm^2), although this condition seldom occurs in Air Force aircraft aivonics bays, which generally . sults in acoustic tests with no equipment failures.

The Drip-Proofness test and the Spray-Proofness tests in DO-160 are optional. The comparable Rain test in MIL-STD-810 is questionable since electrolytic water is not used (pure water is used instead), and since the operational sequence of electrolytic rain-solar radiation-electrolytic rain is not simulated. This condition is of primary concern for fighter aircraft, cockpit equipment. It will be included in the revised MIL-STD-810.

5. ASD/ENES Comparison of Military and Commercial Standards for Failure Warning and Built-in Test Equipment (BITE)

1. The standard requirements and guidance for commercial on-aircraft avionics test capability are included in the following ARINC documents:

a. ARINC Report 415, Failure Warning, addresses the system which alerts the flight crew of conditions which affect safety or performance of the flight mission.

b. ARINC Report 423, Built in Test Equipment (BITE) addresses the system which assists the maintenance personnel in performing the appropriate maintenance action in the event of a failure.

c. ARINC characteristics 563 and 573, Aircraft Integrated Data System (AIDS), addresses the system which acquires and records data from the whole aircraft (and fleet) to be used for maintenance, administrative, and crash history purposes.

The Air Force has requirements for each of these types of on-aircraft systems, and often has additional requirements.

a. MIL-STD-411 and MIL-STD-1472 apply to the type of test addressed by ARINC Report 415.

b. There is no Air Force standard for AIDS type aircraft level test.

c. Built-in-test features for Air Force aircraft have not been standardized. MIL-STD-415D and MIL-STD-1591 address the process of determining the BIT capability required for new electronic systems. However, they do not specify BIT performance or features, nor does ARINC Report 423.

2. There is currently much activity in the Air Force and other military services to improve BIT performance and the process of acquiring BIT. Better standards, specifications, handbooks, figures of merit, and verification techniques are sure to result from this activity. Documents of current interest include:

a. Acquisition Planning Guide for System Fault Detection/Isolation Capability, July 1978, Rome Air Development Center (RADC).

b. BIT Design Guide, September 1976, and undated draft revision, NAVMATINST 3960.9A.

c. A Design Guide for Built-in-Test (BIT), April 1979, RADC-TR-78-224.

d. BIT/SIT Improvement Project (Phase I) report, soon to be released, ASD-TR-79-XX.

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3. There are several levels of integration at which self-test performance could be specified.

a. Fault detection/isolation capabilities can be specified to be resident in each shop replaceable unit (SRU) to detect and isolate to a replaceable component, although this test function usually resides in depot test equipment. Test point specifications then apply.

b. Self-test capabilities can be specified to be resident within each line replaceable unit (LRU) to detect and isolate faulty SRUs, although this test function is usually found in intermediate shop test equipment.

c. Most often found in Air Force avionics is the capability of a subsystem to detect a failure and isolate to an LRU. Sometimes each LRU detects its own failures independently from other LRUs in the subsystem. This is the level of integration addressed by ARINC Report 423.

d. In some complex avionics systems, a system integrated test (SIT) subsystem performs the fault detection/isolation function, and the self-test capabilities are specified at the system level.

e. The last option is to record data on-aircraft for later use in fault detection/isolation (and other uses). This is the approach taken by ARINC characteristics 563 and 573.

4. ARINC Report 423 is a statement of philosophy and some recommendations concerning the design of BITE. On the whole, it is consistent with the Air Force environment, but several exceptions should be noted. The following comments pertain to various paragraphs from this report.

a. Para 1.2 - The document only addresses fault isolation to an LRU and verification of proper operation after maintenance. The Air Force looks at a larger test requirement.

b. Para 1.6, 4.2 - Apparent performance cannot be used as the criteria for need of maintenance action in a system which includes, for reliability or safety reasons, automatically controlled redundancy, or "fault tolerance". In these systems, performance would be satisfactory until all capability is lost, and hence, no maintenance would be performed until then. (See para 7.7).

c. Para 2.8 - With a high level of system integration, especially with processing and display of information, it is often difficult to determine which subsystem is malfunctioning. Therefore, a level of BITE integration at a level higher than the LRU is often justified.

d. Para 4.4.6 - A trade-off study is usually performed to determine whether BITE or support equipment (SE) is more cost effective. Some Air Force aircraft are deployed from a very limited number of bases,

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and often the weight/power costs of BITE are large, especially in small, high performance aircraft or RPVs.

e. Para 5.8 - A standardized output to a higher level test system is a worthwhile feature, but the AIDS interface is not standard with the Air Force. More likely, the MIL-STD-1553 interface bus will be the medium and a software algorithm will be the BIT standard interface. (See also para 7.9).

f. Para 7.2.c)2) - The Air Force does not yet have a standard set of parameters to specify performance of BIT. Due to the differences in the maintenance concepts and data collection techniques, the particular figure of merit cited in this paragraph would probably not be useful to the Air Force.

g. Para 7.12.2 - Sometimes it is necessary to BITE the BITE. On of the ways to increase confidence in BITE (Para 2.9.1) is a test of the test. The logical design of some self-test, typical for computers, is to test some few elementary circuits and logic, and then use them to test more sophisticated circuits and logic, and so on. Self test of an AIDS type system is appropriate.

h. Para 9.3 - The Air Force requires a more comprehensive definition of BITE effectiveness than this one, which only addresses false alarms and isolation accuracy.

i. These comments should not be interpreted as criticisms of ARINC Report 423. This report is well written, appropriate for commercial aircraft, and meets a real need there. Also, most of what it has to say is appropriate for Air Force systems.

5. The Integrated Digital Avionics (IDA) program is developing and validating a set of standards for defining compatible common, supportable avionics and one area to be addressed by IDA is testability. Interface specifications for system level fault detection/isolation will most likely be created as well as standards for internal self-test capabilities and interfaces with support equipment. The IDA standardization effort and this commercial standards effort will surely affect the traditional process of determining new test requirements for each new avionics system, but the magnitude of this impact is difficult to predict at this time.

6. ASD/ENACB Comparison Between ARINC-559A and Military H.F. Radio Specification (ARC-XXX)

1. This report is in response to your request for a comparison between ARINC-559A and military HF radio equipment. The comparison has been divided into two categories: the physical interface parameters of the radios, and the operational parameters of the radios. Only the more significant parameters are considered in this review. The comparison will be between ARINC characteristic 559A and the ARC-XXX HF replacement radio specification. In addition to this comparison, actual equipment items built to these specifications will be discussed: the Collins 728U-2 was built in accordance with the ARC-XXX specification, and the Collins 628T-1 follows the ARINC-559A characteristic. Information about the 628T-1 was obtained from a preliminary brochure text.

2. Physical Interface Parameters.

a. Weight: The ARC-XXX requirement is 50 lbs. or less. (The 728U-2 weighs 48.51 lbs. including R/T unit and control box.) ARINC-559A assumes a weight in the range of 20 to 30 lbs. The 628T-1 weighs 26 lbs. excluding the control box.

b. Size: The ARC-XXX specification gives maximum dimensions of 11.2" w x 20" d x 8.6" h. The actual dimensions of the 728U-2 are 10.12" w x 18.9" d x 7.62" h. ARINC-559A specifies a 3/4 ATR short case, (7.5" w x 12.5625" d x 7.625" h). The ARINC radio is sufficiently smaller so that there should be little problem with retrofit as far as space is concerned.

c. Size (control panel): The Collins remote control for the 728U-2 measures 4.5" d x 5.75" w x 2.62" h. The ARINC dimensions are 3.5" d x 5.75" w x 2.625" h. Again, there should be little problem as far as space is concerned.

d. Power: Both the ARC-XXX and the ARINC-559A radio use 115 volt, 400 Hz, three-phase power.

e. Cooling: The 728U-2 has a mount with a blower for installations where no central cooling air system is used. The ARINC-559A design should comply with ARINC-404A type "A" flow-through cooling, however, a blower should be included for cooling in certain retrofit installations where no cooling air is provided.

f. Audio Output: The 728U-2 military radio has an audio output of 150 mW with an impedance of 150 ohms. The 628T-1 ARINC radio has an audio output of 200 mW into 600 ohms with a source impedance of less than 300 ohms. There should be no problem with driving the military interphone system with the ARINC radios.

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g. Audio Input: The audio input circuit impedance is 150 ohms in the ARC-XXX radio. With an audio input from the interphone system of 4 volts peak to peak, the voice processing within the radio will pass an audio signal with a peak to average ratio of 12 db. For ARINC radios the input impedance is also 150 ohms and the input levels are in accordance with ARINC-412.

h. Wiring: The ARC-XXX is configured to replace the old ARC-65 radio and, therefore, does not have a standard ARINC form factor. Some changes in "Group A" would be required to retrofit an ARINC radio in an ARC-XXX installation. However, many military aircraft use the Collins 618T transceiver which is an ARINC-533A characteristic radio. In these aircraft the newer ARINC-559A radios could be installed with the use of an adapter rack with little or no change in aircraft wiring.

3. Operational Parameters.

a. Frequency Range: Military HF radios have a frequency range of 2 to 30 MHz. ARINC-559A requires a frequency range of 2.8 to 24.0 MHz (the Collins 628T-1 has a range of 2.8 to 26.999 MHz).

b. Frequency Channeling Increments: Military radios use 0.1 KHz increments whereas commercial HF radios use 1.0 KHz increments.

c. Channels: The two previous specifications combine to give military radios 280,000 channels whereas the commercial radios are required to have only 21,200 channels (the 628T-2 has 24,200 channels).

d. RF Power Output: The ARC-XXX radio is required to have 400 watts PEP (Peak Envelope Power) or 400 watts average power. ARINC-559A is asking for 400 watts PEP, but 200 watts PEP will be allowed as a temporary expedient to accommodate solid state transmitters. The 628T-1 is a 200 watt PEP radio; however, it uses speech processing which boosts the radio's "talk power" to that of a 400 watt PEP radio without speech processing.

e. Modes: The ARC-XXX will operate in upper sideband (USB), lower sideband (LSB), amplitude modulation equivalent (AME), cw (continuous wave), and DATA. ARINC-559A radios will operate USB, AME, and DATA. The most significant difference is the lack of LSB mode in ARINC radios.

f. Secure Voice: The ARC-XXX is required to operate with secure voice equipment. The ARINC radios have no such requirement. A bandwidth of at least 300 to 2700 Hz is required for secure voice operation. ARINC radios have a bandwidth of 350 to 2500 Hz. This narrower response may degrade the intelligibility in secure mode. The amount of degredation would have to be determined by testing.

4. In summary, this comparison indicates that in most cases a change in "Group A" equipment would be all that is needed to install an ARINC type radio. In some cases, only an adapter rack will be required.

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However, the operational differences between the two types of radios pose a more serious problem. The lower performance of the ARINC radios in frequency range, frequency channeling increments, RF power output, and modes of operation may not be accepted by military users. Furthermore, there is an increasing concern about nuclear hardening (a requirement for the ARC-XXX) that is not dealt with in commercial radios. The ARINC radios could be modified or specially designed to incorporate all or most of the features presently used by the military. However, a common military/commercial radio is not very foreseeable because commercial users are not willing to pay the extra price for features that they neither need nor want in their HF system.

7. ACD/ENACA Comparison Between Military and Commercial Standard Inertial Systems

ARINC-561-11 (INS) ENAC 77-1 (INS)
ARINC-704 (IRU)*

1. This comparison of ARINC characteristics 561-11 and 704 with the F^3 INS specified in ENAC 77-1 will stress the packaging, mounting and cooling consideration refered to in the tasking for this study however other aspects will be covered. It should be noted that while both ARINC and the ENAC documents define inertial system standardization, ENAC 77-1 covers applications in a wide variety of aircraft and roles; the ARINC characteristics are specifically designed for installation in the rather beneign environment of commercial transport aircraft. The ARINC 561-11 defines an Inertial Navigation System (INS) Navigation Unit, ENAC 77-1 defines a similar INS Inertial Navigation Unit and the ARINC 704 defines an Inertial Reference Unit (IRU) which requires an external computer to be considered equivalent to the ARINC 561-11 and ENAC 77-1 units.

PACKAGING

2. ARINC 704. Specific dimensional requirements of the IRU are fully detailed in ARINC Specification 600. Except for cooling openings and front hold down locations, the unit should comply with the basic standards established in ARINC 600 for the 10 MCU form factor. The location of the cooling openings and front holddowns should be for an 8 MCU rather than a 10 MCU form factor. The IRU has specified dimensions of:

a. length 12.48" to 12.56" (Ref);

b. height 7.60" to 7.64" (Ref); and

c. width 12.69" ± 0.02"

3. This IRU has a volume of approximately 1210 in^3 and approximates a 3/4 Short size box in length and height but exceeds the specified width (it should be 7.50").

4. ARINC 561-11. The commercial inertial navigation unit should comply with the basic standards established in ARINC specifications 404 for the 1 ATR Long size. This navigation unit has the following specified dimensions:

a. length 19.61";

b. height 10.625"(MAX); and

c. width 10.125" ± 0.03125"

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*ARINC-704 Inertial Reference Unit provides all of the basic INS functions. ARINC-702 Flight Management Computer adds sophisticated waypoint navigation.

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5. The Navigation Unit has a volume of 2110 in^3 and violates the 1 ATR Long box size in the height dimension (it should be 7.62") for equipment reasons.

6. F^3 INS (ENAC 77-1). The packaging of the INU for the F^3 INS is defined by the attached drawings. This unit has the following dimensions:

a. length 15.187" (plus 1.41" MAX optional front for connectors and handles and 1.50 MAX for optional doghouse in the back);

b. height 7.625 MAX; and

c. width 7.531" MAX (plus 0.18" optional on both sides).

7. The INU has a volume of approximately 1040 in^3 and fits a 3/4 ATR Short box size in height and width but exceeds the length specification (it should be 12.62").

8. Thus while none of three units under comparison exactly measure to ATR specifications, they approximate a 3/4 ATR Short size for the INU of the F^3 INS and the ARINC IRU and 1 ATR Long for the ARINC Navigation Unit. It is not entirely realistic to include the IRU in this comparison since it does not have the capabilities of the other two units. The point to be made here is that the INU of the F^3 INS which does more than the ARINC 561-11 Navigation Unit, does it in a package of almost half the volume.

MOUNTING

9. ARINC 704. The IRU should use ARINC form factors defined in this specification for the mounting tray. The tray's dimensions are: 12.45" to 12.40" long (outside); 7.64" max height and while overall width is not specified, the two rear mounting pins are 8.158" apart. There are three mounting pins: two on the back; one round, the other diamond shaped and a forward round pin on the tray's center line. The IRU must be capable of proper orientation when it is mounted with its longitudal dimension parallel to the direction of flight. It is normally mounted facing aft (i.e. to be removed it is pulled toward the rear of the aircraft) and if it is mounted facing forward interwiring changes involving program pins must be incorporated. Mounting tolerances (with reference to the principle aircraft axes are ±12 arc minutes in pitch roll and azimuth.

10. ARINC 561-11. The Navigation Unit Tray is similar to the ARINC 704 specification. It has an optional height requirement but is specified as 19.469" ± 0.031" long (inside) and 10.156" (minimum) wide. While the arrangement of round and diamond pins are the same, the pins on the Navigation Unit are slightly larger than the IRU tray (0.3110" OD on the ARINC 561-11 tray; 0.3075" on the ARINC 704 tray). The same restrictions on mounting the Navigation Unit longitudal dimension parallel to

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the direction of flight, facing aft apply as do interwiring changes if it is mounted facing forward. Mounting tolerances are dependent on subsonic and supersonic aircraft and relative to the aircraft or other INSs on the aircraft. Relative to the aircraft, pitch, roll and azimuth accuracy is ± 12 arc minutes on subsonic aircraft and ± 6 arc minutes for pitch and roll and ± 12 arc minutes for azimuth on SST aircraft. Relative to other INSs, pitch and roll accuracies are ± 6 arc minutes and ± 12 arc minutes for azimuth regardless of aircraft type.

11. ENAC 77-1. This specification specifies the mounting rack as reference only. These drawings are attached. It is specified to be 15.00" max long (outside) not including the air inlet, 4.90" high and 7.90" max wide. There are also three mounting pins; 2 diamond pins and one round however the front pin is a diamond pin and is off the center line of the tray. Pin sizes are 0.3097" OD which puts them between the sizes of the previous two units. Fore and aft installation is possible by simply setting the appropriate pin on the power (J132) plug. The ENAC 77-1 document does not specify aircraft to mount tolerances.

12. The three specifications have no apparent physical similarity; no dimension is the same and pin size and locations vary. The ENAC specification makes installation facing forward or aft easier than ARINC characteristics. There is no provision for any unit to be mounted sideways in any aircraft. Of interest is the omission of any tolerances in the mounting of the Navigation Unit to the rack. The ARINC characteristic clearly state there are absolutely no mounting accuracy requirements while the ENAC specification states that mechanical boresighting of sensors will not be required after LRU replacement and that the INU mount shall provide for interchangeable installation of INUs without adjustment to retain INU boresight.

COOLING

13. ARINC 704. This characteristic states that all cooling, thermal design and appraisal should be in accordance with ARINC 600 level 2. The airflow rate provided to the IRU should be that required to cool 200 watts minimum of internal power dissapation (para 3.5.4.3 of ARINC 600). This will require 44 Kg/HR (1.6 lb/min) of 40 degree C inlet air cooling at the Thermal Design Condition of ARINC 600 Section 3.5.1.6. The pressure drop of coolant airflow should be level 2 of 25 ± 5 mm (1 inch) of water.

14. ARINC 561-11. This characteristic states that ARINC Specification 404 (with Supplement 2) must be followed regarding the specific requirements of cooling provisions. This document specifies cooling air for flow-through system as 0.8 lb/min of cooling air per 100 watts of dissapated energy when the unit inlet air is 37.8 degrees C (100 degrees F) at sea level. The unit pressure drop at design air flow rates should not exceed 1 inch of water when measured across the box (does not include tray orifices) and corrected to sea level at 100 degrees F.

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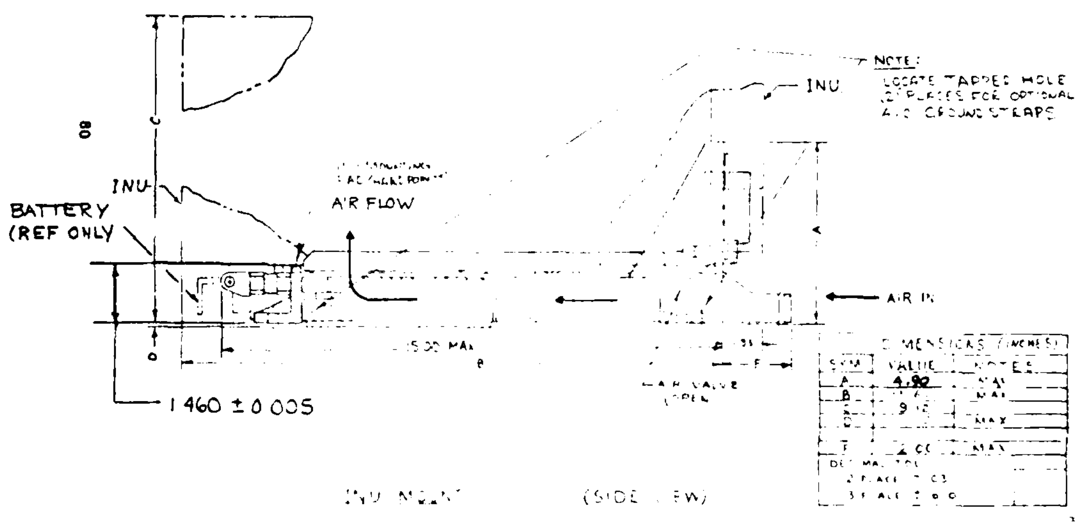
15. ENAC 77-1. This specification states that cooling air shall be provided according to the attached cooling air specifications. The cooling air is to be able to dissapate approximately 340 watts through a temperature range of -51 degrees C to +38 degrees C. The specified pressure drop is specified at 2 inches of water ± 10%. This requirement is at 1.2 lbs/min at 27 degrees C and sea level pressure. ENAC 77-1 also specifies over-cooling and undercooling provisions that require operation but allow degraded performance.

16. Both ARINC characteristics have similar cooling air requirements. The ENAC 77-1 specification is much more demanding in the area of over and under cooling.

17. In general, the three criteria compared above show the F^3 INS requirements are more stringent. This is to be expected: the F^3 system has very high reaction time criteria, the ARINC systems do not specify this criterion; F^3 accuracy is detailed, ARINC is not. There are many other characteristics that the F^3 system has but are absent in the commercially specified systems. For a fuller appreciation of the F^3 system it is recommended that interested parties read ENAC 77-1.



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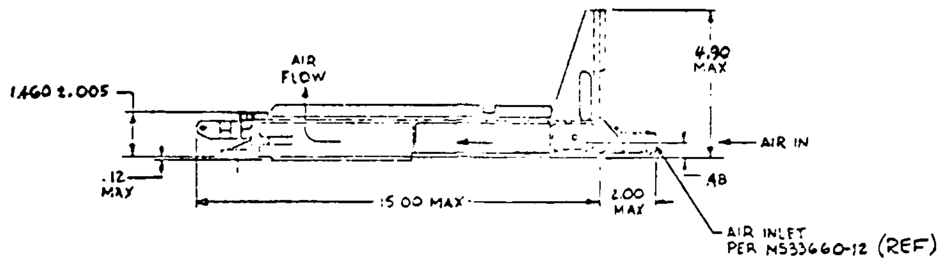
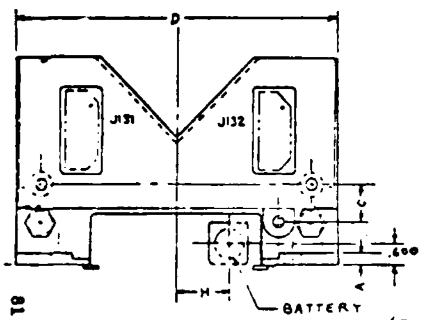
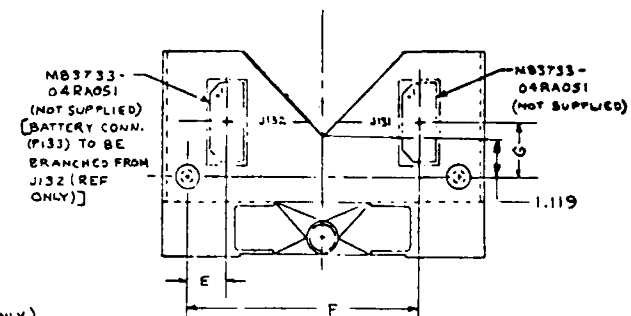


DIMENSIONS IN INCHES		
LINEAR TOL	.XX	±.03
	.XXX	±.010
ANGULAR TOL		±0°30′



(FRONT VIEW)

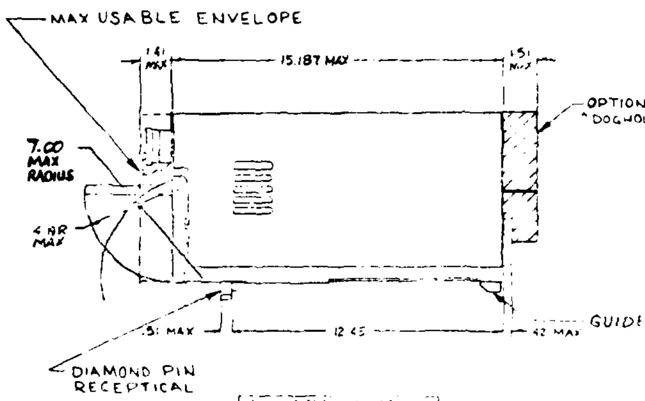


(REAR VIEW)

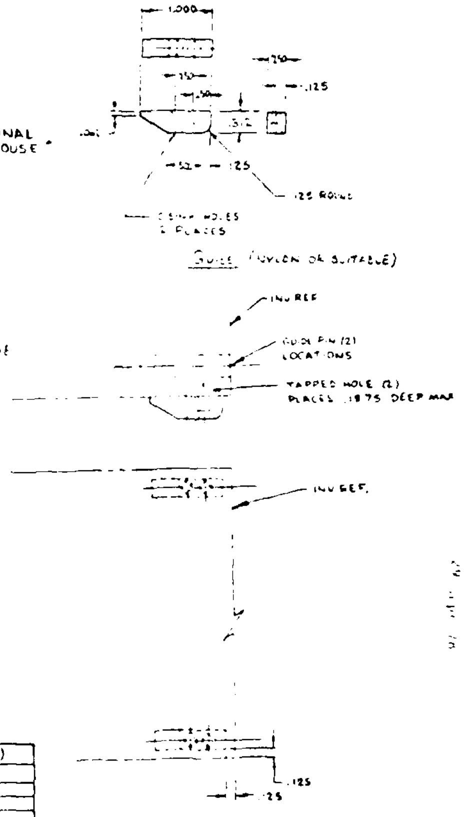
DIMENSIONS (INCHES)		
SYM	VALUE	NOTES
A	.282	±.020
B	.12	MAX
C	.875	±.001
D	7.90	
E	.975	
F	5.775	
G	1.319	
H	1.350	
DECIMAL TOL 2 PLACE ±.03 3 PLACE ±.010		

INU MOUNT

(continued)

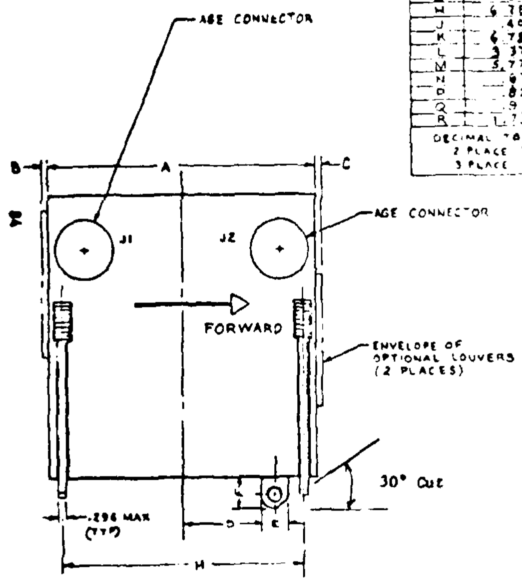


INERTIAL NAVIGATION UNIT (SIDE VIEW)

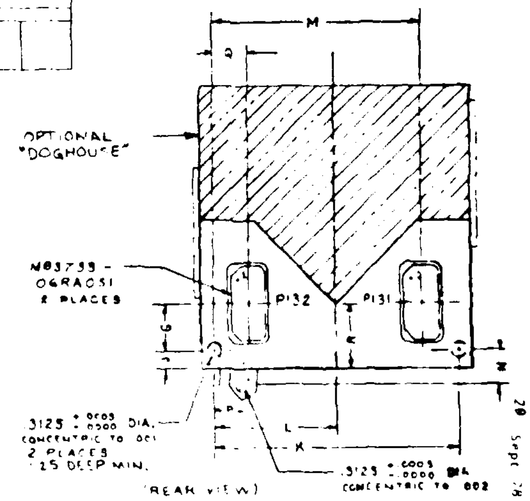


DIMENSIONS (INCHES)		
SYM	VALUE	NOTES
A	7.531	MAX
B/C	.18	MAX
D	2.18	
E	.750	
F	.87	MAX
G	1.319	
H	6.76	
J	.407	+.002 -.000
K	6.750	±.001
L	3.375	
M	5.775	
N	.675	±.001
P	.820	±.001
Q	.975	
R	1.732	

DECIMAL TOL
2 PLACE ± .03
3 PLACE ± .010



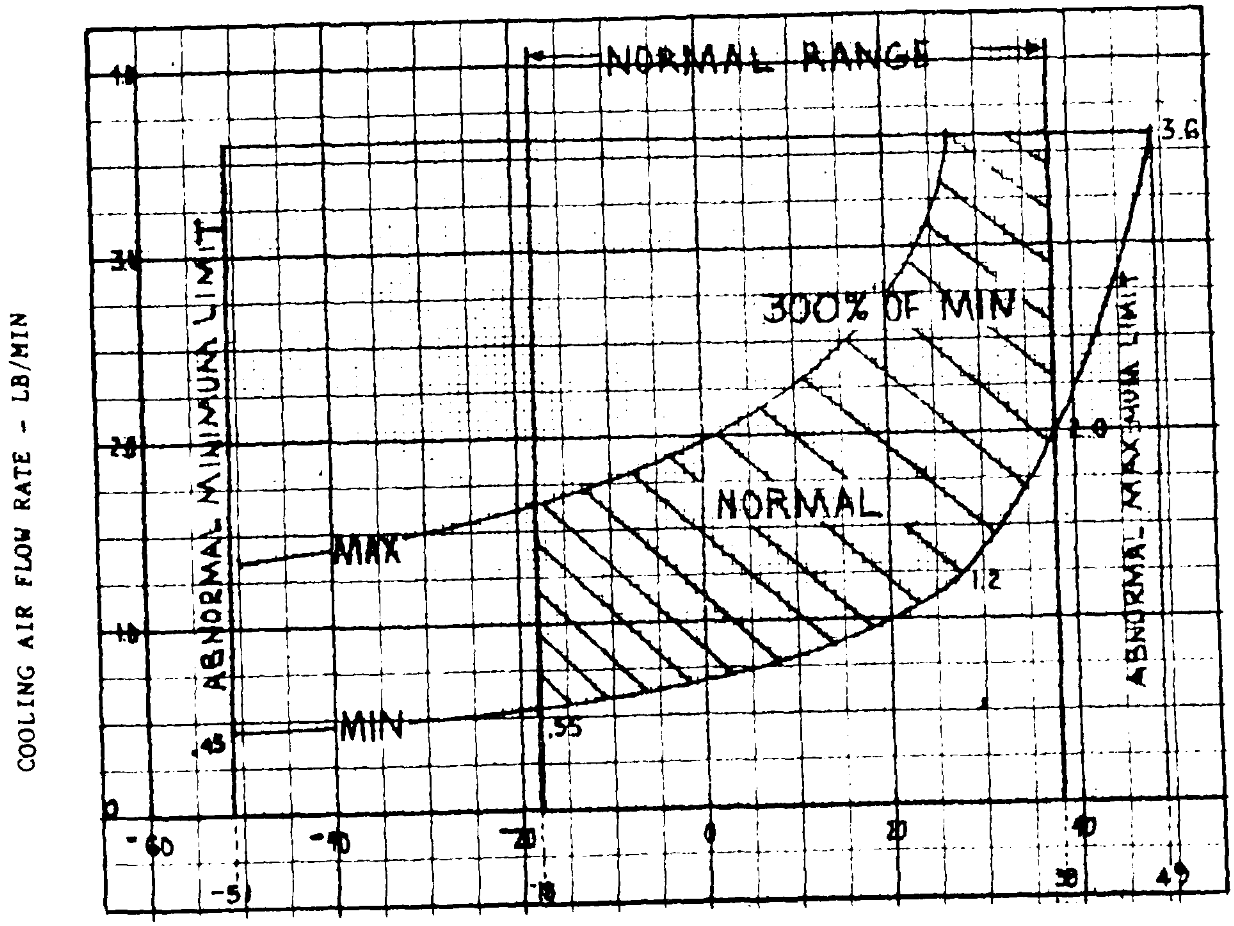
(FRONT VIEW)



(REAR VIEW)

INERTIAL NAVIGATION UNIT

(continued)



COOLING AIR SUPPLY TEMPERATURE - °C

COOLING AIR FLOW

8. ASD/ENAMD Comments on Commercial Standard Weather Radar

1. ARINC Characteristic 708

a. Paragraph 1.1. Weather detection, ranging, and analysis is listed as a primary requirement with ground mapping a secondary requirement. The USAF generally requires ground mapping as well as weather detection. Ranking the two requirements as primary and secondary may not be appropriate.

b. Paragraph 1.2. Emphasis of characteristic 708 is placed on weather detection and analysis.

c. Paragraph 1.3.2. This paragraph specifies all stabilization, control, and display information should be serial digital. Are the standards listed (ARINC 429, ARINC 704, and ARINC 705) compatible with MIL-STD-1553? Military weather radars should be compatible with MIL-STD-1553.

d. Paragraph 1.3.3.1. This paragraph implies that all circuitry necessary for reception, transmission, and signal processing must be in a single box. If ground map modes are also required, it may not be practical to put all three functions in a single box due to size and weight limitations.

e. Paragraph 1.5. FAA TSO standards are called out. These should be checked against appropriate Mil Specs and adjustments made as necessary

f. Paragraph 1.6. No reliability figures are given. This may be okay, but it is a break with Air Force tradition.

g. Paragraphs 2.1 through 2.6. Specifying box shapes and sizes may be okay for airline use, but sometimes these radars need to be installed in small or odd shaped places in USAF aircraft.

h. Paragraph 2.9. The environmental conditions specified are considerably less stringent than those of USAF equipment. A pressurized compartment for the radar would be required.

i. Paragraph 3.3. A pencil beam would not be adequate for most USAF ground mapping requirements.

j. Paragraph 3.8. MIL-STD-469, paragraph 6.4, requires military radars to be frequency tuneable.

k. Paragraph 4.5. A 0.5 nm spot size is specified. Spot size measured in nautical miles is not very meaningful since that number changes with range scale selected even though

(continued)

actual spot size does not. Perhaps paragraph 4.5 contains a typographical error and 0.5 mm was intended.

2. <u>RTCA Document DO-134</u>

The minimum performance standards listed in DO-134 have no relationship to any current USAF weather radar requirements. The standards are minimum acceptable, but all current Air Force weather radar requirements exceed these standards. Our actual requirements are, therefore, used in specifying weather radar performance.

9. ENFTC Comments on Commercial Standard Automatic Flight Control

ARINC 701 Flight Control MIL-F-949D
ARINC 702 Flight Management
ARINC 703 Thrust Control

1. The ARINC characteristics 701, 702 and 703 have been reviewed and evaluated by ENFTC. The documents were found to be useful guidelines for commercial transport aircraft manufacturers and airlines. However, they do not incorporate the necessary criteria needed to specify design characteristics for high performance military aircraft. Furthermore, the ARINC documents provide only general guidelines centered around the operational characteristics of the automatic flight system for commercial transport aircraft. Dynamic flight control requirements are not provided by these documents.

2. The design, mechanization, packaging, mounting, and cooling of the automatic flight control systems used on military aircraft is influenced by mission requirements and operational environments, i.e., attack and fighter aircraft flight control system requirements differ drastically from those of transport aircraft. Specification MIL-F-9490 incorporates the necessary design specifications and comprehensive requirements that cover the total spectrum of flight control systems for military aircraft. Presently the MIL-F-9490 is in the process of being updated (contract no. F33615-79-C-3617) to incorporate state-of-the-art technological advancements in digital avionics, microelectronics, packaging, actuators, sensors, etc..

3. Nevertheless, it is recommended that the Flight Management Computer System ARINC characteristic 702, which describes the next generation of automatic flight guidance, be utilized as a reference document for the development of the automatic flight control systems for future military transport aircraft. This will incorporate into the design of future automatic flight control systems the necessary parameters to accomplish an automatic flight path control mode to accomplish optimum energy efficiency.

APPENDIX C

COMPARISON OF RADAR ALTIMETER SPECIFICATION REQUIREMENTS ARINC 522A AND ARINC 707-1 VERSUS LARA

This appendix presents comparisons between the USAF Low Altitude Radar Altimeter (LARA) requirements (as of July 1979) and the commercial airlines standard low altitude radio altimeter requirements contained in ARINC 522A and ARINC 707-1.

The paragraph numbers quoted in the following sections identify paragraphs in the LARA specification where the LARA requirements are not met by the ARINC Characteristic.

1. DIFFERENCES BETWEEN LARA AND ARINC 552A

Altitude Range

Paragraph 3.2.1.4 requires 0-5000 feet capability. ARINC 552A requires only 0-2500 feet and specifically requires that performance be optimized for the 0-2500 feet region and that any increase in maximum height not interfere with this optimization.

Ground Speed

Paragraph 3.2.1 requires reliable operation at ground speeds up to 2000kts. ARINC 552A does not address ground speed range. However, the RTCA Minimum Performance Requirements-Airborne Low Range Altimeter, DO-155, which is the basis for the FAA Technical Standard Order (TSO), requires performance in the range 0-50 feet/second (29.6 kts) lateral velocity and 0-300 feet/second (177.6 kts) longitudinal velocity. Since these values are more than adequate for final approach and landing of transport aircraft, manufacturers of airlines altimeters have not been motivated to design for the higher ground speed. However, the ability of their equipments to function within specification beyond the DO-155 velocities could be determined by either analysis or test of the individual equipment designs.

Aircraft Altitude

Paragraph 3.2.1.6 requires operation at bank and pitch angles up to ± 45 degrees. ARINC 552A requires operation at roll and pitch angles only up to ± 20 degrees since this is considered adequate for final approach and landing. The low value of roll and pitch has been used by manufacturers of commercial altimeters to permit higher-gain and more directive antennas, which provide more rejection of multipath signals than could be obtained with antennas compatible with the LARA specification. Consequently, it is unlikely that any altimeters in commercial use will satisfy this LARA specification requirement.

Tracking Rate/Time Constant

Paragraph 3.2.1.7 requires following of changes in altitude up to ±2000 feet per second. Because of the intended application of airlines altimeters, the maximum altitude rate for which the altimeters need be designed is about 1,500 feet per minute (25 feet/second). ARINC 552A does not address this requirement. RTCA DO-155 requires that accuracy standards be met at sink rates up to 25 feet/second (1,5000 feet/min).

Cooling

Paragraph 3.2.1.13 requires that no forced air cooling shall be employed. ARINC 552A pe.mits cooling air be supplied to the altimeter R/T unit in accordance with ARINC 404A.

Input Power

Paragraph 3.2.1.14 requires that the LARA operate either from 115 Vac, 400 Hz or from 28 Vdc and that a power off/on switch be provided on the face of the Height Indicator. ARINC 552A does not require operation from 28 Vdc, it specifically recommends that an off/on switch not be used and terms an indicator with such a switch "non-standard". However, a pin on the indicator is reserved for those users who may desire an off/on switch in spite of this admonition, and a "non-standard" indicator with a switch certainly could be procured.

Adjustments

Paragraph 3.4.1.10 requires that the R/T have means available to adjust for aircraft installation delay (AID) without removing the R/T from its case. ARINC 552A requires this adjustment to be made by installing jumpers between pins on the rack connector. AID does not change after installation of antennas and cables; consequently, no ARINC 552A R/T adjustment is required or allowed.

Blanking Pulse

Paragraph 3.4.1.4 requires that the R/T accept and produce blanking pulses to permit blanking of the LARA and other systems. ARINC 552A does not require this capability, and no connector pins are reserved for this purpose.

Clock Synchronization

Paragraph 3.4.1.7 requires that the R/T accept synchronizing signals to synchronize digital outputs. No digital outputs are provided by the ARINC 552A altimeter.

Synchronization Pulse

Paragraph 3.4.1.6 requires that the R/T accept and generate synchronization signals to synchronize the pulse repetition frequency (for pulsed designs). No such provision is specified by ARINC 552A,and no connector pins are reserved for this purpose.

Analog Altitude

Paragraph 3.4.1.2 requires two independent AC analog altitude outputs with linear-8mv/foot scales. ARINC 552A supplies one synchro and one logarithmic, analog output with a radically different scaling factor.

Digital Altitude

Paragraph 3.4.1.3 requires 2 digital outputs. ARINC 552A has none.

Track/No Track Signal

Paragraph 3.4.1.8 requires a discrete "Track" signal. ARINC 552A does not specify this and no connector pin is reserved for this purpose. The flag warning output of 552A altimeters seems to fulfill this requirement, however.

Paragraph 3.4.1.8 requires that the analog output voltage for NO-TRACK rise to -46.7 ± 0.7 volts and that the digital output increase to all ones. ARINC 552A does not specify such output signal changes.

Modulator Pulse Output

Paragraph 3.4.1.5 requires an R/T output video pulse during each transmitted pulse (for a pulsed system). ARINC 552 does not specify this output, and no connector pin is reserved for it.

Time Totalizing Indicators

Paragraphs 3.4.1.12 and 3.2.1.3 require time totalizing indicators for the R/T and Height Indicator, respectively. (Some of the ASD comments on the LARA specification indicate that this is desired in R&D units only.) ARINC 552A does not specify a time totalizing indicator for either the R/T or the Indicator.

Power and Signal Connection

Paragraph 3.4.1.13 specifies power and signal connections different from those specified by ARINC 552A.

Size

The following table shows the differences between sizes listed in paragraphs 3.2.2.1 and 3.2.2.2.2 and those listed in ARINC 552A:

R/T Unit	LARA	552A
Height	3.125"	7.62"
Width	3.75"	4.88"
Depth	7.81"	12.52"
Indicator		
Height	3.25"	3.175"
Width	3.25"	3.175"
Depth	4.54"	5.00"

Nuclear Hardening

Paragraph 3.2.2.5.1 indicates that the degree of nuclear hardening required will be established by the procuring activity. ARINC 552A does not require any degree of nuclear hardening.

Gunfire Vibration

The July 1979 draft of the LARA specification will be modified to require the ability to withstand gunfire-induced vibration. Commercial equipment is not required to withstand this stress, although suitable vibration mounts might provide this capability.

2. DIFFERENCES BETWEEN LARA AND ARINC 707-1

For the following items, the differences between the LARA specification and ARINC 707-1 are identical to those between the LARA specification and ARINC 552A:

Altitude Range	Adjustments
Ground Speed	Blanking Pulse
Aircraft Attitude	Clocking Synchronization
Tracking Rate/Time Constant	Synchronization Pulse
Track/No Track Signal	Time Totalizing Indicators
Modulator Output Pulse	Power and Signal Connector
	Gunfire Vibration

Output Noise Level

Paragraph 3.2.1.1 limits output noise level to a three sigma value of ± 1 least significant bit (0.076 feet for 5000 feet full-scale) on the digital output. Below 100 feet altitude, ARINC 707-1 limits rms noise output to 0.25 feet (in the band 0.05 to 5 Hz), and its least significant bit is 0.125 feet for binary output and 0.1 feet for BCD output. No noise restrictions other than those implied by the accuracy requirement are specified by ARINC 707-1 for altitudes above 100 feet.

Cooling

Paragraph 3.2.1.13 prohibits the use of forced air cooling. ARINC 707-1 requires 11 Kg/hour of 40°C (or less) cooling air. The air is permitted to impinge directly on piece parts and must be dry and clean enough to avoid contamination.

Input Power

Paragraph 3.2.1.14 requires the LARA to be operable from either 115 Vac 400 Hz or 28 Vdc and that an on/off switch be provided on the indicator panel. ARINC 707-1 does not permit the use of 28 Vdc and specifically prohibits "... master on/off power switching within the radio altimeter...".

Height Indication Face

Paragraph 3.4.2.16 requires both an analog pointer and a digital display. Neither of the ARINC 707-1 indicators has a digital display.

Size

The following table shows the differences in size requirements between the LARA specification and ARINC 707-1:

R/T	LARA	ARINC 707
Height	3.125"	7.64"
Width	3.750"	3.56"
Depth	7.81"	12.76"
Indicator		
Height	3.25"	3.975"
Width	3.25"	3.25"
Depth	4.54"	4.54"

APPENDIX D

SURVEY OF INDUSTRY OPINION

This appendix includes the survey questionnaire that was mailed, a summary of the answers received to our specific questions, reproduction of the letter replies received, and a list of firms that were solicited.

Gentlemen:

ARINC Research Corporation is under contract to the Air Force (Contract Number F33657-79-C-0717) to evaluate and report on the possible costs/benefits of the standardization of USAF avionics packaging, mounting, environmental control requirements (PME) and to determine the extent to which such standardization, if beneficial, could utilize civil airline avionics standards. As a part of this contract, we are required to solicit inputs from aircraft and avionics manufacturers to obtain opinions and viewpoints on at least the following questions.

a. Is a military standard based on ARINC 600 concepts a viable approach to simplifying avionics installations obtaining greater equipment reliability and achieving reduced acquisition, modification, and support costs?

b. What qualitative or quantative benefits has the manufacturer previously observed in commercial practice versus military practices?

c. If the new USAF standard requires a new design of mounting racks and connectors, and an upgraded environmental control system, what are the expected areas of concerns and impacts?

   1. for a new aircraft

   2. for major avionics modernization programs

d. Should the USAF standard attempt to be all inclusive across all types of aircraft and core/common/mission avionics, or should it address only certain subsets of these?

We would appreciate your comments on these questions together with any related information or observations that you feel may be of benefit to our study. If possible, we would like to receive your comments by 15 August so that we may expand or clarify comments recieved, if necessary, by in-plant visits and more detailed discussions during the period 15 August-September 7. In addition to your textual response to the listed questions, we would appreciate your completing the attached form to supply background information about your company and to summarize your overall opinions in a way suited for easy tabulation.

Thank you for your assistance in this matter. Should you desire further information, you are encouraged to call either Mr. Neil Sullivan, (301)224-4000, extension 289 or Mr. James Russell, extension 576.

Very truly yours,

Kenneth E. Lyons
Manager, Acquisition
Systems Program

KL:kb

Enclosures (2)
1. Industry Survey Form
2. ARINC Specification #600-1

INDUSTRY SURVEY: AVIONICS PACKAGING, MOUNTING, ENVIRONMENTAL STANDARD

RETURN TO:

ARINC Research Corporation
2551 Riva Road
Annapolis, Maryland 21401

Attention: Mr. N. Sullivan

COMPANY ____________________

ADDRESS ____________________ CODE __________

POINT OF CONTACT ____________________

PHONE NUMBER ____________________

PRINCIPAL AVIATION PRODUCT LINES	COMMERCIAL	MILITARY

1. Organization feels that standards would be beneficial?

	Yes	*No*
Packaging	☐	☐
Mounting	☐	☐
Cooling	☐	☐
Power	☐	☐

2. Organization feels that standard should be:

   Direct adoption of ARINC 600 ☐

   Adaptation of ARINC 600 ☐

   Other concept ☐

3. Standard should be made applicable to:

   New design aircraft only ☐

   New and older aircraft ☐

4. Standard should address:

   Core avionics (e.g., computers) ☐

   Common avionics (e.g., radios) ☐

   Mission avionics (e.g., EW equipment) ☐

ANSWERS TO INDUSTRY QUESTIONNAIRE												
Company Responding	Form of Standard			Standard Should Cover:				Standard Should Be Applicable to:				
								Aircraft		Avionics		
	ARINC 600	Adaptation of ARINC 600	Other Concept	Packaging	Mounting	Cooling	Power	New	New and Old	Core	Common	Mission
Bendix		X		X	X	X	X		X		X	
Boeing		X		X	X	X	X	X			X	
Collins		X		X	X	X	X		X	X	X	X
Emerson							X		X	X	X	X
General Dynamics		X		X	X	X	X		X	X	X	
Singer		X				X		X		X	X	
Sperry		X		X	X	X	X		X	X	X	X

Bendix

Avionics Division

2100 Northwest 62nd St
P.O. Box 94[illegible]
Fort Lauderdale, F[illegible] 333[illegible]
Tel. 305 [illegible]76 4[illegible]

The Bendix Corporation

ARINC Research Corporation
2551 Riva Road
Annapolis, MD. 21401

August 15, 1979

Attention : Neil Sullivan

Subject : Standardization of Avionics Packaging

Gentlemen:

In response to your inquiry of July 30, 1979 we are pleased to offer our opinions relative to the use of ARINC 600 and other standardization philosophies for possible application to Air Force avionics. The comments below relate to the four questions of your letter by letter designation.

a. A military standard based on ARINC concepts probably is a viable approach for certain classes of aircraft. It must be recognized, however, that the ARINC concept prohibits many practices common in military design and vice versa. For example, all ARINC boxes have blind rear panel connectors and permit forced air cooling while the military counterparts have screw on or bayonet locking connectors (often on the front panel) and sometimes require sealed cases for environmental protection. Military equipment, on the other hand, does not utilize the edge connected PC boards which are common in airline equipment.

   If these differences can be accommodated, a military standard could be an important step toward improved reliability and reduced cost of future avionics hardware.

b. The major advantages observed in commercial practice lie in the areas of productivity, maintainability and minimum aircraft down time. ARINC standardization permits a great degree of commonality between boxes which are functionally different. This commonality helps produce better products and lower cost through larger production runs, transfer of proven technology and standardized test fixtures.

   ARINC characteristics and specifications are devoted to the definition of equipment which can be easily maintained through accessibility and abundant test points. The rapid interchangeability feature keeps aircraft down time to a minimum.

Bendix
Avionics
Division

The price paid for these features is flexibility. ARINC equipment does not generally represent the ultimate in compact design and the standardized packages do not permit optimum space utilization in the equipment rack.

c. The military has long proclaimed that blind push-on connectors are not as reliable as the positive contact type. While this may be true, the connector in most ARINC equipment is not the weakest link from a reliability point of view. The use of new mounting racks, with front or rear connections, would be most appropriate for new aircraft, but may also be applicable in major modification program. This would be determined primarily by the type of aircraft involved.

d. If a standardization program is implemented, it should be as all inclusive as possible to realize benefit from economies of scale. From this point, exceptions are required to meet all installation requirements. If the exceptions exceed the standardized installations, the benefits of standardization will be essentially lost. In this event, standardization by subsets should be considered as an alternative to full standardization even though some of the benefits cited in b will not be realized.

Very truly yours,

W.E. Rupp

W.E. Rupp, Manager
Government Engineering
/kc

Enclosure: Industry Survey

BOEING AEROSPACE COMPANY

P O Box 3999
Seattle, Washington 98124

A Division of The Boeing Company

October 22, 1979
2-8080-LAI-130

ARINC Research Corp.
2551 Riva Road
Annapolis, Maryland 21401

Attention: Mr. G. E. Flowers

Dear Mr. Flowers:

The Avionics Technology Staff of the Boeing Military Airplane Development organization is pleased to review the several questions asked by you in your letter. We apologize for the tardiness of our reply.

In answer to your questions:

We don't believe that a military standard based strictly upon ARINC 600 is a viable approach. The accompanying diagram explains this belief.

In a broad sense and approached as a philosophy, standardization of USAF avionics packaging, mounting, cooling, etc. will be beneficial. Application and use of such a standard will reduce costs of installation and also the life cycle cost.

ARINC 600 standard is applicable to certain types of equipment, generally using air as the coolant. For this reason, ARINC 600 cannot be adopted "as is." Adaptation of ARINC 600 will only cover a small portion of the avionic equipment installed on military airplanes. An examination of the attached diagram will help to understand this point.

The avionic equipment installed in military airplanes can be classified in a number of groups as shown in Figure 1. ARINC 600 or an adaptation of it, can be used for a portion of the equipment installed on transport type airplanes. However, this comprises a small portion of avionic equipment installed on military airplanes. Other groups have different constraints and operational requirements, which make the application of ARINC 600 a hindrance.

As the amount of total avionic equipment goes up, which is the case on patrol and command type airplanes, cooling air requirement exceeds the airflow available. This necessitates use of closed loop systems or use of coolants

BOEING

other than air. In the case of bombers and fighters, a standard such as ARINC 600, which specifies rack and box sizes, will result in space limitations. Similarly requiring a box of logic card files to meet a standard designed for electronic equipment will be wasteful.

To conclude, a standard such as ARINC 600 would be desirable. However, such a standard will have to be divided into sections to serve the different types of airplanes, different types of avionic equipment and also to leave room for newer equipment that is expected to be installed on future airplanes.

Yours truly,

L. A. Irish

Enclosure

AD-A082 166 ARINC RESEARCH CORP ANNAPOLIS MD F/G 1/3
STANDARD AVIONICS PACKAGING, MOUNTING, AND COOLING BASELINE STU--ETC(U)
JAN 80 S BAILY, A JACKSON, J RUSSELL F33657-79-C-0717
UNCLASSIFIED 1753-01-1-2124 NL

3 of 3
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GENERAL DYNAMICS
Fort Worth Division
P.O. Box 748, Fort Worth, Texas 76101 • 817-732-4811

GRE/MCD:jw/Gen.FW#060-12675
17 August 1979

ARINC Research Corporation
2251 Riva Road
Annapolis, Maryland 21401

Attention: Mr. N. Sullivan

Subject: Industry Survey: Avionics Packaging, Mounting Environmental Standard

Reference: (a) ARINC Letter, ASG/ASP/A&V-79-140, dated 31 July 1979

(b) ARINC Specification 600-1

Gentlemen:

We appreciate being included in your survey with regard to standardizing environmental control requirements. We feel that there is much to be gained by an effort toward such standardization. The comments in the following paragraphs are keyed to the specific questions in your letter. We would be glad to work with you in more detail if you desire.

Reference paragraph a

The concept of a recognized standard for the physical aspects of avionics equipment is appealing for all the reasons listed in paragraph "a" of reference message. Such a standard would improve or simplify communications between the aircraft provisions designer and the avionics manufacturer by providing a common baseline either to follow or to take exception to if the standards were not applicable. Certainly, there will be exceptions because of the special packaging requirements of small, high-density military aircraft. As an example of this, the F-16 has an approximate total of 70 LRUs; of these 70 LRUs, 42 (60%) have a volume of 1 MCU (1/8 ATR) or more. To best utilize available space of these 42 LRUs, 22 need to be less than 12.56 long and/or 7.62 high (ref MCU box size), 5 need to be more than 12.56 long and 9 LRUs are form fitted. Of the 42 LRUs having a volume greater than 1 MCU, 6 LRUs (9% of 70) are adaptable to a MCU size. These numbers suggest that to best utilize the aircraft space, the LRUs will need to have some flexibility in length and height and at time also in shape. ARINC 600 is certainly a viable approach and should be a useful tool to the aircraft and avionics community if applied to aircraft/avionics development/production programs in proper context.

Reference paragraph b

The resolution of differences between commercial and military specifications for commonly used avionics should lead to fewer development programs for the relatively small quantity requirements of the military. Systems such as communication, identification, civil navigation, computers, etc., could be identical in the same time frame and could benefit by the maturing effect of the longer production runs produced by common military and commercial requirements.

Reference paragraph c

It is generally expected that each new airplane could require mounting racks that are unique due to the specific physical interfaces involved, but if the new rack requires vibration isolators, the problem becomes difficult not only from a space standpoint, but the question of qualification test must be addressed and much of the advantage of using standard equipment disappears with the start of a rack development program. If the equipment were specified to be "hard mounted" and some appropriate criteria defined, the impact on aircraft space and program dollars would be less on new and modified aircraft than if the rack "served as an attenuator of aircraft vibration modes" as required in paragraph 3.2.5.1 of referenced specification.

More efficient connectors are always desirable if the logistics problems of supply, multiple source, tools, and training are solved at the same time that design requirements are met. We have successfully used rack-and-panel connectors on many installations and would not resist applying any standard hardware specified.

The thermal design requirements in section 3.5 of referenced specification indicate a need for drier air in larger quantities per KW than is presently provided. In either new or modernized aircraft, the increased requirements would require more bleed air from the engine which would in turn reduce airplane performance. There are some ways of minimizing the impact of providing dry air, but more space is required than is usually available on tactical military aircraft. If the "cold plate" method of cooling is used rather than the implied open component/air wash arrangement, the stringent requirement of paragraph 3.5.4.2 could be relieved.

Reference paragraph d

It would seem useful to apply the USAF standard as an objective to all aspects of avionics at the onset of a program and depart from it only as the best interests of the program are served. As mentioned in the opening paragraphs of this message, there will be many variations, but repetitive deviations will serve to update the document.

Mr. John M. Murphy, Manager, Electrical Systems and Installation Section, is responsible for avionics packaging in our organization. John will be most pleased to discuss this subject in more detail if you so desire (phone (817) 732-4811, ext. 4101).

Sincerely,

GENERAL DYNAMICS CORPORATION
Fort Worth Division

G. R. England
Director of Avionics

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Cedar Rapids, Iowa 52406
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August 15, 1979

ARINC Research Corporation
2551 Riva Road
Anapolis, Maryland 21401

Attention: Mr. Kenneth E. Lyons
Acquisitions Systems Program

Gentlemen:

As a major supplier of avionics equipment for both civil and military requirements, we are very pleased to respond to your inquiry of using civil airline type avionics standards for military installations. Our response to your specific questions is as follows:

a) "Is a military standard based on ARINC 600 concepts a viable approach to simplifying avionics installations, obtaining greater equipment reliability, and achieving reduced acquisition, modification, and support costs?"

Yes! The ARINC 600 specification establishes interfaces between the avionics, its associated racking, and the aircraft which offers the capability for mutually sharing trade-off analysis responsibilities on all design parameters like acquisition costs, reliability, support costs, etc.

A specification of this type could provide the military with a means to:

(1) specify a cost effective and reliable avionics environment for all aircraft. (Due to the wide range of military aircraft and variable mission requirements, a single specification may not be practical but instead could contain categories.)

(2) assure interchangeability of avionics and provide a preplanned means for updating and modernization of aircraft.

(3) realize some degree of standardization of hardware and allow for the perfection of these standardized areas without affection technology advancement of other areas.

(4) establish a workable and consistent maintenance test program.

b) "What qualitative or quantative benefits have the manufacturers previously observed in commercial practices versus military practices?"

As an avionics manufacturer, benefits from commercial versus military practices have been realized in higher reliabilities, lower support costs and lower manufacturing costs.

The apparent higher reliability of commercial avionics is contributed to a more favorable and consistent environment and maintenance. Reliability of comparable commercial equipments will vary from two times to well over four times that of the military.

Benefits in manufacturing costs are realized from hardware standardization, self-imposed quality control standards, and reduced environmental requirements. Military products will typically run 15% to 20% higher in quality control costs.

c) "If the new USAF standard requires a new design of mounting racks and connectors and an upgraded environmental control system, what are the expected areas of concern and impacts?"

For new aircraft, the procurement procedures and attitudes of stressing the reduction of weight and volume will have to give way to the results of other trade-off studies involving cost, reliability and equipment support.

For major avionics modernization programs, the cost of retrofitting the aircraft to the new standard must be traded-off against benefits expected.

d) "Should the USAF standard attempt to be all inclusive across all types of aircraft and cor/common/mission avionics or should it address only certain subsets of these?"

Avionics standardization becomes more and more difficult to implement across more aircraft with various and more missions. It is felt that some degree of standardization across the entire fleet would be beneficial and could be handled by categories within a specification. It is also felt that all types of avionics, or portions of avionic systems, that can functionally be remote mounted in an aircraft, should be controlled by the standard.

Thank you for allowing us to comment on a subject we consider of major importance.

Should additional information be required, please feel free to contact us.

Yours truly,

R A Saunders

R. A. Saunders
Mechanical Design Manager
Government Avionics & Missiles Group

RS:11

SINGER

AEROSPACE & MARINE SYSTEMS
KEARFOTT DIVISION

18 September 1979

ARINC Research Corporation
2551 Riva Road
Annapolis, Maryland 21401

Attention: Mr. N. Sullivan

Subject: Comments on ARINC Specification #600-1 as regards its use as a basis for Military Standards

Reference: Your Letter ASG/ASP/A&V-79-140, dated 7/31/79.

Gentlemen:

The Kearfott Division of The Singer Company is pleased to present its comments relative to the referenced subject.

The summation of Kearfott's opinion is that the subject specification is sufficiently different *from actual military requirements* that it would have to be severely modified in order to be suitable for military application. Further, we think that a new USAF standard should apply only to new design aircraft and those existing aircraft that will undergo complete overhaul. Our comments, which are enclosed, elaborate on the opinion summarized in this paragraph.

We trust that the comments provided herein will assist you in that portion of your evaluation regarding the extent to which civil airline avionics standards can be used for military applications. Also enclosed is the complete industry survey as requested.

Should you require any additional information, please do not hesitate to call the undersigned.

Sincerely,

Joseph P. Savino
Marketing Manager

JPS:bea

Enclosures: (1) Comments on ARINC Specification #600-1 as regards its use as a basis for Military Standards.
(2) Completed Industry Survey.

1150 McBRIDE AVE LITTLE FALLS N J 07424 201-256-4000 TWX 710-988-5700

ENCLOSURE I

Comments on ARINC Specification #600-1 as regards its use as a basis for Military Standards.

Question (a) Is a military standard based on ARINC 600 concepts a viable approach to simplifying avionics installations obtaining greater equipment reliability and achieving reduced acquisition, modification, and support costs?

Answer Standardization of military equipment is a feasible method of obtaining the benefits of reduced cost of ownership and increased reliability. Kearfott is already vigorously engaged in providing support to the USAF for this concept for the Standard (Form, Fit, Function) Moderate Accuracy Inertial Navigation System. This program is designed to meet USAF requirements through the 1980's and into the '90's. The Phase I requirements of ARINC 600 conflict with the packaging committed to the Standard F^3 unit. Moreover, it is unknown at this time what impact the evolution of ARINC 600 through Phases II and III might have on the Standard F^3 program. It is conceivable that much of the design effort would have to be repeated, thus opening the fiscal floodgates because of new tooling requirements, requalification of hardware, and logistic considerations.

Specific areas where ARINC 600 differs from the requirements of the Standard F^3 INS are:

- o Package dimensions
- o Cooling air pressure drop too low
- o Ratio of power dissipation to volume is too low for dense military packaging
- o Vibration input to MCU appears unrealistically low

While these differences may be resolved by the process of specification give and take, a more fundamental problem exists in any attempt to make an inertial navigation unit compatible with an ARINC 600 installation in which it is mounted in a common rack, shelf, or cabinet with other equipment. This problem concerns the need for the inertial navigation unit to be precisely aligned on its mount which, in turn, is adjustable through limited angles with respect to the aircraft axis. In addition, the mounting rack must maintain its orientation highly stable to allow removal and replacement of the inertial navigation unit without the need for re-alignment.

Question (b) What qualitative or quantitative benefits has the manufacturer previously observed in commercial practice versus military practices?

Answer An answer to this question is quite classical in context. Namely, there are the rigorous design requirements (environmental in particular) imposed by the military that result in units being very well designed indeed and possibly er designed in some instances. This statement is not critical of said rigorous design requirements, but rather a reporting of the results of these requirements, for it is understood that a significant safety factor must be incorporated into military design in order to allow for unpredictable extreme environmental conditions. These rigorous military requirements certainly make for more expensive items as would be expected. While these military requirements do not inhibit innovative designs, actually in some cases the military requirements act as a spur to innovations, they are sufficiently restrictive so as to channel the design development by independent manufacturers along parallel paths thus resulting in similar designs.

The corallary to the above is also classical. Namely, designing to the more relaxed commercial standards yields a design that is generally less costly to manufacture and generally not as good as one designed to military standards. Commercial standards also tend to have more room for innovative design and can result in independent manufacturers coming up with designs that are quite different for the same item.

Notwithstanding the previous comments, there is a somewhat unexpected benefit in the area of reliability associated with commercial practices. Kearfott has observed an improvement in reliability in commercial vs. military practices for avionics equipments that is from 2 or 3 times better to as much as 10 times better. Among other things, this improvement is associated with the relatively benign operating environment, longer equipment operating times, and different (better) maintenance procedures that commercial equipments experience versus military equipments.

Question (c)	If the new USAF standard requires a new design of mounting racks and connectors, and an upgraded environmental control system, what are the expected areas of concerns and impacts? 1. for a new aircraft 2. for major avionics modernization programs
Answer	The response to this question as it pertains to inertial equipment is included in Answer (a) above.
Question (d)	Should the USAF standard attempt to be all inclusive across all types of aircraft and core/common/mission avionics, or should it address only certain subsets of these?
Answer	The ARINC 600 specification appears more appropriate to transport type aircraft, whose installations can be made to accommodate the new packaging and mounting schemes, than to smaller aircraft. Also, we would recommend it only for new aircraft and aircraft slated for major avionics overhaul. Ideally a new USAF standard should apply to and benefit core, common and mission avionics equipments across the board, however, in our opinion it would be impractical to have this new standard address mission avionics equipments due to the specialized nature of this type of equipment.

SPERRY
FLIGHT SYSTEMS

P O BOX 21111
PHOENIX, ARIZONA 85036
TELEPHONE (602) 942-2311

10 August 1979

Reference: Letter dated 31 July 1979
ASG/ASP/A&V-79-140

Mr. N. Sullivan
ARINC Research Corporation
2551 Riva Road
Annapolis, MD 21401

Dear Mr. Sullivan:

The attached information is provided in response to the request contained in the referenced letter. As you are no doubt aware, the question of using commercial packaging standards for military equipment is a many-faceted one that is difficult to discuss in a few paragraphs.

The information attached has been prepared by our Engineering group that is responsible for packaging all of our products; both military and commercial.

I hope that our response will be useful and if we can be of further assistance, please do not hesitate to advise.

Sincerely,

D.A. Few

Donald A. Few
Commercial Marketing Manager
International Marketing

DAF:lmc

Attachment

cc: W. Squires
D. Burkholder

RESPONSES TO ARINC LETTER ASG/ASP/A&V-79-140, dtd 7/31/79

a. It must be recognized that the ARINC 600 concepts are based on a more benign environment, both thermally and structurally, than that normally encountered for military equipment. In addition, ARINC 600 does not address requirements such as human factors which, when imposed by military specifications, have an adverse effect on equipment cost.

b. It is difficult to be specific relative to benefits of commercial versus military practices. In general, commercial equipment has less structural weight, simpler access for maintenance and lower fabrication cost.

c. In any new specification for equipment installation concerns would include:

   1. Location of cooling air inlet and outlet

   2. Quantity and quality of cooling air provided

   3. Nature of unit hold-down fittings

   4. Grounding and bonding of the unit to the air frame

   5. Connector types - zero or low insertion force, locating features, whether the units are plug-in and, if so, whether the rear connector supports the unit, sealing requirements, number of spare pins, whether spare pins are installed, etc.

   6. Unit finish requirements, paint systems, color, etc.

   7. Will handles have to provide for gloves or mittens?

d. It is not felt that a single requirement will be effective for all classes of aircraft. The thermal and structural requirements for fighters are significantly more severe than those for transports. If a single standard was used it would require all equipment to be designed to meet the most severe environment.

APPENDIX E

COST-BENEFIT MODEL

1. INTRODUCTION

This appendix contains an expansion of the methodology used in the formulation of the cost-benefit model, together with the necessary procedures to run the program.

2. METHODOLOGY

The cost-benefit model is divided into three cost areas -- initial integration, operation and support, and avionics update modification -- each of which has two subroutines. One of these subroutines is selected for each cost area on the basis of the complexity of the available data, which has been stored in the associated file. A description of the various subroutines in mathematical form is presented in Tables E-1 through E-6. The cost-benefit model does not use these equations as written because the multidimensional arrays require too much core allocation, which causes the program to become core-limited in the time-sharing system being used (Mark III, FORTRAN 77). Instead, performing the individual computations and writing them to tape accomplishes the objective indicated by the equations in Tables E-1 through E-6, while only using a small core allocation. A unique record number is assigned automatically by the program for writing to tape and reading back from tape for subsequent computational steps.

The subroutines are used to compute a baseline cost element for each of the designated avionics groups in each of the three cost areas. These computations are then repeated for each of the chosen standardization alternatives, by use of the cost-weighting factor appropriate to each case.

The main program computes the cost saving by taking the cost difference between the baseline and each of the chosen standardization alternatives for each cost area of each avionics group and accumulates the baseline LCC and the avionics life-cycle-cost saving for each standardization alternative and each avionics group. In the course of this computation, the annual cost saving (or required additional investment, if negative) for each aircraft type is calculated, together with an annual total for all of the aircraft types programmed, for each standardization alternative. A discount factor can be applied separately to certain annual subtotals, thereby providing discounted values for the following totals of each standardization alternative:

Table E-1. SUBROUTINE INITIAL

Initial Design and Integration Costs (J,I,K,L)	= K_1 (J,I,K,L,1) × Engineering Development (J,I,K) × Engineering Development Inflation (I) + K_1 (J,I,K,L,2) × Tooling (J,I,K) × Tooling Inflation (I) + K_1 (J,I,K,L,3) × Model Manufacture (J,I,K) × Model Manufacture Inflation (I) + K_1 (J,I,K,L,4) × Contractor Drawing and Documentation (J,I,K) × Contractor Drawing and Documentation Inflation (I) + K_1 (J,I,K,L,5) × Test and Evaluate (J,I,K) × Test and Evaluate Inflation (I)
Initial Design and Integration Cost Discounted (J,I,K,L)	= Initial Design and Integration Costs (J,I,K,L) × $(1 - P)^{(I-1)}$
Initial Investment Cost (J,I,K,L)	= Group "A" Cost (J,I,K,L) + Group "B" Cost (J,I,K,L) + Labor Cost (J,I,K,L)
Group "A" Cost (J,I,K,L)	= K_1 (J,I,K,L,6) × Unit Cost "A" (J,I,K) × Number Unit "A" (J,I,K) × Learning Curve Value (I,K) × Group "A" Inflation (I)
Group "B" Cost (J,I,K,L)	= K_1 (J,I,K,L,7) × Unit Cost "B" (J,I,K) × Number Unit "B" (J,I,K) × Learning Curve Value (I,K) × Group "B" Inflation (I)
Labor Cost (J,I,K,L)	= K_1 (J,I,K,L,8) × Average Number of Hours for Installation (J,I,K) × Average Cost per Hour × Number of Installations (J,I,K) × Learning Curve Value (I,K) × Labor Cost Inflation (I)
Initial Investment Cost Discounted (J,I,K,L)	= Initial Investment Cost (J,I,K,L) × $(1 - P)^{(I-1)}$

Note: J = Number of Aircraft Types, I = Number of Years, K = Number of Avionics Types, L = Number of Standardization Alternatives, and P = Discount Percentage.

Table E-2. SUBROUTINE OAS

Operation and Support Cost (J,I,K,L)	= Replenishment Spares Cost (J,I,K,L) + Labor Cost (J,I,K,L) + Material Cost (J,I,K,L) + Other Cost (J,I,K,L)
Operation and Support Cost Discounted (J,I,K,L)	= Operation and Support Cost (J,I,K,L)
Replenishment Spares Cost (J,I,K,L)	= Average Cost per Module (J,I,K,L) × Number of Repair Actions per Year per Set (J,I,K,L) × Discard Rate (J,I,K) × Risk Factor Due to Degraded MTBF (J,I,K,L) × Cumulative Number of Sets in Field (J,I,K) × Inflation Rate (I)
Labor Cost (J,I,K,L)	= Number of Repair Actions per Year per Set (J,I,K,L) × Average Man-Hours per Module (J,I,K,L) × Average Cost per Hour (J,I,K) × Cumulative Number of Sets in Field (J,I,K) × Labor Cost Inflation (I)
Average Cost per Module (J,I,K,L)	= K_3 (J,I,K,L,1) × Unit Price Cost (J,K) × Learning Curve Value (I,K)
Number of Repair Actions per Year per Set (J,I,K,L)	= K_3 (J,I,K,L,2) × Operating Hours (J,I,K)/[MTBF(K) × {1 - Percentage MTBF(K)}]
Risk Factor Due to Degraded MTBF (J,I,K,L)	= K_3 (J,I,K,L,3)/[1 - Percentage MTBF(K)]
Material Cost (J,I,K,L)	= K_3 (J,I,K,L,4) × Labor Cost (J,I,K)
Other Cost (J,I,K,L)	= K_3 (J,I,K,L,5) × Other Cost 1 (J,I,K)
Note: J = Number of Aircraft Types, I = Number of Years, K = Number of Avionics Types, L = Number of Standardization Alternatives, and P = Discount Percentage.	

Table E-3. SUBROUTINE MODD

Modification Costs (J,I,K,L)	$= K_2$ (J,I,K,L,1) × Interface Analysis (J,I,K) × Interface Analysis Inflation (I)
	$+ K_2$ (J,I,K,L,2) × Installation Design (J,I,K) × Installation Design Inflation (I)
	$+ K_2$ (J,I,K,L,3) × Installation Data (J,I,K) × Installation Data Inflation (I)
	$+ K_2$ (J,I,K,L,4) × R&D (J,I,K) × R&D Inflation (I)
	$+ K_2$ (J,I,K,L,5) × Installation Cost (J,I,K) × Installation Cost Inflation (I)
	$+ K_2$ (J,I,K,L,6) × "B" Kit Cost (J,I,K) × "B" Kit Cost Installation (I)
Modification Costs Discounted (J,I,K,L)	= Modification Costs (J,I,K,L) × $(1 - P)^{(I-1)}$

Note: J = Number of Aircraft Types, I = Number of Years, K = Number of Avionics Types, L = Number of Standardization Alternatives, and P = Discount Percentage.

Table E-4. SUBROUTINE INITIAL 1

Initial Design and Integration Costs (J,I,K,L)	$= K_4$ (J,I,K,L,1) × Initial Design and Integration Costs 1 (J,I,K)
Initial Design and Integration Costs Discounted (J,I,K,L)	= Initial Design and Integration Costs (J,I,K,L) × $(1 - P)^{(I-1)}$
Initial Installation Costs (J,I,K,L)	= Group "A" Cost (J,I,K,L) + Group "B" Cost (J,I,K,L) + Labor Cost (J,I,K,L)
Initial Installation Costs Discounted (J,I,K,L)	= Initial Installation Costs (J,I,K,L) × $(1 - P)^{(I-1)}$
Group "A" Cost (J,I,K,L)	$= K_4$ (J,I,K,L,2) × Group "A" Cost 1 (J,I,K)
Group "B" Cost (J,I,K,L)	$= K_4$ (J,I,K,L,3) × Group "B" Cost 1 (J,I,K)
Labor Cost (J,I,K,L)	$= K_4$ (J,I,K,L,4) × Labor Cost 1 (J,I,K)

Note: J = Number of Aircraft Types, I = Number of Years, K = Number of Avionics Types, L = Number of Standardization Alternatives, and P = Discount Percentage.

Table E-5. SUBROUTINE OAS 1

Operation and Support Cost (J,I,K,L)	$= K_5$ (J,I,K,L) × Operation and Support Cost 1 (J,I,K)
Operation and Support Cost Discounted (J,I,K,L)	= Operation and Support Cost (J,I,K,L) × $(1 - P)^{(I-1)}$

Note: J = Number of Aircraft Types, I = Number of Years, K = Number of Avionics Types, L = Number of Standardization Alternatives, and P = Discount Percentage.

Table E-6. SUBROUTINE MOD 1

Modification Cost (J,I,K,L)	$= K_6$ (J,I,K,L) × Modification Cost 1 (J,I,K)
Modification Cost Discounted (J,I,K,L)	= Modification Cost (J,I,K,L) × $(1 - P)^{(I-1)}$

Note: J = Number of Aircraft Types, I = Number of Years, K = Number of Avionics Types, L = Number of Standardization Alternatives, and P = Discount Percentage.

- Annual total cost savings (i.e., all aircraft types and all avionics groups together)
- Life-cycle-cost savings for each avionics group (i.e., all aircraft types together)
- Life-cycle-cost savings for each aircraft type (i.e., all aircraft types together)
- Life-cycle-cost savings for all aircraft and all avionics groups together

Figure E-1 illustrates a flow diagram of the overall concept of the cost-benefit model.

3. INPUT REQUIREMENTS

The input requirements are separated into data inputs and control inputs. The control inputs are used in selecting cost areas to evaluate data inputs and the range associated with selected "DO loops." The data inputs contain the values of interest for the various elements in the euquations (Tables E-1 through E-6) for the cost areas being evaluated. There are two control input files, designated INIT9 and ARRAYAC. The first control file, INIT9, is basically a vector that contains 11 terms, as defined in Table E-7. The second control file, ARRAYAC, contains the operational status of each aircraft for each year of interest in an array format. There are five operational status situations used to branch to the various cost areas in the program, as illustrated in Table E-8.

Table E-7. INIT9 VARIABLES

Variable Number	Program Variable	Variable Description
1	L0	Number of aircraft
2	L1	Number of years
3	L2	Number of avionics
4	L3	Number of weighting factors (7)
5	L4	Number of standardizations (6)
6	L5	One dimension of K1 array (8)
7	L6	One dimension of K3 array (5)
8	L7	"0" Initial or "1" Initial 1
9	L8	"0" OAS or "1" OAS 1
10	L9	"0" MODD or "1" MOD 1
11	L10	One dimension of K4 array (4)

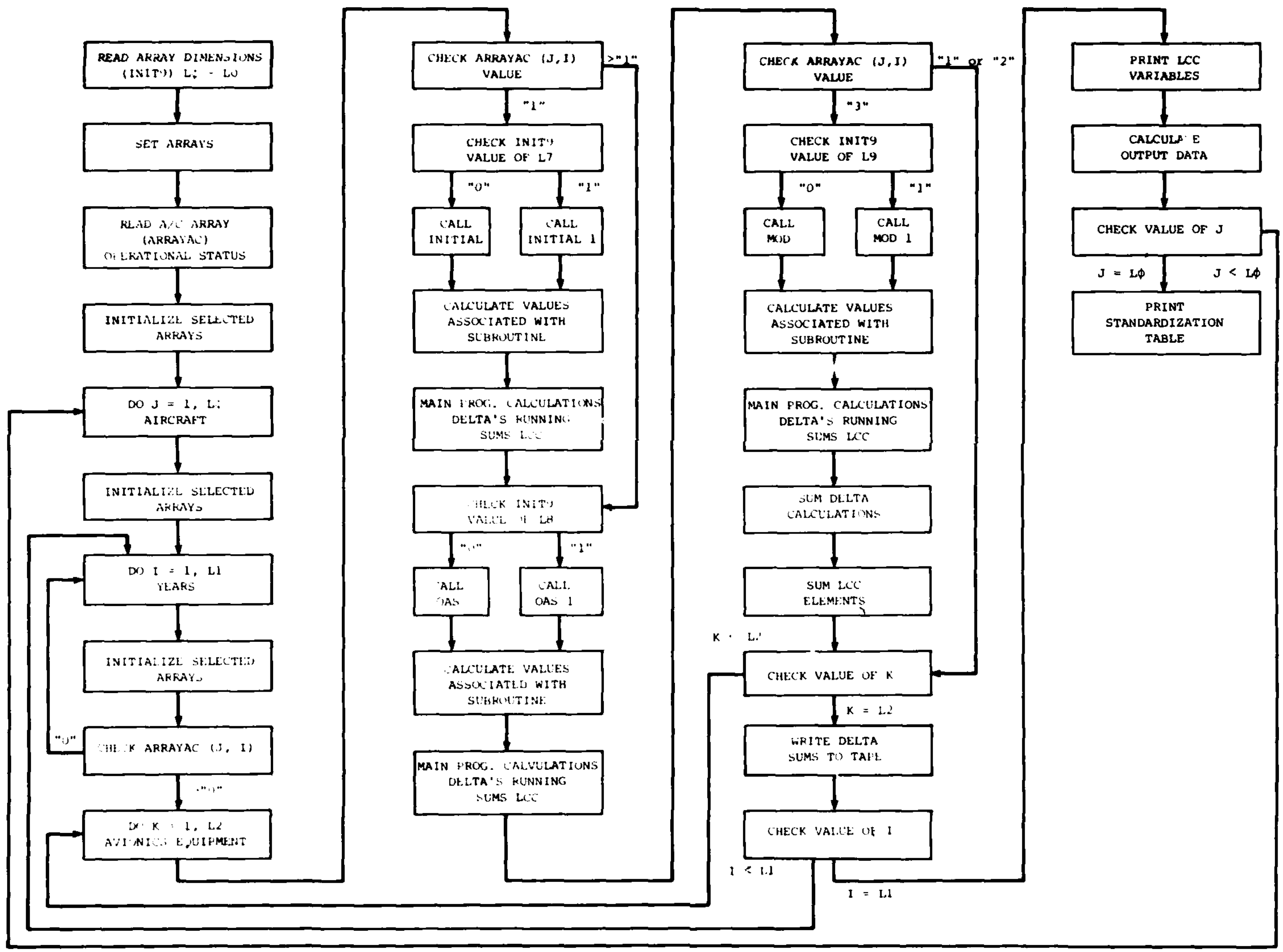

Figure E-1. P-M-C MODEL FLOW DIAGRAM

Table E-8. ARRAYAC VARIABLES		
Variable	Subroutines Available for Activation	Variable Description
0	None	Aircraft not operational that year
1	Initial 1 or Initial OAS 1 or OAS	Initial year of operation
2	OAS 1 or OAS	Operational this year
3	OAS 1 or OAS MOD 1 or MODD	Modification this year
4	Initial 1 or Initial OAS 1 or OAS MOD 1 or MODD	Additional initial equipment and modifications to existing equipment

The array format is such that the rows define aircraft type while the columns contain years. Therefore, the intersection of a row and column will have a 0, 1, 2, 3, or 4 in its place, depicting the operational status of that aircraft type for that year. The particular subroutines that are activated depend on the variables L7, L8, and L9 of INIT9, as shown in Table E-7.

Data for each cost area are set up in a dummy file that describes the aircraft type, year, avionics, and weighting factors for that particular aircraft type, year, and avionics. Data are entered in a prescribed manner as indicated in the read statement of the subroutine of interest. The data consist of the weighting factors (which are also entered in a prescribed manner) and the variables associated with the equations (as shown in Tables E-1 through E-6). A unique record format is used in entering the data that are read and converted to a unique record number, which the program uses to read and write to tape. The unique record format is straightforward -- the first aircraft type of interest is labeled "1", while the second is labeled "2", and so forth; the first year of interest is labeled "1", the second year is "2", etc; and the first avionics piece or group is labeled "1", and follows the same technique as for the aircraft type and years. Therefore, the third aircraft type in the seventh year for the fourth avionics would be indicated as "3, 7, 4". This unique record format is converted to a unique record number and is in a look-up table that has been previously computed.

The weighting factors used for this task are presented in Tables E-9 through E-11. A copy of the computer program has been provided separately to ASD/XRE.

Standardization Alternative	Present	I&D	GP-A	GP-B	Labor	O&S	MOD
Common Equipment							
PME	1.0	1.2	1.1	0.9	1.0	0.8	0.4
LRU	1.0	0.8	0.6	0.8	1.0	1.0	0.5
Rack/Mounting	1.0	0.8	0.6	0.8	1.0	1.0	0.4
Environmental	1.0	1.2	1.1	1.0	1.0	0.8	1.0
Common Power	1.0	1.1	1.0	0.9	1.0	0.9	1.0
Environmental Equipment							
PME	1.0	1.3	1.2	1.5	1.2	1.1	1.0
LRU	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rack/Mounting	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Environmental	1.0	1.3	1.2	1.5	1.2	1.1	1.0
Common Power	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mission-Unique Equipment							
PME	1.0	1.2	1.1	0.9	1.0	0.8	0.6
LRU	1.0	0.8	0.6	0.8	1.0	1.0	0.7
Rack/Mounting	1.0	0.9	0.8	0.9	1.0	1.0	0.6
Environmental	1.0	1.2	1.1	1.0	1.0	0.8	1.0
Common Power	1.0	1.1	1.0	0.9	1.0	0.9	1.0

Table E-9. WEIGHTING FACTORS FOR AIRCRAFT A

4. CREATING FILES

Creating files is a two-stage operation -- creating the space required for the data and calling a routine that reads the dummy files and restructures them into the files that the program will be calling, allocating unique record numbers, and packaging the data.

Since the cost of storing data is directly related to the space used for storage, it is essential that core space be allocated judiciously. A second factor to be considered is how often will the storage space need to be enlarged or decreased. If the core space required is going to vary significantly, it may be more cost-effective to place the core space in the largest size necessary and pay for the unused space than to incur the additional cost of computer time to recreate new file space and the unique record number look-up tables.

Table E-10. WEIGHTING FACTORS FOR AIRCRAFT B							
Standardization Alternative	Present	I&D	GP-A	GP-B	Labor	O&S	MOD
Common Equipment							
PME	1.0	1.2	1.1	0.9	1.0	0.8	0.4
LRU	1.0	0.8	0.6	0.8	1.0	1.0	0.5
Rack/Mounting	1.0	0.8	0.6	0.8	1.0	1.0	0.4
Environmental	1.0	1.2	1.1	1.0	1.0	0.8	1.0
Common Power	1.0	1.1	1.0	0.9	1.0	0.9	1.0
Environmental Equipment							
PME	1.0	1.2	1.2	1.0	1.2	1.0	1.0
LRU	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rack/Mounting	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Environmental	1.0	1.2	1.2	1.0	1.2	1.0	1.0
Common Power	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mission-Unique Equipment							
PME	1.0	1.2	1.1	0.9	1.0	0.8	0.4
LRU	1.0	0.8	0.6	0.8	1.0	1.0	0.5
Rack/Mounting	1.0	0.9	0.8	0.9	1.0	1.0	0.4
Environmental	1.0	1.2	1.1	1.0	1.0	0.8	1.0
Common Power	1.0	1.1	1.0	0.9	1.0	0.9	1.0

The required core space allocation is determined by an algorithm that makes use of the number of aircraft types, years of interest, and avionics classifications.

5. RUNNING THE PROGRAM

Running the program is straightforward once all the files have been created. However, there are a few lines in the program that may require changing if the data sets are going to be changed in the areas of the number of aircraft types, years of interest, or avionics classifications. If the program is going to be used for sensitivity analysis, then it is not necessary to make changes to the program. In fact, the program can be loaded and saved, which will decrease the overall cost when the program is to be run

Table E-11. WEIGHTING FACTORS FOR AIRCRAFT C							
Standardization Alternative	Present	I&D	GP-A	GP-B	Labor	O&S	MOD
Common Equipment							
PME	1.0	1.2	1.1	0.9	1.0	0.9	0.5
LRU	1.0	0.8	0.6	0.8	1.0	1.0	0.6
Rack/Mounting	1.0	0.8	0.6	0.8	1.0	1.0	0.5
Environmental	1.0	1.2	1.1	1.0	1.0	0.9	1.0
Common Power	1.0	1.1	1.0	0.9	1.0	0.9	1.0
Environmental Equipment							
PME	1.0	1.0	1.0	1.0	1.0	1.0	1.0
LRU	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rack/Mounting	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Environmental	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Common Power	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mission-Unique Equipment							
PME	1.0	1.0	1.0	1.0	1.0	1.0	1.0
LRU	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rack/Mounting	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Environmental	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Common Power	1.0	1.0	1.0	1.0	1.0	1.0	1.0

repeatedly with only perturbations to the data set. The program is run by simply saying "run" and citing the name of the program. Each time a change is made to the dummy data set, it is necessary to call the routine that updates the file and repacks the data. Once this is done, the program can be run again for the new output.

6. OUTPUT

The output from the computer model contains the following:

- Total LCC (and discounted LCC) for life span of aircraft
- Total LCC for each piece of avionics equipment

- Tabulated payback from each standardization alternative as a function of aircraft type and years

Typical tabulated output for the five standardization alternatives, as used in this task, are presented in Table E-12. These tables show the cost savings and discounted cost savings per year for all aircraft types of interest or for the lifetime of interest. Application of the remaining data output was used in the computations for sensitivity analysis as outlined in Chapter Four.

Table E-12. OUTPUT FOR STANDARDIZATION ALTERNATIVES

PMC COST BENEFIT SUMMARY IN THOUSAND DOLLARS (1979)

YEAR	AC-A	AC-B	AC-C	SUM	DSUM
1985	0.	0.	0.	0.	0.
1986	0.	0.	0.	0.	0.
1987	0.	-137.	-191.	-328.	-265.
1988	0.	180.	90.	271.	197.
1989	419.	655.	[illegible]	[illegible]	[illegible]
1990	3142.	1077.	412.	4630.	[illegible]
1991	3497.	782.	641.	4922.	[illegible]
1992	3649.	1945.	1655.	7351.	[illegible]
1993	3971.	1437.	1294.	6707.	[illegible]
1994	4460.	1487.	1167.	7115.	[illegible]
1995	4460.	1487.	1167.	7115.	3421.
1996	4460.	1487.	1167.	7115.	[illegible]
1997	4460.	1487.	1167.	7115.	[illegible]
1998	4460.	1487.	1167.	7115.	[illegible]
1999	4460.	1487.	1167.	7115.	1625.
2000	4460.	1487.	1167.	7115.	[illegible]
2001	4460.	1487.	1167.	7115.	[illegible]
2002	4460.	239.	122.	4821.	[illegible]
2003	4460.	239.	122.	4821.	[illegible]
2004	1102.	299.	122.	[illegible]	[illegible]
SUM	[illegible]	[illegible]	[illegible]	[illegible]	
DSUM	[illegible]	6514.	[illegible]		[illegible]

(continued)

Table E-12. (continued)

LRU PACKAGING COST BENEFIT SUMMARY IN THOUSAND DOLLARS (1979)

YEAR	AC-A	AC-B	AC-C	SUM	DSUM
1985	0.	0.	0.	0.	0.
1986	0.	0.	0.	0.	0.
1987	0.	532.	537.	1068.	865.
1988	0.	422.	260.	682.	497.
1989	10035.	1584.	909.	12527.	8219.
1990	11648.	2499.	1169.	15316.	9044.
1991	12160.	1514.	1796.	15470.	8221.
1992	12032.	2402.	2583.	17018.	8140.
1993	12032.	990.	1226.	14248.	6133.
1994	2627.	990.	837.	4454.	1725.
1995	2627.	990.	837.	4454.	1553.
1996	2627.	990.	837.	4454.	1398.
1997	2627.	990.	837.	4454.	1258.
1998	2627.	990.	837.	4454.	1132.
1999	2627.	990.	837.	4454.	1019.
2000	2627.	990.	837.	4454.	917.
2001	2627.	990.	837.	4454.	825.
2002	2627.	0.	0.	2627.	438.
2003	2627.	0.	0.	2627.	394.
2004	0.	0.	0.	0.	0.
SUM	84176.	17863.	15172.	117211.	
DSUM	37487.	7818.	6474.		51779.

RACK/MOUNTING COST BENEFIT SUMMARY IN THOUSAND DOLLARS (1979)

YEAR	AC-A	AC-B	AC-C	SUM	DSUM
1985	0.	0.	0.	0.	0.
1986	0.	0.	0.	0.	0.
1987	0.	482.	537.	1019.	826.
1988	0.	282.	260.	642.	468.
1989	5459.	1433.	909.	7800.	5118.
1990	6290.	2261.	1169.	9719.	5739.
1991	6566.	1369.	1796.	9732.	5172.
1992	6497.	2467.	2780.	11744.	5617.
1993	6497.	1188.	1435.	9121.	3926.
1994	3358.	1188.	1046.	5592.	2167.
1995	3358.	1188.	1046.	5592.	1950.
1996	3358.	1188.	1046.	5592.	1755.
1997	3358.	1188.	1046.	5592.	1579.
1998	3358.	1188.	1046.	5592.	1421.
1999	3358.	1188.	1046.	5592.	1279.
2000	3358.	1188.	1046.	5592.	1151.
2001	3358.	1188.	1046.	5592.	1036.
2002	3358.	0.	0.	3358.	560.
2003	3358.	0.	0.	3358.	504.
2004	0.	0.	0.	0.	0.
SUM	64893.	19086.	17251.	101231.	
DSUM	25164.	7935.	7120.		40268.

(continued)

Table E-12. (continued)

ENVIRONMENT COST BENEFIT SUMMARY IN THOUSAND DOLLARS (1979)

YEAR	AC-A	AC-B	AC-C	SUM	DSUM
1985	0.	0.	0.	0.	0.
1986	0.	0.	0.	0.	0.
1987	0.	-293.	-289.	-581.	-471.
1988	0.	-7.	-7.	-14.	-10.
1989	-3901.	-47.	-31.	-3979.	-2610.
1990	-2318.	-31.	-25.	-2375.	-1402.
1991	-2203.	114.	-32.	-2121.	-1127.
1992	-1941.	177.	2.	-1762.	-843.
1993	-1709.	299.	97.	-1313.	-565.
1994	1102.	299.	122.	1522.	590.
1995	1102.	299.	122.	1522.	531.
1996	1102.	299.	122.	1522.	478.
1997	1102.	299.	122.	1522.	430.
1998	1102.	299.	122.	1522.	387.
1999	1102.	299.	122.	1522.	348.
2000	1102.	299.	122.	1522.	313.
2001	1102.	299.	122.	1522.	282.
2002	1102.	299.	122.	1522.	254.
2003	1102.	299.	122.	1522.	229.
2004	1102.	299.	122.	1522.	206.
SUM	46.	3503.	1053.	4602.	
DSUM	-3834.	778.	75.		-2982.

COMMON POWER COST BENEFIT SUMMARY IN THOUSAND DOLLARS (1979)

YEAR	AC-A	AC-B	AC-C	SUM	DSUM
1985	0.	0.	0.	0.	0.
1986	0.	0.	0.	0.	0.
1987	0.	73.	-36.	37.	30.
1988	0.	202.	107.	309.	225.
1989	4009.	748.	367.	5123.	3361.
1990	5682.	1201.	485.	7368.	4351.
1991	6051.	794.	753.	7598.	4038.
1992	6119.	774.	787.	7680.	3673.
1993	6247.	150.	267.	6664.	2868.
1994	607.	150.	122.	878.	340.
1995	607.	150.	122.	878.	306.
1996	607.	150.	122.	878.	275.
1997	607.	150.	122.	878.	248.
1998	607.	150.	122.	878.	223.
1999	607.	150.	122.	878.	201.
2000	607.	150.	122.	878.	181.
2001	607.	150.	122.	878.	163.
2002	607.	150.	122.	878.	146.
2003	607.	150.	122.	878.	132.
2004	607.	150.	122.	878.	119.
SUM	34779.	5588.	4068.	44434.	
DSUM	16429.	2661.	1791.		20880.