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THE COSTS AND BENEFITS OF PRE-PLANNED PRODUCT IMPROVEMENTS FOR THE CONSOLIDATED AUTOMATED SUPPORT SYSTEM (CASS)

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The purpose of this study was to estimate the costs and benefits of Pre-Planned Product Improvements (P^3Is) to the Consolidated Automated Support System (CASS). CASS was designed in the late 1980s to early 1990s to eventually become the Navy's single tester for avionics, and is presently the most comprehensive general-purpose automatic test equipment in the Department of Defense. There is now interest in the Navy, OSD, and the Congress in further expanding the capability of CASS to test the new, emerging avionics systems, and also in applying CASS to Navy shipboard electronics, as well as electronics for the Marine Corps, Army, and Air Force. This study contributes to the improvement effort by constructing and analyzing a list of candidate P^3Is that appear worthy of follow-on detailed engineering analysis. The costs of the improvements are estimated by the expenses of procuring the equipment (and supporting software), integrating the system into the CASS, and operating and supporting the new capability at operational sites. The benefits of the P^3Is are estimated by their ability to test the emerging avionics systems that are being designed for new Navy and Air Force aircraft (F/A-18E/F, F-22, and A/F-X).

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PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) for the Office of the Assistant Secretary of Defense (Production and Logistics) under a task entitled "Pre-Planned Product Improvements for Consolidated Automated Support System (CASS)." The objective of this task is to identify options for Pre-Planned Product Improvements to CASS and to assess the costs and benefits of these options in meeting the automated test equipment requirements of the Navy, Marine Corps, and other services.

This work was reviewed within IDA by Bruce R. Harmon, Stanley A. Horowitz, Robert M. Rolfe, Herbert R. Brown, and William J. E. Shafer.

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EXECUTIVE SUMMARY

This report describes an analysis by the Institute for Defense Analyses of Pre-Planned Product Improvements (P^3Is) for the Consolidated Automated Support System (CASS). The work was performed for the CASS Program Office (PMA-260) in the Naval Air Systems Command, and was sponsored by the Office of the Assistant Secretary of Defense (Production and Logistics) [OASD(P&L)].

CASS is being developed by the Navy to become the single test system for all Navy avionics. It's development is part of a major, long-term effort by the Department of Defense (DoD) to reduce the cost of testing by developing a small number of highly-capable, multi-purpose testers to replace the many unique testers tailored for individual weapon systems.

The multi-purpose feature is not an entirely new idea; the Navy's VAST system was such an attempt. However, the new electronics technologies of "instruments on a card" and open architecture offer the joint benefits of wider applicability and expandability at lower cost. First, development and procurement costs should fall by avoiding the need to develop a separate new tester for each new weapons system. Multi-purpose testers with open architectures can meet the testing needs of new avionics systems by adding new functionalities and ancillary equipment (power, cooling, etc.) at relatively small incremental cost.

Multi-purpose, or comprehensive testers should also lead to savings in operating and support costs as fewer people and smaller stocks of spare parts are needed to maintain a smaller number of testers. For example, although an aircraft carrier with a single comprehensive tester would need enough people and parts to handle the workload, it would not have to maintain a team of trained people and stock spare parts to support each one of a variety of unique testers that might be used only part-time. Training costs would decrease through reductions in the number of instructors and training courses.

To date, the DoD has developed two comprehensive testers. CASS is the most advanced. The Army's Integrated Family of Testers (IFTE) has similar coverage to CASS, but is less capable in some areas mentioned in Reference [1]. The present study focuses on CASS alone.

CASS is a state-of-the-art system in both coverage and technology. According to an IDA DoD-wide strategic investment study [1], CASS has greater capability than any other unique or consolidated avionics tester that DoD has ever developed, being able to meet over 95 percent of the current testing needs of the F-15, F-18, and AH-64, as well as the anticipated needs of the F-22.

The timeliness of the CASS technology was ensured by a feature of the Navy's contract with the General Electric Corporation, the system's developer. The test requirements (voltages, pulse widths, etc.) were defined by specifications delivered at the front panel, rather than produced by individual instruments. Moreover, these front-panel specifications were chosen to anticipate the stimulus and measurement instruments that would be available in 1992, when production was to begin. The developer thus had the freedom and incentive to incorporate new architectures, as well as new instruments. For example, the RF (Radio Frequency) portion of the tester is now being built using the Modular Measurement System (MMS), a new open architecture that has been developed to process low-power, high frequency signals.

Although the current CASS system possesses the capability for testing current and emerging Navy avionics systems, Congress, OSD and the Navy's CASS Program Office are now interested in further developing CASS to take maximum advantage of the efficiencies and low-cost expansion capabilities of consolidated testers designed with flexible architectures. The intention is for CASS to grow in two dimensions. The first is time: developing the capability to become the Navy's single avionic tester in the next decade and through the year 2015, as new weapons are developed and the existing unique (single-purpose) testers retire. The second dimension of growth is an expansion in the role of CASS beyond Navy avionics so that it can perform the testing of avionics and other electronic systems of the three services.

A word on the scope of this study. The capability of a tester to diagnose avionic problems depends critically on three major components: the station hardware, the station software, and the Test Program Sets (software, cables, and interface devices, or IDs) that mediate between the test station and the avionic units under test. The present study, however, is limited to analyzing improvements in only one of these components, the station hardware.

We have made no systematic study of TPSs, whose IDs can themselves contain stimulus and measurement instruments that contribute to the overall capability of the tester. Station software, also neglected in the present research, will be a major area of analysis in a planned follow-on study. That study will analyze improvements in both the development of test software and the application of the software in the runtime environment. The study will also explore the possible benefits to TPS development (lower cost, improved scheduling) resulting from improved test environments such as ABBET (A Broad-Based Environment for Test), as well as new commercial test strategies and software approaches.

Even in its present state, however, the CASS station is a highly capable system that, with the appropriate TPSs, will be able to test virtually all avionic systems that are both existing and currently under development [1].

The Navy still retains many of the older, unique testers tailored for the older weapon systems. However, these old testers will be retired in the coming years as the old weapon systems retire and are replaced with new ones. Our focus, in this study, is on the next decade and beyond, when all these changes have occurred and CASS becomes the Navy's single avionics tester. The question for analysis is, what improvements to CASS should the Navy be making now, in anticipation of its future role. The study is further limited to consideration of improvements to the station itself. We have not addressed the broader issue of what total configuration, station plus TPSs (which number in the thousands) the Navy should be working toward. The implication is that while the P^3I we recommend would improve the ability of the CASS station to diagnose avionic problems, it is *not* true that these avionics problems would necessarily go unsolved if the improvements were not made. New functionality can be built into the TPSs as well.

The study's research consists in assembling a list of P^3Is that will equip the CASS station for its future role, and then evaluating the costs and benefits of the improvements. Most of the analysis is limited to improving the testing of Navy and Air Force avionics. Time was not available to study improvements to enable CASS to test other electronics. Although the improvements are defined by specific electronic instruments for purposes of estimating costs and benefits, the analysis is not a "bottom up" engineering analysis. Rather, the study's objective was to assemble enough information on costs and benefits to identify P^3Is that appeared worthy enough for the CASS Program Office to commission more detailed engineering analysis leading to final judgments regarding implementation. As part of the study, we evaluated the extent to which the P^3Is would improve the ability of CASS to meet a coherent set of future anticipated test needs constructed from specifications developed by the Joint Integrated Avionics Working Group (JIAWG), and features being incorporated in the Common Automatic Test System (CATS), the factory tester for the F-22.

Although we have considered more than one option in analyzing several of the P^3Is, our recommendations are largely judgments about whether the benefits appear to justify the costs. The study is therefore not a tight comparison of alternatives in which cost or effectiveness is held constant.

Ideas for P^3Is were obtained by consulting Navy personnel, civilian analysts, and contractors involved in the CASS development program. Other ideas for improvement were obtained through discussions with the avionics and testing communities. The focus of these improvements are to anticipate testing needs that will emerge in the next decade and beyond, until the year 2015. We assume that the Navy will retain some of the existing testers in the intervening years to handle any special needs of the older systems until they retire.

The costs of the P^3Is were estimated by the annual recurring and non-recurring costs of acquiring the equipment, integrating it into CASS, and supporting the improvement during the 1993-2003 time period. The time of implementation was chosen somewhat arbitrarily, by considering the availability of new test instruments and ATE technology. Although most of the equipment was commercial-off-the-shelf (COTS), the commercial prices were adjusted by several factors to allow for ruggedization, future price reductions due to technology trends, and quantity discounts for the purchase of hundreds of units. Allowances were included for integrating the equipment and software into CASS. Annual costs for operating and support (O&S) were included in total cost. The study did not, however, analyze "total system" issues such as where the equipment might be placed in the CASS station, whether new racks would be required, and whether the improvement would require bringing in more power and cooling. These questions can best be answered after the CASS Program Office has completed the detailed engineering analyses and decided on which combination of improvements to implement.

The benefits of the P^3Is were evaluated primarily by their ability to test the expected future avionics systems. Another benefit is the ability to accomplish tests at reduced cost and time. These benefits were evaluated by assembling available information. Although more than one alternative was studied in many of the areas of improvement, and much of the benefit information appears compelling, the study group's recommendations are finally based on qualitative judgments regarding the measures of cost and the gains in effectiveness. It would therefore be useful, in deciding which P^3Is to implement, to perform a mission-based analysis of test requirements, in addition to the detailed engineering studies of the P^3Is mentioned above. Such an analysis would determine which test capabilities were most necessary for maintaining the ability of military aircraft to perform their missions.

Other caveats are that the study does not address the implications of CASS P^3Is on the number and training of maintenance technicians, and it does not consider other alternatives for improving readiness such as increasing the stock of avionics spares and relying more heavily on depot-level repair. Finally, the study does not compare the costs and benefits of improving the CASS station hardware with other ways of obtaining additional test capability: improving the station software, adding instruments to the interface devices of Test Program Sets, procuring more CASS stations, and meeting the test requirements of new aircraft by the traditional technique of designing a unique (single-system) tester for each new weapon system.

As a result of the analysis, the study recommends the P^3Is in the following list for follow-on engineering study during the remainder of this decade, for possible implementation early next decade. The information in parentheses indicates the principal areas of benefit (improved diagnostic capability, reduced test time) and the total acquisition and O&S cost during the years 1993-2003. The study does not quantify the effect of improved diagnostics or reduced test time on more ultimate measures of effectiveness such as maintenance throughput and mission-capable rate. The total 10-year cost of the recommended P^3Is, acquisition plus O&S, is approximately $650 million in discounted dollars.

1. Replace the current VAX-3800 in all 662 CASS stations with a new VAX-4000/90 computer (reduced test time; $9 million *savings*).
2. Add station interfaces to all CASS configurations to accommodate the new communication buses being designed by the Joint Integrated Avionics Working Group (JIAWG) for the F-22 and follow-on aircraft (improved diagnostics and reduced test time; $46 million).
3. Add a bus analyzer to all configurations to help diagnose problems in the MilStd-1553 bus that is used to communicate signals between avionics systems on many aircraft (reduced test time; $11 million).
4. Add another arbitrary waveform generator to all configurations in response to needs expressed by engineers who are re-hosting F-14 TPSs to CASS (reduced test time; $24 million).
5. Add more channels, pins, memory, and boundary scan capability to the Digital Test Unit located in all configurations to give it the ability to test new digital avionics systems (improved diagnostics; $93 million).
6. Add an array processor to all configurations to generate real-time signals for testing radar signal processors (improved diagnostics; $21 million).

7. Add a bit error rate tester to the RF and CNI configurations to aid in diagnosing problems with digital equipment (improved diagnostics; $52 million).

8. Add a phase-noise tester to the radio frequency (RF), electro-optical (EO), and communication, navigation, and identification (CNI) stations (improved diagnostics; $70 million).

9. Add a noise-figure tester to the RF and CNI configurations (improved diagnostics; $58 million).

10. Add a millimeter wave source to the RF and CNI configurations to generate high-frequency signals to test missiles that operate above the X and Ku bands used by aircraft radar (improved diagnostics; $26 million).

11. Add a high-power tester to enable the RF and electro-optical (EO) configurations to test newer radars and electronic warfare systems (improved diagnostics; $220 million, excluding a phase noise tester and array processor provided separately).

12. Add more switching to the RF interface in the RF and CNI configurations to avoid the costs of obtaining the capability by creating active interface devices (IDs) in the TPSs (reduced test time; $36 million).

13. Add a cockpit display tester to the RF, CNI, and EO configurations, in order to diagnose problems in the electronics and displays that convey sensor and other information to pilots and electronics officers in real time (reduced test time; $9 million).

I. ANALYSIS

This report presents the findings of a study by the Institute for Defense Analyses (IDA) of Pre-Planned Product Improvements (P^3I) for the Consolidated Automated Support System (CASS). The study was sponsored by the Office of the Secretary of Defense (Production and Logistics) [OASD(P&L)] in support of the CASS Program Office, Naval Air Systems Command, PMA-260. The report is divided into four chapters. This chapter, Chapter I, describes the background of the study, presents the methodology of the analysis, gives a brief description of each P^3I, and presents the findings and recommendations. Chapter II presents a detailed discussion of each P^3I we recommend for action by the CASS Program Office, Chapter III describes those P^3Is we do not recommend, and Chapter IV presents the information we have assembled on ideas for possible improvements that have not been fully analyzed. An appendix contains an extended discussion of emerging avionics.

A. BACKGROUND

The Office of Secretary of Defense has embarked on a major, long-term effort to reduce the cost of testing avionics and other electronics. The thrust of the effort is to develop families of highly-capable, multi-purpose testers that will eventually replace the multitude of existing, single-purpose testers that are each tailored to a single weapon system.

Using multi-purpose testers should reduce the costs of RDT&E (Research, Development, Test and Evaluation (RDT&E) and O&S (Operations and Support). Development costs will be reduced by avoiding the design of a new tester every time a service develops a new weapon system. Developing a new tester requires ground-up design and development of power and cooling systems, test instruments, computer and control circuitry, and input and output ports. Alternatively, if the service uses an existing multi-purpose tester such as CASS, the development costs would be limited to the incremental costs of adding any new testing functionalities or ancillary capabilities that may be required (stimulus or measurement instruments, power, cooling, etc.).

Multi-purpose testers will also reduce O&S costs because the services will not have to provide as many spare parts and maintainers to support weapon system-specific testers.

An aircraft carrier, for example, will still need to maintain enough technicians and parts to handle the workload; it will not, however, have to stock a full set of these resources for each tester that might be needed only part-time. Training costs would be reduced because fewer instructors and training courses would be required.

The Department of Defense has already begun the transition to multi-purpose testers. The Navy has developed the Consolidated Automated Support System (CASS), and the Army has developed the Integrated Family of Test Equipment (IFTE). IFTE has similar coverage to CASS, but is less capable in some areas, as mentioned in Reference [1]. The present study focuses on CASS.

The Navy is developing the CASS to become the standard automatic test equipment (ATE) system for all Navy avionic systems. It will be installed in Aircraft Intermediate Maintenance Departments on aircraft carriers and ashore, and at Naval Depots. There are also plans to put commercial versions of CASS stations at systems development and production sites in order to obtain the efficiencies of using a single, consolidated tester during the entire history of a weapon system, from development through operation.

When this study was begun in the fall of 1992, the General Electric Corporation (Automated Systems Division) was the prime contractor, and Martin Marietta was the *second source.* The GE division was acquired by Martin Marietta in April 1993. When the bulk of the present analysis was carried out, the Navy had completed an initial Technical Evaluation (TechEval) and Operational Evaluation (OpEval). Although some problems were uncovered during these evaluations, leading DoD to arrange for a second set of evaluations, CASS performed well enough to lead DoD to justify Low-Rate Initial Production (LRIP). Contracts had been signed for 55 stations under LRIP 1 and 60 stations under LRIP 2 (plus 15 Pre-Production stations). That is the state of production assumed in the analysis carried out in this report.

CASS has recently had further successes. Given the improvements GE made following the initial evaluations, CASS recently passed the second TechEval. The second OpEval has been completed, but the results have not yet been released. Early indications, however, suggest that CASS received high marks. An LRIP 3 contract was recently signed for 70 stations, and Martin Marietta has submitted the proposal for Lot 4 (63 stations) to the Navy.

CASS is a state-of-the-art system in both coverage and technology. According to an IDA DoD-wide strategic investment study [1], CASS has greater capability than any other unique or consolidated avionics tester that DoD has ever developed. In terms of coverage, it meets over 95 percent of the testing needs of the F-15, F-18, and AH–64, as well as the anticipated needs of the F-22.

The timeliness of the CASS technology was ensured by a feature of the Navy's contract with the General Electric Corporation, the system's developer. Test requirements were defined by specifications (voltages, pulse widths, etc.) delivered at the front panel, rather than produced by individual instruments. Although much of the development work was performed in the mid-1980s, these front-panel specifications were selected to anticipate the stimulus and measurement instruments that would be available in 1992, when production was to begin. The developer thus had the freedom and incentive to incorporate new architectures, as well as new instruments. For example, the RF (Radio Frequency) portion of the tester is now being built using the Modular Measurement System (MMS), a new architecture developed to process low-power, high frequency signals.

Although CASS possesses the technology for testing current and emerging Navy avionics systems, Congress, OSD, and the Navy are now interested in further developing CASS to take advantage of the efficiencies of consolidated testers designed with flexible architectures. Growth is desired in two dimensions, the first being time. As older weapon systems are deactivated during the remainder of this decade, the Navy will also be retiring the unique testers tailored for these weapons in order to achieve the cost savings promised by CASS. At the same time, new systems will be designed to replace the old. We must therefore take steps now to develop CASS for its intended future role as the Navy's single avionics tester. The present study focuses on improvements designed to test avionics that will be developed in the next decade and beyond.

The second dimension of growth is the scope of the mission of CASS. Because of the efficiencies and expansion capabilities of consolidated testers designed with flexible architectures, CASS is an attractive candidate to become the general-purpose tester for all DoD electronics.

To achieve the goals of a comprehensive tester for all military electronics in the next decade and beyond, CASS must evolve to address:

- new developments in aircraft avionics that are expected to occur in the next decade,
- new developments in ATE technology, both hardware and software, and
- new testing missions:
  - additional Navy electronics, including missiles and shipboard systems
  - avionics and other electronics for other services (Marine Corps, Air Force, and Army).

The expected future developments in aircraft avionics are discussed in detail in the Appendix. A major trend is the development of sensors with greater capability. Radars are increasing in processing capability in order to detect low-observable targets and to pick out moving vehicles from ground clutter at longer ranges. Infrared (IR) imaging sensors are being developed with higher resolutions to detect and distinguish between targets at longer ranges. Sensor fusion techniques are being developed to coordinate the data from all sensors. Digital avionics systems with higher clock speeds and faster data rates are being developed to handle the increased flow of information. Conventional computer systems are being replaced with integrated systems that share in the information processing rather than being dedicated to narrowly-defined tasks.

New testing technologies are being developed in parallel with the new avionics. New computers offer improvements in cost, size, and capability. Digital testers are being developed with higher clock speeds, faster data rates, and new technologies such as the "boundary scan" test method that promises major increases in diagnostic capability through built-in-test circuitry. New analog test instruments are also being designed. By equipping CASS with these new ATE technologies, the Department of Defense (DoD) will be able to realize not only future savings in the cost of testing, but also improvements in readiness. Cost will be saved through reductions in the number of personnel and stocks of spare parts. Training costs will fall, as well. Readiness will increase as improved diagnostic ability leads to lower test times, higher maintenance throughput, and thus provide the capability for higher sortie rates.

New ATE technologies can also increase the role of CASS in tri-service testing. Although CASS was originally intended to test Navy avionics, the Navy, the Office of the Secretary of Defense (OSD), and the Congress are focusing attention on using CASS to test Navy missiles and shipboard electronics, the new avionics systems operated by the Marines, Air Force and Army, and the new vehicle electronics (vetronics) employed by Army tanks and other ground weapons.

In order to enable CASS to meet these future demands and opportunities for improved readiness and cost savings, the CASS Program Office is committed to a program of Pre-Planned Product Improvements (P^3Is). Deciding which P^3Is to fund is a question of costs and benefits, and OASD(P&L) and the CASS Program Office have asked IDA for analysis in this regard.

We used the Prime Item Development Specification [2] as the definition for CASS in this study. The approved program is sized at 720 systems, including the 58 Common Test Set (CTS) stations that are devoted to missile testing and that are being developed separately. This study does not address the CTS stations; it deals only with the 662 stations that consist of four configurations: hybrid, radio frequency (RF), communication, navigation, and identification (CNI), and electro-optical (EO).

B. ANALYTICAL TASKS

The task order calls for reviewing prior cost-benefit analyses of CASS as well as service plans for evolving avionics and other electronics, the development of new ATE technologies, and new weapon system support concepts such as the Air Force's two-level maintenance. Based on these reviews, the study is asked to construct a list of candidate P^3Is and analyze them by their life-cycle costs and operational benefits. The P^3Is should include those that would help CASS meet not only Navy testing requirements through 2015 but also the testing needs of the other services. In addition to addressing the testing of avionics, we were asked to consider, if funding and schedule allow, improvements relating to the test of shipboard electronic and missile systems.

The objective of the study is to first develop a list of candidate P^3Is that appear to offer capability to CASS, and to then assemble enough information on the costs and benefits of these improvements to indicate those that appear worthy enough to justify more detailed engineering and costing. As a related goal, we evaluated the extent to which the P^3Is improve the ability of the CASS station to meet a coherent set of anticipated future test needs defined by the Joint Integrated Avionics Working Group (JIAWG), and specifications being designed into the Common Automatic Test System (CATS), the F-22 factory tester.

Although some of the P^3I analyses consider more than one option, our recommendations are generally judgments of whether the benefits appear to justify the costs. The study is not a cost-effectiveness study in the sense of a tight comparison of alternatives holding either cost or effectiveness constant.

The following sections describe our efforts to carry out the major steps of the analysis: identifying candidate P^3Is, estimating their cost, and evaluating their benefits.

C. METHODOLOGY

1. Developing Candidate P^3Is

We constructed a list of P^3Is by studying those trends in avionics that determine the emerging needs for testing, identifying testing requirements that would improve the testing capability of the CASS station, and identifying equipment that would enable CASS to meet these needs. The P^3Is fall into two general categories: instruments such as noise meters that improve diagnostic ability, and those such as a new computer that reduce test time.

The list of candidate P^3Is was constructed through discussions with people in the avionics, CASS, and ATE communities:

- Navy offices that manage the CASS program
  - PMA-260 in the Naval Air Systems Command
  - Air-552 in the Naval Air Systems Command
- CASS contractors
  - GE, Daytona Beach
  - Martin Marietta, Orlando
- Service laboratories and technical facilities
  - Naval Air Warfare Center Aircraft Division (NAWCAD), Lakehurst
  - NAWCAD, Warminster
  - Point Mugu Program Management and Test Measurement and Diagnostic Equipment, Huntsville
  - Patuxent River Naval Air Station
  - North Island Naval Air Station
  - Wright-Patterson Laboratory
- Test equipment manufacturers
  - Hewlett Packard
  - Teradyne
  - Racal Dana
  - Tern Technology, Inc.
  - General Dynamics Electronics
  - Hughes Aircraft Corporation
  - Support Systems Associates, Inc.
  - Pentastar (part of Chrysler Corporation) Electronics and Space Corporation
- Test Program Set (TPS) developers
  - TPS Integration Facility, Norfolk
  - TPS Integration Facility, Jacksonville
  - TPS Integration Facility, North Island
  - Grumman, Long Island
  - Hughes Radar Systems Group
- Analysts working in IDA's Computer and Software Engineering Division

The study team also obtained information from a considerable number of reports on avionics and ATE technology. Some of the reports are listed in the references at the end of the paper. Based on all this information, we formed a list of those P^3Is that appeared attractive enough to justify study of their costs and benefits. Not all of the ideas for improvements were original with us; many were obtained from the people with whom we talked.

In assembling our list of P^3Is, we focused attention on the avionics of the new Navy and Air Force aircraft: the F-22, the F/A-18E/F, and the A/F-X. Missile testing received less attention, and there has not been enough time to consider the testing needs of Navy shipboard electronics, or Army avionics and vetronics.

We restricted the scope of improvements to those that might be worthy of development and procurement funding during the remainder of this decade. We thus ignored technologies that are still in basic research: superconductivity, wafer scale integration, virtual reality, optical computers, and artificial intelligence.

The P^3Is are defined and analyzed at a level of detail that is consistent with the purpose of the study, which is to help the CASS Program Office decide which improvements are worth pursuing in more engineering and cost detail. Although we have dealt with specific instruments listed in the catalogs of specific vendors for purposes of determining general specifications and costs, we have not made a systematic study of which instruments produced by which vendors are best. We leave it to those doing the follow-on engineering studies to decide on detailed numerical specifications and to select which designs of which vendors are best in terms of cost and performance.

The findings of this study can also be used to estimate how much to budget for P^3Is in the future, even if the particular specifications require more engineering analysis. As another budgeting issue, we have not tried to determine whether the improvements we have considered would, or would not involve a change in the scope of the current program.

As another point of methodology, we acted on the philosophy of the Program Office that CASS should look to the future. We thus focused on improvements that would enable CASS to meet the testing needs of emerging avionics, rather than the requirements of the older weapon systems that the current version of CASS may not be able to meet. The assumption is that the Navy can retain the existing ATE systems long enough to test the older weapon systems until they retire. As an example, the Navy can rely on older testers to handle the 28-volt digital systems of older weapons such as the Mk-46 torpedo, rather than modifying the current CASS Digital Test Unit. Replacing the older testers with CASS will, in any case, be a process lasting through this decade, given the fact that the CASS procurement program will not be completed until 2003.

To avoid overlooking candidate P^3Is that were worthy of consideration, we have compared our list with two compilations of CASS deficiencies retained at NAWCAD, Lakehurst. The first list contains "Exception Reports" obtained by feeding the characteristics of avionics units under test (UUTs) into the Systems Synthesis Model

(SSM) developed by Lakehurst. The SSM outputs those characteristics that cannot be tested by the current CASS without some additional capability added to the interface devices (IDs). In a recent run, Lakehurst used the SSM to analyze 2,500 avionics UUTs comprised of both weapon-replaceable assemblies (WRAs) and shop-replaceable assemblies (SRAs) for the F-14, the F/A-18A/B/C/D, and other aircraft. (WRAs are electronic "boxes" composed of SRAs, the electronic "boards.") The Lakehurst analysis indicated that CASS is providing 80- to 90-percent coverage, close to the goal set by the Program Office. We did not obtain ideas for P^3Is from the Exception Reports because the output of the SSM provides no information on either the number or extent of the problems. It only states, for each CASS specification, whether there is at least one UUT that cannot be fully tested. A CASS specification that is one volt shy on one UUT produces the same negative report as a specification that is deficient by 10 volts and 50 percent pulse width on 100 UUTs.

The second list of deficiencies is the System Problem Reports (SPRs) submitted to Lakehurst by Navy and contractor people who have been working with CASS during TechEval and OpEval, and during the process of developing TPSs. We analyzed the 83 SPRs contained in the Lakehurst report, approximately one half of the 153 SPRs received through February 1993. Table 1 summarizes the topics covered. Of those that are software-related, about half refer to functionality that could usefully be added. These all appear, however, to require only minor software changes, the kind that might be handled by ECNs, not P^3Is. Of the 24 percent of the SPRs that are hardware-related, about two-thirds involve documentation and minor mechanical discrepancies. Most of the other hardware items fall within current specifications requirements that would likely be handled by ECNs. The only hardware SPR that might be a potential P^3I is a case in which engineers who were testing a WRA found they needed 17 power supply sources, more than the 11 in the current CASS design. We have not analyzed this potential P^3I further.

2. Costing Methodology

This subsection presents a description of the cost model, first in general terms, and then with an example. The focus is on the direct costs of the P^3Is, the development, procurement and O&S expenses associated with making the improvement. The section ends with a brief discussion of a major *indirect* cost implication of P^3Is, the effect they have on the time and cost of developing TPSs.

Table 1. System Problem Reports

Type of Problem	Percent
Software	
Functional	38.6
ATLAS	19.3
Documentation	13.3
Compiler	2.4
Security	2.4
Total software	76.0
Hardware	
Documentation	8.4
Mechanical	8.4
Functional	3.6
Reliability	3.6
Total hardware	24.0
Total	100.0

Once the Navy and Martin Marietta have done the initial planning for an improvement (whose costs we have not included), making the improvement to CASS will involve three major steps: (1) Martin Marietta will buy the equipment from the producer, (2) Martin Marietta will integrate the equipment into CASS, and (3) DoD will maintain the improved stations at operational sites afloat and ashore. These steps will be discussed in detail.

The CASS design has a flexible architecture that is compatible with commercial-off-the-shelf (COTS) equipment that represents the leading-edge technology. Therefore, most of the P^3Is involve COTS equipment, and for these improvements the purchase costs are solely recurring costs, which we estimated by starting with catalog prices and making three multiplicative adjustments. (Non-recurring costs were added in for the few P^3Is that involve new development.)

The first adjustment is a "military price" factor to pay for meeting environmental requirements. As a general matter, electronic instruments are classified in four grades: commercial, industrial, ruggedized, and military. Many test instruments, even those that are called COTS, are produced to industrial standards, and we assumed that this is the case for the equipment in the P^3Is we have analyzed. We assumed, however, that P^3I equipment should be modified, either by the producer or by Martin Marietta, to meet the next higher classification, ruggedization. (We rejected the full military standard on grounds that CASS is not placed in the most demanding military environment. Except for Marine Corps vans, the installations are permanent, rather than mobile, and even shipboard units are installed on aircraft carriers, which give them some protection from extremes of temperature, shock, and vibration.) We multiplied the vendor prices by a factor of 2.0 to allow for the cost of ruggedization. This factor was obtained from cost data in Reference [3], which showed that the ratio of ruggedized to industrial equipment for various types of computer electronics varied from 1.26 to 2.05.

Next is a "technology trend factor" that assumes that present trends in the price of electronics will continue in the future. For the computer-related P^3Is (the station computer, the array processor, and the digital test unit), we used a multiplicative factor of .75 derived in a detailed IDA analysis [4] that found that the prices of microcomputers (for constant capability) fell by 25–30 percent annually in constant dollars during 1984–92. The other P^3Is were assumed to fall much less, 1.2 percent annually in constant dollars, based on the experience during 1984–92 in the Bureau of Labor Statistics price series for Standard Industrial Classification 3825, "Instruments for Measuring and Testing of Electricity and Electrical Signals." (The Bureau of Labor Statistics price indices are in then-year dollars, and were divided by the Consumer Price Index to convert the indices to constant dollars before calculating the yearly trend.) For each P^3I, the yearly price trend was applied from now (1993) until the start of development (discussed later).

The last adjustment is a "quantity discount factor" that Martin Marietta would likely receive because of the large buy of hundreds of items. We assumed a multiplicative factor of 0.85 (a 15-percent discount). The commercial price multiplied by the three adjustment factors we have just discussed yields the "net price."

The costs that Martin Marietta pays to install the equipment into CASS is the sum of three factors. First are the non-recurring "integration" costs of modifying the station mechanical and electrical hardware, adding software to handle the new functions, designing new cables, writing new documentation, and performing test and evaluation of the modified CASS. The integration cost was obtained by multiplying the interface cost (described next) by 100, a factor derived from a detailed study of avionics costs carried out by IDA [5]. Data in Table 6 of that study showed that for 17 aircraft avionic systems, the ratio of Engineering and Manufacturing Development cost to 100^{th}-unit procurement cost clustered around a mean of 147 with a standard deviation of 139. We used a ratio of 100 because test equipment involves less severe design requirements than avionics. Second is the recurring "interface" cost of new cables and other fixtures. This is assumed to be 20 percent of the net price, which was GE's experience with a typical instrument, the Digital MultiMeter (DMM). Last is the allowance for "profit and general and administrative (G&A)," which was applied to both recurring and non-recurring costs. We estimated profit plus G&A at 15 percent of the net price plus the interface cost. (This profit plus G&A rate may be too low, but it has only a small effect on total cost. A sensitivity test indicated that doubling the rate adds only 13 percent to total cost.) Note that although those P^3Is that involve COTS equipment have no *producer* development costs, they do impose development (non-recurring) costs of integration.

The last two cost elements are those DoD pays for directly. First is the recurring cost of "support investment" for spares, peculiar support equipment, documentation, and so on. This was estimated at 26 percent of the sum of net price, interface, and profit and G&A. The 26-percent ratio was derived from a detailed CASS cost analysis performed by the Naval Aviation Maintenance Office at Patuxent River, Maryland [6]. It is the ratio of spending during 1990–2000 for technical publications, supply support, support equipment, and computer resources ($231.8 in FY 1994 dollars) to the total station cost ($893.6 million). Last is the recurring annual O&S costs for manpower, materials, and equipment to maintain the improvement. We estimated unit annual O&S costs at 10 percent of the sum of net price, interface, and profit and G&A, drawing on the study by the Naval Aviation Maintenance Office [6]. The Patuxent analysis found that O&S costs were 9.77 percent of recurring costs. Annual O&S cost (i.e., for all units) was calculated by multiplying 10 percent by the total number of CASS stations that had been produced up to that year.

The cost model thus estimates cost by starting with two basic inputs, the producer price and the development cost, and calculating the other elements using simple factors derived from other studies and the experience of the study members. The basic inputs for each P^3I are listed in the general definitions of the P^3Is in the remainder of this chapter, as well as in the more detailed material in Chapter II.

The time aspects of the estimates were handled as follows. We chose a time horizon from now (1993) to the year 2003, the end of the CASS procurement program. For each P^3I, we selected a "start of development" year at which the development (non-recurring) costs would first be incurred. The selection of the development year was a judgment call that takes note of when the technology would be available.

The development costs are spread over one or two years, depending on the amount of development effort the P^3I would seem to require. The process of procuring the P^3I—purchasing the equipment and installing it in CASS stations—would commence at a "start of procurement" occurring after development is completed. Procurement would proceed at a constant yearly rate until 2003. For example, if the P^3I begins procurement in 1996 and is to be installed in all four configurations (662 stations in all), there would be 662/8, or approximately 83 installations annually for eight years. Alternatively, if the P^3I were to be installed in just the 384 RF and CNI configurations, the rate would be 384/8, or 48 per year. In this way, all the CASS stations will have been procured and modified with the P^3I by the year 2003.

We have assumed that all stations of the selected configurations would receive the P^3I. The Navy could choose to improve just the new stations, but the P^3Is we have analyzed are all major contributions to testing, and modifying just some of a given configuration would violate the CASS "single tester" concept.

The improvements would be made to new CASS stations as they are produced in the factory, and by retrofit to existing stations that have already been deployed to operational sites. We assumed that the recurring costs of retrofitting the existing installations would be 35 percent higher than the cost of the new factory installations. This is an estimate, made by a member of the study team, of the average additional cost of incorporating production changes for the F-16 tester (the Avionics Intermediate Shop) into previously delivered equipment. It was therefore necessary to know the number of new and retrofit installations, and these numbers were set equal to the number of new and existing stations that would exist at the start of procurement, according to a recent CASS production schedule [7].

Yearly *unit O&S costs* are applied to the cumulative number of improvements that have been made each year.

There are several other points of methodology: only future costs are considered (sunk costs are ignored), all costs are in constant FY 1993 dollars, and we focused on the *incremental* costs that DoD would have to pay for the P^3Is, over and above the costs of the current program through the year 2003. Most of the P^3Is involve new additions to CASS capability, and for these cases the incremental costs are simply the acquisition and O&S costs of the new equipment. If the Navy should decide to upgrade the computer, however, procurements of the old computer would cease when purchases of the new computer began, and the incremental costs would therefore reflect the savings associated with terminating the old program.

To summarize, the cost of a given P^3I is the yearly stream of acquisition and O&S costs from the year of development to 2003. In the discussion of results to be presented later in this chapter, we show the stream of acquisition costs for each P^3I. For a summary cost measure, we chose the present value of the acquisition and O&S cost stream using the 3.6-percent annual discount rate specified for 10-year cost in the recently-revised version of Office of Management and Budget (OMB) Circular A-94.

Table 2 illustrates the cost calculations using a hypothetical P^3I involving purchase of a $10,000 COTS instrument, with development starting in 1993 and procurement of 662 items occurring during 1994-2003. (The total 10-year cost at the bottom of the table is calculated without discounting, for simplicity.) As the table indicates, all costs are calculated from two basic inputs, the producer development costs and the unit price.

3. Digression on TPS Cost

The indirect cost implications of P^3Is are generally cost *savings* that may result elsewhere in the logistics system. Especially noteworthy are the savings that P^3Is can make in developing and constructing TPSs, the resources that mediate between the tester and the UUT:

- the software that controls the instruments,
- the interface device (ID) that fits onto the tester's interface (the general purpose interface (GPI) in the case of CASS), and
- the cables that connect the ID to the UUT.

A P^3I that provides a needed new capability to the CASS station will relieve TPS developers of the costs of providing that capability through creating "active IDs"—putting instruments into IDs that would otherwise contain only inactive components such as wires and relays connecting the input and output pins. The P^3I thus avoids the incremental money and time associated with developing active IDs, and also eliminates the operational problems caused by the complexity of the active ID. Active IDs do not, for example, share in the self-test routines that are developed for the CASS station. Therefore, additional self-test routines would have to be performed during testing operations.

Nevertheless, developing active IDs might be the least-cost way of obtaining new capability that would be required for only a few avionic systems, or that could be installed in IDs much more cheaply than in the CASS station.

In discussions with the people who are offloading TPSs to CASS, we have found many instances, listed in Table 3, in which IDs have been made active in order to supplement CASS's capability. These examples were all reported by people at the Norfolk TPS Integration Facility, except for the last one, which comes from Grumman. Similar examples were reported by people at the Jacksonville and North Island TPS Integration Facilities, as well as at Hughes.

Table 2. Illustration of Cost Model

Type of Cost	Comments	Value
Non-recurring acquisition		
Producer development	Input	0
Start of development		1993
Technology trend factor	1.2% annually during 1993–94	.988
GE integration	100 × GE interface	$335,900
GE profit and G&A	15% × (producer development + GE integration)	$50,385
Total		$386,285
Recurring unit acquisition costs		
Producer commercial price	Input	$10,000
Start of procurement		1994
Technology trend factor	1.2% annually during 1993–94	.988
Military price factor		2
Quantity discount factor		.85
Net price to GE		$16,796
GE interface	20% of net price	$3,359
GE profit + G&A	15% × (net price + GE interface)	$3,023
Support investment	26% × (net price + GE interface + GE profit/G&A)	$6,026
Total		
For new installations	Net price + GE interface + GE profit and G&A + *support investment*	$29,204
For retrofit installations	135 × (previous entry)	$39,425
Unit annual O&S cost	10% × (GE net price + GE interface + GE profit/G&A) per year	$2,318
Number of stations		
Start of procurement		1994
Number of stations		
New	From production schedule	507
Retrofit	From production schedule	155
Total		662
Total program costs		
Total non-recurring cost		$0.4 million
Total recurring cost		
New stations	Unit recurring cost × (number of new stations)	$14.8 million
Retrofit stations	Unit recurring cost × (number of retrofit stations)	$6.1 million
Total		$20.9 million
10-year O&S	Unit annual O&S cost × (average number of completed installations during procurement period) × procurement period = 2,318 × (662/10+662)/2 × 10	$8.4 million
Total 10-year cost		$29.7 million

Note: Costs are in FY 1993 dollars.

Table 3. Active Interface Devices Developed for F-14 Offload to CASS

Active Element	Cost	Benefit
More digital pins	$5,500 for design, $1,000 recurring per OTPS	—
28-volt boards for OTPS-04 and OTPS-06	—	—
Extra MilStd-1553 memory board for four OTPSs	$5,000 non-recurring, $1,500 recurring per board	Reduction in test time from 400 to 3 minutes for ASM-614 data storage unit
Matrix switch for OTPS-01	—	Reduction of 1 man-month of TPS development time for re-wiring
TI-608 video monitor for OTPS-02 and OTPS-04	—	Reduction in test time from 45 to 20 minutes for part of OTPS-02 (45 minutes is the test time for VAST, which has no video monitor)
Arbitrary waveform generator for OTPS-04	—	—
Raster video generator card for OTPS-03	$7,000 non-recurring, $3,000 recurring	—
Sweep capability	—	—

Note: OTPS stands for Operational Test Program Set. An OTPS is the collection of TPSs that have the same interface device.

Note, however, that only a few offload and new re-hosting contracts have been initiated so far, and the examples in Table 3 are for only those contracts to offload the F-14. According to a study by Prospective Computer Analysts, Inc. [8], over 6,000 UUTs will eventually be offloaded to CASS from other testers (see Table 4), and more TPSs will be added as new weapon systems are developed. The costs of single TPSs in Table 3 are therefore a negligible part of total Navy costs for all TPSs. The total Navy costs should be estimated and applied as write-offs to the direct costs of the P^3Is, but this calculation is beyond the scope of this study.

Table 4. UUTs Scheduled for Offload to CASS From Other Testers

Aircraft	WRA	SRA	Total
F/A-18	68	723	791
F-14A	96	306	402
F-14D	53	266	319
A-6E	119	230	349
P-3C	51	1,082	1,133
EA-6B	131	492	623
V-22	78	175	253
SH-60	60	412	472
AV-8B	77	386	463
Common	110	406	516
E-2C	133	666	799
S-3B	126	387	513
Total	1,102	5,531	6,633

4. Effectiveness

The effectiveness of a P^3I is ultimately related to the increase it brings to Fleet readiness. The P^3I might improve the tester's diagnostic capability, thereby helping the maintenance shop to determine why an aircraft may be failing to perform a mission. Alternatively, the P^3I might contribute to readiness by reducing the time for performing tests.

Improvements in aircraft readiness can be quantified by measuring the increase in variables such as maintenance throughput and mission-capable (MC) rates. Performing this type of calculation, however, requires collecting data and modeling such variables as avionics failure rates and maintenance shop scheduling. It was beyond the scope of the present study. Our analysis has been limited to assembling available information on details such as which UUTs would be better tested if the improvement were made.

We have dealt with this information systematically by categorizing each P^3I according to how it contributes to readiness: by increasing the tester's diagnostic capability, and by reducing the time to perform tests.

D. CAVEATS

Because our search for P^3Is has not been an exhaustive, "bottom up" engineering analysis of all testing and CASS operations, we make no claim that our list of candidates includes all attractive improvements for the future. Another issue concerns the goal of measuring the *incremental* effectiveness of the P^3Is—what the P^3I adds to current capability. Our discussions of benefit provide qualitative information along these lines, and some of it appears compelling. However, because we have not developed quantitative measures of effectiveness, we cannot quantify the incremental contribution of the P^3Is to readiness. In this regard, the CASS Program Office could well use a requirements study to determine exactly which avionic malfunctions really degrade aircraft operational missions, and by how much.

Many of the factors used in the cost model, such as for militarization, involve considerable uncertainty. Our cost estimates should be good enough, however, to satisfy the study's objective, which was to recommend P^3I for more detailed engineering and cost analyses leading to future implementation.

We have not analyzed all of the considerations that should enter into decisions of which P^3Is to fund. One feature that has been ignored is the availability of funds. We have considered only one P^3I that obviously saves money, replacing the current VAX 3800 computer with a new Digital Equipment Corporation (DEC) computer. Some of the other P^3Is might cost less than we have estimated. Others, while they may reduce the cost of TPS construction, may not offset the ATE development and integration costs, and these P^3Is should be justified on the basis of further testing requirements. Another issue that has not been considered is the implications of P^3Is on the number and training of maintenance technicians.

A related caveat is that our analysis of individual P^3Is ignores the full range of alternative ways of dealing with maintenance problems. For example, money for a P^3I that speeds up radar testing might be better spent in buying more CASS stations, or on stocking more spares and sending radar WRAs back to depots for repair at the first sign of trouble. Nor does the study compare the costs and benefits of improving the CASS station with adding instruments to the interface devices of TPSs, procuring more CASS stations, and meeting the test requirements of new aircraft by the older technique of designing unique (single-system) testers, rather than by using the newer strategy of expanding the capability of CASS.

Finally, although we have added in a liberal amount of cost for interfaces and integration, we have not looked at the engineering details. Installing a given P^3I might require changes in such factors as the possible need for extra power and cooling, the size and layout of the GPI and RF interface, the availability of space and particular location needs of new instruments, the space and access to new cabling that might be required, and the cost of new racks to accommodate the implementation of many P^3Is. As a corollary of this caveat, we have recommended enough changes in the RF area to justify at least an initial look at the costs and benefits of re-designing the entire RF rack.

E. SUMMARY OF ANALYSIS

To summarize the analysis to date, we begin with a brief description of each P^3I, a rough indication of how it contributes to testing, and the development and unit procurement price (not 10-year costs) to give an idea of its cost. More information on the value and cost of these P^3Is is given in Chapters II and III.

Following the description of the P^3Is is a section that summarizes our findings regarding those P^3I we have recommended for further action by the CASS Program Office. This section includes tables showing the 10-year costs of each P^3I, as well as the stream of yearly acquisition costs.

1. List of P^3Is

Table 5 lists the P^3Is that met our general criteria for analysis. They are grouped under headings that indicate whether the improvement would increase general testing capability (and should therefore be installed in all configurations), or whether it would affect only a subset of tests (and should therefore be installed in only some of the configurations, such as RF/CNI). The "Analyzed and Recommended" improvements are those that we have analyzed enough to have formed a judgment about merit, and where that analysis has yielded a recommendation that the CASS Program Office undertake more detailed engineering and cost analysis, possibly leading to future implementation. Chapter II of this paper discusses these P^3Is in more detail. The second category is composed of those P^3Is that our analysis indicates are not worthy of further consideration at this time. More detail on these P^3Is is given in Chapter III. Finally, the last category are P^3Is that have not been analyzed adequately to justify a recommendation either for or against. Whatever information we have assembled on these improvements is given in Chapter IV.

2. Description of P^3Is

The subsections that follow present the P^3Is in the order listed in Table 5. The last part of each subsection title refers to the configurations to which the P^3I is applicable. We have listed the prices of the instruments (and development costs for those items that are not COTS) in order to indicate the general magnitude of the improvement. These figures are only the basic inputs to the calculation of total cost described previously.

3. Improvements Analyzed and Recommended

a. Replace the Station Computer With a VAX 4000/90 (All)

This P^3I would replace the current VAX 3800 (Micro VAX) station computer with a new VAX 4000/90. The newer computer dominates the VAX 3800 in every way: it has six times as much performance (according to the Spec Mark rating system), much more memory, and costs less than the VAX 3800 ($50,000 for the VAX 4000/90 versus the $63,000 that the CASS program office is paying for the VAX 3800 for the lot 2 stations). The VAX 4000/90 has been on the commercial market for several years, is used in the commercial version of CASS, and is compatible with the Navy's test software according to recent tests. A new computer would save money over the entire program.

Table 5. List of P^{3}Is Assembled for Analysis

IMPROVEMENTS ANALYZED AND RECOMMENDED
Improvements in General Capability: Analog
Replace the Station Computer With a VAX 4000/90
Add Station Interfaces for New Buses
Add a Bus Analyzer to the MilStd-1553 Interface
Add Another Arbitrary Waveform Generator
Improvements in General Capability: Digital
Add More Channels, Pins, Memory, and Boundary Scan to the Digital Test Unit
Add an Array Processor
Improvements in Specific Areas of Test: Analog
Add a Bit-Error-Rate Tester (RF/CNI)
Add a Phase-Noise Tester (RF/CNI)
Add a Noise-Figure Tester (RF/CNI)
Add a Millimeter-Wave Source (RF/CNI)
Add a High-Power Tester (RF/EO)
Add More Switching to the RF Interface (RF/CNI)
Add a Cockpit-Display Tester (RF/CNI/EO)
IMPROVEMENTS ANALYZED AND REJECTED
Add More Switching to the General Purpose Interface
Replace the Pulse Generator
POSSIBLE AREAS OF IMPROVEMENT NOT FULLY ANALYZED
Electro-Optical Rack
Gold Dot Interface
Station Software
Optical Disk
VXI Architecture
Low-Power Testing
Testing Fiber-Optic Sensors

b. Add Station Interfaces for New Buses (All)

Avionics systems in aircraft pass data and control signals via communication buses. To simulate these signals during test, CASS has several interfaces that connect to the communication buses, which then connect to the UUTs. This P^{3}I would add interfaces for the new buses designed for next-generation aircraft, for example the Signal Data Distribution Network (SDDN) and the High Bandwidth Data Bus (HBDB) designed for the F-22. These interfaces will not be needed until the end of the decade. There would be a development cost of $1.35 million, and a unit procurement cost of $45,000 based on catalog prices of interfaces of comparable complexity.

c. Add a Bus Analyzer to the MilStd-1553 Interface (All)

One of the current station interfaces is that for the MilStd-1553 bus, the common link between avionics systems in current and planned future Navy and Air Force aircraft, including the F-14, F-15, F-16, F/A-18, and F-22. A bus analyzer would read the information flowing in this bus to help diagnose problems during tests. The price for a Tektronix commercial unit is $9,200.

d. Add Another Arbitrary Waveform Generator (All)

The RF CASS station uses arbitrary waveform generators (AWGs) developed by GE that produce a variety of analog waveforms for use in tests. The hybrid, RF, and CNI stations have one, two, and three AWGs, respectively. Engineers who are engaged in offloading TPSs for the F-14 aircraft at the Naval Depot in Norfolk have found that more AWGs are useful, and have added a fourth one to the interface device. This P^3I adds another AWG to each configuration to avoid the costs of adding more AWGs to the interface devices. The estimate of a commercial price of $20,000 per AWG was provided by GE.

e. Add More Channels, Pins, Memory, and Boundary Scan to the Digital Test Unit (All)

The current DTU has a data rate of 20 MHz (40 MHz with interleaving), which is fast enough to meet the minimum testing needs of digital WRAs and SRAs through the end of the decade. Modular SRAs are now being developed with 400-558 pins, which exceeds the 336 pins and channels provided by the current DTU. However, the DTU could meet the new requirements by adding two more channel cards, which would increase the number of channels from 336 to 360 and increase the number of pins from 336 to 588, and also by increasing the pattern depth (memory) behind each pin from 16K to 64K. The DTU should also be given the capability to test the new boundary scan devices being installed on the Advanced Medium-Range Air-to-Air Missile (AMRAAM) and to be installed on future aircraft. Boundary scan chips have self-test circuitry that can be actuated by simple input/output signals applied to digital SRAs and WRAs ("boards and boxes"). The cost is $70,000 for making the modification to new stations, and $136,000 for retrofits. These costs are based on an estimate supplied by Teradyne, the producer of the current CASS DTU. We recommend that the Navy plan to study, for future implementation, a DTU that can accommodate higher clock speeds and data rates.

f. Add an Array Processor (All)

Aircraft radar systems use signal processors (SPs) to analyze the complex (real-time, high-data-rate) signals that are detected by the radar's antenna and receiver. Array processors are used to generate such signals for the purpose of realistic testing. A 1-GFLOPS (billion floating point operations per second) array processor would handle the testing needs of the JIAWG signal processor being designed for the F-22, but is not needed until the F-22 reaches initial operating capability next decade. A 0.2 GFLOPS array processor meets immediate needs, including the current design of the F-22, and would cost approximately $9,000.

g. Add a Bit-Error-Rate Tester (RF/CNI)

Digital signals have less redundancy than analog signals, so losing a single bit of information can be more harmful. This P^3I would add a Bit Error Rate (BER) tester, a signal generator and a comparator to detect missed bits by measuring the correlation between input and output signals. The cost is $38,000, based on Tektronix catalog prices.

h. Add a Phase-Noise Tester (RF/CNI)

This P^3I adds instruments to measure the degree of phase noise, or unwanted fluctuations in frequency generated by electronic devices. Phase noise reduces the signal-to-noise ratio of radar receivers and amplifiers that are designed to detect targets through Doppler shift. Ground-attack aircraft, for example, may be unable to pick out moving vehicles from background clutter if the phase noise in the radar is not working properly. The current CASS design has some capability to test phase noise by using the Microwave Transition Analyzer to compare UUT frequency with the Rubidium frequency standard located in the station. A phase-noise tester would provide improved capability. Estimates by vendors indicate a commercial price of $90,000 plus $600,000 for development.

i. Add a Noise-Figure Tester (RF/CNI)

"Noise figure" measures the reduction in signal-to-noise ratio that signals suffer in passing through electronic devices. (A reduction from 10 to 9, for example, would yield a noise figure of 10/9, or 1.1.) Noise is especially harmful to the operation of low-power devices such as receivers for radar sets and communication systems (such as the F/A-18 Advanced Tactical Airborne Reconnaissance System, or ATARS), RF devices that already have low signal-to-noise ratios. The current CASS design can detect noise using the Microwave Transition Analyzer or one of the spectrum analyzers, but these instruments cannot measure the noise figure quantitatively. The commercial price of a noise-figure tester is about $38,000, based on prices listed in the 1993 Hewlett Packard catalog [9].

j. Add a Millimeter-Wave Source (RF/CNI)

CASS can generate signals up to 40 GHz, which suffices for testing aircraft RF components such as radar amplifiers and receivers that typically operate in the range of 10 to 18 GHz. This P^3I would add a signal source in the millimeter region (up to approximately 100 GHz) to test the seeker radars in missiles, which operate at higher frequencies. This P^3I would not be needed if the Common Test Set (CTS) being designed for testing missiles includes a millimeter wave source. Otherwise, the P^3I would be useful; the commercial cost would be $43,500 for continuous coverage from 40 to 110 GHz, based on Hewlett Packard catalog prices [9].

k. Add a High-Power Tester (RF/EO)

GE has proposed a 1-3/4 bay High-Power Device Tester (HPDT) that would enable CASS to fully test all Navy and Air Force aircraft except for the EA-6B, which has higher power than all other aircraft, and is currently tested only at Naval Depots. (High-power testing will not be needed for future phased-array radars, but will continue to be needed for electronic warfare systems.) According to a GE estimate, the unit cost of the full, 1-3/4 bay HPDT would be about $700,000 plus $8.0 million for development. It contains an array processor and a phase-noise tester, instruments that we have analyzed as separate P^3Is. The implication is that if the Navy should decide to improve all three areas of testing—high power, array processor, and phase noise—it would have to determine whether it is more efficient to obtain the latter two devices as a part of a high-power tester or as separate instruments.

l. Add More Switching to the RF Interface (RF/CNI)

TPS developers of RF systems have been incorporating some RF switching into active IDs. Additional RF switching would reduce the time and cost of developing TPSs for radar electronic warfare systems and other UUTs that generate RF power. We estimated the cost of the RF interface at $50,000 plus $1.5 million for development.

m. Add a Cockpit-Display Tester (RF/CNI/EO)

Modern aircraft use sophisticated video displays to present pilots and electronic officers with the complex information developed by sensors. The current CASS lacks capability to test these displays. (The monitor that is used for running tests is a plasma device that lacks the resolution and brightness of cathode ray tubes.) This P^3I consists of a video monitor to test the electronics that pass the information to the displays, and a symbology generator (stimulus) to test the display itself. Photometric units yield quicker and more objective tests than human operators. The commercial price is $5,500, based on a prices in a Texas Instruments catalog for the monitor ($2,500) and discussions with TPS developers at the Norfolk Naval Depot for the symbology generator ($3,000).

4. Improvements Analyzed and Rejected

a. Add More Switching to the General Purpose Interface

Testers use switching relays to apply different test blocks without having to reposition cables. The CASS general-purpose (non-RF) switches are located behind the Virginia panel (patch panel) and are reached by signals routed to the ID and back into the station. Although some TPS developers have added some general-purpose switches to active IDs, an involved analysis would be needed to demonstrate that more switching should be added to the general purpose interface. The question thus remains an open issue.

b. Replace the Pulse Generator

Some tests require pulses of small width. The Lakehurst study [10] states that the minimum pulse width of the current CASS pulse generator is 1 microsecond, somewhat wider than the pulses required for future testing. (The precise requirement is classified.) However, the CASS specification [11] states that the pulse generator can generate 2-nanosecond pulses, much smaller than the figure quoted by Reference [10].

5. Possible Areas of Improvement Not Fully Analyzed

a. Electro-Optical Rack

Reference [10] mentions upgrading three features of the EO tester to enable CASS to test the newer IR imaging systems such as the AAS-42 infrared search and track set (IRSTS) on the F-14D, and other systems found on the F/A-18 and projected for the F-22 and the A/F-X. The improvements are widening the field of view, increasing the spectral bandwidth of the instruments, and increasing the minimum temperature resolution. The recommended specifications listed in Reference [10] are classified, and are not given here.

Also discussed in Reference [10] is the prospect of improving several features of the EO tester to enable CASS to test the antisubmarine warfare and countermine laser systems that are operated by helicopters, the S-3 and the P-3 in shallow, coastal waters where acoustic techniques are not viable. The improvements involve lowering the minimum wavelength, increasing the range of pulse-repetition rates, increasing the angle of regard, and improving the receiver uniformity. (The recommended specifications are classified.)

b. Gold Dot Interface

Gold dot technology applied to patch panel design means that the pins are made of gold to increase conductivity, and the IDs are clamped on the tester panel so the pins make contact by touching with zero injection force (ZIF). ZIF would minimize the type of problem that CASS has had recently, in that the pins on the patch panel were pushed in when IDs were attached. GE recently solved the mechanical problem, however, by simply strengthening and beveling the pins.

c. Station Software

Various alternatives for upgrading the CASS software have been constructed by software engineers at NAWC Lakehurst (three alternatives) and GE, Daytona Beach (one alternative). The improvements vary from low-cost modification to costly re-design, and contribute in varying degrees to the goals of correcting deficiencies, improving functional performance, increasing throughput, and decreasing TPS development cost, time, and complexity.

d. Optical Disk

Test programs, which are stored on optical disks, must be loaded onto the computer hard disk in order to run tests. Running classified programs thus permanently contaminates the hard disk, creating operational inconvenience.

e. VXI Architecture

VXI architecture is becoming a commercial standard for the electronics industry. DoD might save money by modifying CASS so it can accept commercially-developed VXI instruments in future modifications. (Savings might still be possible even if the instruments needed modifications for ruggedization and other environmental requirements.)

f. Low-Power Testing

This P^3I would widen the range (lower the minimum and increase the maximum) of low power stimulus and measurement instruments used in testing current radar and electronic warfare (EW) systems.

g. Testing Fiber-Optic Sensors

This P^3I would add instruments to test emerging inertial navigation systems that are expected, within 10 years, to employ fiber-optic sensors rather than the current ring-laser gyros. (Systems that employ superconductivity are not expected within the next 20 years.)

F. SUMMARY OF FINDINGS

Table 6 summarizes the results of the P^3I analysis. The order of items does not signify priority. (The extent to which the P^3Is would enable CASS to meet a full set of anticipated future avionics testing needs is given in the following Section G.) The second column indicates the CASS configurations in which the P^3I would be installed, judging from the nature of the improvement. The phase-noise tester, for example, would be installed in the RF and CNI stations. "All" refers to the hybrid, RF, CNI, and EO stations. The next column is a partial indication of effectiveness. "Impact" indicates the effectiveness category the P^3I fits into, using the definitions given previously. The last column gives the ten-year life-cycle cost of the candidate P^3I.

Table 6. Summary of Analysis for Those P^3Is Recommended for Further Action

Improvement	Configurations	Impact	10-Year Cost
1. Replace the Station Computer With a VAX 4000/90			
VAX 4000/90	All	Reduced test time	$71.1
VAX 3800	All	Reduced test time	$80.3
Incremental Cost of VAX 4000/90			$-9.2
2. Add Station Interfaces for New Buses	All	Improved Diagnostic	$46.3
3. Add a Bus Analyzer to the MilStd-1553 Interface	All	Reduced test time	$10.9
4. Add Another Arbitrary Waveform Generator	All	Reduced test time	$23.7
5. Add Channels, Pins, Memory, and Boundary Scan to the DTU	All	Improved Diagnostic	$93.1
6. Add an Array Processor	All	Improved Diagnostic	$21.1
7. Add a Bit-Error-Rate Tester	RF, CNI	Improved Diagnostic	$51.9
8. Add a Phase-Noise Tester	RF, CNI	Improved Diagnostic	$69.6
9. Add a Noise-Figure Tester	RF, CNI	Improved Diagnostic	$58.3
10. Add a Millimeter-Wave Source	RF, CNI	Improved Diagnostic	$25.6
11. Add a High-Power Tester[a]	RF, EO	Improved Diagnostic	$219.7
12. Add More Switching to the RF Interface	RF, CNI	Reduced test time	$35.6
13. Add a Cockpit-Display Tester	RF, EO, CNI	Reduced test time	$8.7

Note: Costs are 10-year totals of development, procurement, and O&S during 1993–2003 in millions of discounted FY 1993 dollars.

[a] High-power tester does not include a phase-noise tester and an array processor.

Table 7 lays out a tentative acquisition and funding schedule for the P^3Is (O&S costs are not included). The acquisition costs were obtained by applying the cost model to the development and procurement costs listed in the detailed descriptions of the P^3Is. (The COTS instruments require no development costs to the producer, but GE (Martin Marietta) pays development costs to integrate the instruments into CASS.) The funding stream for each P^{3}I starts out with a year or two of development costs, starting early this decade (nominally 1993 for estimating purposes) with two exceptions. The station interfaces for the new buses and the millimeter-wave source start development in 1998 because of an assumption that they will not be needed until well into the next decade.

Table 7. Illustrative Acquisition Spending Stream for Recommended P^{3}Is

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
1. Replace the Station Computer With a VAX 4000/90												
VAX 4000/90	6.6	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	59.6
VAX 3800	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	61.6
Incremental Cost of VAX 4000/90	*1.0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-2.0
2. Add Station Interfaces for New Buses	0.0	0.0	0.0	0.0	0.0	*1.0	*1.0	13.6	13.6	13.6	13.6	56.4
3. Add a Bus Analyzer to the MilStd-1553 Interface	*0.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.2
4. Add Another Arbitrary Waveform Generator	*0.4	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	21.4
5. Add Channels, Pins, Memory, and Boundary Scan to the DTU	*0.7	*0.7	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	92.5
6. Add an Array Processor	*0.2	*0.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	20.2
7. Add a Bit-Error-Rate Tester	*0.7	*0.7	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	49.1
8. Add a Phase-Noise Tester	*1.2	*1.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	67.2
9. Add a Noise-Figure Tester	*0.7	*0.7	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	56.3
10. Add a Millimeter-Wave Source	0.0	0.0	0.0	0.0	0.0	*0.4	*0.4	7.6	7.6	7.6	7.6	31.2
11. Add a High-Power Tester[a]	*4.0	*4.0	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	209.9
12. Add More Switching to the RF Interface	*1.2	*1.2	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	33.9
13. Add a Cockpit-Display Tester	*0.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	8.2
Total Development	10.5	8.7	0.0	0.0	0.0	1.4	1.4	0.0	0.0	0.0	0.0	22.0
Total Acquisition	*10.5*	*12.3*	*60.43*	*60.43*	*60.43*	*61.83*	*61.83*	*81.63*	*81.63*	*81.63*	*81.63*	*654.27*

Notes: Costs are in millions of undiscounted FY 1993 dollars. Development costs are denoted with an asterisk.

[a] Does not include cost of phase-noise tester and array processor.

The initial development costs are followed by a stream of (much larger) yearly procurement costs. The procurement spending is constant year to year on the assumption of a smooth production schedule in which the same number of P^{3}I systems are bought each year. The yearly cost is equal to the total recurring cost calculated by the cost model, divided by the number of years from the start of production to the year 2003. The assumption of a smooth production schedule is consistent with the approximately linear cumulative production schedule of the CASS stations themselves, shown in Figure 1. (A linear cumulative curve means a constant yearly buy.)

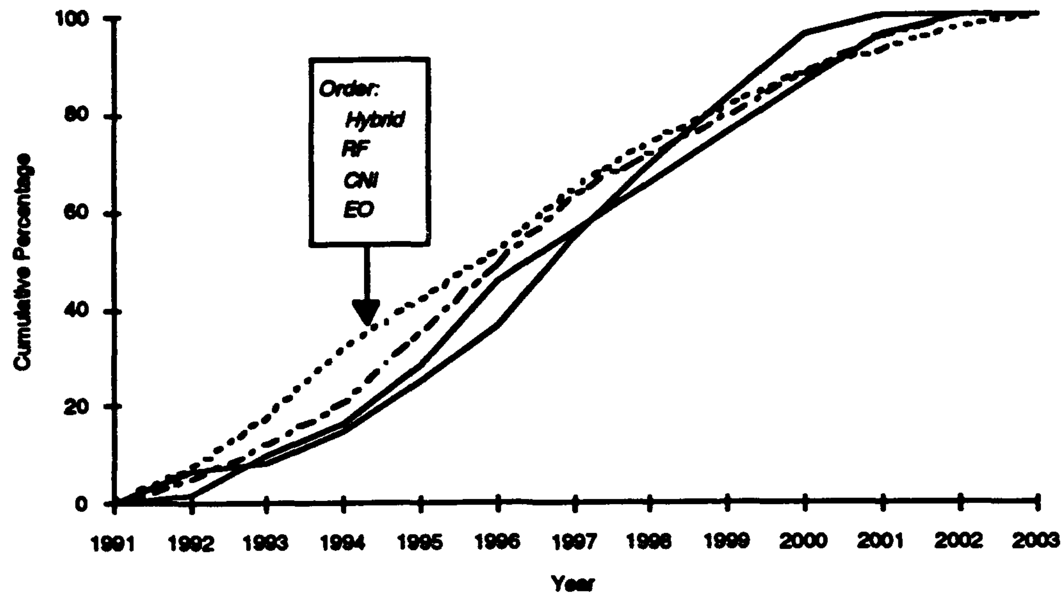

Figure 1. CASS Production Schedule (Cumulative Percentage of Total Production)

G. THE ABILITY OF CASS TO MEET ANTICIPATED FUTURE TEST NEEDS

The previous material has discussed P^3Is by test area. This section focuses on the extent to which these improvements would increase the ability of CASS to meet a single coherent set of avionic test requirements anticipated for the future.

The analysis is shown in Table 8. Column 1 lists the test requirements. They were constructed to anticipate the avionic systems expected to be developed during the next decade. Most of the digital test requirements were derived from the avionic specifications developed by the Joint Integrated Avionics Working Group (JIAWG). We used the specifications in the Common Avionics Baseline CAB III Revision 3, reported in Reference [17]. At least some of these specifications, including the needs for the Parallel Inter-Module (PI) Bus and High-Speed Data Bus (HSDB), are used in the F-22.

The JIAWG specifications do not cover all digital functions, however. For those digital functions lacking a JIAWG specification ("Non-JIAWG Technology" in Table 8), we used the specifications that the Air Force is designing into their Common Automatic Test System (CATS). CATS is the factory tester for the F-22. (Factory testers are generally designed to be equally or more capable than the testers developed for depot or intermediate-level use.) These specifications are still preliminary since the CATS is still under development. We used the figures in Reference [1] as the source.

Table 8. Capability of the Current CASS Plus P³Is To Meet Anticipated Future F-22 Test Needs

Anticipated Future Test Needs	Current Capability of the CASS Station	Capability Added by P^3I	Remaining Shortfall[a]
DIGITAL			
JIAWG Architecture			
General Characteristics of SRAs (LRMs), Except for Special Cases Listed Below			
20 MHz data rate	Sufficient (DTU can test up to 40 MHz)[b]		None
Various logic types	Sufficient (DTU covers all logic types used)[b]		None
Various voltages	Sufficient (DTU covers all voltages used)[b]		None
380 connector pins	Limited (DTU has only 336 pins)	252 DTU pins	None
Data Buses, within WRAs (LRUs)			
Parallel inter-module (PI) bus	Sufficient (DTU has the capability)[b]		None
Data Buses, between WRAs (LRUs)			
50-MHz High-Speed Data Bus, (HSDB)	Sufficient (CASS has a HSDB interface)		None
6.25-MHz Test and Maintenance (TM) Bus	Sufficient (DTU has the capability)[b]		None
250-MHz Signal Data Distribution Network (SDDN)	Limited (CASS lacks a SDDN interface)[b]	SSDN interface	None
250-MHz High-Bandwidth Interface (HBI)	Limited (CASS lacks an HBI interface)[b]	HBI interface	None
800 MHz Video Data Distribution Network (VDDN)	Limited (CASS lacks a VDDN interface)[b]	VDDN interface	None
Computer Processors			
J88-M2D Common Avionics Processor (CAP-32)	Sufficient (DTU has the capability)[b]		None
J88-M1D Common Avionics Processor (CAP-16)	Sufficient (DTU has the capability)[b]		None
J89-SP-01 signal processor	Sufficient (DTU has the capability)[b]		None
Common Integrated Processor (CIP)	Limited (DTU can test sub-elements but not the total CIP)	Array processor for tests to 200 MFLOPs	Limited[c]
Non-JIAWG Technology			
Electrical Characteristics of SRUs and LRMs			
Various data rates up to 250 MHz	Limited (DTU can test up to 40 MHz)	Bit error tester for tests to 700 MHz	Limited[c]
Various logic types	Limited (DTU covers most logic types used)		Limited[c]
Various logic voltages	Limited (DTU covers most voltages used)		Limited[c]
550 connector pins	Limited (DTU has only 336 pins)	252 DTU pins	None

Table 8. Capability of the Current CASS Plus P^3Is To Meet Anticipated Future F-22 Test Needs (Continued)

Anticipated Future Test Needs	Current Capability of the CASS Station	Capability Added by P^3I	Remaining Shortfall[a]
Data Buses, between WRAs (LRUs)			
MilStd-1553	Sufficient (CASS has a MilStd- 1553 interface)	MilStd-1553 Bus Analyzer[d]	None
RS-232/422	Sufficient (DTU has an RS-232/422 interface.)		None
Boundary Scan Test Capability	Limited (DTU has limited capability)	Boundary scan software and a test vector generator station	None
ANALOG			
Low and Radio Frequency Systems[e]			
25-MHz arbitrary waveform generator (AWG)	Sufficient (AWG can test up to 25 MHz)	Another AWG[f]	None
100-nanosecond width pulse generator (PG)	Sufficient (PG can produce pulses down to 4 nanosecond width)		None
160-MHz time/frequency counter	Sufficient (TFC operates up to 200 MHz)		None
300-volt AC measurement	Sufficient (CASS can measure 200 VRMS directly, 700 VRMS with a probe)		None
300-volt DC measurement	Sufficient (CASS can test 200 volts directly, up to 1,000 volts with a probe)		None
1-amp AC/DC measurement	Sufficient (CASS can test up to 2 amps AC/DC)		None
30-gigaohm resistance measurement	Limited (CASS can test up to 30 megaohms)		Limited[g]
250-MHz waveform digitizer	Sufficient (CASS can test up to 500 MHz)		None
20-MHz RF synthesizer	Sufficient (CASS can test up to 40 GHz)	RF Synthesizer (capability to 110 GHz)[h]	None
Phase noise (not specified for CATS)	Limited (CASS can test down to only -80 dBc)	Phase Noise Tester (with capability to -140 dBc)[i]	None
22-GHz spectrum analyzer	Sufficient (CASS can test up to 22 GHz)		None
High power loads (not specific for CATS)	Limited (CASS can test up to only 500 watts)	High-Power Device Tester and RF Switches[j,k]	None
26.5-GHz power meter	Sufficient (CASS can test down to -70 dBm)		None
30-dB RF noise meter	Limited (CASS capability is limited)[l]	30 dB RF Noise Meter	None
50-GHz network analyzer	Limited (network analyzer can operate up to only 26.5 GHz)		Limited[c]
2-GHz vector voltmeter	Limited (The volt-meter can operate up to only 1 GHz)		Limited[c]
26.5-GHz broadband noise source	Sufficient (noise source operates up to 26.5 GHz)		None

Table 8. Capability of the Current CASS Plus P³Is To Meet Anticipated Future F-22 Test Needs (Continued)

Anticipated Future Test Needs	Current Capability of the CASS Station	Capability Added by P³I	Remaining Shortfall[a]
Display			
F-22 test requirements not known	Insufficient (CASS has no special display tester)	Display tester	None
Communication			
Modulation (F-22 test requirements not known)	Sufficient (CASS can test a wide range of communication and navigation modulation techniques)[m]		None
Synchro (F-22 test requirements not known)	Sufficient (CASS can test synchro resolvers and generators)		None
Electro-Optical			
F-22 requirements not fully known	Limited (CASS can test laser transmitters and receivers, plus infrared and visual systems)		Optical laser source and attenuator plus light wave multimeter[n]

a All test capabilities require the development of TPSs to test specific UUTs.

b Capability evaluation based on study done for AIR-552 which assessed CASS's ability to test JIAWG technology as specified by the JIAWG Common Avionics Baseline (CAB III) released December 1991 [17]. JIAWG technology was developed as a tri-service initiative targeted for the F-22, RAH-66, and the A-12 (replaced by the A/F-X) and their variants.

c Capability shortfall assessment of "limited" implies that CASS would have the ability to perform most of the tests required for the test characteristic under consideration. In an analysis of F-22 and A/F-X test requirements, an IDA study showed that CASS *capability currently exceeds* 95 percent of the technical test requirements [1].

d CASS is equipped with a MilStd-1553 interface, which permits CASS to exchange data with WRAs/SRAs that make use of this standard data bus. Information from CASS user's suggested that adding a MilStd-1553 data bus analyzer, which permits viewing data passing through the bus, would facilitate maintenance of WRAs/SRAs that use the MilStd-1553 standard.

e Analog test requirements are inferred from a review of preliminary information on the Common Automatic Test System (CATS), which will be used to conduct F-22 factory test.

f TPS developers have found the need to use multiple AWGs for selected tests.

g The capability gap is a factor of 1,000. However, in the maintenance environment, requirements for resistance checks above 30 megaohms will be infrequent.

h Other requirements drive the need for higher frequency stimuli generation [10].

i F-22 phase noise needs are not known. Requirements are derived from [10].

j Power requirements of F-22 are not fully known. HPDT power levels were set by GE after review of 25 current radar and EW systems by GE [11].

k CASS currently contains a limited number of RF switches. One of our P³Is recommends that RF switches be added to facilitate RF tests.

l Capability is available to make manual noise figure measurements using the CASS spectrum analyzer and broadband noise source. Proposed improvements would perform Noise Figure tests to 30 dB without manual intervention.

m The full CNI requirement for the F-22 is not known. However, CASS contains a complete set of spread spectrum stimuli and detectors capable of testing current CNI equipment. Capabilities include amplitude modulation, frequency modulation, phase modulation, frequency shift keying, minimum shift keying, quadrature phase shift keying, and bi-phase shift keying. Stimuli can be generated for standard navigation systems including the Instrument Landing System (ILS), VOR, TACAN, and GPS.

n CASS has a significant EO test capability for laser transmitters, receivers, and trackers, for infrared systems, and for visual systems that is not matched by CATS, according to our analysis of CATS documentation. Conversely, CATS information shows the availability of aoptical laser source (HP81551MM/81552SM), an optical attentuator (HP8158B), and a Lightwave Multimeter (HP81153A/81503A/85131B) that offer functionality not available in CASS. Further analysis of EO systems test requirements is required.

The analog requirements in Table 8 were also obtained from the CATS specifications listed in Reference [1]. Thus, many of the "Anticipated Future Test Needs" listed in the first column of Table 6 are those of the F-22.

The second column describes the capability of the current CASS station to meet the anticipated future requirements listed in the first column. The emphasis on CASS *station* needs some explanation. CASS is a highly-capable tester that can, with the appropriate TPSs, meet virtually all current test requirements. Some of these TPSs, however, would require active IDs. What we are describing in the second column is whether each of the various test needs could be met by the current CASS station *with only passive IDs*. In other words, does the CASS station itself have all of the required functionality, so that active IDs would not be necessary? A notation of "Sufficient" means "yes," the test could be fully performed without active IDs. A notation of "Limited" means that an active ID would probably be required.

An important note: There is no implication in this discussion that active IDs are inefficient in general. Some new test functions would be more economically obtained by constructing active IDs, others by improving the station itself. An active ID would likely be the preferred option, for example, in developing a new test capability that would be required by only a few systems located at a small number of sites, especially if it cost much less to modify the ID than the station.

The third column indicates the capability that would be added by the P^3Is we have recommended, and the last column indicates those test requirements that would still be "Limited" (i.e., require TPSs with active IDs).

The findings of this analysis are as follows: The current CASS station can meet most "Anticipated Future Test Needs" without using active IDs. The proposed P^3Is fill in almost all of the "Limited" areas, Although an active ID would be required to meet a few test requirements, such as those involving high data-rate buses, the high power loads, and additional pins for the DTU.

H. RECOMMENDATIONS

We recommend that the Navy perform detailed engineering studies of the P^3Is listed in Table 9 during the remainder of this decade, leading to possible implementation during the next decade.

Note that the GE 1-3/4 bay high-power tester includes a phase-noise tester and an array processor. Thus, if the Navy should decide to increase capability in all three areas, it would have to decide whether it would be more economical to obtain the phase-noise tester and array processor separately, or as part of the high-power tester. An added point concerning the high-power tester: The CASS Program Office has been considering the option of purchasing approximately 100 of these testers, roughly a third of the 296 we have considered by assuming that a tester would be bought for each RF and EO station. The smaller procurement quantity would clearly reduce the ten-year total cost of this P³I by a significant factor.

Table 9. Costs of P³Is Recommended for More Detailed Engineering Study

	Development Cost (Undiscounted)	10-Year Acquisition Cost (Undiscounted)	10-Year Total Cost (Discounted)
1. Replace the Station Computer With a VAX 4000/90			
VAX 4000/90	$6.6	$59.6	$71.1
VAX 3800	5.6	61.6	- 80.3
Incremental Cost	$1.0	-$2.0	- $9.2
2. Add Station Interfaces for New Buses	2.0	$56.5	46.3
3. Add a Bus Analyzer to the MilStd-1553 Interface	0.2	$10.2	10.9
4. Add Another Arbitrary Waveform Generator	0.4	$21.4	23.7
5. Add Channels, Pins, Memory, and Boundary Scan to the DTU	1.4	$92.3	93.1
6. Add an Array Processor	0.4	$20.2	21.1
7. Add a Bit-Error-Rate Tester	1.4	$49.1	51.9
8. Add a Phase-Noise Tester	2.4	$67.2	69.6
9. Add a Noise-Figure Tester	1.4	$56.3	58.3
10. Add a Millimeter-Wave Source	0.8	$31.2	25.6
11. Add a High-Power Tester (Less the Cost of the Phase-Noise Tester and Array Processor)	$18.8	$209.9	219.7
12. Add More Switching to the RF Interface	2.4	33.9	35.6
13. Add a Cockpit-Display Tester	0.2	8.2	8.7
Total	$32.8	$654.4	$655.2

Note: Acquisition costs are total development plus procurement during 1993–2003 in millions of undiscounted FY 1993 dollars. Ten-year costs are totals of development, procurement and O&S during 1993–2003 in millions of FY 1993 dollars discounted at 3.8 percent annually.

II. PRE-PLANNED PRODUCT IMPROVEMENTS ANALYZED AND RECOMMENDED

This chapter presents the full discussion of those P^3Is that we studied in detail, and for which this analysis leads us to recommend that the CASS Program Office initiate detailed engineering and costing analysis, leading to possible implementation. The configurations for each P^3I are shown in parentheses in the section titles.

A. REPLACE THE STATION COMPUTER WITH A VAX 4000/90 (ALL)

1. Background

The current CASS is controlled by a Digital Equipment Corporation (DEC) Micro-VAX 3800 computer. However, there are new computers on the market that cost much less and offer much greater performance. We have had some discussions with engineers who are offloading TPSs to CASS, and they tell us that UUTs often wait for CASS (rather than the other way around) during tests, and that newer computers could substantially reduce TPS operating times. Some of the current delays, however, are due to the current system architecture and software. Another question in changing computers is whether the system could continue to use the existing software and the TPSs that are now being re-hosted to CASS.

2. Alternatives

We considered only new DEC computers as possible replacements for CASS, on the assumption that they would be more compatible with the current DEC computer:

A. VAX 3800 (current system),

B. VAX 4000/90, or

C. DEC Alpha (3000-400 AXP).

In the following subsections, we compare these alternatives with regard to several features: performance, compatibility of the computer hardware with the existing operating system software, compatibility of the computer hardware and operating system software with the test software (both station and TPS), and cost.

a. Performance

Table 10 lists the major technical and performance characteristics for the computer alternatives. According to the Spec Mark, a relative measure of overall performance (the VAX 11/780 is 1.00), the new DEC computers are from 6 to 19 times more capable than the current VAX 3800. Moreover, they all exceed the 32-MB memory of the current VAX 3800 (although this might not be the best the VAX 3800 can do). There is a question, however, about the extent to which improved computer performance and memory would lead to shorter test times and to higher throughputs in the maintenance shop. A detailed analysis is needed to quantify these benefits. The new candidates can all communicate via Ethernet, the primary communication path in the current CASS architecture.

Table 10. Candidate Computer Systems

	Spec Mark	Maximum Memory	Hard Disk	Operating System	Contract Availability
A. VAX 3800 (Current)	5.5	32 MB	385 MB	VMS 5.2	Current
B. VAX 4000/90	32.7	128 MB	426 MB	Open VMS	May 1994
C. DEC Alpha (3000–400 AXP)	104.0	512 MB	426 MB	Open VMS, Alpha AXP	May 1996

Alternative B offers lower technical risk because it is an off-the-shelf item that has been on the market for several years. Alternative C offers much more performance than Alternative B, but at a somewhat higher risk because it is a new product not tested yet by the market.

b. Compatibility With Operating System Software

None of the two new alternatives can use CASS's current operating system, the VMS 5.2. They can all, however, use DEC's new Open VMS operating system, which is the current upgrade to their VMS software products. DEC indicates that the VAX 4000/90 will be capable of being upgraded to the Alpha architecture.

c. Compatibility With Test Software (Station and TPSs)

Automated Test International (ATI) has been carrying out tests to determine if the new VAX computers and the Open VMS operating system are compatible with the test software of the CASS station and the TPSs that are being re-hosted to CASS. (ATI is a test equipment consortium composed of GE, Hewlett Packard, and Teradyne, and International Trading Company.) These tests have revealed no problems to date. ATI people state, moreover, that they have had no problems running TPSs on the new DEC computers and operating system installed in their commercial CASS system, the CITE-2000. This provides some circumstantial evidence that things will also go well with the military version (CASS). ATI has, in fact, selected the VAX 4000/90 computer for the CITE it is bringing to market.

However, both the new DEC alternatives would require modifying the CASS station software to accommodate the MOTIFF graphics interface. The current station software uses the VWS graphics package. The modification might take 1–2 man-years, according to DEC.

There is an untested area with the DEC Alpha. Running a VMS application on this computer requires not only the Open VMS operating system, but also the Alpha AXP operating system. DEC has stated that it intends to design the VMS software to be transportable to the Alpha series computers, but since this product is just becoming available, the degree of transportability is untested. DEC does state that if the VAX 3800 is replaced by a DEC Alpha computer, all station software would have to be recompiled and re-linked, an effort requiring several man-months. (Transportability only means that code would not have to be re-written; it does not guarantee that it might not have to be re-compiled.) The DEC Alpha alternative thus involves somewhat greater risk with regard to both software and hardware.

3. Costs

The prices for the new computers were obtained from DEC, and are shown in Table 11. The new alternatives meet the requirements of MilStd-461.

Table 11. Unit Procurement Costs of Candidate Computer Systems

Alternative	Unit Procurement
A. VAX 3800	$63,000
B. VAX 4000/90	$50,000
C. DEC Alpha (3000-400 AXP)	Approximately the same as the VAX 4000/90.

Note: Costs are in FY 1993 dollars.

The systems described in Table 11 include the CPU, memory, hard disk, Ethernet and other serial interfaces, the TURBO-Unibus parallel interface, and the other peripherals on the current VAX 3800 (plasma display, printer, optical disk unit, etc.).

The unit procurement costs in Table 11 indicate that the Navy should consider replacing the VAX 3800 with one of the newer DEC computers in the near future. The newer computers are less costly and much more capable. Their procurement costs, and thus 10-year systems costs, are less than the costs of the VAX 3800. (The 10-year systems cost is a linear function of the procurement cost for COTS items, for which the producer's development costs are included in the price.) The VAX 4000/90 is an especially attractive alternative.

The remaining question is whether the Navy should consider the DEC Alpha. It is much more capable than the VAX 4000/90, but we have not determined to what extent its increased capability would speed up test time. Note, however, that the Navy has everything to gain and nothing to lose by upgrading to the VAX 4000/90 immediately. The VAX 3800 is so expensive that it would be cheaper to upgrade immediately to the VAX 4000/90, even if the Navy made a subsequent move to the DEC Alpha once that technology was proven. The Navy would realize savings by abandoning the VAX 3800. Note that the Navy would not have to pay the 35-percent retrofit differential for any more systems than if the Navy waited for three years before making the VAX Alpha upgrade. In either cases, the Navy would presumably upgrade all 662 computers.

A minor caveat to this analysis is that whereas the VAX 4000/90 can only read optical disks that use a 512-byte format, the Navy has been using a 1,024-byte format to store TPS information. We expect, however, that converting the TPS disks to the lower format would not be costly. In addition, it would reduce the cost of offline optical disk operations by allowing these operations to be performed by a less costly computer.

We recommend the Navy initiate a demonstration test of the VAX 4000/90 to verify that it is compatible with the CASS station hardware and software, and also current TPSs. Implementation is recommended if the test finds no problems. If there are problems that would take several years to solve, the Navy should consider upgrading directly to the DEC Alpha instead of the VAX 4000/90.

4. Impact

Implementing this P^3I would increase throughput (to an extent not yet estimated) and save acquisition cost.

B. ADD STATION INTERFACES FOR NEW BUSES (ALL)

1. Background

Data buses are the means that most modern electronic devices use to communicate data and control signals within and between themselves. A variety of data buses have been developed over the years, and CASS has a number of interfaces for communicating with several military and commercial buses (Table 12).

Table 12. CASS Data Bus Interfaces

Military Buses
MilStd-1553 bus interface
MilStd-1553 interface, 1 Mbps serial
MilStd-1773, contains MilStd-1553 protocol plus fiber-optic connection
MCAIR A3818, conforms to McDonnell-Douglas specification A3818
Ancillary instruments interfaces
AR-57A inertial navigation system interface, serial data, 5-10 KHz
Advanced communication bus interface
– RS-485, 1 Mbps asynchronous or 10 Mbps synchronous
– Manchester code interface, 1 Mbps, MilStd-1553 format
– Harpoon interface, accommodates Harpoon/Slam signals
– High-Speed Data Bus, 50 Mbps, fiber-optic or wire, serial, linear token ring, conforms to standard set by the JIAWG
– Fiber-optic data bus interface, implements fiber-optic commun./command protocols, 10 MHz
– Military communications bus interface (MilStd-1397A), two 18-bit or one 36-bit parallel bus
Commercial Buses
IEEE-488 test instrument data bus (8-bit parallel)
IEEE-802.3 Ethernet
EIA-RS-232 serial bus, 50 to 19200 baud
EIA-RS-422, serial bus, 50 to 38.4 baud
ARINC 429-10 bus interface

Table 12 shows that CASS provides good coverage of data buses that are in current usage. These include the military MilStd-1553 and AR-57A buses that are commonly used in current avionics equipment, as well as the IEEE-488 (Instrument Bus) and IEEE 802.3 (Ethernet) commercial bus standards. Internally, CASS is able to communicate with VME, MMS, or IEEE-488 buses used by a wide range of test instruments.

Some additional bus interfaces, however, would help CASS meet the needs of new avionics that will become operational during the next decade with the introduction of the F-22 followed by the RAH-66, the F/A-18E/F and the F/A-X aircraft. These aircraft will use faster and higher-capacity data buses defined by the JIAWG and other standard initiatives. We used the F-22 as a model to determine the new bus interfaces that should be installed in

CASS. This aircraft is much further along in development than the other new aircraft mentioned above, and the avionics architectures have not yet been determined. We will, however, comment on the new Futurebus II+ that will likely be used on the F/A-18E/F and the A/F-X.

Table 13 lists the major new buses installed in the F-22. The PI bus is used on the backplane, and is thus the primary means of communication between line-replaceable modules (LRMs). The performance characteristics of the PI bus are within the current parameters of the CASS DTU, and are thus testable now. Software drivers will be required to handle the bus protocols, but these drivers can probably be written in FORTRAN and called by the ATLAS program. The PI bus drivers in the current design of the F-22 are written in Ada and machine languages, which use bit manipulation to facilitate the handling of protocols. Emulating this capability could be difficult.

Table 13. F-22 Major Data Bus Interfaces

Interface	Characteristics	CASS Test Approach
MilStd-1553	Serial, 1 MHz	CASS has a MilStd-1553 interface
PI Bus (JIAWG)	Parallel bus with 12.504 MHz clock speed, 32 data lines each way, 16- or 32-bit options	Within DTU capability, but requires software drivers
High-Speed Data Bus (HSDB)	Serial linear token ring bus, 50 Mbps, JIAWG, fiber-optic	CASS has HSDS interface
Signal Data Distribution Network (SDDN)	250 MHz	Not available
High-Bandwidth Data Bus (HBDB)	250 MHz fiber-optic	Not available
Video Data Distribution Network (VDDN)	Bandwidth to 800 MHz	Not available
Test and Maintenance Bus (TM)	Clock speed 6.25 MHz with user console inteface protocol	Within DTU capability, but requires software drivers

The DoD Next-Generation Computer Resources (NGCR) Group is developing standards for the Futurebus II+, a backplane similar to the JIAWG PI bus that may find application on the F/A-18E/F and the A/F-X aircraft. Although the features have not been decided finally, the Futurebus II+ may require an upgrade of the current CASS DTU to handle the higher data rates.

The High-Speed Data Bus (HSDB) used in the F-22 is the primary means of communicating between WRAs. CASS currently includes an interface for the fiber-optic version of the HSDB, and can conduct tests using this bus.

The last three buses listed in Table 13 (SDDN, HBDB, and VDDN) cannot be tested by the current CASS station because they operate at much higher frequencies than either the current bus interfaces or the DTU. Although these buses are used in the F-22 in fewer places than the PI bus or the HSDB, CASS will need to communicate with them if it is to have full capability to test the F-22. The most economical way to give CASS this capability is to create three new interfaces, rather than upgrading the DTU. A 200-MHz DTU would cost over $500,000, compared with $45,000 to purchase the three new interfaces (discussed later).

Because the F-22, F/A-18E/F, and A/F-X are still under development, it is quite possible that one or more additional new interfaces will emerge. We will thus consider adding four new data bus interfaces.

2. Alternatives

Alternatives for acquiring the interfaces include:

A. develop separate interface units for four new data buses: the SDDN, the HBDB, the VDDN, and a place-holder for an additional bus, or

B. develop a single, multi-mode gateway unit consisting of all four interfaces.

Both alternatives are *achievable using current* technology. We recommend alternative B. It is more risky from a technical standpoint, in that placing all the interfaces into a single unit and sharing resources creates the possibility for timing problems. However, such problems can be solved if they arise, and alternative B is also less costly because the common circuit elements are bought only once. Alternative A has the advantage of flexibility, in that different CASS configurations (or different CASS stations within a given configuration) could be outfitted with different combinations of interfaces. Doing this, however, would create the problems of different configurations, and violate the CASS goal of commonality.

Either alternative A or B could be installed in various ways: (1) in the current GE VME architecture, (2) as a self-contained module, or (3) in a future VXI architecture, should the Navy make this major modification. Given the flexible value of the CASS architecture, any of these options would be relatively easy to accommodate in the future. Installation is thus a separate issue from the choice between alternatives A and B; however, the relative costs and benefits of the two alternatives would be the same. We have used alternative B as the basis of our cost estimates, and we believe that is the preferred alternative.

3. Costs

Table 14 lists the development and unit procurement costs for the two alternatives. These costs were derived from catalog prices for similar devices, and other sources. Alternative B's integrated, multi-function structure would cost more to develop but less to procure than building the same number of interfaces separately, as in alternative A. Functions such as the computer's central processing unit and memory would be shared.

Table 14. Cost of New Interfaces

Alternatives	Development Cost	Procurement Cost
A. Interface Unit		
Per interface	$0.4–0.8 million	$15,000–25,000
All four interfaces	$1.6–3.2 million	$60,000–100,000
B. Multi-mode Gateway (four interfaces)	$1.35–2.25 million	$45,000–75,000

Note: Costs are in FY 1993 dollars.

4. Impact

Many of the new avionics systems being built for the F-22, the F/A-18E/F, and the A/F-X will use one or more of the new data buses listed above. The CASS station will be able to test the UUTs for these aircraft if the new interfaces are installed. Otherwise, the needed test capability could be incorporated into active IDs, adding to development time, development cost, and incomplete self-test.

C. ADD MORE SWITCHING TO THE RF INTERFACE (RF/CNI)

1. Background

The CASS RF interface, which is contained in the RF and CNI stations, has a limited number of RF relays dedicated to switching RF loads and power measurement instruments. Unlike GPI switching, CASS provides only a limited amount of RF switching. As we discussed previously, several of the engineers who have been offloading radar TPSs have developed a number of active IDs to accommodate additional RF switching.

The additional equipment contained in the RF IDs included matrix relays, circulators, and other devices commonly used to switch RF circuits during test sequences. Because these items are commonly used for RF tests, we have analyzed the possibility of installing more switching in the CASS station, behind the RF interface on the RF and CNI stations.

2. Alternatives

The alternatives are as follows:

A. develop a new RF interface for the RF and CNI stations that incorporates more RF switching or

B. continue the current practice of installing additional RF switching in the separate, unique IDs that are developed for each operational TPS (OTPS).

Table 15 compares the costs of alternatives A and B. Alternative A obtains added RF switching by developing and procuring new RF interfaces that include switching relays, and installing the new interfaces in the 366 RF and CNI configurations (Air-552 data [7]), which all have RF interfaces. Several industry data points suggest that an RF interface with switching would cost about $1.5 million for development plus $50,000 per unit for procurement. The total cost for the RF and CNI stations is thus $19.8 million. The Navy would continue to procure "nominal" (non-active) IDs for the RF and CNI UUTs. (We have to include ID costs in both alternatives to make a legitimate comparison.) We assumed a unit cost of $20,000 for a nominal ID. (The much more complex CID costs $36,000.) The number of IDs to be procured would equal 628, the number of RF plus CNI operational TPSs (Air-552 data [12]). (An operational TPS, or OTPS, is the hardware part of a TPS, consisting of the ID plus the cables. The Navy has to buy only 628 OTPSs, or IDs, to support the approximately 7,000 TPSs.) Alternative A thus costs $32.4 million in total.

For Alternative B, we assumed that the same RF switching equipment installed in the station for Alternative A would be installed in the IDs in Alternative B, at the same incremental cost of $50,000. (There are no station modifications for Alternative B.) An active ID would thus cost $70,000 in total, which adds up to $44.0 million for all 628 OTPSs.

The calculation in Table 15 thus indicates that it would cost only about 74 percent as much, or a saving of approximately $12 million, to put additional RF switching into the CASS RF and CNI stations rather than into the RF and CNI IDs. The cost inputs (the $20,000 and $50,000) to the calculation are uncertain, but the effect of the uncertainty is reduced by the fact that the same inputs are used in both alternatives. In short, we assumed that it costs the same to put RF switching into a single station as into a single ID, so that the saving is determined by the fact that Alternative A makes fewer improvements: 366 stations versus 628 IDs.

Table 15. RF Interface Analysis

	Alternative A	Alternative B
Station costs of new RF interface		
Development cost	$1.5 million	-
Recurring cost		
Unit cost	$50,000	-
Number of RF and CNI stations	366	-
Total recurring cost	$18.3 million	-
Total	$19.8 million	-
ID costs		
Recurring cost of a nominal ID	$20,000	$20,000
Incremental cost of RF switching	-	$50,000
Total cost of an ID	$20,000	$70,000
Number of IDs (OTPSs)	628	628
Total	$12.6 million	$44.0 million
Total cost of alternative	$32.4 million	$44.0 million

Note: Costs are in FY 1993 dollars.

We therefore recommend additional RF switching should be procured, and that it should be obtained using Alternative A.

Note that if the Navy chooses to adopt a high-power tester, any new RF switches should be placed in that tester rather than behind the current RF interface. This would eliminate changes to the current RF station, and would place the RF switching next to the RF loads and monitoring equipment in the high-power tester.

3. Costs

The costs of the recommended RF switching interface is $1.5 million for development plus $50,000 recurring. The recurring cost is based on a vendor's estimate of $30,000, which we felt was much too optimistic, given the fact that the interface has not yet been developed.

4. Impact

The proposed RF switching matrix will reduce the time and cost of developing and manufacturing IDs for RF TPSs. The new interface would also decrease TPS run times.

D. ADD A BUS ANALYZER TO THE MILSTD-1553 INTERFACE (ALL)

1. Background

One of the current station interfaces is that for the MilStd-1553 bus, the common link between avionics systems in current and planned future Navy and Air Force aircraft, including the F-14, F-15, F-16, F/A-18, and F-22. A bus analyzer would read the information flowing in this bus to help diagnose problems arising during tests. The need for a bus analyzer is immediate.

2. Alternative

We identified only one alternative:

A. install a COTS bus analyzer in the station.

If other TPS developers follow the practice of the engineers at the Norfolk Naval Depot of putting bus analyzers in active IDs, the cost could be much greater than the cost of installing bus analyzers in the CASS stations.

3. Costs

According to prices in a Tektronix catalog, COTS bus analyzers cost approximately $9,200. These instruments are rack-mounted units, and we therefore did not apply the ruggedization cost factor.

4. Impact

Incorporating this P^3I would reduce test time. Although the magnitude of the reduction has not yet been estimated. As note above, installing the capability in the CASS station would avoid the cost of designing active IDs for the OTPSs.

E. ADD ANOTHER ARBITRARY WAVEFORM GENERATOR (ALL)

1. Background

The CASS hybrid, RF, and CNI configurations are is currently equipped with one, two, and three arbitrary waveform generators (AWGs), respectively. These devices, which were developed by General Electric, are dual-channel instruments capable of generating a variety of wave shapes varying in frequency from 0.01 Hz to 20 MHz. The frequency may be swept in either linear or logarithmic modes across the total frequency range at rates of

1.4 microseconds to 40 seconds. The signals may be modulated using frequency, amplitude, frequency shift keying, or frequency hopping modes.

2. Alternatives

The alternative to be analyzed is adding another AWG to each configuration. We have not considered the alternative of adding less capable (and less costly) AWGs in order to avoid compatibility with the current AWGs. (There is a possible need to add several AWGs to the hybrid station, which has only one at present. We have not studied this option.)

3. Costs

We assume that the new AWGs would be replicas of those GE is already using in order to minimize compatibility problems. GE states these cost $20,000 each to procure.

4. Impact

Adding more AWGs would avoid the development costs associated with active IDs. In discussions with engineers at Norfolk and Grumman who are engaged in offloading TPSs for the F-14 aircraft, we learned that an additional AWG or sweep generator has been added to the ID. (The Norfolk effort involves the OTPS-04.)

F. ADD A PHASE-NOISE TESTER (RF/CNI)

1. Background

Phase noise refers to unwanted fluctuations (jitter) in the frequencies or phase generated by electronic components such as oscillators and amplifiers. It thus degrades the performance of all radar and communication systems that rely on measuring Doppler shifts (frequency shift). In the case of aircraft radars that have a ground-attack mission, for example, phase noise in the receiver amplifier lowers the probability that the radar will be able to pick out moving targets such as tanks from the ground clutter. The pilot may not know that his radar has a problem; he will simply fail to pick up targets.

Testers measure the phase noise of UUTs by using phase detectors to compare the frequencies emitted by the UUTs with the frequency of a precision local standard. The current CASS has a limited ability to measure phase noise by using the Microwave Transition Analyzer to compare UUT frequency with the rubidium frequency standard located in the station. This method, however, would lack the sensitivity to detect phase noise in radar receivers that are designed to detect signals in the region of nanowatts (10^{-9} watts).

Engineers from Hughes Aircraft Company have told us that CASS does not need phase-noise testers, and they are not being installed in the IDs under Hughes's $21 million contract to develop new TPSs for three WRAs (receiver, data processor, and power supply) for the APG-73, the F/A-18 radar). Hughes's argument is that current radar receivers are extremely reliable, a conclusion based on data that there have been only six phase noise failures on the F-15 in 177,000 flight hours.

We do not, however, find this argument compelling. First, the six failures may not be a reliable statistic. Weapons are not tested systematically, but only when someone notices a problem. Phase-noise failures are most likely to show up when (1) the mission is to find small or distant ground targets using Doppler radar, (2) the targets are there, (3) the aircraft does not see them, and (4) someone else *does* see them (or knows they were there). The real question is, what percentage of the time is the radar's phase noise capability actually down—or better, what fraction of the targets would be missed in actual operations, when it counts. As a final point, when asked how many of the testers on the factory floor lacked a phase-noise tester, the Hughes engineers replied, "None."

2. Alternatives

The alternatives are:

A. add a commercially-available MMS phase-noise system, but without a spectrum analyzer, relying on the one in the current CASS, or

B. develop and add a new MMS system that has a lower noise floor than existing systems, again, without a spectrum analyzer, relying on the one in the current CASS station.

According to our most recent information, the spectrum analyzer in the present CASS design has enough capability to serve as the measurement instrument for a phase-noise tester. Note that procuring a separate phase-noise tester would not be needed if the Navy decides to procure the full High-Power Device Tester (HPDT) that GE has recommended; the full HPDT system includes a phase noise tester. Another alternative, not analyzed here, would be to develop an end-to-end tester for phase noise. Phase noise could be generated in wave guides and other components than the oscillators and amplifiers that would be tested by the instruments we are considering here.

Table 16 describes a characteristic of the two alternatives.

Table 16. Phase-Noise Tester Characteristics

Architecture	Frequency	Noise Floor of Alternative A	Noise Floor of Alternative B
MMS	1.5-18 GHz	-80 dBc @ 100 Hz -115 dBc @ 1 KHz -127 dBc @ 10 KHz	-90 dBc @ 100 Hz -125 dBc @ 1 KHz -137 dBc @ 10 KHz

One question is whether a currently-available phase-noise tester could meet military requirements, shown in Table 17. Figure 2 indicates that both alternatives easily meet the communications requirements, but only Alternative B meets the current RF requirement. Should the RF requirement become more stringent, even alternative B will be deficient, although better instruments *may* be available in the future. The issue is uncertain because noise instruments are starting to reach theoretical limits.

Table 17. Phase-Noise Requirements for Military Aircraft

	Carrier	Offset	Power Reduction
Communication (ATARS)	-3 dBm, 10 MHz	200 Hz	-66.4 dBc
		1 MHz	-133 dBc
Radar (X-band)	10 GHz	3 KHz	-130 dBc

We recommend the Navy take action to implement the Alternative B phase-noise system.

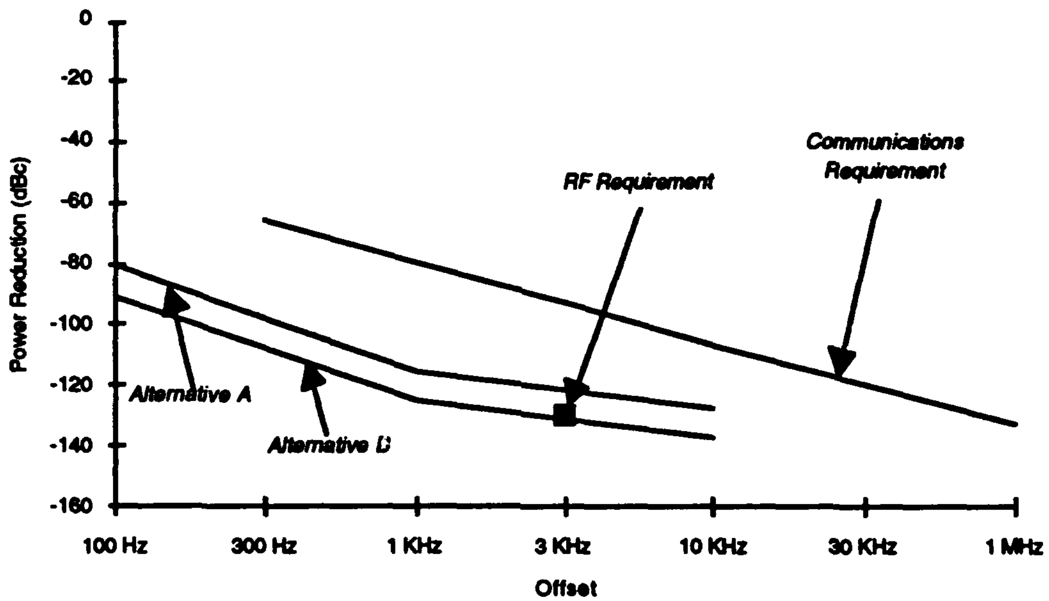

Figure 2. Phase-Noise Requirements and Capability

3. Costs

The costs cited in Table 18 are typical of the phase-noise systems offered by current vendors. Our information indicates that the current CASS spectrum analyzer can be used for a new phase-noise tester, which would lead to a substantial saving. The costs of both alternatives are based on information from vendors. Alternative A is a COTS phase-noise tester for a price of $55,000 and no development cost. It does not perform as well as a more expensive system that has been recently proposed, shown in Alternative B. Since alternative B has not yet been developed, achieving the performance involves some uncertainty.

Table 18. Costs of Upgrading CASS Phase-Noise Test Capability

Alternative	Development Cost	Recurring Cost
A. COTS MMS	—	$55,000
B. New MMS	$600,000	$90,000

Note: Costs are in FY 1993 dollars.

4. Impact

The ability to test for phase noise is a critical capability because the lack of it may eliminate the ability of fighter and attack aircraft to perform their missions. The systems that are affected include these:

- multi-mode aircraft radars such as the F-14 APG-71, the F/A-18A/B/C/D APG-65, and the F/A-18E/F APG-73;
- reconnaissance systems such as the synthetic aperture radar (SAR) and the Advanced Tactical Reconnaissance System (ATARS); and
- radar-guided air-to-air missiles such as the Phoenix and AMRAAM.

G. ADD A NOISE-FIGURE TESTER (RF/CNI)

1. Background

All electronic devices suffer from noise because of the random movement of electrons: impulse (ignition) and quantizing (decoding) noise in digital systems, shot noise in transistors, and thermal noise in resistors. Noise degrades performance by reducing the signal-to-noise ratio. A radar low-power receiver, for example, will boost both the incoming signal and noise by the same factor, but will add in its own noise, thus reducing the signal-to-noise ratio. A reduction in signal-to-noise ratio from 10 to 9, for example, will have a "noise figure" of 10/9, or 1.1.

It is especially important to measure the noise figure of low-power devices, which typically have low signal-to-noise ratios. Examples are RF receiver amplifiers, up/down converters that increase or decrease a carrier wavelength, traveling wave tubes, and low-power detectors such as RF receivers detecting long-range or stealthy (low radar cross-section) targets.

The Microwave Transition Analyzer or one of the spectrum analyzers in the current CASS station can be used to measure noise figure, but they would have to make a sequential series of voltage measurements, both with and without an applied noise source. A noise-figure tester would make the measurements automatically. Various types are available: electronic noise source (ENS), Y factor, signal generator, and hot/cold load methods. The ENS is the most capable.

2. Alternatives

Our alternatives are as follows:

A. add accessory components to improve the capability of the current CASS *instruments* (a local oscillator, noise source, low- and high-pass filters, and a mixer) or

B. add a complete automatic noise-figure capability.

With the additional components of Alternative A, CASS could possibly perform noise-figure measurements in connection with the existing power meter, noise source, and 40-GHz synthesizer. A detailed analysis would be needed to verify that the CASS instruments have a large-enough frequency range and input sensitivity to make the noise figure measurements. In addition, some laboratory testing would be required to test the new approach.

Alternative B would use commercial noise measurement instruments: a noise-figure meter, noise-figure test set, and noise source. The CASS 40-GHz synthesizer would be used as a local oscillator. None are currently available with the VXI or MMS architecture. Alternative B would be capable of covering the range of 10 MHz to 26.5 GHz, with a noise figure range from 0 to 30 dB. The test would be conducted automatically and would yield a direct readout of the noise figure. Since the capability of Alternative A is uncertain, Alternative B is recommended. It would be good, however, to perform a more detailed engineering analysis to determine if the less costly alternative (Alternative A) would perform well enough.

3. Costs

Table 19 shows that Alternative B costs much more than Alternative A. The costs are based on Hewlett Packard catalog prices for their HP 8970B and HP 8971C equipment [9].

Table 19. Automatic Noise-Figure Tester for CASS

Alternative	Components	Unit Procurement Cost
A. Improve current capability	Mixer, noise source, low-pass filter, high-pass filter	$7,000
B. Add new capability	Noise-figure meter, noise-figure test set, local oscillator, noise source	$38,000

Note: Costs are in FY 1993 dollars.

4. Impact

A good noise-figure tester will reduce the "re-test OK" and "cannot duplicate" rates, thus improving mission readiness for all aircraft.

H. ADD A MILLIMETER-WAVE SOURCE (RF/CNI)

1. Background

The RF stimulus instruments in the current CASS are limited to 40 GHz. Although aircraft radars typically operate no higher than 10–18 GHz (X or Ku band), newer seeker-radars of some missiles will operate in the millimeter-wave region of up to 100 GHz. A millimeter-wave source module would thus give CASS the ability to test missile-seeker radars at their operational frequencies.

2. Costs

Hewlett Packard produces millimeter wave source modules costing $43,500 for a set that covers frequencies in the range of 40 to 110 GHz, sufficient for testing current missile-seeker radars. These are enclosed units, and we therefore applied no ruggedization cost factor. The source module set includes the instruments shown in Table 20.

Table 20. Costs of Millimeter Wave Source

Instrument	Frequency Range	Price
HP 83556A	40–60 GHz	$11,500
HP 83557A	50–75 GHz	$16,000
HP 83558A	75–110 GHz	$16,000
Total		$43,500

Note: Costs are in FY 1993 dollars.

3. Impact

The capability will aid testing of the mission readiness of seeker-radars.

I. ADD A HIGH-POWER TESTER (RF/EO)

1. Background

The RF transmitters used in radars, electronic warfare suites and communications systems typically employ peak power outputs in the range of 50 to 100 kilowatts (kw). These transmitters are driven by high-voltage power supplies that produce output voltages of up to 10 kilovolts (kv). The current CASS RF station can test these high-power and high-voltage devices below their full ratings. This kind of test, however, would fail to detect voltage breakdowns and overheating that are common failure modes at full power. To avoid these testing shortcomings, TPS offloaders will probably design complex active IDs that include the high-voltage, high-power devices. Developing active IDs, however, is a costly and time-consuming process, and leads to problems in operational testing situations. (Maintainers will not be sure whether a problem lies with the UUT or the active ID. The CASS station itself is self-tested every day.)

An alternative is to design a high-power tester as a part or add-on to the CASS station, and GE and the Electronic and Space Corporation (the GE team) have collaborated on a preliminary design, the High-Power Device Tester (HPDT). Two preliminary options have been developed, a single bay and a 1-3/4 bay version. Table 21 lists the major functions contained in each unit. The HPDT will contain a range of RF high-power loads, DC loads, high-voltage power supplies, and a variety of ancillary equipment to provide the cooling and pressurization needed to operate high-power equipment.

The 1-3/4-bay design includes a phase-noise tester and an array processor, two instruments that are analyzed as separate P^3Is in this study. If the Navy decides to obtain all three capabilities—high-power tester, a phase-noise tester, and an array processor—it would have to determine whether the last two capabilities are more efficiently obtained as part of a high-power tester such as the GE version, or as separate instruments. This decision would require an analysis of the incremental costs and capability of the phase-noise tester and array processor that are included in the full HPDT, so that the results can be compared with cost and capability of the separate instruments.

Table 21. HPDT Major Functions

1 Bay	3/4 Bay	Ancillary Equipment
Video monitor, 6 inches, 20 MHz	Low-band RF loads, DC to 3.9 GHz at 2.6 kw and 4.5 kw	Roll-about cart
RF monitor, 0.3 MHz to 40 GHz	High-band RF loads, 12.4–18.2 GHz, 1 kw	Liquid cooling unit
VXI chassis and controller	High-power DC load, 2–20 kw	Miscellaneous fixtures
AC power/UUT interface	High-current supply, 50–140 vdc, 24 amps	
X-band loads, 100 w to 2.7 kw average	High-voltage supply 12.5 kv and 20 kv	
Mid-band load, 3.9 kw to 8.2 kw average		
DC loads, 25 w to 5 kw		
High-voltage DC power 10 kv		
Phase-noise tester		

The question is whether the HPDT provides a substantial increase in the ability to test actual UUTs. Reference [11] provides partial information by listing the numerical specifications that are needed to test 25 major UUTs. The reference indicates those specifications in which CASS is deficient but HPDT is capable, but does not give numerical results that would indicate how badly the HPDT is needed. How many UUTs does CASS lack the ability to test, are they components of major systems, and by what margin does CASS fail?

Table 22 throws some light on these questions by focusing information contained in [11, 13, and 14]. The table lists those items of equipment that [11] states cannot be fully tested by CASS, and estimates the magnitude of the major deficiency by comparing the specifications that are: (1) delivered by CASS, (2) required by the UUT, and (3) provided by the HPDT. The first row, for example, shows that CASS cannot fully test the transmitter of the AWG-9 weapon control system for the F-14A because it lacks enough DC power: CASS can deliver only 0.450 kv of DC power to a UUT, whereas the transmitter requires 19.2 kv—and the GE HPDT can supply the 19.2 kv. Similarly, the

Table 22. Capability of GE High-Power Device Tester

System	Item of Equipment	DC High-Power Supply	DC High-Power Load
AWG-9 weapon control system for F-14A	Transmitter	.450 kv/19.2 kv/ 19.2 kv	
	Grid modulator		
	Beam power supply		.5 kw/3 kw/20 kw 5kΩ/120 kΩ/1350 kΩ
	Collector power supply		.5 kw/20 kw/20 kw 5kΩ/8.5 kΩ/1350 kΩ
	Solenoid power supply		.5 kw/3 kw/20 kw
APG-71 fire control radar for F-14D	Transmitter	.450 kv/19.2 kv/ 19.2 kv	
	Grid modulator		
	Beam power supply		.5 kw/3 kw/20 kw 5 kΩ/120kΩ/1350 kΩ
	Collector power supply		.5 kw/20 kw/20 kw 5kΩ/8.5kΩ/1350 kΩ
	Solenoid power supply		.5 kw/3 kw/20 kw
	Master oscillator		
	Receiver		
	Synchronizer		
	Signal data processor high-power RF		
	Signal data processor low-power RF		
APG-63 fire control radar for F-15A/B/C/D	Transmitter		
	TWT power supply		.5 kw/10 kw/20 kw 5kΩ/120 kΩ/ 1350 kΩ
	Solenoid power supply		.5 kw/2 kw/20 kw
APG-70 radar for F-15E	Transmitter		
APG-65 radar for F/A-18A/B/C/D	Transmitter		
	High voltage power supply		.5 kw/4.5 kw/20 kw 5kΩ/180 kΩ/1350 kΩ
	Power converter		.5 kw/4 kw/20 kw
	Switching regulator		.5 kw/4 kw/20 kw
APG-73 radar for F/A-18E/F	Transmitter		
APS-116 search radar for S-3A	Transmitter	.450 kv/10 kv/19.2 kv	
APS-137 search radar for S-3B	Transmitter	.450 kv/10 kv/19.2 kv	
APS-124 radar for SH-60B	Transmitter		
APQ-148 search radar for TC-4C	Transmitter		
ALQ-99 ECM set for EA-6B	Transmitter		
ALQ-165 ECM set for AV-8B, F-14D, F/A-18C/D	Transmitter		
	High-voltage power supply		.5 kw/1 kw/20 kw 5kΩ/91kΩ/1350 kΩ
APS-130 search radar for EA-6B	Transmitter	.450 kv//19.2 kv	

Notes: The entries show capability of CASS/requirements of UUT/capability of GE HPDT. ECM = electronic countermeasures, Ω = ohms.

beam power supply for the AWG-9 radar cannot be fully tested because it requires a load that is lacking in two dimensions, power (wattage) and resistance, and once again, the HPDT has the needed capability. The HPDT can also test the F-15 Tactical Electronic Warfare System (TEWS).

The need for high-power testing of radar systems will decline in the future with the development of phased-array architecture. Phased-array systems are comprised of many low-power units, which will lead to greater reliability and lower testing voltage and power levels. EW and communications systems will continue to require high-power testing, however, and radars will continue to need high-power testing until phased-array systems have replaced the older systems.

2. Alternatives

The alternatives available include:

A. acquire a tester modeled after the single-bay HPDT proposed by the GE team or

B. acquire a tester modeled after the 1-3/4-bay HPDT proposed by the GE team.

To design these new bays, the GE team first determined the requirements for high-power testing by analyzing the specifications of 25 avionics WRAs. These test requirements are compared in Table 23 to the capability that would be provided by the two HPDT units. We recommend the full 1-3/4 system, which can fully test most of the current avionics inventory. (GE determined that the HPDT requirements were driven by the AWG-9/APQ-71 and the APS-116/137 high-power WRAs.)

Table 23. Capability of HPDT Alternatives

Alternative	Partial Test	Full Test
A. Single Bay	ALQ-99, ALQ-165	APQ-156, APG-65, APG-73, APS-116, APS-137, APS-130
B. 1-3/4 Bay		ALQ-99, ALQ-165, AWG-9, APS-71, most radar and EW WRAs

3. Costs

Since the HPDT is a new item, significant development effort will be required. Development costs for the HPDT was estimated by GE to be approximately $5.0 million for the 1-bay tester and $8 million for the full, 1-3/4-bay tester.

The various estimates for the unit recurring cost for the HPDT systems are as follows:

Organization	1 Bay	1-3/4 Bay
GE	$590,000	$700,000
NavAir 522	$750,000	
IDA	$580,000	

The IDA estimate for the 1-bay tester was derived by summing catalog costs for the individual instruments. The unit cost of the 1-3/4-bay tester we have recommended was provided by GE, and is understood to include a phase-noise tester and an array processor.

4. Impact

The HPDT would aid the testing of the radars of aircraft such as the Navy F-14, F/A-18, S-3, and P-3 and the Air Force F-15, F-16, and future F-22. (The Navy EA-6B is an exception; it has higher power than other military aircraft, and is tested at Naval Depots.) The HPDT can also fully test the F-15 TEWS. The availability of the HPDT will reduce the need and the cost of developing an array of active IDs. Simplification of the ID and provision of more automated high-power test should decrease test time.

J. ADD AN ARRAY PROCESSOR (ALL)

1. Background

Aircraft radar and IR systems use signal processors to extract information from target return signals after the signals have been digitized by an analog-digital converter. For realistic testing, these processors must be stimulated with the same types of signals that they receive in operational use. Data rates must be at least equal to (ideally, several times greater than) operational rates, and the signals must be as complex. Testers commonly include array processors to provide these stimuli. For example, the Radar System Test Set (RSTS) for the F/A-18 aircraft has an array processor. The current CASS, however, lacks an array processor. The station's DTU can generate digital test signals at 40 Mbits per second (with interleaving) for each of the 336 channels, or 13.4 GBits per second, in total. (The current DTU can sustain this data rate for only 0.4 milliseconds, however, because each channel is backed up by only 16 Kbits of memory. Increasing the pin memory to 64 Kbits, however, would allow the DTU to generate longer test sequences.)

Figure 3 shows the processing rates of next-generation aircraft (F-22 and A/F-X), which will operate at processing rates exceeding 0.1 billion floating point operations per second (GFLOPS). The figure shows the year the technology is first introduced into the program; testing will not be needed until several years later, when the aircraft reaches the production stage.

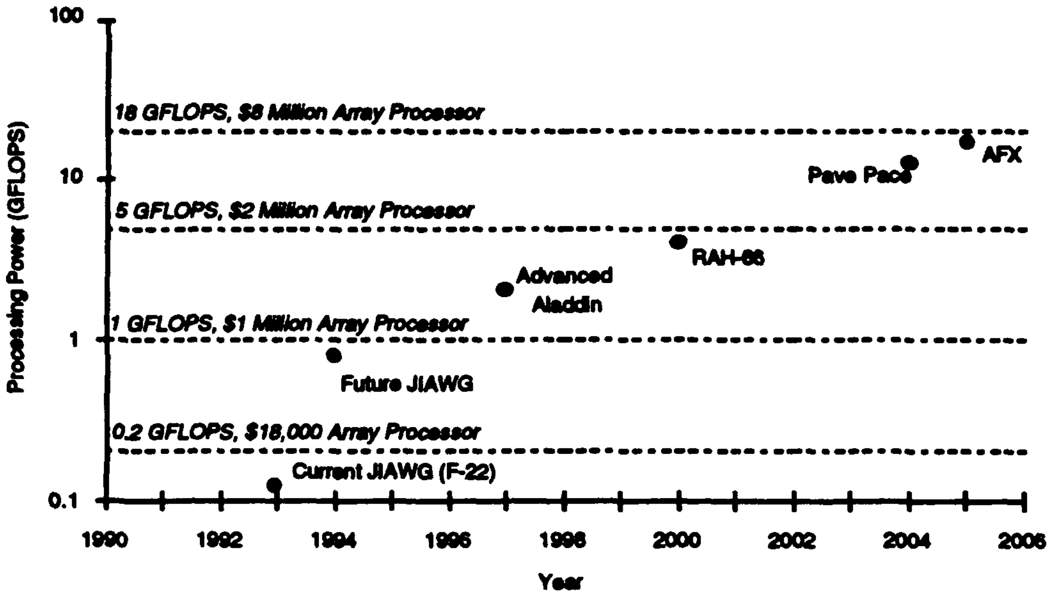

Figure 3. Testing Requirements of Future Signal Processors

A 0.2-GFLOPS array processor would meet immediate needs at the relatively small cost of $9,000. It would be much more costly to obtain capability beyond this level today: 1 GFLOPS to meet near-future requirements, or 5 GFLOPS to cover needs until the end of the century. In the long run, CASS may need an 18-GFLOPS system, costing an estimated $8 million if purchased today. Processor costs will fall significantly over the next several years, if present trends in electronic equipment continue, so acquisition of a large processor should be delayed until needed.

2. Alternatives

Among the alternatives are:

A. add a 0.2-GFLOPS array processor,

B. add a 1-GFLOPS array processor, or

C. add a 5-GFLOPS array processor.

Alternative A appears to be attractive at present, since delaying acquisition of the more capable instruments will permit the Navy to take advantage of the falling trend in prices of computer-related instruments (approximately 25 percent per year). As mentioned elsewhere in this paper, the Navy would not have to acquire a separate array processor if it chose to develop the full 1-3/4 bay GE High-Power Device Tester, which contains an array processor. We recommend acquiring the 0.2-GFLOPS array processor to meet immediate needs.

3. Costs

Table 24 gives the recurring costs of new COTS array processors obtained from catalog prices for Convex, Intel, and DY-4 Systems, Inc.

Table 24. Acquisition Cost of Array Processors

GFLOPS	Recurring Cost
.2	$9,000
1	$1 million
5	$2 million
18	$8 million

Note: Costs are in FY 1993 dollars.

Although Figure 3 indicates that a 5- or 18-GFLOPS array processor may be needed in the long run, a 1-GFLOPS processor would fill test needs for 10 years, and could be cheaply upgraded to meet future needs. (Most array processors use a building-block architecture that permits slower machines to be scaled upward.)

4. Impact

Installing an array processor in the CASS station would yield shorter test times and the ability to perform real-time tests, which are critical for testing missiles. The Common Test Set that will soon be in development will have real-time capability.

K. ADD A COCKPIT-DISPLAY TESTER (RF/CNI/EO)

1. Background

Cockpit displays are becoming more complex for several reasons. First, sensors are becoming more capable. Longer detection range means more targets in view, and greater resolution in imaging means more information per target. Secondly, data from different sensors are being integrated (sensor fusion) in order to improve the degree and reliability of the information provided the pilot. As a result, aircraft designers are presenting more and more information to the pilot, and techniques such as graphical displays are being developed to avoid the possibility of "information overload."

The CASS station has no capability, at present, to test cockpit displays. Malfunctions can occur because of problems in either the electronics that present the information to the display, or the video monitor itself. Testing thus requires a video display to test the electronics, and a symbology generator and photometric unit to test the displays. The photometric unit makes an electronic and automatic comparison of what is on the screen with the shapes sent by the symbology generator, thus providing a more objective measurement than obtained from human judgment. CASS has a plasma display that is used in operating the station, but it is inadequate for testing, because it has lower resolution, brightness, and contrast than cathode ray (i.e., TV) monitors.

2. Alternatives

The alternatives include:

A. add a display tester by adding a video monitor and a display generator or

B. add a display analysis system.

Alternative A can perform functional (go-no go) tests of display units, whereas alternative B can perform the more detailed parametric, or diagnostic tests that give maintainers more information for use in repair. Alternative A is recommended because Alternative B costs *much* more (see the next subsection) for little commensurate increase in capability.

3. Costs

Alternative A would cost approximately $5,500, based on prices in a Texas Instruments catalog for the monitor ($2,500) and discussions with TPS developers at the Norfolk Naval Depot for the symbology generator ($3,000). A display analysis system (Alternative B) would cost much more, approximately $200,000 [15].

4. Impact

Adding a display tester to CASS will reduce test times and eliminate the need to put this kind of capability in the active ID. Because the CASS station now lacks a video monitor, Norfolk has added one as ancillary equipment to an F-14 offload OTPS (for the MDIG control power supply). This reduced a typical test time from 45 to 20 minutes, tending to double testing throughput. Installing a video monitor in CASS would yield the same benefit in reduced test time. Norfolk also added a limited display generator PC card to the ID for the F-14 OTP-03 offload.

L. ADD MORE CHANNELS, PINS, MEMORY, AND BOUNDARY SCAN TO THE DIGITAL TEST UNIT (ALL)

1. Background

The digital test unit (DTU) enables CASS to test digital devices (WRAs and SRAs) by generating digital test vectors, sending them to the UUT, and evaluating the received responses. The current DTU has 336 channels accessed through 336 pins on the general purpose interface. The unit operates at data rates up to 20 MHz (40 MHz with interleaving), and each channel has 16K of random access memory (RAM) that is used to store test vectors or responses. The current DTU can accommodate logic voltage swings of -5 to +15 volts, and is compatible with many circuit types, including TTL, ECL, and CMOS.

Although the current DTU can test a wide range of digital devices, emerging avionics will lead to new test requirements:

- higher data rates,
- more test channels and access pins,
- increased memory, and
- the need to accommodate new built-in test concepts such as boundary scan.

We discuss each topic by describing the new testing requirements, listing the capability in the current CASS, and the major alternatives for obtaining new capability.

a. Data Rate

Digital devices in new aircraft such as the F/A-18E/F, the F-22, and the A/F-X will have data rates many times faster than the current 20 MHz:

- the 50-Mbps JIAWG PI bus, which is used as the primary backplane control and communication link;
- the 50-MHz JIAWG High-Speed Data Bus (HSDB), which is used to communicate between WRAs and other systems;
- the 250-MHz Signal Data Distribution Network;
- the 250-MHz high-bandwidth interface; and
- the 800-MHz Video Data Distribution Network.

The first two of these buses can be handled by the current CASS. The PI bus has a 12.504-MHz clock rate and logic voltage levels that are within DTU limits and are testable by CASS. CASS currently has an interface that is compatible with the HSDB and will be able to test this key interface. The CASS general purpose or RF interfaces will provide the resources to test the normal range of signal, control, or power circuits contained in a WRA or SRA.

The CASS station lacks the ability to test the last three, which are very high-speed buses. Testing these buses, however, could be handled much more economically with special interface devices rather than by modifying the DTU. The interfaces would have buffers that could accept bursts of test vectors that would then be evaluated at slower data rates. As we indicated in the P^3I on station interfaces, new interfaces cost only $15,000 to $25,000 each. Modifying the DTU to achieve these higher rates would require moving from the current CMOS technology to the more costly gallium arsenide (GaAs). A DTU with a data rate of 200 MHz, for example, would cost $571,000 for a 336-channel unit. (At some point in the future, increasing data rates may be more affordable with the "Tester Per Channel" concept now in development.)

Given the high acquisition cost and that interfaces can handle the special high-data-rate UUTs, we see no reason to increase the speed of the DTU at present. The use of interfaces to handle the high-speed testing needs is supported by two independent studies, one by GE [16] and one by a Navy study group [17]. The high-speed requirements could also be met economically by using either the bit-error-measurement system (recommended in a separate P^3I), which could provide data rates up to 700 MHz, or the array processor (analyzed as a separate P^3I), which is included in the GE HPDT. Finally, an alternative we have not studied is to construct a special tester configuration to supplement the DTU in handling high-speed data.

b. Channels and Access Pins

The DTU has 18 access slots, of which only 14 are filled at present. Each card contains 24 channels, giving a total of 336 channels that are connected to 336 pins on the GPI. By comparison, the testers used by firms that maintain complex military equipment often have 450 channels or more. The tester for the Air Force F-15C/D also has 450 channels, and as we mentioned in an early section, the engineers at the Norfolk Naval Depot added more channels and pins to the ID in offloading TPSs for the F-14.

The need for additional DTU pins stems from SRA testing requirements. Modules now being developed for avionics systems have connectors with large numbers of pins.

These are needed to accommodate the backplate data buses used to communicate between modules. For example, the SEM-E modules to be used in the F-22 and the RAH-66 have connectors with 386 pins. The Light Airborne Multi-Purpose System (LAMPS) modules have 550 pins, and the NGCR modules that may find application on the A/F-X and F/A-18E/F are forecast to have 556 pins.

Given the increasing complexity of emerging avionics, it appears to be warranted to increase the number of channels in the DTU. Table 25 lists several options that can be accommodated in the current DTU by employing the four unused slots. Option B fills the four remaining slots with the same type cards that are in the current DTU, adding 96 more channels and pins. Option C makes use of multiplex cards, a new innovation involving 12 channels and 126 pins. The pins are multiplexed (switched) to provide greater flexibility in allocating the lesser numbers of channels. Filling up two of the four free slots would yield a substantial increase in access pins and also afford a digital-switching capability, as discussed in the section on the GPI. (The $44,000 cost covers the $21,000 price per card, plus $2,000 to add more pins to the general purpose interface. The current GPI has excess capacity of 96 pins, 156 short of the 252 required for the two multiplex cards.) Option D fills up all four slots with the multiplex cards, but there is some uncertainty about whether they could be retrofitted to existing stations because of limited space for cables.

Table 25. DTU Channel/Pin Expansion Options

Options	Additions to Current DTU			Totals		Cost
	Cards	Channels	Pins	Channels	Pins	
A. Baseline	—	—	—	336	336	—
B. Add four current cards	4	96	96	432	432	$80,000
C. Add two multiplex cards	2	24	252	360	588	$44,000
D. Add four multiplex cards	4	48	504	408	840	$84,000

Note: Costs are in FY 1993 dollars.

c. DTU Memory

Each pin in the current DTU is now backed by 16K of RAM memory, which is used to buffer incoming or outgoing test vectors. The memory can be readily expanded to 64K, the memory size most often used by commercial testers. The larger memory takes four times longer to fill (3.2 versus 0.8 milliseconds at the 20-MHz data rate), but there is a net saving in time because a given test would require only one-fourth as many time-consuming setups (refills). Expanding the memory would cost $80,000 to retrofit an existing station, but only $14,000 in incremental costs for new production.

d. DTU Features

Boundary scan is a self-test feature for digital devices that is already being incorporated into the Advanced Medium-Range Air-to-Air Missile (AMRAAM), and that is planned for new aircraft such as the F-22 that are being designed according to JIAWG standards. Each chip of the device (WRA or SRA) has circuits that self-test the chip's operation when a test vector is applied to the device. Receiving a prescribed response to the test vector indicates that the device is functioning properly. The DTU can be modified at a cost of $12,000 per station to incorporate an interface to test boundary scan devices. Improving a DTU to test boundary scan chips costs $8,000 plus a prorated average of $4,000 for a boundary scan workstation. These workstations cost $26,000 each, but we assume that only one would be needed for every six CASS stations. (According to Reference [7], the 662 CASS stations will be distributed over approximately 100 sites, or an average of 6 stations per site.)

Voltage swing is another issue. Some of the older weapons that use 28-volt logic are being offloaded to CASS. Examples are the F-14 Camera Electronics and Data Display Set. Since CASS does not have the capability to test 28-volt systems at present, engineers at the Norfolk Naval Depot who have been performing the offload have been inserting active circuitry into the IDs. We have followed the CASS program office's philosophy to focus on improvements that enable CASS to meet emerging requirements, and have not considered a P^3I to add a 28-volt capability to CASS. The ID circuitry consists of only a voltage amplifier and resistor pad costing well under $1,000. (The Navy could also delay offloading the 28-volt systems and relying on the older testers until the older weapon systems retire.)

2. Alternatives

Our single alternative has three parts:

A. procure a package of added capability:

   1. bring capability up to 360 channels and 588 pins by adding two new multiplex cards with 12 channels and 126 pins each (alternative C from Table 25),
   2. increase channel memory from 16K to 64K, and
   3. incorporate ability to test boundary scan devices.

We recommend the full package be implemented.

3. Costs

The costs for the three DTU improvements we have recommended were obtained from Teradyne, and are recapped in Table 26. The new devices are all COTS, so there are no development costs beyond those included in the price (recurring cost).

Table 26. DTU Upgrade Costs

Item	Recurring Cost	
	Retrofit	New
1. Bring capability up to 360 channels and 588 pins	$44,000	$44,000
2. Increase channel memory from 16K to 64K	$80,000	$14,000
3. Incorporate ability to test boundary scan devices	$12,000	$12,000
Total	$136,000	$70,000

Note: Costs are in FY 1993 dollars.

We recommend that the Navy undertake an R&D effort to investigate the means to test the higher-speed electronics that will be fielded in the future. Such an effort might cost $500,000.

4. Impact

More channels, pins, and memory will allow CASS to test more complex UUTs, and will ease the development of TPSs and the design of IDs by providing more access lines. The added memory will also improve tester throughput by permitting more vectors to be transferred in each setup. Adding boundary scan will permit more rapid and effective test analysis to be conducted for UUTs that incorporate this test feature.

M. ADD A BIT-ERROR-RATE TESTER (RF/CNI)

1. Background

Electronic instruments use a variety of methods to reduce the chance of introducing and accepting data errors: redundancy, parity checks, checksums, and error-correction techniques. Bit-error-rate (BER) tests are used to determine whether these methods are working by introducing known bit patterns into the channel and comparing the data stream processed by the UUT. The test thus identifies equipment needing repair.

The current CASS could make BER tests on channels with data rates up to 40 MHz by modifying and reprogramming the current DTU. (The DTU can achieve a 40-MHz data rate with interleaving.) The current CASS station has no capability, however, to test channels with higher data rates, such as the Advanced Tactical Reconnaissance System (ATARS), which has data rates in the range of 82 to 137 MHz.

2. Alternatives

The alternatives are:

A. develop an accessory kit to modify the current DTU to perform BER tests at data rates up to 40 MHz or

B. add a new BER instrument to RF and CNI CASS stations, capable of testing to 700 MHz.

The DTU already has a capability to generate bit patterns and compare them between different channels. The BER kit in Alternative A would therefore require only some cables and a breakout box to tap off signals. Current BER instruments contain serial, high-speed pattern generators and error-detection units controlled by IEEE-488 buses. They typically cover the range of 150 KHz to 700 MHz.

We have not considered the alternative of upgrading the DTU to handle higher data rates, and modifying it to perform BER tests. Because of the data rate limitations of the DTU, we recommend the Navy implement Alternative B.

3. Costs

We made a rough estimate that the BER kit (Alternative A) would cost $250,000 to develop and $2,500 per unit thereafter. There would be no integration costs because the DTU is already a part of CASS.

Commercially-available BER instruments (Alternative B) are available from Tektronix at a unit procurement cost of $38,000. This option costs more than Alternative A in total (i.e., for all CASS stations), despite the development cost for Alternative A.

4. Impact

Adding a new instrument would permit CASS to perform BER tests on the ATARS, as well as the F-22 High Bandwidth Interface (250 MHz) and Signal Data Distribution Network (250 MHz).

III. PRE-PLANNED PRODUCT IMPROVEMENTS ANALYZED AND REJECTED

This chapter presents the full discussion of those P^{3}Is that we studied in detail, and for which this analysis does not lead to recommendation for more detailed analysis or implementation.

A. ADD MORE SWITCHING TO THE GENERAL PURPOSE INTERFACE

It is often necessary, during the course of a test, to re-connect stimuli and measurement instruments to different test points on the UUT. CASS does this switching by means of relay switches that lie just behind the GPI. GPI switches fall into three broad classes: low-frequency switches from DC to 1 MHz, power switches of low frequency, and coax switches for low-power RF testing (see Table 27). High-power RF is handled by the separate, RF interface that is located on the RF and CNI configurations. Switching for this interface is analyzed separately in the previous chapter.

Table 27. CASS Input/Output Pin Distribution on the GPI

	Quantity	Percentage
Feedthroughs		
Low Frequency (DC to 10 MHz)	210	14
Power (20 amps)	76	5
Coax (RF, DC to 2 GHz)	64	4
Digital (336 now activated)	448	30
Subtotal	798	53
Switching		
Low Frequency (DC to 1 MHz	420	29
Power	76	5
Coax (RF, DC to 16 GHz)	192	13
Subtotal	688	47
Grand Total	1,486	100

The GPI relay switches in CASS are of the discrete type, which must be connected in series and parallel arrangements in order to provide the required switching functionality. Programming the switching sequences during TPS preparation is a time-consuming task.

Matrix switches, by contrast, are much simpler to use, deriving from their ability to route any input to any output by a single command.

The issue of GPI switching is not completely settled. On the one hand, it appears that CASS has as much GPI switching as the Army's IFTE and the Air Force's F-16 Improved Avionics Intermediate Shop (IAIS) testers. Table 28 shows the comparison. Switching capability is measured by the different number of paths that can be selected for a given signal. In the case of IFTE and IAIS, the number of paths is simply equal to the number of switching pins. The IFTE uses switching cards to connect internal instruments to a variety of pins on the UUT interface panel, and the IAIS uses a similar procedure. CASS uses a different switching technology, however. Each instrument lead is hard-wired to only a single GPI pin, and switching is accomplished by wiring the ID so that it re-routes signals back through the GPI to the switching relays inside CASS. The switched signals are then sent back out through the GPI once again. It thus takes two GPI switching pins to switch one path in CASS, so the number of switching pins must be divided by two to obtain the number of switchable paths.

Table 28. Tester Switching Comparisons

	CASS			
Switch Type	Total	Equivalent	IFTE	IAIS
Low Frequency	420	220	130	180
Coax, RF	192	96	0	32
Power	76	38	96	132
Total	688	344	226	344

The figures in Table 28 thus suggest that CASS has the same amount of switching capability as the IAIS, and approximately 50 percent more than the IFTE. Further evidence that CASS has enough GPI switching is that there were no reports of major switching problems by CASS users and TPS developers in the sample of 83 Special Problem Reports (SPRs) we obtained from Naval Air Warfare Center, Lakehurst.

On the other hand, several TPS developers have reported that the re-routing procedure used by CASS leads to a need for more wiring in the ID, which adds to TPS development cost. They offered a rough estimate that TPS development costs were 10 percent higher, as a result of the CASS switching procedure. (Installing a matrix switch behind the GPI would simplify switching, but would also be costly.) Moreover, one TPS developer reported that relays were being added to the ID to obtain more switching. This adds substantially to the cost of developing IDs. If this procedure of making IDs active becomes a pattern as the task of re-hosting TPS to CASS continues, the GPI switching issue should be revisited by comparing the costs of adding more switching by installing a matrix switch in back of the GPI with the costs of obtaining the switching by making IDs active.

B. REPLACE THE PULSE GENERATOR

The pulse generator is used in all CASS configurations and represents a major stimulus resource for testing digital circuits. The Lakehurst study [10] states that the minimum pulse width of the current CASS pulse generator is 1 microsecond, and that this is wider than the minimum width required for future testing. (The figure is classified.) However, the CASS specifications stated in [2] show that the pulse generator can generate pulses much smaller than the figure quoted by Lakehurst. The Lakehurst study also understated the accuracy of the pulse width generated by CASS. We therefore recommend no action.

IV. POSSIBLE AREAS OF IMPROVEMENT NOT FULLY ANALYZED

This chapter lists some problem areas that people in the testing community have suggested for product improvement at one time or another, but which we have not analyzed for either lack of time or because the problem has been resolved. We will include the partial information we have gathered on each topic.

A. ELECTRO-OPTICAL RACK

The CASS Electro-Optical Station, which was developed by Northrop, has the capability to perform various types of measurements:

- electro-optical (EO),
- multisensor optical reference and boresight,
- TV (videcon) camera,
- laser transmitter,
- laser receiver,
- trackers, and
- forward-looking infrared (FLIR).

A number of the test procedures are automated, and thus require no operator intervention. (Examples are measuring modulation transfer, the noise equivalent temperature, the signal transfer function, and spatial fidelity, plus a range of laser and range-finder characteristics.) The EO tester is a laboratory-quality instrument.

The EO tester has some strong drawbacks, however. It requires precise alignment, which makes it difficult to achieve and maintain calibration aboard ship. Second, the Naval Warfare Center Aircraft Division, in its assessment of the CASS EO station [10] identified several capability shortfalls listed in Table 29. (The specific requirements are classified.) These requirements were driven largely by the need for testing such avionics systems as the AAS-42 infrared search and track (IRST) system on the F-14D, F/A-18, and F-22, as well as the antisubmarine warfare and countermine laser systems on helicopters and the P-3 and S-3 aircraft. Other problems with the CASS EO station are its size and its $2 million acquisition cost.

Table 29. Requirements Versus Capability of the CASS EO Tester

Parameter	Current CASS	Requirement
IR field of view	30 × 40 degrees	wider
IR spectral band	7-12 microns	wider
Minimum temperature resolution	.05 degree	smaller
Wavelength	1.604 microns	smaller
Pulse repetition rate	8-20 Hz	higher
Angle of regard	+/- .6 degrees	higher
Receiver uniformity	3 percent	smaller

There are some other alternatives for the Navy to consider. Although the Army has planned to buy approximately 100 of the CASS EO units for the IFTE, in order to cover its EO test needs at depots and field sites, the Army is studying a down-sized tester, the electro-optics assembly (EOA), for intermediate-level and field applications. The EOA is presently planned to be a derivative of the EO unit developed by Pentastar. It is much smaller and much less costly than the CASS EO, weighing about 80 pounds (compared to the CASS at 1,200 pounds) and estimated to sell in the range of $700,000 plus non-recurring costs (compared to the CASS at $2 million). In addition, Northrop, the developer of the CASS EO tester, is developing a new version of the CASS EO tester using internal funds. It is targeted to weigh approximately 150 pounds and cost about $1 million. Additional study is therefore needed.

The Navy should consider studying the possibility of replacing the current CASS EO tester with a new system, at least for afloat facilities. The current tester provides significant electro-optical test capability, but its cost, size, and capability shortfalls raise questions about using the EO tester at facilities other than depots. Recent developments in EO technology may produce testers that are smaller, less costly, and better equipped for deployment in the field. We recommend that the Navy initiate a study to review the EO test requirements for Navy weapon systems and survey EO tester alternatives. The study should recommend a general maintenance concept for electro-optical systems, define the requirements for EO tester(s) to support the concept, and identify candidate testers and their cost.

B. GOLD DOT INTERFACE

The general purpose interface (GPI) connects the tester to the unit under test (UUT) via an interface device (ID). The current GPI uses a male-female pin interface built by Virginia Panel. GE had an initial problem with the interface, in that the ID pins caught the receptacle of the GPI when they were inserted, and punched out the GPI pins. The Navy considered the possibility of replacing the Virginia Panel male-female pin structure with a contact-finger interface known as "gold dot." The gold dot interface would presumably have solved the mechanical punch-out problem because it involves zero injection force. Gold contacts have the added benefit of lower resistivity.

GE says that it has now solved the mechanical problem by beveling the pins, which has greatly lowered the failure rate. Given the fact that CASS appears to have no problems with resistivity, there appears to be no compelling reason to change the GPI interface.

C. STATION SOFTWARE

The major elements of the station software are:

- intermediate maintenance operations management:
  - station management,
  - production management, and
  - data management;
- support software:
  - ATLAS language processing and
  - TPS editing, compiling, and binding functions;
- station control software:
  - test executive,
  - instrument personality interface,
  - automated technical information, and
  - operator interface.

Other components of the station software are Operations Management System, Asset Allocation, Embedded Training System, and a number of bus and communications handlers plus other support programs.

Several proposals have been made to upgrade the CASS station software to improve its performance. CASS software contains some errors and performance shortfalls. At least some of these are being identified, as evidenced by the sample of System Problem Reports cited in the introduction of this report. We showed that 76 percent of the SPRs were found to be software related. A number of the errors are being corrected by the CASS contractors and documented through the Engineering Change Notice process.

Naval Air Warfare Center, Lakehurst, has made three proposals and GE has made one proposal for major changes to CASS software, to achieve several purposes:

- improve run time and throughput,
- maintain currency of operating system,
- facilitate TPS production, and
- increase functionality of maintenance data systems.

The Lakehurst and GE proposals cover the spectrum from upgrading selected software packages to changing the basic architecture of the CASS station. Lakehurst's most ambitious proposal identifies 136 actions, which are estimated to cost $40 million. (We made a quick independent check of this estimate by looking at the historical costs of developing the current CASS software, and the results suggested the cost would be at least twice as high.) GE's proposal suggests 17 areas for software enhancement, at a total estimated cost of $ 11.4 million. (GE states that the Lakehurst recommendations were considered in developing its proposal.)

At far as we have been able to tell, neither Lakehurst nor GE have developed detailed estimates of either the cost of their proposals or the benefits they might yield to readiness (through increased maintenance throughput) or to the cost of developing TPSs. We therefore recommend that the Navy conduct a study of CASS software in order to evaluate the costs and benefits of the proposals by Lakehurst, GE, and any others that may be suggested by the study. The analysis should include the following factors: the transportability of TPSs, the station run time and throughput, the ease of calibration and error control, the life-cycle costs (including implementation), the ability to leverage commercial technology and standards, and the avoidance of technical obsolescence.

D. OPTICAL DISK

TPS software is stored on optical disks, and must be loaded onto the computer's hard disk in order to run tests. Running classified programs thus permanently contaminates the hard disk, creating operational inconvenience.

E. VXI ARCHITECTURE

VXI architecture is becoming a commercial standard for the electronics industry. The Navy might be able to save money by modifying CASS to accept VXI architecture so that future capability can be obtained by acquiring commercially-developed VXI instruments. Savings might still be possible even if the instruments require modifications for ruggedization and other environmental needs.

F. LOW-POWER TESTING

Reference [10] offers some evidence that low-power stimulus and measurement instruments need a wider range of specifications (lower minimums and higher maximums) in order to perform full testing of new radar and EW systems.

G. TESTING FIBER-OPTIC SENSORS

New instruments will eventually be needed to test emerging inertial navigation systems that are expected, within 10 years, to employ fiber-optic sensors rather than the current ring-laser gyros. (Inertial navigation systems are not likely to employ superconductivity for 20 years.)

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APPENDIX

FUTURE AVIONICS SYSTEMS

APPENDIX

FUTURE AVIONICS SYSTEMS

INTRODUCTION

This appendix is a summary of current and projected future developments in military avionics systems technologies. It is written with an eye towards automatic test equipment (ATE) requirements but does not address those requirements explicitly. Specific types of systems, technologies, and architectures that are entering the active inventory or are being planned are addressed here. Avionics systems generally fall into the categories of

- radar,
- electronic warfare (EW),
- electro-optical (EO), and
- *communications, navigation, and identification* (CNI).

It appears that avionics technologies will continue to improve through the foreseeable future, pushed by the advanced weapons systems that are currently under development, and pulled by the enabling technologies such as micro-electronics, advanced antenna arrays, software, fiber-optics, and signal and information processing. The steady improvement in performance and reliability that avionics equipment demonstrated during the past decade will likely continue unabated. Future avionics hardware architectures will become simpler in several ways, including the use of individual subsystems with fewer components and interfaces [A-1]. Conversely, the amount and complexity of software and integrated circuits, driven by advances in microcircuitry, will increase dramatically, placing new demands on configuration management, testing, and repair. Some of the most important technologies that are now emerging from the government laboratories that will stress avionics testing capabilities include [A-2]:

- advanced integrated circuits,
- broad-band fiber-optic data networks,
- Distributed Multiplexed Data Processing,

- high-speed digital signal processing,
- flat panel displays,
- Monolithic Microwave/Millimeter Wave Integrated Circuits (MMIC),
- active aperture/conformal array antennas, and
- electro-optical/infrared (IR) charge coupled devices and lasers.

As these advanced technologies are incorporated into operational avionics systems, avionics testers will have to be modified to keep pace and remain effective

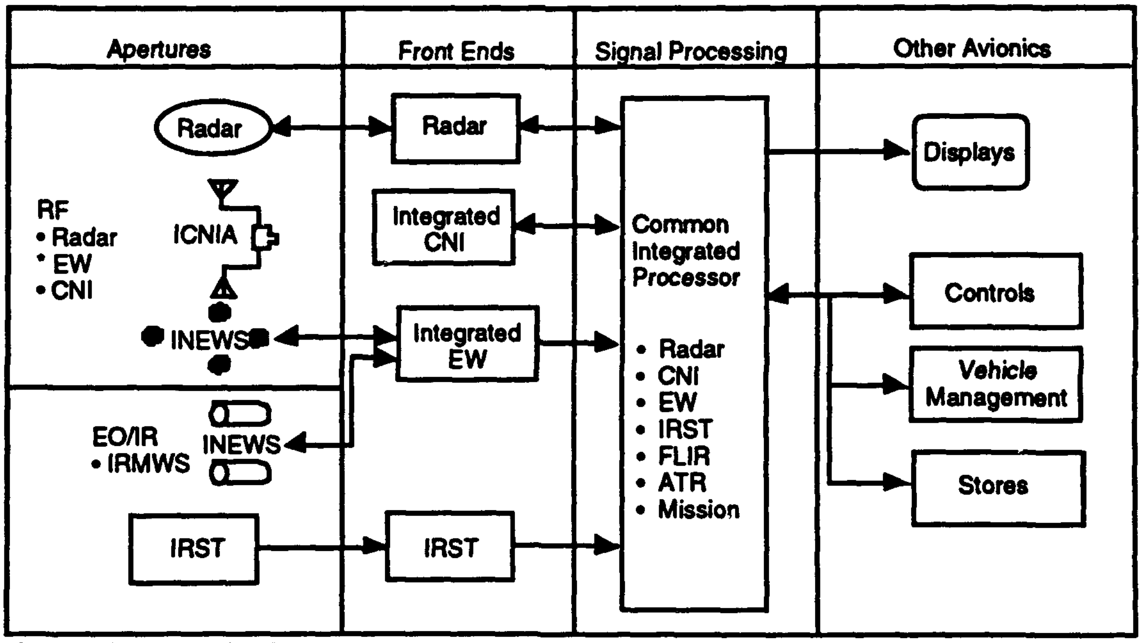
Avionics systems are designed to support specific Naval mission areas. For fighter aircraft these are primarily for antiair warfare (AAW) and strike warfare (STW)/antisurface warfare (ASUW). The two primary missions of naval tactical aircraft in AAW are to provide fleet air defense/maritime air superiority for the carrier task force/amphibious task force and air superiority over hostile territory in support of strike groups or a Marine expeditionary site ashore. For this type of mission, long-range detection and acquisition of hostile air targets is very important. Such a mission demands a high-performance fire-control radar. In addition, as the radar cross-section of potential threats is reduced, the potential for the use of EO systems such as infrared search and track (IRST) sets and television camera systems (TCSs) become more important. The *STW/ASUW mission* area includes close air support, battle area interdiction, and defense suppression. For these mission areas, radar, when it is needed, is for detection of ground targets in clutter, which requires a different type of search mode(s) from air search. For the strike mission, the use of forward-looking infrared (FLIR) with its high resolution becomes a very useful device. In addition, because these roles tend to take the strike aircraft into high-threat areas, the EW systems come into play.

ARCHITECTURES

The Joint Integrated Avionics Working Group (JIAWG) standard defines *architecture* as "the overall description of the structure and function of an avionic system, including the top-level functional partitioning, topology, data communications protocols, interfaces, and procedures for system control and resource management, including hardware and software." (The JIAWG is a joint government-industry effort that is responsible for developing and maintaining a tri-service family of standards to include architectural specifications, hardware, and software standards and supportability standards.) The modern concept is for the avionics suite to be conceived, designed, and fabricated as an integrated system. The conventional avionics architecture was "federated";

that is, each avionics subsystem was a self-contained set of boxes. New system architectures are being designed for both survivability, through redundancy and the use of multifunction modules, and streamlined integration. The latter permits the use of non-developmental systems, standardized interfaces and data buses, and industry standard protocols.

Avionics architectures define standards, specifications, protocols, and formats to which system hardware and software must conform to meet an established goal. Architecture issues have been the concern of the avionics community for over a decade, and many programs have been somewhat driven by them. Some examples are the Digital Avionics Integrated System (DAIS—for the F-16), the PAVE PILLAR (F-22, RAH-66, and possibly the Navy's future medium attack airplane A/F-X), and the PAVE PACE, for future advanced integrated platforms. The DAIS provided the transition from mixed analog and digital systems to an integrated digital avionics package, which permits many processing and communications advantages. The PAVE PILLAR program established a baseline avionics architecture utilizing new technologies with line replaceable and common avionic modules (See Figure A-1). Its specification is part of the Advanced Avionics Architecture (A^3) of the JIAWG. The intent of the PAVE PACE program is to extend the modular approach to twenty-first-century platforms, integrating new technologies that will enable a low-cost, multi-role capability. All indications are that the twenty-first-century platform requires a highly integrated, low-cost, fault-tolerant avionics architecture.



Source: Reference [A-3].

Figure A-1. The F-22 PAVE PILLAR Avionics Architecture

The PAVE PILLAR architecture sets a current standard for functional integration. The Common Signal Processor (CSP), the 1750A computer, Integrated Communications, Navigation, Identification Avionics (ICNIA), Integrated Electronic Warfare System (INEWS), and Ultra-Reliable Radar (URR) represent pioneering efforts in improving avionics availability, reducing cost of ownership, and improving performance of modern fighter aircraft. As a result of these efforts, the F-16, F-22, and F-117A all employ some of the PAVE PILLAR's approach to avionics integration. In addition, the Navy is considering this architecture for the A/F-X, and the Army has adopted it for the RAH-66 Comanche helicopter.

The PAVE PACE architecture represents an approach for the next generation of avionics. It exploits improvements in integrated radio frequency (RF) assemblies, highly available avionics hardware (signal and data processors, high-speed data buses, etc.), robust and adaptive processing architectures, software and system-level optimization techniques to improve effectiveness of the avionics and reduce pilot workload. The PAVE PACE architecture is pushing technology initiatives into practical modular avionics packages, including modular parallel processing network architectures, improved techniques in software development tools, replicated hardware modules, and continued research into high-speed data bus and operating systems requirements. It will integrate such technologies as

- wide-band monolithic RF components for applications such as high-resolution radars,
- high-data-rate fiber-optic interconnections for moving large volumes of information about the aircraft such as is required for high-resolution video,
- highly programmable and high-throughput signal and data processors for applications such as processing the EW environment in a high-threat area,
- efficient multi-processor operating systems that will allow for modularity and redundancy in for example CNI systems,
- multi-user broad band apertures for use by different RF systems such as radar and EW to permit optimal use of aircraft resources, and
- artificial intelligence, for example, to improve situational awareness.

Additionally, PAVE PACE should develop this architecture while applying the JIAWG standards of interfacing, standard built-in system test (BIST), fault tolerance, and so on. The PAVE PACE architecture is shown in Figure A-2.

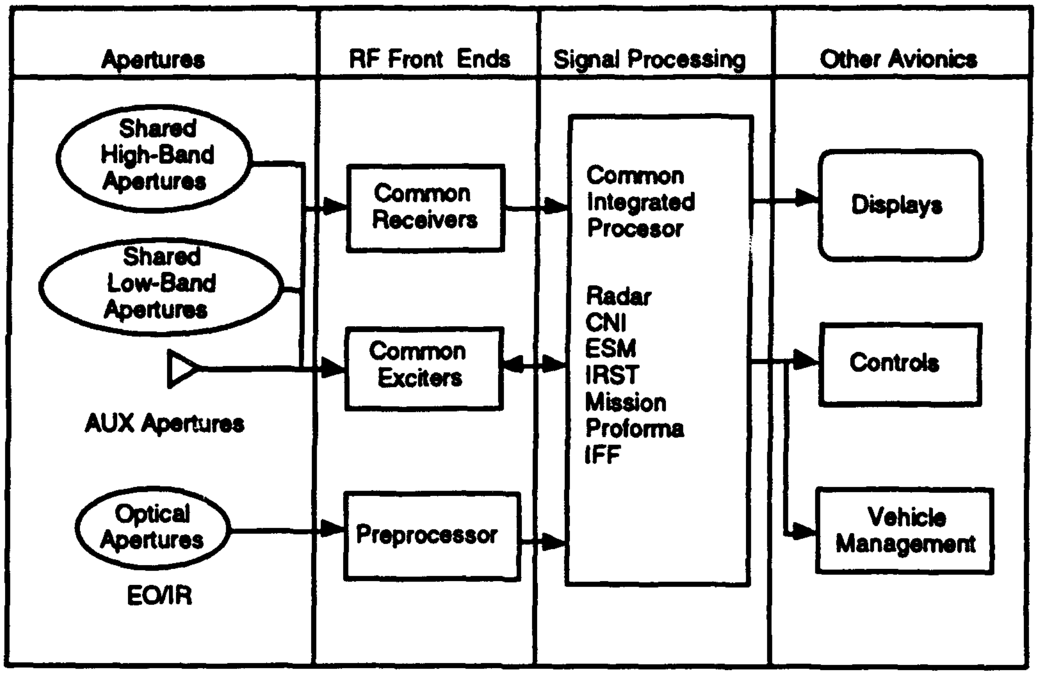


Figure A-2. PAVE PACE Avionics Architecture

SENSOR SYSTEMS

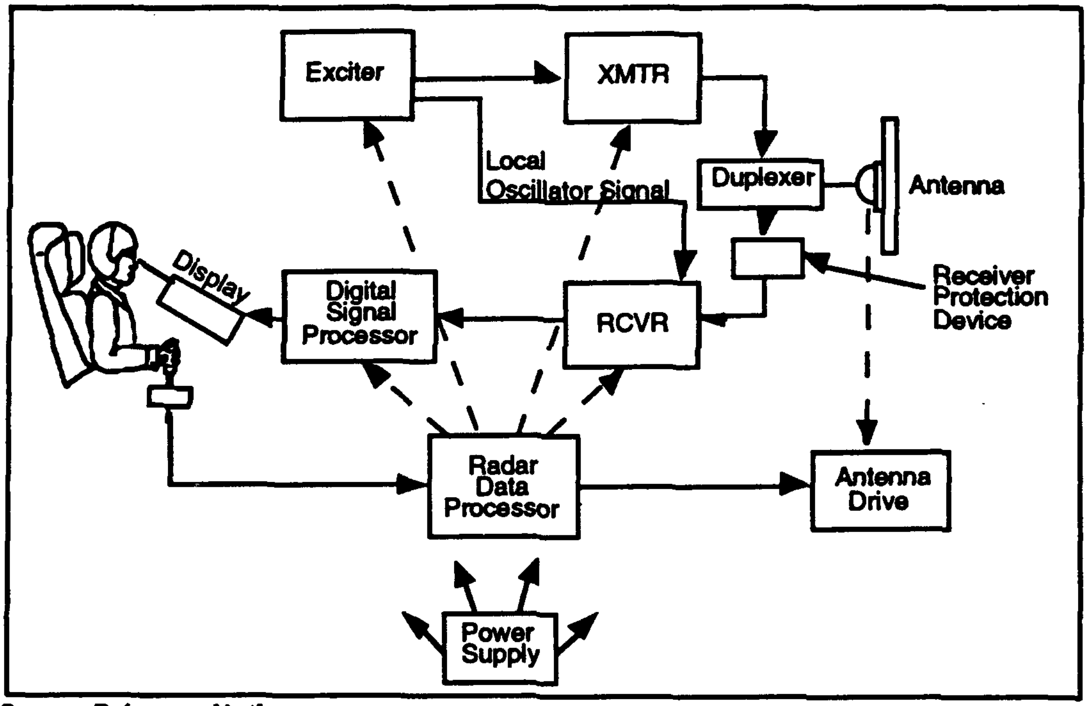
Current and future-generation fighter aircraft will rely very heavily on advanced sensors, many of which will have imaging capabilities. These improved sensors will allow for more sensitive detection, for example, against low-observable targets, for more precise location and tracking, and better target identification. These system improvements will result in enhanced mission capability of the fighter aircraft in higher performance surveillance and targeting, ultimately enhancing the lethality and survivability of fighter aircraft.

Radar Systems

The technology of airborne radar systems is evolving rapidly. Fighter radars are becoming reliable, capable, multi-mode systems with enhanced resolution capabilities. They will be employed in both counterair and air-to-ground missions and must operate effectively in both domains. Figure A-3 shows a block diagram of a modern fighter radar system. Technologies that are being given priority by the government laboratories will contribute to improved cost effectiveness and availability:

- solid-state high-power RF device technology,
- microwave/millimeter wave transceiver antenna array technology,

- high-speed data bus technology,
- custom very large-scale integration (VLSI)/wafer-scale integration (WSI) technology,
- weapon hand-off from synthetic aperture radar (SAR) imaging techniques,
- land and sea clutter reduction,
- non-cooperative target recognition (NCTR) techniques,
- MMIC and surface acoustic wave technologies,
- modular radar concepts,
- and module standardization concepts.



Source: Reference [A-4].

Figure A-3. A Block Diagram of a Current Fighter Aircraft Radar System

The radar block diagram shows two dedicated processors. The first processor is for signal processing. This processor is a highly pipelined, typically single instruction multiple data (SIMD) architecture; that is, all of the processing elements are executing the same instruction on different pieces of data. Such an architecture stresses raw speed over flexibility. The primary purpose of this processor is to execute target-detection algorithms such as

- fast Fourier transforms (FFTs) for pulse Doppler,
- constant false alarm rate (CFAR),
- airborne moving target indicator (AMTI),
- Doppler beam sharpening (DBS),
- image formation for SAR,
- electronic counter-countermeasures (ECCM), and
- other types of processing.

The data processor, on the other hand, is a lower throughput system that executes algorithms such as data association for multiple-target track, Kalman filtering for tracking, NCTR processing, general housekeeping functions, and so on. The data processor must be more flexible, but it does not have to possess the raw computing throughput of the signal processor.

Radars employed in airborne reconnaissance and ground attack roles will offer imaging capabilities such as DBS and/or SAR modes. In both of these modes the radar exploits differences in Doppler shift of targets in the radar antenna beam to be able to resolve them. The advantage of SAR in surveillance and targeting for ground attack is that this sensor offers the potential for simultaneous:

- high area-coverage rates,
- fine resolution for scene understanding and target recognition, and
- all-weather, day or night operation.

The price that is paid for this capability is extremely high processing rates. In addition, SAR and DBS images, cannot be formed directly off the nose of the aircraft, for conventional monostatic (transmitter and receiver share the same antenna) radars, since there is almost no differential Doppler shift at that geometry.

New radars will begin to rely on *active aperture antennas*, structures that more nearly replicate the foveal structure of the human eye. Active aperture phased arrays provide for multiple-target detection and tracking capabilities. This type of antenna is composed of thousands of independent but synchronized transmit/receive (TR) units, each integrated with its own antenna element. This is a significant departure from conventional radar architectures. In addition to the two processors associated with conventional modern airborne radars, the signal and data processor, the active aperture radar requires a dedicated processor for beam control. This type of radar is capable of achieving much higher reliability (e.g., the Air Force URR program) than conventional *corporate* architectures employing a single high power train, because of two major factors:

- each TR unit is a low-power, solid-state component that yields very reliable systems, and
- the overall radar degrades very gracefully as individual TR units fail.

Air-to-air modes incorporate track-while-scan (TWS) that allows for the tracking of multiple targets as well as the ability to simultaneously track and search. The active aperture architecture through its electronically agile beamforming supports TWS and rapid mode switching very well. The active aperture radar allows for the optimal management of the RF energy in space and permits the radar to be performing different functions on different targets in real time. For example, the radar may be performing radar signal modulation NCTR on one target, accurate tracking on another target, and inverse synthetic aperture imaging on another target. The active aperture configuration permits dynamic beamforming which can be used for

- forming multiple beams simultaneously,
- extremely rapid switching among beams,
- adaptive nulling for the cancellation of jammers or other interferers, and
- rapid switching among radar modes.

Modern fighter radars such as those on the F-14 and F-15 are of the look-down-shoot-down variety. This type of radar is technically known as a pulse Doppler radar since it is pulsed but still is able to directly measure Doppler information. Such a radar typically operates at three different pulse-repetition frequencies (PRFs): high, medium, and low. The high-PRF mode, the actual pulse Doppler mode, is optimal for long-range search (sometimes called velocity search), since it applies the greatest amount of energy to the target, and for detecting targets in ground clutter. The disadvantage of the high-PRF mode is that it is not very accurate for measuring range. The low-PRF mode is optimal for measuring range to the target, while the medium-PRF mode is a compromise between the other two.

Because of stealthiness issues stemming from survivability concerns, there is a desire to make the modern radar as stealthy as possible. There are two aspects of the radar that must be dealt with to make it stealthy: the waveform and the antenna. The waveform is probably the easier of the two, and the typical technique is to spread the waveform in frequency as much as possible to make it appear to a potential intercepting system as a very noise-like signal. Such a technique imparts the property of low probability of intercept (LPI) to the radar.

The second issue deals with the fact that a conventional radar antenna, by its very nature has a very high radar cross-section (RCS). Probably the leading technology for reducing the radar antenna RCS is to adopt *conformal array* technology. A conformal array antenna is one in which the elements of the antenna are "painted" onto the skin of the aircraft. This technology will likely begin to become operational within the next decade.

Multifunction Reliable Radar

Operationally, a key goal for the radar is to cause no mission aborts because of an electronic failure. An obvious means to increase reliability is to significantly lower the number of parts utilized in a multifunction radar system while also increasing the reliability of each component or software module. A reliable radar system must be designed in a manner such that failure of one component does not cause total system failure but, at worst, graceful degradation. The use of embedded system test and diagnostics including BIST and fault isolation will aid in system test prior to, during, and after a mission to isolate possible failing components or modules.

The Demonstration-Validation version of the F-22 Advanced Tactical Fighter radar based on the URR technology is illustrative of the current state of the art in reliable multifunction radar. The system combines PAVE PILLAR architecture with a solid-state, active-aperture, phased-array radar with the IBM-designed CSP. The solid-state, active-aperture, phased-array uses approximately 3000 TR modules, significantly improving reliability by replacing the single transmitter tube, which represented one of the primary system single point failure mode.

Low Radar Cross-Section Target Detection Approaches

Current operational fighter radars have significant limitations operating against low-RCS targets. A key to obtaining usable detection ranges against low RCS targets is maintaining high average power, which is most easily obtained by increasing the duty cycle of the radar (the ratio of on-time to off-time of the radar transmitter). Disadvantages of doing this are that long pulses or high PRFs are required. These fixes, if uncompensated, imply loss of target information through low-range resolution, eclipsing losses (having the target return arrive while the receiver is off because the pulse is being transmitted), or range ambiguities (second or third time around returns). New technology advances such as fast high-power RF switches and processing capabilities and wide-band transmitter technology may solve some of these problems by allowing near 100-percent duty cycles using very high time-bandwidth product signals.

High-gain airborne antennas, as exemplified by the one meter antenna on the F-15, have typically been used to enhance target detection ranges, but they are typically large causing significant increase in aircraft RCS. Current developments, such as conformal active aperture arrays and wideband high-duty-cycle waveforms, will provide high payoff in terms of smaller effective antenna aperture requirements and lower installed RCS.

Shorter-range radar systems (where size and weight are a premium) will likely evolve to millimeter wave (MMW) frequencies. The application of MMW is beginning to occur in helicopters (e.g., the Long Bow radar) and in tanks. The application of MMW radars is constrained to the shorter-range regimes because of atmospheric absorption. Two significant windows exist at 35 GHz and 95 GHz; however, absorption at 35 GHz is still about 0.1 dB/kilometer and is higher at 95 GHz.

Electro-Optical Systems

Electro-optic sensors are becoming more commonplace on modern fighter aircraft because the technology is maturing, becoming more reliable, and is inherently stealthy. Among the typical EO systems are

- forward looking infrared (FLIR) systems,
- infrared search and track (IRST) systems,
- television camera systems (TCS), and
- laser systems.

It is planned that the Advanced Tactical Reconnaissance System (ATARS), which is being developed by the Air Force but has been adopted by the Navy as well, will develop EO sensors, "digital" IR sensors, digital recorders, data link, reconnaissance management system, and a processing ground station, which will support both manned and unmanned aircraft.

Forward-Looking Infrared

Staring focal plane arrays offer advantages in sensitivity, on-chip signal processing, and the ability to alter the detector array parameters (readout rates, integration times, frame rates, etc.). The challenges are in reducing the spatial contribution to internal noise and in increasing the field of view (FOV) for a given resolution through larger arrays. Figure A-4 illustrates the configuration of a second-generation FLIR.

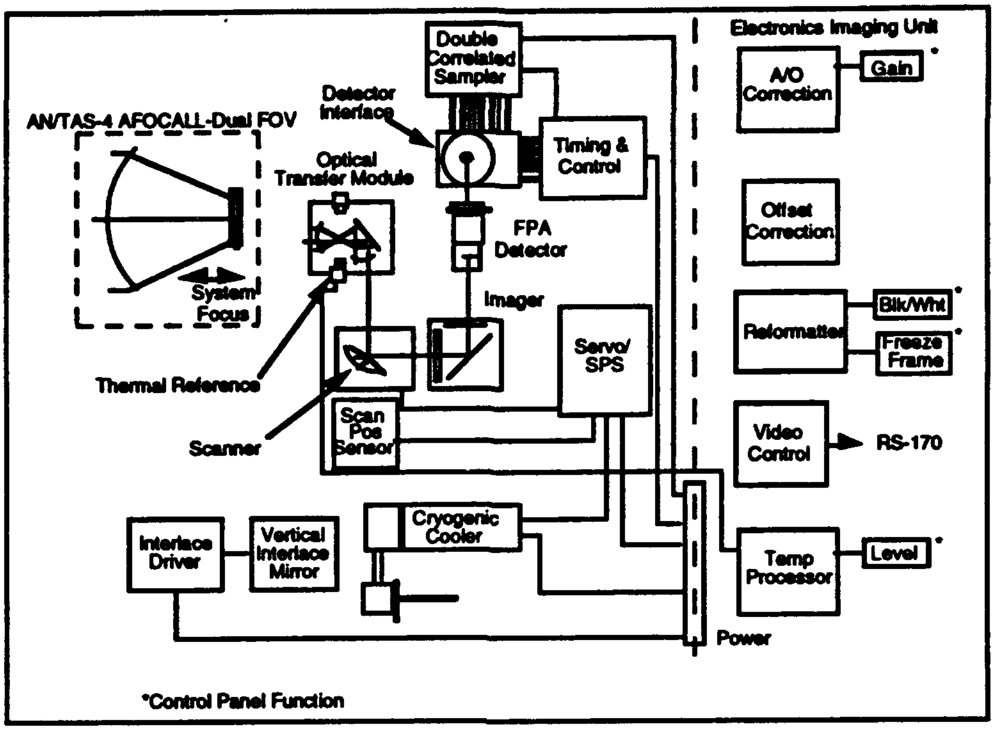


Figure A-4. Second-Generation FLIR

Providing an increased FOV requires special optical lens design, but to increase the number of pixels in the FOV, the number of detectors must be increased. The state of the art for the near future in staring focal plane array sizes for HgCdTe (mercury cadmium telluride) and InSb (indium sulfide) will probably be 180 × 640 or 512 × 512 detectors (arrays about one inch on a side). GaAs (gallium arsenide)/AlGaAs (aluminum gallium arsenide) has advantages over HgCdTe, including being less brittle (permitting larger size arrays) and allowing greater uniformity which reduces internal noise and permits better use of the material's dynamic range. GaAs/AlGaAs detectors are, however, less sensitive than HgCdTe.

The major issues with FLIR detection algorithms for mobile or imprecisely located targets pertain to the FOV for search (a hardware issue that has to do with sensitivity, resolution and size of detector array) and the number of false alarms passed onto the next stage of the process. The larger focal planes with increased sensitivity alleviate some of the critical sensor hardware issues for detection of mobile or imprecisely located targets.

Infrared Search and Track

The addition of the IRST on interceptor type of aircraft allows for potentially long-range detection of target aircraft passively. The limitations of the IRST arise primarily due most useful on a relatively high-altitude fighter that is targeting other high-altitude targets. There are plans to install IRSTs on the F-14D, F/A-18E/F, F-22, and the A/F-X.

Television Camera Systems

The F-14 employs a TCS that is boresighted with the fire-control radar. This system allows for beyond-visual-range detection and classification of aircraft targets by the pilot.

Laser Systems

Laser systems have primarily been employed as ordnance designators on fighter aircraft and as range finders for tanks. The primary advantages of the laser are the extremely high resolution because of the small beam size and the inherent low probability of detection of the beam. Disadvantages have traditionally been very low efficiencies and difficulty in acquiring targets unaided by other sensors (because of the small spot size). Lasers will likely be employed in wider roles in the future, including laser radars and laser altimeters. The Army is considering using laser radars on helicopters for obstacle avoidance.

COMMUNICATIONS, NAVIGATION, AND IDENTIFICATION SYSTEMS

Future-generation avionics concepts include integrated communications, navigation, and identification (CNI), which will be comprised of high frequency (HF), very high frequency (VHF), and ultra-high frequency (UHF) voice and data either in narrow band or spread spectrum modes, navigation, and identification friend or foe (IFF) capabilities all in a single system [A-2]. One of the key concepts is that of dynamically reconfigurable modular building blocks, which involves a set of multifunction modules grouped into three major functional areas:

- RF group,
- signal receiving group, and
- data processing group.

Communications

Trends in tactical communications include incorporation of spread spectrum technology and increasing use of data as opposed to all voice. Spreading the spectrum of the communications signal has two militarily significant consequences:

- low probability of intercept (LPI) and
- antijam (AJ).

Spread spectrum is a technique that causes the transmission bandwidth of the signal to be greater than the information bandwidth. The spread spectrum modulation is performed by direct sequence, frequency hopping, or a hybrid of the two. In direct sequence spread spectrum, a pseudo-random sequence of pulses is used to modulate the information signal. Since the pseudo-noise sequence has a much wider bandwidth than the information signal, the resulting transmitted signal also has a broad bandwidth. Frequency-hopping systems cause the transmitted frequency to be moved around the frequency spectrum in a pseudo-random fashion.

Information Transmission

Current information transmission developments focus on the development of jam resistant, LPI voice and data communications and the integration of complex waveforms into a common CNI module. Long-range communications data link efforts focus on supporting reconnaissance and surveillance operations. Long-range communications may be accomplished by satellite communications or HF link. Line-of-sight transmission programs, such as Joint Tactical Information Display System (JTIDS), focus on LPI/AJ voice and data including intra-flight communications. Future avionics suites such as Integrated Communications, Navigation, Identification Architecture (ICNIA) and PAVE PACE are pushing the current state of the art. The PAVE PACE program goals call for an integrated RF electronics suite that supports the functions of communication, navigation, identification, radar, and electronic combat. The PAVE PACE receiver suite will provide a modular architecture of RF transmission and reception capability using VHF/UHF superheterodyne, wide band superheterodyne, digital instantaneous frequency measurement, channelized, digital RF memory, multifunction modulation, and frequency converter technology.

Navigation

Future advances in navigation will provide new concepts, devices, and sensors to support next-generation navigation subsystems for aircraft, missiles, and aerospace platforms. The technologies include: stellar position reference, passive velocity references, communications/navigation/EW antenna assemblies and ballistic missile guidance sensors/seekers and electronics. New technologies under investigation include fiber-optic and integrated optics, very high-speed integrated circuits (VHSICs), and micro-machining technologies for reference systems with a mean time between failures of greater than 40,000 hours.

There are a number of navigation and/or reference system technologies for a wide array of vehicles. The focus of recent technologies (e.g., fiber optics and quartz sensors) has driven down cost, size, and complexity of inertial measurement units, while retaining accuracies to satisfy a large variety of vehicle applications. Due to the tremendous advances in computational technology, today's systems are shifting to strapdown instruments.

Some of the current developments in aircraft navigation technology that the Navy is developing include [A-2]:

- Naval Aircraft Collision Warning System,
- inertial navigation systems (INS) with Global Positioning System (GPS),
- Standard Attitude Heading Reference System (SAHRS) using mini-ring-laser gyro (RLG),
- compass/AHRS using fiber-optic gyro,
- advanced accelerometer integration (CAINS II),
- multimode receiver (AN/ARN-138),
- Signature Approach and Landing System,
- Terrain Reference Navigation (Advanced Digital Map Set, VHSIC insertion), and
- low probability of intercept (LPI) altimeter.

Identification Friend or Foe

The Mark XII IFF system is the current-generation system. It is a dated system, but the Mark XV was scrapped recently because of cost problems and difficulties in gaining consensus. The Mark XII does not present any testing problems, but a next-generation system would likely incorporate much more advanced waveforms, specifically spread spectrum, and may pose some testing challenges.

ELECTRONIC WARFARE SYSTEMS

Threat Warning Receivers

Radar Warning Receivers

The Navy's new generation ALR-67(V) airborne radar warning receiver will use 350 MMIC chips.

Missile Approach Warning System

Operation Desert Storm demonstrated the need for threat detection and warning, especially missile warning. More than half of the aircraft lost or damaged were due to IR missiles in which the pilots were unaware they were under attack; reliable missile warning systems and real-time countermeasures-effectiveness evaluation techniques were required to take advantage of decoy capabilities [A-5].

The effectiveness of IR decoys and jammers is enhanced by use of a reliable missile warning system. Missile warning receivers currently in use are either active (pulse Doppler radar) or passive (scanning/staring IR or ultraviolet). Active systems provide missile range and range rate, to estimate missile time-to-intercept (TTI), but are subject to intercept and exploitation by enemy forces. Passive techniques are covert, but provide only crude TTI estimates. Use of a passive sensor for detection, combined with an LPI pulse Doppler radar offers a promising technique for obtaining good TTI estimates while maintaining a certain level of stealth.

The Multifunctional Strike and Avoidance System (MFSAS) and other missile warning efforts provide missile warning to countermeasures performance. Missile seeker design has evolved to sophisticated multi-spectral, conical scan and rosette-scan reticles, and imaging seekers. This threat has placed stringent demands on countermeasures techniques. Continuing support of EO/IR missile countermeasures development (e.g., HAVE GLANCE and the Advanced Strategic and Tactical Infrared Expendables Program) represent the state of the art in EO/IR countermeasures technology.

The missile threat has become more sophisticated through processing target signals in narrow bands, in different spectral bands to enhance performance. Integrated EO/IR and IR/MMW seekers are now a reality. The integrated threats give rise to numerous technical issues in the design of new countermeasures systems. Power, size, weight, and affordability constraints require that countermeasures techniques covering different portions of the spectrum be merged in the early design phases to exploit design synergy. Current design approaches are beginning to address the integration of EO/IR and RF/MMW EW systems. Sensor fusion, parallel signal processing and other advanced technologies are required to implement such integration.

Jammers

An active aperture jammer antenna is being developed under the MMIC program for possible use as a part of the F-22 defensive avionics suite [A-5].

Expendables Dispensers

The MMIC technology is being employed in the Gen-X expendable radar decoy to reduce size and minimize cost [A-5].

COMPONENT TECHNOLOGIES

Data Bus

The avionics suites of tomorrow will require high-speed networks within the aircraft and secure networks spanning multiple aircraft. Ideally, within the aircraft there is one fault-tolerant network connecting avionics systems. Applications of fiber optics are planned for use in all future aircraft in order to speed the transfer of large amounts of data. Other networks internal to an avionics subsystem may also be required to meet the specific needs of the subsystem's architecture. Finally, the links to outside systems that are currently required for command and control may be expanded to the interchange of avionics subsystem information, for example, cooperative electronic support measures and electronic countermeasures. All three types of networks need to be analyzed to determine cost-effective implementations.

A critical issue for any complex network high-speed architecture is the time taken to transfer information. In future platforms, data throughput rates will increase. With shared resources, such as sensor signal processing modules, an efficient network manager must support data rates on the order of 7 Gbps between an integrated radar sensor suite and a core processor. For an EO suite, the core transmission requirement is approximately 2 Gbps to the cockpit displays. These baud rates will compel the internal high-speed network to a fiber-optic solution.

The aircraft-to-aircraft interchange represents the greatest challenge. Using a common link is the desired method; however, this may not be adequate for the critical timing needed. The use of specialized links is costly because of requirements for unique equipment and maintenance.

Processors

No technology is moving forward at a faster pace than signal/data processor hardware. This rapid pace is being pushed by commercial technologies such as those of very large scale integration (VLSI) chips. It is simultaneously being pulled by military requirements for extremely high-performance processors. These high-performance military requirements were somewhat manifest in the Very High-Speed Integrated Circuit program that has now run its course.

An *open system* is one that implements sufficient open specifications for interfaces, services, and supporting formats to enable properly engineered components to be used across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style which facilitates user portability [A-6]. The open systems concept is consistent with the industry trend toward multi-vendor interoperable products. It is not a computer design but a well-defined, widely used, non-proprietary set of interfaces and protocols. It is a framework for systems design that should be relatively insensitive to technology developments and the general environment.

Next-Generation Computer Resources Program

The Navy has established the Next-Generation Computer Resources (NGCR) Program to provide computer resource standards capable of meeting Navy mission critical computer resources (MCCR) requirements in the mid-1990s and beyond [A-7]. The NGCR standards will provide the tools for program managers and systems developers to build compatible MCCR systems. The NGCR standards are applicable to naval air-, surface-, subsurface- and land-based tactical systems. Specific program objectives are to apply open systems architecture concepts to:

- facilitate interoperability of fleet MCCR products;
- encourage modular adaptable system designs;
- permit competition for product development and system upgrades;
- meet the wide range of application requirements:
  - air, surface, subsurface, and land,
  - environment (commercial—full military specification), and
  - processing capability; and
- accommodate rapid advances in technology.

One of the primary goals of NGCR is to leverage the commercial market by selecting widely used non-proprietary commercial standards and avoid "re-inventing the wheel." The strategy of the program office is to establish open forum industry/Navy working groups for standards selection and to influence selected commercial standards

(IEEE, ANSI, ISO, etc.) to meet Navy requirements. The three areas of NGCR standardization include

- multiprocessor interconnect standards:
  - backplane,
  - high-speed data transfer network, and
  - high-performance backplane;
- multisystem interconnect standards:
  - local area network (LAN) and
  - high-performance network;
- software interface standards:
  - operating system,
  - data base management system,
  - project support environment, and
  - graphics language/interface.

The NGCR backplane standard is IEEE 896, FUTUREBUS+, while SAFENET I (Survivable Adaptable Fiber Optic Embedded Network) and SAFENET II are the LAN standards. All Navy programs entering Milestone II after September 1992 will be required to conform to the FUTUREBUS+ and SAFENET standards. The operating system standard is IEEE 1003 (POSIX).

Processor Requirements

Some predicted stressing requirements for avionics processors are shown in Table A-1.

Table A-1. Tactical Air-to-Air Requirements Summary

Sensor/ Subsystem (Mode)	Signal Processing Throughput (GOPS)	Data Memory (Mbytes)	Data Processing Throughput (MIPS)	Interface Requirement (MIPS)	Precision (Bits)
Radar RWS (STAR)	144	1200	—	—	—
Radar NCID	6.6	45–450	5	9,600	16–32
IRST TWS	3.3	3	7.5	360	16
Defensive Subsystem	3.8	8	57.3	450	32
CNI	6.7	0.4	5.6	850	16
Display	0.946	10.2	5	3	16
Integrated Vehicle Control	—	4 × 4	30 × 4	—	—
Pilot's Associate	10–20	100–20	300–500	<1 Gbps	—
Totals	185	1,840	600	>12 Gbps	16–32

Source: Reference [A-8].

Notes: RWS = range while search, STAR = simultaneous transmit and receive, andNCID = non-cooperative target identification.

Hardware

Hardware consists of signal and data processors and distribution networks. Developments in these areas are driven by three factors: (1) improved reliability to enhance avionics availability and reduce maintenance and support costs; (2) size/weight/power reduction to reduce the avionics burden on the aircraft; and (3) improved performance to respond to a larger variety of threat environments and target types. Aladdin and GAPP II processor base sees typical processing requirements being up to 1.5 GOPS/500 MFLOPS/180 MIPS for image processing and 10-20 GOPS/1500 MFLOPS/500 MIPS for electronic warfare. Data transmission from the sensors to the processors may require data transfer rates of 3 Gbits/second.

Modern aircraft avionics has to meet performance requirements that demand high-speed data processing and distributed fault-tolerant architectures. Today's avionics architecture is built around the MilStd-1750A central processor, capable of executing two MIPS and the high-speed fiber-optic 50 Mbps data bus, network using a token-passing access protocol. Being able to rapidly transfer data throughout the system is critical to achieving the fault-tolerance reconfiguration and resource sharing. The Advanced Avionics Architecture requires a high-speed processing mode that can provide high performance, distributed processing, fault tolerance, high reliability, interoperability, and standardized devices.

Automatic Target Recognizers

Sensor data rates flowing into automatic target recognizers (ATR) can exceed 8 megabytes per second. In order for an ATR to be effective, this data must be converted to decisions within seconds, a process that requires real-time data-handling and -reduction. Current techniques use multiple filtering steps to reduce the computational load including: detection screeners, region classification, estimating target range/orientations, feature extraction, and class features. Chaining greatly reduces the processing load at each subsequent step. Specialized processors, such as FFT chips and fine grain array processors improve overall performance.

Software

The government has made a major commitment to Ada, and is now requiring that avionics embedded software be written in Ada code. The advantages of this approach seem to lie in Ada's superior systems features. It appears to provide good facility for requirements analysis, for software maintenance, and for reusability. Ada's biggest drawback seems to be in very high-throughput, real-time operations, characteristic of avionics signal processors.

RF Hardware

Microwave and millimeter-wave device design, test, and fabrication capabilities have advanced rapidly within recent years with the support of DoD, in particular the MMIC program. Integrated design packages have been developed for microwave entry and simulations as well as modeling. The development of high electron mobility transistor (HEMT) and hetero-junction bipolar transistor (HBT) technology has extended the frequency range and capabilities of device performance. A number of foundries, fabrication lines and in-house DoD facilities now have capabilities for producing microwave and millimeter wave circuits. Advances in wafer probing of microwave devices have decreased costs by reducing the need to package the die before screening, other than for parametric testing.

The MMIC program is in the fifth year of its six-year life, and is beginning to deliver technologies that will soon be incorporated into operational weapons systems in the areas of radar, EW, smart munitions, and satellite communications [A-5]. Application of MMIC technology to traveling wave tubes (TWT), which typically are used in avionics systems as power amplifiers for jammers and radars, shows promise of reducing size, weight, and cost while simultaneously improving their reliability.

During the three-year Phase I effort, the contractors focused on proven metal semiconductor field effect transistor designs. Now the efforts have moved to HEMT, HBT, and pseudomorphic HEMT (P-HEMT). The P-HEMT technology offers the potential to reduce system noise figure as well as to improve efficiency, while the HBT shows promise for high-power, pulsed applications [A-5]. One of the MMIC contractors has developed a 6- to 18-GHz amplifier with a dramatically low noise figure of less than 2 dB using P-HEMT transistors.

CONCLUSIONS

There are a number of developments underway in sensors, processors, software, data buses, and so on, that will significantly affect avionics systems architectures and realizations in the next two decades. If the CASS system is to continue to meet operational requirements, a carefully planned Pre-Planned Product Improvement plan is required.

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ABBREVIATIONS

ABBREVIATIONS

A^3	Advanced Avionics Architecture
AAW	antiair warfare
AJ	antijam
AlGaAs	aluminum gallium arsenide
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AMTI	airborne moving target indicator
ASUW	antisurface warfare
ATARS	Advanced Tactical Reconnaissance System
ATE	automatic test equipment
ATI	Automated Test International
ATLAS	Abbreviated Test Language for All Systems
ATR	automatic target recognizer
AWG	arbitrary waveform generators
BER	bit-error-rate
BIST	built-in system test
BOPS	billion operations per second
CAP	Common Avionics Processor
CASS	Consolidated Automated Support System
CATS	Common Automated Test System
CFAR	constant false alarm rate
CID	common interface device
CIP	common integrated processor
CNI	communication, navigation, and identification
COTS	commercial off-the-shelf
CSP	Common Signal Processor
CTS	Common Test Set
DAIS	Digital Avionics Integrated System
dB	decibel
dBc	decibels relative to the carrier
DBS	Doppler beam sharpening
DEC	Digital Equipment Corporation

DMM	Digital MultiMeter
DoD	Department of Defense
DTU	digital test unit
ECCM	electronic counter-countermeasures
ECM	electronic countermeasures
ECN	Engineering Change Notice
ECP	Engineering Change Proposal
ENS	electronic noise source
EO	electro-optical
EOA	Electro-Optics Assembly
EW	electronic warfare
FFT	fast Fourier transform
FLIR	forward-looking infrared
FOV	field of view
G&A	general and administrative
GaAs	gallium arsenide
Gbit	gigabit
Gbps	gigabits per second
GDE	General Dynamics Electronics
GE	General Electric
GFLOPS	billion (giga) floating point operations per second
GHz	gigahertz
GOPS	billion (giga) operations per second
GPI	general purpose interface
GPS	Global Positioning System
HBDB	High-Bandwidth Data Bus
HBI	High-Bandwidth Interface
HBT	heterojunction bipolar transistor
HEMT	high electron mobility transistor
HF	high frequency
HgCdte	mercury cadmium telluride
HPDT	High-Power Device Tester
HSDB	High-Speed Data Bus
Hz	hertz
IAIS	Improved Avionics Intermediate Shop
ICNIA	Integrated Communications, Navigation, Identification Avionics

ID	interface device
IDA	Institute for Defense Analyses
IFF	identification friend or foe
IFTE	Integrated Family of Testers
INEWS	Integrated Electronic Warfare System
InSb	indium sulfide
IR	infrared
IRST	infrared search and track
IRSTS	infrared search and track set
JIAWG	Joint Integrated Avionics Working Group
JTIDS	Joint Tactical Information Display System
K	kilobyte
Kbit	kilobit
KHz	kilohertz
kv	kilovolt
kw	kilowatt
LAMPS	Light Airborne Multipurpose System
LAN	local area network
LPI	low probability of intercept
LRIP	Low-Rate Initial Production
LRM	line-replaceable module
LRU	line-replaceable unit
Mbit	megabit
Mbps	megabits per second
MC	mission capable
MCCR	mission critical computer resources
MFSAS	Multifunctional Strike and Avoidance System
MHz	megahertz
MilStd	Military Standard
MIPS	million instructions per second
MMIC	Monolithic Microwave/Millimeter-Wave Integrated Circuits
MMW	millimeter wave
NAWCAD	Naval Air Warfare Center Aircraft Division
NCID	non-cooperative target identification
NCTR	non-cooperative target recognition
NGCR	Next-Generation Computer Resources

O&S	operating and support
OASD(P&L)	Office of the Assistant Secretary of Defense (Production and Logistics)
OMB	Office of the Secretary of Defense
OpEval	Operational Evaluation
OSD	Office of the Secretary of Defense
OTPS	operational test program set
P-HEMT	pseudomorphic high electron mobility transistor
P^3I	Pre-Planned Product Improvement
PG	Pulse Generator
PI	parallel inter-module
PRF	pulse-repetition frequency
RAM	random access memory
RCS	radar cross-section
RF	radio frequency
RLG	ring-laser gyro
RSTS	Radar System Test Set
RWS	range while search
SAFENET	Survivable Adaptable Fiber Optic Embedded Network
SAHRS	Standard Attitude Heading Reference System
SAR	synthetic aperture radar
SDDN	Signal Data Distribution Network
SIMD	single instruction multiple data
SP	signal processor
SPR	System Problem Report
SRA	shop-replaceable assembly
SSM	Systems Synthesis Model
STAR	simultaneous transmit and receive
STW	strike warfare
TCS	television camera systems
TechEval	Technical Evaluation
TM	Test and Maintenance
TEWS	Tactical Electronic Warfare System
TPS	Test Program Set
TR	transmit/receive
TTI	time-to-intercept
TWS	track-while-scan

TWT	traveling-wave tube
UHF	ultra high frequency
URR	Ultra-Reliable Radar
UUT	unit under test
VAST	Versatile Avionics Shop Tester
vdc	volts, direct current
VDDN	Video Data Distribution Network
vetronics	vehicle electronics
VHF	very high frequency
VLSI	very large-scale integration
w	watt
WRA	weapon-replaceable assembly
WSI	wafer-scale integration
ZIF	zero injection force