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THE CONSOLIDATED AUTOMATED SUPPORT SYSTEM (CASS): A COMPARATIVE EVALUATION

by

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This thesis is an evaluation of the Consolidated Automated Support System (CASS) to determine whether it is likely to solve a host of long-standing problems with use of automatic test equipment (ATE) for support of Naval aircraft. CASS is a new ATE program nearing the end of full scale development which will replace all current ATE systems and many smaller manual testers to form a single, general purpose test system for all intermediate level and some depot level avionic testing. It is intended ultimately to be the Navy standard test system for all NAVAIR and NAVSEA requirements. The study involves an overview of the environment in which ATE is used, a history of ATE problems and development leading up to the start of the CASS program, a detailed description of the program itself, a description of the repair process using ATE, and an evaluation of the CASS program. Its conclusions are that CASS is technically capable of solving or alleviating virtually every significant problem affecting use of existing ATE systems and will lead to large savings in weapon system support costs and improved readiness during surges in operating tempo. Its success is very vulnerable, however, to decisions made during introduction planning. Such decisions include funding cuts which cause the schedule to slip or reductions in CASS system testing performance and maintainability, and decisions resulting from an inaccurate analysis of CASS hardware requirements to support the intended testing load at each site.

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The Consolidated Automated Support System (CASS): A Comparative Evaluation

by

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ABSTRACT

This thesis is an evaluation of the Consolidated Automated Support System (CASS) to determine whether it is likely to solve a host of long-standing problems with use of automatic test equipment (ATE) for support of Naval aircraft. CASS is a new ATE program nearing the end of full scale development which will replace all current ATE systems and many smaller manual testers to form a single, general purpose test system for all intermediate level and some depot level avionic testing. It is intended ultimately to be the Navy standard test system for all NAVAIR and NAVSEA requirements. The study involves an overview of the environment in which ATE is used, a history of ATE problems and development leading up to inception of the CASS program, a detailed description of the program itself, a description of the repair process using ATE, and an evaluation of the CASS program. Its conclusions are that CASS is technically capable of solving or alleviating virtually every significant problem affecting use of existing ATE systems, lead to large savings in weapon system support costs, and improve readiness during surges in operating tempo. Its success is very vulnerable, however, to decisions made during introduction planning. Such decisions include funding cuts which cause the schedule t o slip or reduce CASS system testing performance and maintainability, and inaccurate a nalysis of CASS hardware requirements to support the intended testing load at each site.

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I. INTRODUCTION

A. PERSPECTIVE

Computerized Automatic Test Equipment (ATE) is a critical element of logistic support of Naval aircraft. It is also costly. Over $10 billion must be spent over the next 20 years to replace obsolete ATE systems and acquire testing capabilities for weapon systems now nearing fleet introduction. [Ref. 1:p. 1.3]

ATE is used to perform intermediate and depot level electronic testing of aviation electronic components and circuit boards. It has been increasingly relied upon since the first major ATE system, known as the Versatile Avionics Shop Tester (VAST), was introduced to the fleet in 1972. Today, intermediate maintenance shops aboard carriers operate as many as 24 types of ATE systems plus over 300 manual electronic testers to support the diverse testing requirements of modern weapon systems. [Ref. 1:p. 3-2]

Unfortunately, these many different automatic and manual testers have a very low level of equipment standardization, which has created serious supportability problems. To operate and maintain them, an average ship must carry over 30,000 line items of spare parts, 624 technical manuals, 250 technicians, and dedicate 15,000 square feet of space. [Ref. 2] The complexity of ATE logistic support is a critical concern not only because of its high cost, but because ATE supportability is closely related to aircraft availability and stockage requirements for avionic system spares.

The Consolidated Automated Support System (CASS) is a new ATE system developed to replace all existing ATE systems and many manual testers used in intermediate maintenance. CASS will serve as the Navy standard test system through the early twenty-first century. Nearing the end of full scale development by General Electric, CASS will begin operational test and evaluation in mid-1990, with initial deliveries beginning in 1992. Fleet introduction should begin in 1994. CASS attempts to solve the supportability problems of existing ATE systems through:

- Improved testing throughput capability using advanced technology and testing concepts.
- Improved reliability, maintainability and standardization of hardware and software.
- Improved ability to be upgraded and reconfigured to satisfy changing testing requirements.
- Reduced life cycle costs.
- Improved support system stability because CASS will be a single test system serving both present and future testing needs. This will enable future weapon systems to be designed for testability starting at program initiation and reduce dependence on aircraft contractors to provide peculiar support equipment and interim support.

B. THESIS OBJECTIVES AND RESEARCH QUESTIONS

The purpose of this thesis is to evaluate CASS to determine whether it is likely to solve the host of long-standing problems with use of automatic test equipment for support of Naval aircraft.

The primary research question is:

What are the critical problems plaguing the current family of testers (FOT), and to what extent is the Naval Air Systems Command (NAVAIR) solving these problems in the acquisition and fielding of the Consolidated Automated Support System (CASS)?

Relevant subsidiary research questions are:

- What is the history of the acquisition of ATE in Naval Air? What were the contrasting weapon system support philosophies and acquisition strategies for the FOT and CASS?
- What is the impact of ATE supportability deficiencies on weapon system support and cost of spares?

C. METHODOLOGY

Research began with a review of articles, Navy documents and data relating to two areas. First, general ATE issues were examined, including evolution, problems, and the relationships between ATE supportability, performance and weapon system spares requirements. Second, specific CASS program issues were examined, including its goals, acquisition history, attributes and introduction plan.

Visits were also made to various sites to attend the ATE Cognizant Field Activity (CFA) Review, CASS Program Review and CASS Logistic Support Analysis (LSA) Review.

Finally, personal and telephone interviews were conducted with representatives of the NAVAIR CASS Program Office and introduction team, CASS introduction team members at the Naval Air Engineering Center and Naval Aviation Depot Jacksonville, various NAVAIR and type commander ATE managers, and fleet ATE production personnel at NAS Norfolk and aboard USS America.

D. THESIS CHAPTER SUMMARY

Chapter II begins with an introduction to the role and environment of ATE in avionics repair. It then traces the evolution of ATE systems and problems leading up to the present family of testers and to CASS. Chapter III describes the CASS program in detail, including its goals, current status, acquisition history, system architecture, and introduction plan. Chapter IV describes the intermediate level repair process using ATE, to lay the foundation for analyzing the performance and supportability of the FOT and CASS. Chapter V compares CASS with the FOT. Finally, Chapter VI presents a summary of the research, conclusions and recommendations.

II. ATE OVERVIEW

This chapter is an introduction to the environment, function and evolution of ATE systems in support of Naval aviation. It begins with a description of automated test equipment within the context of the avionics maintenance environment: the maintenance concept, levels of repair, ATE facilities, and ATE system architecture. The chapter then reviews the development of ATE systems, requirements, problems and change initiatives that led up to CASS.

A. ATE SYSTEM ROLE AND ENVIRONMENT

1. ATE in the Avionics Maintenance Concept

The maintenance concept for a weapon system describes its overall system support environment. It includes descriptions of maintenance levels, repair policies, effectiveness factors and logistic support requirements such as test equipment, facilities, manpower and training, and supply support. Because ATE is an integral part of the maintenance concept of many of the avionics systems presently in the fleet and most of the systems being developed, ATE critically influences weapon system design and the other logistic elements needed to support it throughout its life cycle.

Figure 1 illustrates the place of automatic test equipment in the global classification of test equipment. [Ref. 3:p. 1.2] As this taxonomy shows, test equipment is a specific catagory of support equipment that is formally termed test, measurement, and diagnostic equipment (TMDE). It includes manual electronic test equpment (ETE), automatic test equipment (ATE), test program sets (TPS) and calibration equipment (reference and transfer standards). Each of these four catagories of test equipment can be further subdivided as shown in the figure. ATE is defined as:

> Aviation Support Equipment that is capable, under program control, of automatically generating and independently furnishing programmed stimuli, measuring selected parameters of an electronic or electro-mechanical item being

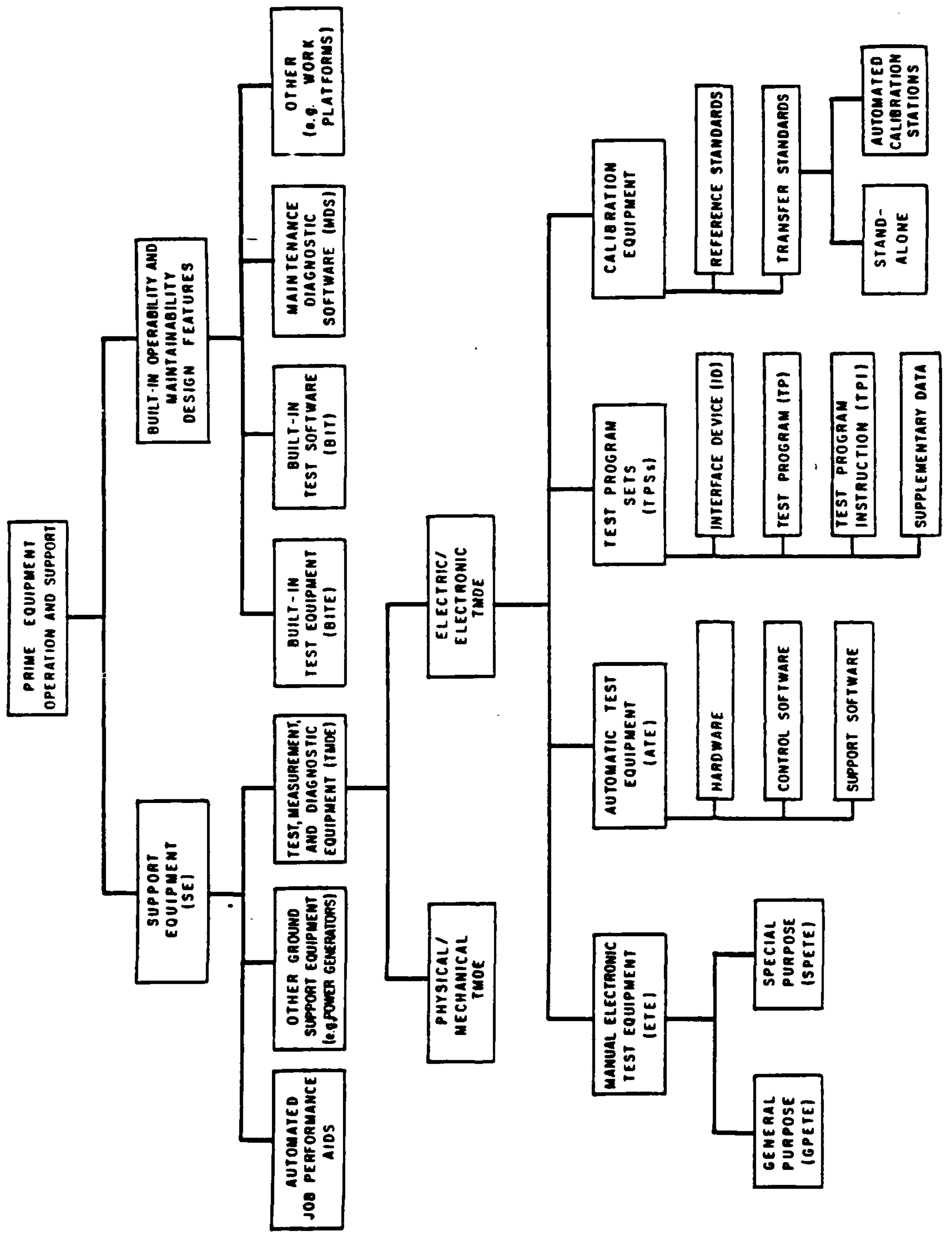

Figure 1. Taxonomy for Classifying Test Equipment.

tested and making a comparison to accept or reject the measured values in accordance with predetermined limits...Included in this definition are ATE self-test and self-check test program sets (TPSs) and weapon system or equipment application TPSs. [Ref. 4]

The diversity and complexity of aircraft weapon systems in today's Navy make automated testing an essential element of their support, especially aboard carriers. Intermediate level maintenance shops must possess a broad and flexible electronic support capability; shipboard ATE systems typically test 650 diverse 'black boxes' and 2580 subcomponents, most with very low failure rates. [Ref. 1:p. 6-2] To do so manually would be a monumental task in terms of the required troubleshooting time, training, manpower and technical publications. Automation has demonstrated its ability to reduce test times by as much as 30% over manual testing [Ref. 5:p. 63], and meet the fundamental constraints posed by a carrier's limited space, manpower, and off-ship logistics pipeline. For these reasons, ATE is a mainstay of the Navy's organic maintenance support concept for avionics.

2. Level of Repair

The Naval Aviation Maintenance Program (NAMP) is a six volume instruction that sets CNO policy for aircraft maintenance. [Ref. 6] It defines three levels of maintenance:

- Organizational: Squadron level on-equipment maintenance functions such as aircraft inspecting, servicing, trouble shooting and replacing parts at the Weapons Replaceable Assembly (WRA) level. Avionics WRA's are the 'black boxes,' packaged functionally and for ease of removal and replacement.
- Intermediate: Support organizations that perform off-equipment functions such as calibration, limited manufacturing, and repair down to the WRA level and limited repair of avionics Shop Replaceable Assemblies (SRA) such as circuit boards. ATE is employed extensively at this level for fault isolation of avionic WRAs and SRAs. An Aircraft Intermediate Maintenance Department (AIMD) avionics division is typically co-located at sea or ashore with the squadrons it supports and consists of 200-400 Navy technicians.
- Depot: Support organizations that perform both on and off-equipment functions such as overhaul, modifications, calibration, manufacturing, repair and condemnation of end items, including aircraft, WRAs and SRAs, to a greater depth

than is performed at the O or I level. The same ATE as is used at the I level performs much of the avionics repair, although it is often augmented with more capable test equipment. They are not co-located with squadrons/AIMDs, have extensive facilities, and typically employ several thousand civilian technicians.

NAMP policy dictates that maintenance will be performed at the level "which will ensure optimum economic use of resources, consistent with assigned readiness and availability standards." [Ref. 6:p. 8-7] This level is determined by Level of Repair Analysis (LORA), the operational need for quick turn-around of aircraft, and the physical, manning and training constraints of O and I level facilities. These considerations drive the relative capabilities of ATE systems developed for each level. Most avionics WRAs are removed and replaced at the O level, tested and repaired at the I level, and their SRAs are tested and repaired at either the I or D level.

Organizational level testing capability significantly influences I and D level ATE requirements. Using either 'suitcase' testers or Built in Test Equipment (BITE) designed into the WRA, extensive fault isolation may be performed by the flight crew or O level maintenance technicians without removing WRAs from the aircraft. This may reduce unnecessary component removals and aircraft down time. Such Built in Test (BIT) capability may also be integrated with I and D level ATE test strategies. If circuitry for self test is contained within the failed component, the ATE system may monitor it to speed fault isolation and to reduce hardware and software requirements of the ATE. Such integration is achieved in newer tester/weapon system mixes such as the Intermediate-level Avionics Fault Tree Analyzer (IAFTA) for the F-18. Through such a BIT/BITE strategy, the Navy seeks to reduce and ultimately eliminate I level ATE altogether and adopt a two-level maintenance concept for avionics. Under this concept, O level technicians will isolate faults down to the SRA (circuit card) level, which will then be repaired using ATE at the depot. Weapon system components will be packaged differently than they are today to facilitate quick removal and replacement of circuit cards, perhaps by replacing the current WRA packaging concept with banks of SRAs accessible simply by removing an aircraft panel. This 'O to D' concept will be more technically feasible and justified (based on life cycle cost analysis) as advances continue in weapon system reliability, BIT design, manufacturing and packaging. [Ref. 7]

3. Facilities

ATE must perform in three types of I level maintenance facilities: forward deployed Mobile Maintenance Facilities (8x8x20 foot vans) powered by portable generators; permanent shore sites (of which there are 46, though many of the smaller ones currently have no ATE); and ships. Aircraft carriers are by far the largest users of forward deployed ATE, although there is a growing requirement for support of aircraft such as the H-60 and V-22 using ATE installed in vans and aboard amphibious ships.

There is no standard facility layout or standard ATE requirement list for each type of AIMD activity. Each shore NAS specializes in the support of a few types of aircraft such as fighter, attack, ASW, or helicopter, and no two facilities are alike. While aircraft carriers have far more commonality, they nevertheless vary in their complement of aircraft because of differing deckloads. For example, many older ships cannot support F-14s, so several combinations of F-18s and A-6s have been used to meet mission requirements. The result is that every sea and shore-based I level ATE suite must be tailored to the systems it supports and undergoes constant change as aircraft and their weapon systems are phased in and out.

The carrier ATE shop is a difficult physical environment for electronic systems such as ATE that operate at high power and generate heat. ATE is used in close quarters and faces extremes in shock, input power transients, and unreliable air conditioning systems. ATE must perform and be supportable despite the inherent stresses of this operating environment.

4. ATE Architecture

Architecture refers to the packaging of the required set of functional components of the ATE system. Functions may be combined in one package, as in a suitcase tester, or they may be modular instruments and interface devices, as in large semi-permanently mounted ATE systems.

Every ATE system shares a common set of basic functional components. It must have a:

- Control processor: A computer and software;
- Operator interface device: A CRT and keyboard;
- Power distribution system;
- Suite of instrumentation assets: Devices to stimulate and measure the response of the unit under test (UUT);
- Interconnection Device (ID): The electronic and mechanical interface between the ATE station and the UUT.

The ID is often a large, heavy, electronic device set on a cart. It contains active circuitry plus interface hookups such as wiring harnesses. It may also be a passive device that is little more than an electrical junction box and cables.

In general purpose ATE systems, the ID is one functional unit in the complete Test Program Set (TPS). The TPS contains everything needed to adapt a particular UUT to an ATE station and perform a test, including:

- Test Program (TP): Application software containing the test instructions for component stimulation and output measurement. It may be stored on tape (as in VAST) or hard disk (single or stacked) and is installed or called up to run the desired test.
- Test Program Instruction (TPI): A paper or software description of the operating procedures to connect the station, UUT, ID and other devices that may be required, such as portable power supplies, and initiate and execute the test.
- Supplementary Data: Also known as engineering support data (ESD), they may include test strategies, signal interfaces, functional block diagrams and diagnostic flow charts of the UUT and TPS that may be needed to complete a test.

Figure 2 illustrates these TPS components, showing a CASS station in the background. [Ref. 8] Because every WRA and SRA tested on ATE has a unique TPS, some 5500 TPSs currently exist to support NAVAIR weapon systems. [Ref. 1:p. 6-2]

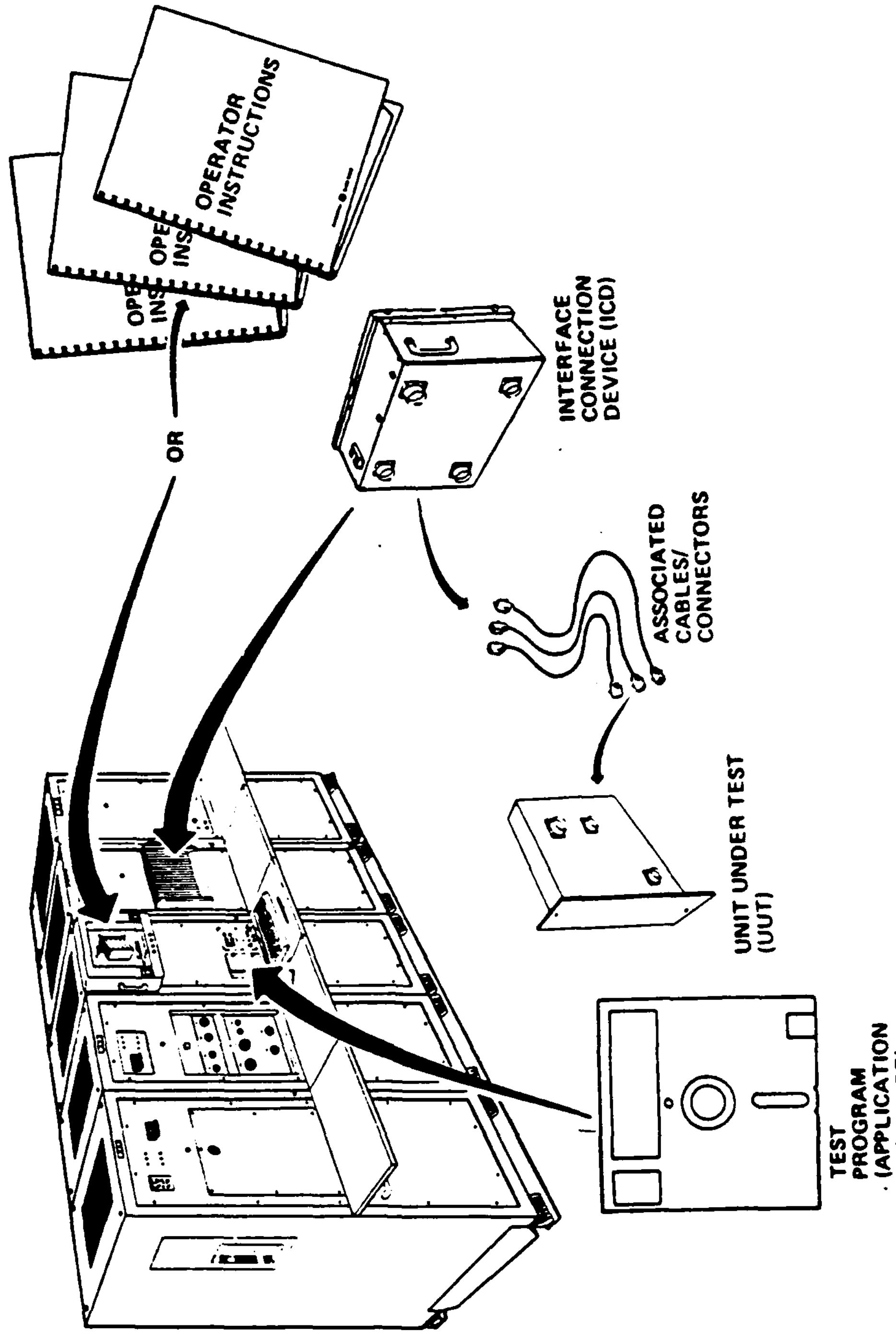

Figure 2. Test Program Set Components.

B. EVOLUTION OF ATE

This section highlights the evolution of ATE support of Naval aircraft, with particular emphasis on the problems and change initiatives that led to development of CASS. These problems and initiatives are not merely of historical interest, but are also relevant to the current state of automatic testing because every generation of ATE is still in the fleet.

1. Peculiar Support Equipment

Prior to the introduction of common (or general purpose) ATE systems in the early 1970s, the Navy supported its avionic testing needs using manual peculiar support equipment (PSE), each type designed for testing a single avionic system. The rapid growth in diversity and complexity of weapon systems, however, made deployment of system-specific PSE an unworkable concept for supporting an entire aircraft or carrier air wing, for the reasons discussed below.

PSE testers have many advantages over general purpose testers; this accounts for their continued importance in our support equipment inventory. Acquisition of PSE rather than common ATE minimizes technical, schedule and cost risks because the avionic support is generally developed in small packages to support each sub-system by the weapon system contractor. This approach optimizes cost effectiveness at the subsystem level because PSE can be developed quickly and cheaply and can be tailored to provide the exact testing capability needed with no frills.

At the aircraft or carrier air wing levels, however, use of PSE developed by the weapon system contractor is a case study in sub-optimization. It results in proliferation of different types of test equipment, very high life cycle costs for the weapon and support systems, high demands for manpower and facility space, short test equipment obsolescence cycles, redundant development costs, little competition in development and production, and limited flexibility to support increased testing needs during a surge in operating tempo. Optimization of test equipment at the sub-system level comes at a high price when viewed from this perspective, making acquisition of general purpose ATE a more cost effective alternative. [Ref. 9]

2. VAST

The Versatile Avionics Shop Tester (VAST) was a new way of doing business. It was the first general purpose ATE aboard carriers, the product of a concept adopted by NAVAIR in the mid-60s with the goals of reducing weapon system support costs and supportability problems inherent in reliance on the growing collection of PSE.

The first production contract for the Versatile Avionics Shop Tester was awarded in 1968, and VAST stations were first installed aboard carriers and at shore I level and D level sites in 1972. The 95 stations bought were phased in between 1972 and 1978 at a total production cost of $1 billion, plus at least another billion for TPS. [Ref. 3:p. 5-11] The largest ATE ever developed for DOD, VAST consists of 10 bays of hardware.

VAST was designed to support the new 'Grumman Air Wing' of F-14, E-2 and S-3 aircraft, including over 150 WRAs and several thousand SRAs. It was itself initially supported both technically and logistically by the contractors (Harris for the station and Grumman for TPS). VAST was expected eventually to support the testing and calibration of its own components. Each carrier was to have three identical stations, with as many as five stations going to some large shore AIMDs. [Ref. 10]

Within the first two years of its introduction, however, concern arose over VAST's ability to support the existing and emerging testing workload. Because VAST had an unexpectedly low throughput and required TPSs that were both expensive and time consuming to develop, many test requirements initially scheduled for VAST support were offloaded to manual PSE testers that were already developed. New general purpose ATE systems were also developed, so that by 1976 VAST had been augmented by the Electronic Module Test Console (EMTC), Digital Module Test Console (DMTC), Central Air Data Computer (CADC), Automatic Test Set (ATS), Display Automatic Test Set (DATS), Hybrid Automatic Test System (HATS), and CAT IID/CAT IIID digital SRA testers. [Ref. 5:p. 16] A 'Tailored VAST' was also created by reconfiguring along functional lines to test only digital SRAs. Even with all these additional testers, a fourth VAST was soon added to carriers to satisfy workload requirements. [Ref. 10:p. 4.5] Figure 3 shows this complex mix of testers required by a typical shipboard AIMD. [Ref. 5:p. 17]

Despite its development as a 'universal tester' for the S-3, E-2 and F-14, by 1976 VAST actually supported 87% of the WRAs and 27% of the SRAs for these aircraft, and other ATE and PSE supported the remainder. These smaller ATE and PSE systems also supported the remaining carrier deckload, including the A-6E, EA-6B, KA-6D, A-7B, SH-3D and C-2A aircraft. [Ref. 5:p. 17]

Part of VAST's difficulty in supporting the full load of WRAs and SRAs was that the VAST station itself was difficult to support. The system was complex both technically and logistically, and was supported largely by the contractor. It was soon observed that whenever the VAST stations were down aboard carriers, within a few days the readiness measures of all three weapon systems decreased.

VAST demonstrated the impracticality of using a single, general-purpose tester to support such a wide spectrum of functions and large testing workload given the technology of the time. It did, however, validate the concept and feasibility of standardized testing. It also taught a major lesson about support of support equipment: there is a direct, dependent relationship between ATE availability and aircraft readiness. [Ref. 11]

3. The Marcy Report

In response to widespread problems reported by the fleet with VAST and other test equipment, the Assistant Secretary of the Navy for Research and Development (Mr. Marcy) in 1975 requested a quick study of problems and solutions. An ad hoc committee was created, composed of representatives from the Naval Material Command (NAVMAT), the Systems Commands, their field activities, the fleet and industry consultants. [Ref. 5:p. 2] Their 1976 study, known as the Marcy Report, charted a new course in the way the

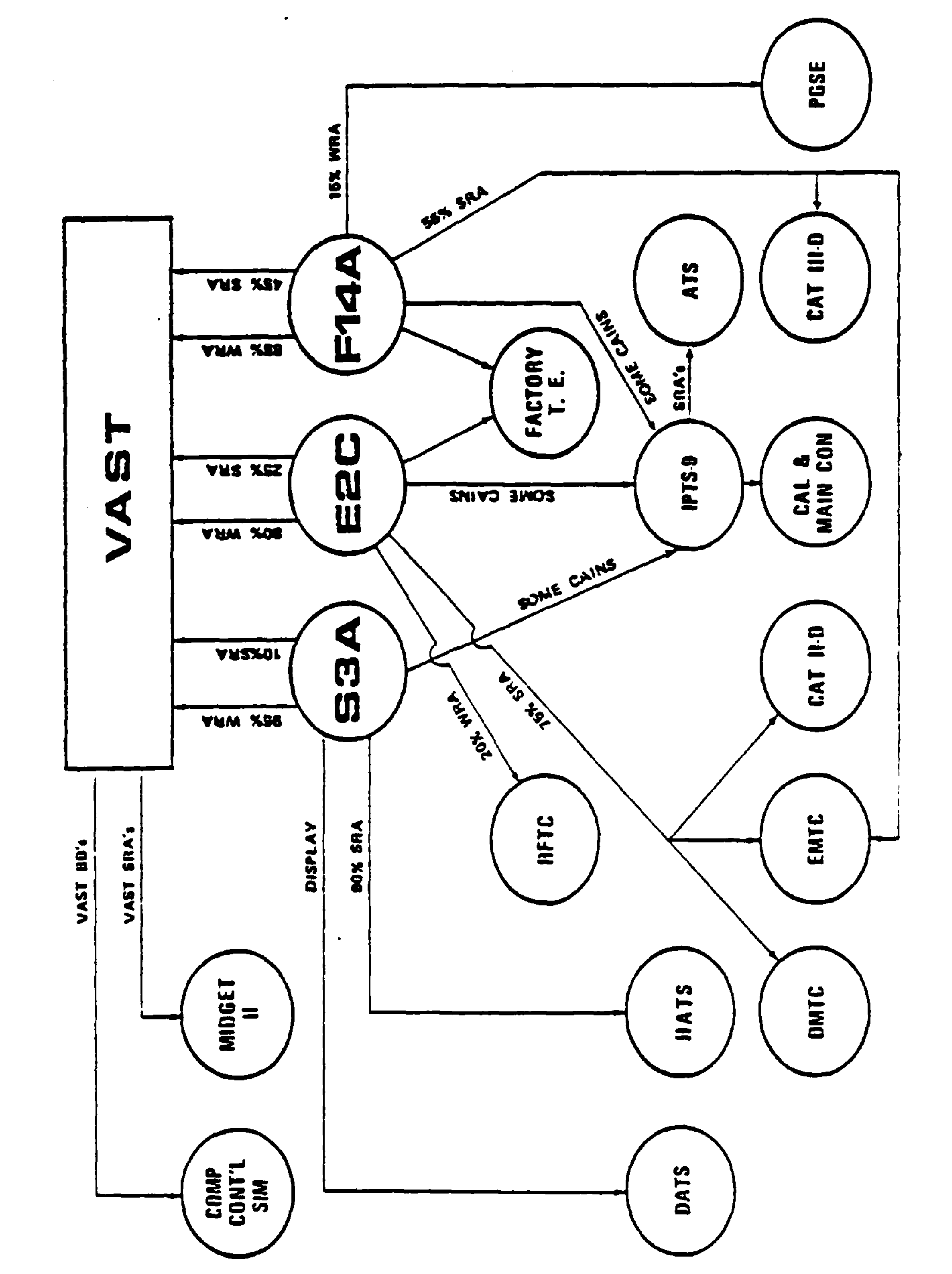

Figure 3. Typical AIMD Avionic Support of the S-3A, E-2C and F-14A in 1976.

Navy acquired and managed ATE systems, one which will continue to guide decisionmakers into the next century.

The ad hoc committee explored the entire spectrum of problems plaguing electronic test equipment, including hardware, software, TPS, acquisition, integrated logistic support (ILS) management, and the Navy actions required to solve them. They concluded that the Navy had not done a good job in acquiring, deploying and utilizing its ATE for reasons deeply ingrained in the way the Navy did business. Chief among these was the lack of emphasis on 'front-end' spending during the initial phases of weapon system and ATE design. Too often systems were developed to minimize the initial procurement costs even when higher levels of spending at this stage (for reliability improvements, for example) would result in lower total life cycle costs and fewer downstream logistics problems. [Ref. 5:p. 68]

Figure 4 summarizes the report's findings in a problem/solution matrix. [Ref. 5:p. 6] These 20 problems and 14 solutions show the complex and often overlapping technical and management issues the ad hoc commitee determined must be addressed to improve ATE operation and supportability in the fleet. The report's recommendations included the following: [Ref. 3:p. 5-12]

- Enforce existing Navy policy in weapon system acquisition to ensure their supportability.
- Educate management personnel in the technical and management issues involved in weapon system acquisition, including the practical problems of BIT and off-line ATE hardware/software.
- Provide quick relief to the fleet by (1) initiating engineering changes to improve the reliability of high-failure rate items of prime equipment as well as ATE, (2) establishing "tiger teams" to respond to ATE problems, (3) developing organic test programming capabilities, and (4) prohibiting deployment of ATE without prior approval from NAVMAT.
- Develop a new family of general-purpose ATE.
- Initiate and support both a short-range and long-term research and development program in automatic testing technology under supervision of a central NAVMAT ATE management office.

PROBLEMS \ SOLUTIONS	ATE ACQUISITION	CALIBRATION	TRAINING AND MANPOWER	DOCUMENTATION	TEAMS IMPROVEMENT	COMMAND INFORMATION	END-ITEM REQT ANAL SUPPORT SYSTEMS	EDUCATION	END-ITEM REL. & SPARE IMPROVEMENT	VAST EQUIPMENT IMPROVEMENT	ADVANCED TESTING TECHNOLOGY – R&D	CONFIGURATION AND SOFTWARE MANAGEMENT	FAMILY OF ATE	MANAGEMENT
TPS DEFICIENCIES				X			X		X	X	X	X		X
LENGTHY PERIOD OF TEST	X		X				X		X		X	X	X	X
ATE END-ITEM INTERFACE INCOMPATABILITY							X			X	X		X	X
CONFIGURATION CONTROL	X				X			X				X	X	X
PROLIFERATION	X						X	X	X		X		X	X
SIZE AND COMPLEXITY OF ATE	X						X			X	X		X	X
ATE CAPABILITY/ LIMITATIONS					X					X			X	X
ATE MAINTAINABILITY	X	X	X	X	X		X			X	X	X	X	X
LACK OF RELIABILITY OF ATE	X				X		X			X	X	X	X	X
ATE/HUMAN INTERFACES	X		X	X										X
POOR RESPONSE TO FLEET PROBLEMS														X
SHOP FACILITIES AND MANAGEMENT							X	X	X					X
SPARES	X						X	X	X					X
CALIBRATION	X	X									X			X
DOCUMENTATION	X			X							X	X		X
TRAINING AND MANPOWER			X					X						X
LACK OF EFFECTIVE BIT	X					X	X	X			X			X
LACK OF COMMAND INFORMATION						X	X				X			X
PLANNED MAINTENANCE SYSTEM NOT EFFICIENT		X				X					X			X
ITEMS NOT AMENABLE TO TEST							X		X		X			X

Figure 4. Marcy Report Problem/Solution Matrix.

The last two recommendations formed the core of NAVAIR's ATE development plans for the 1980s and resulted ultimately in the CASS program.

4. The NAVAIR ATE Program Plan

NAVAIR began formulating plans for the 1980s and beyond by assessing the recommendations of the Marcy report, two subsequent ATE projects involving many DOD and industry participants, and the experiences of the previous decade of ATE support. The resulting plans were documented in the 1979 NAVAIR ATE Program Plan which focused on achieving seven primary goals: [Ref. 3:p. 5-16]

- Integrate ATE program management
- Improve ATE acquisition
- Design avionics for testability and maintainability
- Minimize the variety of ATE
- Consolidate and improve ATE software
- Improve the quality of test program sets
- Attain full and timely organic capability

The ATE Program Plan also responded to tasking from the Office of the Secretary of Defense to develop plans to standardize weapon and support systems, improve weapon system support and readiness, and implement sequential system upgrades through Pre-Planned Product Improvement (P^3I) efforts. [Ref. 12:p. 7]

NAVAIR regarded standardizing ATE aboard carriers as the central objective of this plan, because standardization encompasses and integrates many of the other program goals. To achieve this objective, the plan established a short range goal and a long range goal. These were, first, to create a functional family of common ATE to serve through the 1980s and next, to define and acquire a Consolidated Support System (CSS) as CASS was first called, to serve into the next century. [Ref. 1:p. 2-2]

5. The Short Range Goal: A Functional Family of Testers

To achieve an immediate reduction in proliferation, NAVAIR sought to identify a group of existing testers most able to accept general purpose testing functions to support a broadened range of weapon system types. These testers would form a functional family of testers (FOT). Program managers would be required to give preference to one of these testers in planning support for new weapon systems. However, establishing a preferred family of testers was slow. It took until 1981 to standardize the ATE selection process and until 1982 to publish a preferred ATE list. [Ref. 3:p. 5-15]

Many of the 24 general purpose ATE systems and hundreds of PSE types now in the fleet were developed after the decision to standardize because it is difficult to enforce exclusive use of FOT members given the cost and schedule pressures of weapon system acquisition and the advantages of procuring PSE support, such as low up-front costs and rapid development and fielding.

The 24 ATE systems are classified by the functions of the weapon systems they support, because these functions dictate the test requirements and instrumentation of the ATE. Functional classes are shown in Figure 5: [Ref. 1]

WRA Support	*SRA Support*
* General avionics	* Digital
* Inertial navigation	* Analog and hybrid
* Electro-optical	
* Electronic warfare	
* Radar/display	

Figure 5. ATE Functional Classifications.

The current preferred family of testers is shown in Table I. [Ref. 13:p. 3.3] Also shown is their year of initial delivery, manufacturer, functional classification, and original weapon system application. While most were initially developed to test a single weapon system, each now supports a broad mix of aircraft types and many different WRAs and SRAs. For example, the CAT IIID was designed as a digital SRA tester for the F-14A, but now also supports SRA testing and some WRA testing for the A-7E, A-6E, E-2C and EA-6B. Others were developed from the start as standard functional testers, such as the Hybrid Test System (HTS) which is designed to test all hybrid and analog SRAs not testable by the CAT IIID.

Table I. The Functional Family of ATE.

Year	Name/Nomenclature	Mfg.	Functional Type	Initial Application
1972	VAST (AN/USM-247)	Harris	Digital-Analog-Hybrid	Common
1975	CAT IIID (AN/USM-429(V))	Grumman	Digital-Analog-Hybrid	F-14A
1976	IMUTS II (AN/USM-608(V))	Litton	Inertial Navigation	F/A-18
1979	EOSTS (AN/AAM-60(V-6))	Boeing	Electro-Optics	S-3A
1980	NEWTS (AN/USM-458)	Sanders	Electronic Warfare	ALQ-126B
1981	RADCOM (AN/USM-467)	Grumman	Radar	E-2C
1983	ATS (AN/USM-470(V-1))	Harris	Digital-Analog-Hybrid	F/A-18
1983	HTS (AN/USM-484)	Harris	Hybrid	Common
1984	ATS (AN/USM-470(V-2))	Harris	Digital-Analog-Hybrid	SH-60
1985	AEWTS (AN/USM-487)	Honeywell	Electronic Warfare	ASPJ

6. The Long-Range Goal: CASS

The Consolidated Automated Support System is the outcome of the long-range goal established by NAVAIR in 1979. Research and development work actually began after the 1976 Marcy Report to explore new testing technology in recognition of two factors. First, the Navy's existing test equipment, including test systems then under development, had limited capability to meet the advanced testing needs of avionics to be introduced in the late 1990s, so new systems were needed. Second, the functional family of testers would be able to provide the short term support needed until a new general purpose test system could be developed and fielded in an orderly and controlled manner. [Ref. 1:p. 2-2]

Advances in microelectronics promised to be both a challenge and an opportunity in this long-range development effort, presenting many problems in weapon system measurement and diagnostics, while offering many opportunities for improved test system capabilities. Research and development focused on several areas: [Ref. 5:App. E]

- Avionic design for testability, including BIT, large scale integrated (LSI) circuits, self-test and self-repair through reconfiguration, printed circuit boards, non-electronic equipment, and packaging.
- Advanced ATE concepts, including test system fault isolation (to eliminate ambiguity between faults in the ATE, TPS and UUT), improved interface devices, human factors, and use of microcomputers for program control and stimulation.
- ATE software, including design and verification, automation of documentation, built in checks for test programs, and program standardization.
- Automatic test program generation, including development of circuit analysis algorithms and failure mode analysis techniques.
- Self-calibration technology, including development of built-in standards, mobile calibrating packs and automatic calibration techniques.
- Hardware and software configuration management, including development of distributed data bases and mass storage to manage specifications, engineering changes, and software test programs and documentation.
- ATE technical training, including development of interactive programs and simulators to improve learning, cut costs and reduce reliance on ATE equipment for operator training.
- Microcomputer testing technology, including development of BIT design and acquisition strategies to improve testing and fault detection/isolation in microcomputer based electronic subsystems.

While many avionic and ATE systems acquired in recent years have benefited from these R&D efforts, the CASS program has sought to integrate the state of the art in each of these areas to achieve an optimal, standardized test system. The outcome of this development effort is the subject of the next chapter.

III. THE CASS PROGRAM

This Chapter describes the CASS program in terms of equipment, acquisition strategy and introduction plan to lay the groundwork for later evaluation of the system. It is organized first to provide program goals and an overview, then to present progressively greater detail about its relevant attributes and acquisition/introduction strategy.

A. PROGRAM OBJECTIVES

The Consolidated Support System Project was established in 1978 in response to the NAVAIR ATE Program Plan to provide a long-term solution to the many historical ATE problems and meet the challenge of emerging testing needs through the year 2000.

Its objectives are two-fold; first, to improve throughput (by reducing repair cycle time) which will result in improved weapon system operational availability (A_o), readiness and capability to meet combat sortie requirements; second, to standardize ATE hardware, software and support, which will result in decreased cost of ownership of both avionic systems and avionic test equipment. [Ref. 12:Addendum A, p. 1]

B. PROGRAM OVERVIEW

NAVAIR has called CASS and the T-45 jet trainer its two most important acquisition programs. CASS receives this high priority for two reasons. First, schedules for new weapon systems can slip with far less damage to the Naval Air mission than even a small slip in the CASS program schedule. The latter could have a ripple effect on the timing of many weapon system introductions. [Ref. 14] Second, failure to achieve its technical, logistic or performance goals could seriously impact operational readiness of weapons systems targeted for CASS support. [Ref. 15:p. 8]

CASS is assigned acquisition category (ACAT) IIS due to its relatively high cost and special SECNAV interest (ACAT I is the highest level, generally assigned to weapon system programs costing over $1 billion). Right on schedule so far, it is nearing the end of Phase II, full scale engineering development (FSED), by General Electric Company in Huntsville, Alabama. Its next major milestone (IIIA) is set for August 1990, when low rate initial production (LRIP) of 81 CASS stations is scheduled to begin. Full production will result in a total inventory of 775 CASS stations and their ancillary hardware. Technical evaluation (TECHEVAL, DT-IIC1) and pre-operational evaluation (OPEVAL, OT-IIA) are being conducted concurrently during Spring, 1990 at the Naval Air Test Center in Patuxent River, Maryland.

The remainder of this overview highlights the significant events in the development schedule and fleet introduction of CASS.

1. Schedule

Significant future events are summarized in the program schedule shown in Figure 6. [Ref. 12] Following TECHEVAL, CASS stations will be provided to the Operational Test and Evaluation Force (OPTEVFOR) for full OPEVAL (OT-IIB). In this evaluation, CASS must demonstrate its technical performance as well as the performance of all logistic elements, including training, spare parts and technical data needed to keep CASS operational. TPS developed for 'support of support' (SOS) for CASS SRAs will be also be tested. (SOS TPS enable one CASS station to test failed SRAs from another CASS station.)

After successful completion of testing and correction of any problems, a decision will be sought to proceed to full rate production (FRP) in mid 1991 (Milestone IIIB). The Option I deliverables shown in the figure are the CASS stations produced during LRIP (81 stations), and Option II and III deliverables are those produced during FRP. The physical configuration audit (PCA) is scheduled to take place in early 1991,

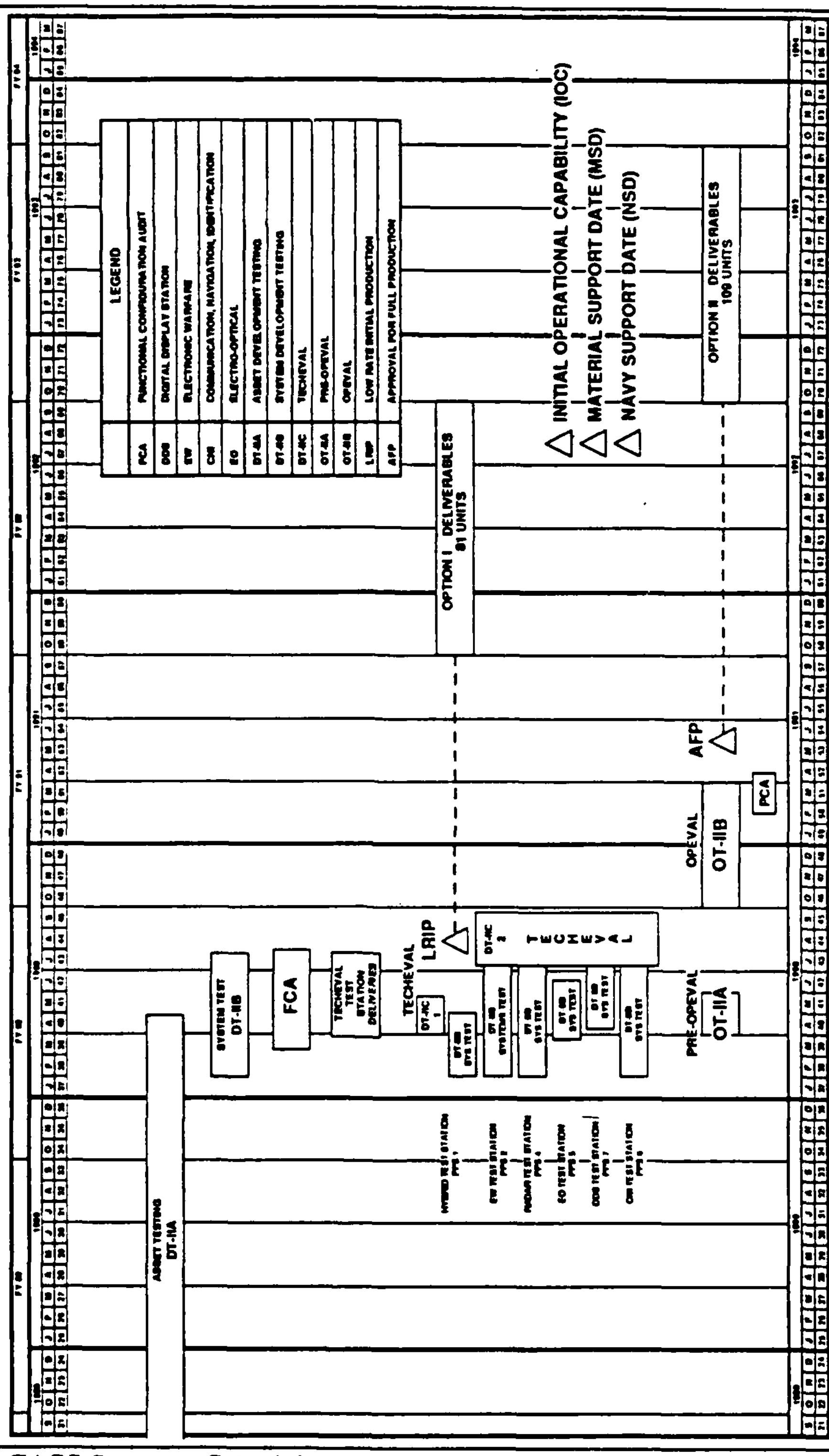

Figure 6. CASS Program Schedule.

which is the earliest date the Navy will accept any production articles. Initial operating capability (IOC) will occur concurrently with the material support date (MSD) and Navy support date (NSD) in mid-1992. [Ref. 15:Attach. 1]

2. Fleet Introduction Overview

Some of the CASS stations produced during LRIP are scheduled to be delivered beginning in late 1991 to weapon system contractors and Naval Aviation Depots (NADEPS) for TPS development, and to Naval Air Maintenance Training Groups (NAMTRAGRUs) for operator and maintainer training. [Ref. 16:p. 1]

Fleet deliveries to sea and shore AIMDs for operational support of weapon systems are scheduled to begin in mid-1993 after all logistic elements are in place. These elements include training of fleet technicians, provisioning and delivery of spares, and organic depot support. There will be no phased support; all logistics will be delivered up front with the CASS station, and all elements are priced into the single firm fixed price development contract.

During its transition into operational service, CASS must accept the workload of many existing testers as well as the workload of new weapon systems never before supported, such as the A-12 aircraft. The sequencing of TPS development and stand-up of CASS at each site will be based on the timing of weapon system support requirements and the urgency of replacing obsolete testers. NAVAIR has drafted an introduction plan covering the period FY-90 to FY-99 which is based on a policy requiring all new aviation electronic systems to be supported by CASS and all existing systems to make the transition to CASS as they are modified.

The Navy Program Decision Meeting which granted CASS approval to enter full scale engineering development (FSED) in 1986 also directed that CASS be integrated into the surface Navy as the single Navy-wide standard test system, with NAVAIR as the lead hardware systems command for equipment acquisition. While its current operational requirement is for support of avionic systems only, it will be rewritten in the future to reflect this expanded tasking and CASS development will continue.

C. SYSTEM DESCRIPTION

The CASS system is a modular, reconfigurable, computer driven automatic test station capable of providing performance verification and diagnostic fault isolation for all complex electronic components. It is primarily intended for I level shore, carrier and mobile van maintenance environments, but will also be used at the depot. Its design is intended to make it versatile and expandable to accept the Navy's testing needs through the year 2011.

1. Configurations

CASS has five configurations which together are able to perform the same testing functions as the full family of testers (FOT). These are:

- Core or Hybrid station for testing general digital, RF, and analog SRAs and WRAs.
- Electro-optical (EO)
- Electronic warfare (EW)
- Digital/display (DDS)
- Communications, navigation and identification (CNI)
- Radar

There is also a portable version, the CASS Portable Test Set (CPTS), designed to meet Marine Corps forward deployed needs and future NAVSEA shipboard requirements. The portable version is a series of stacked suitcases that may be configured to be functionally identical to any of the mainframe CASS stations except that it lacks some power protection devices. [Ref. 15]

Figure 7 illustrates these configurations. [Ref. 8] The hybrid station has five racks and is the core of each of the others. It can be reconfigured into any of the other stations by adding additional circuit cards and a sixth rack. For example, the hybrid can be converted into an EO station by adding an EO rack and circuit cards, or into an EW, CNI or radar station by adding a radio frequency (RF) rack and the appropriate additional circuit cards. The CPTS may be similarly tailored to meet the functional testing requirements of a particular forward-deployed maintenance activity.

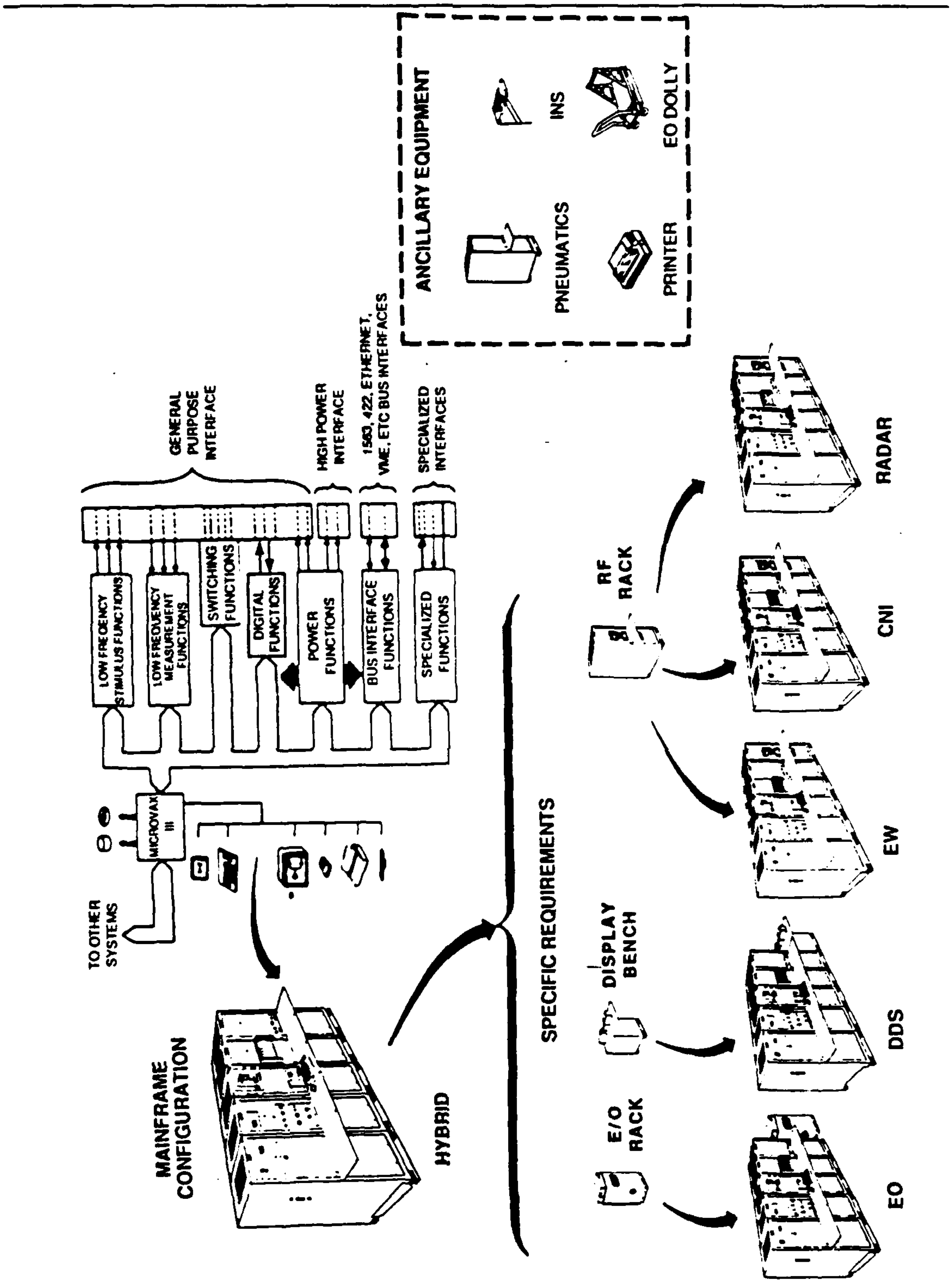

Figure 7. CASS Station Configurations.

Figure 7 also shows the ancillary equipment required, such as another rack to enable pneumatic component testing, a printer, and an EO dolly to support the A-6E forward looking infra-red (FLIR)/laser turret. The next section explains the upper portion of the figure by describing the station architecture.

2. Architecture

The basic station functions, such as stimulus, measurement, switching, digital, power, and bus interface are all contained in the hybrid station, with additional stimulus and response functions provided in other configurations. Rather than using a separate instrument for each of these functions (such as a digital voltmeter) as in many current ATE which use commercial off-the-shelf instruments, CASS uses a modular approach, with each function shown in Figure 7 performed by a series of circuit cards. This enables elimination of all unneeded functions such as displays, display electronics, packaging and enclosures, and consolidation of common functions such as switching, power and control electronics. A distributed set of microprocessor asset controllers combine the circuit cards to create each instrument function needed. The single Microvax III miniprocessor serves as the station controller for the test program, peripherals such as a printer, and the asset controllers, which are linked by an internal ethernet. An external ethernet may be used to establish a local area network (LAN) connecting many widely distributed CASS stations and a management information system such as NALCOMIS, presently being implemented to provide I level maintenance management and reporting. [Ref. 8]

The five core racks contain, from left to right: [Ref. 17]

- Power circuitry needed to protect the station, TPS and UUT from power transients and harmonic distortion, including a limited battery backup and circuitry to provide automatic shutdown of the station for longer transients.
- Programmable power supplies needed for testing present and future UUTs.
- Station control, containing the Microvax III computer, Winchester drive for magnetic disks, optical disks drive, embedded standards for self-calibration, and operator interface, which consists of a plasma display, keyboard, bar code reader and trackball.

- General purpose interface (GPI) for adapting to TPS, and digital test unit (DTU) and DTU power supplies.
- Additional DTU power supplies and space for growth to accommodate new testing requirements.

These hardware components are designed to place all required capability in the CASS station, eliminating the need for complex active circuitry in interconnection devices (IDs), as is often required for existing testers.

There is a high degree of commonality among the internal components of the various configurations, as illustrated by Figure 8. For example, circuit cards (SRAs) in the EW station are 84% common to the hybrid. To convert a hybrid station into an EW requires insertion of 24 SRAs internally in the hybrid station, plus connection of the RF rack. [Ref. 8]

This commonality between the five configurations is important for several reasons. First, it enables easy reconfiguration, as discussed above. This reconfigurability allows the suite of CASS stations at a site to be tailored to meet the site-specific workload of WRAs and SRAs, which constantly changes with the aircraft deckload and introduction of new avionic systems. Second, commonality is the key to standardizing ATE logistic support because it results in fewer types of components and fewer spares, less technical data, and reduced requirements for operator and maintainer training. Third, it permits limited TPS transportability between stations. Transportability means that a TPS that will work on one configuration will also work on other CASS configurations. For example, some TPSs designed for the CNI configuration will also work on the radar configuration. All TPSs designed for the hybrid will transport to any other station. This attribute creates considerable flexibility at a site; workload may be redistributed to other CASS stations when a station goes down, and the site has improved capacity to respond to surges in operating tempo without creation of long testing backlog. [Ref. 8]

3. System Software

CASS software consists of the following elements, described below: [Ref. 18: Annex A]

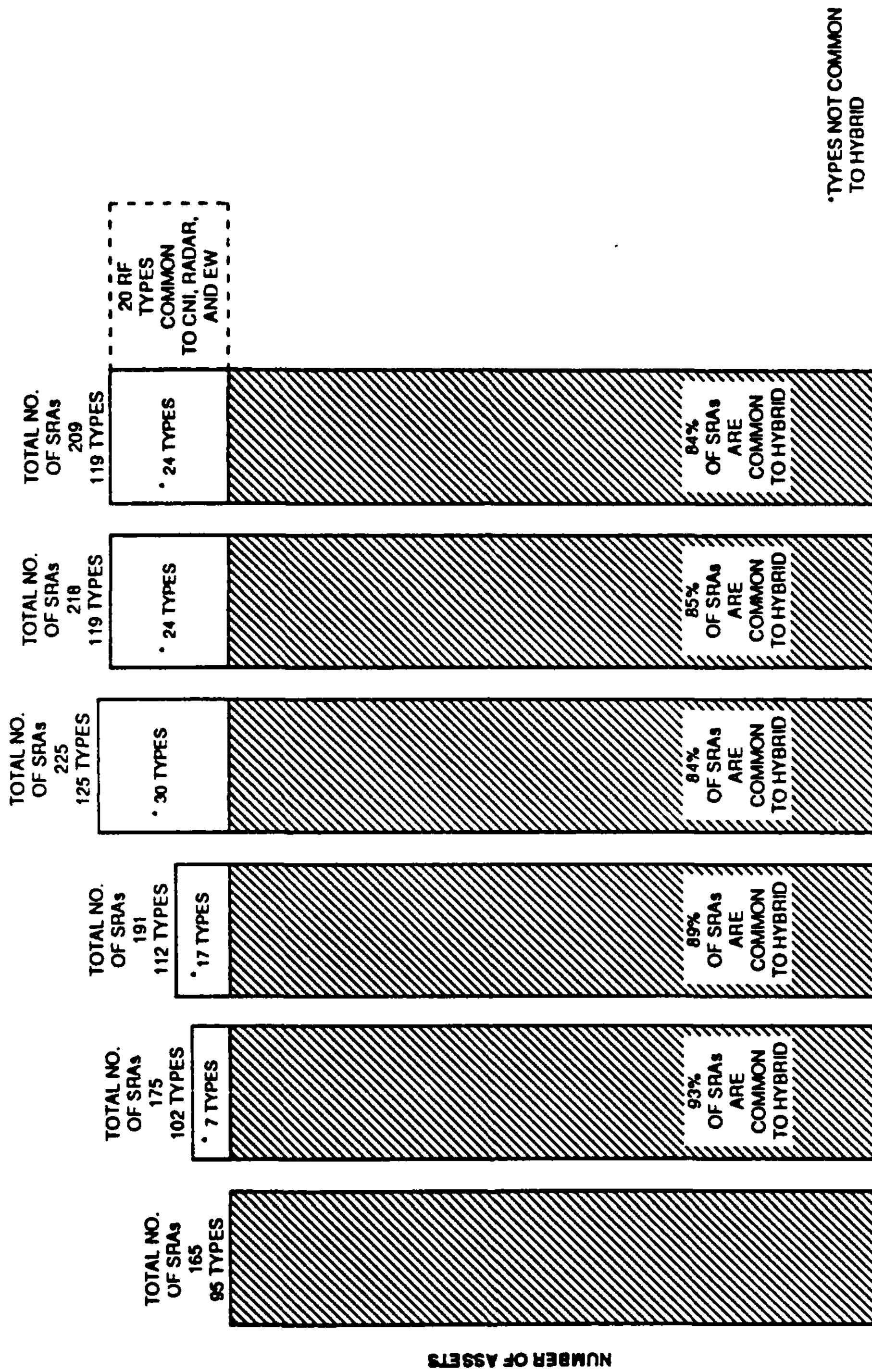

Figure 8. CASS Configuration Commonality.

- CASS station operating system
- Weapon system, or operational TPS programs (OTPS)
- Self-maintenance
- Intermediate Maintenance Operations Management (IMOM) System
- Operational Management System (OMS)
- Support

The station operating software, called the Test Executive, runs on the Microvax III computer. It accepts code from the TPS program to execute the test, controls stimulus and measurement devices to exercise the UUT, and returns measurement data to the Microvax III station controller computer for evaluation. It also controls operator interfaces such as the plasma display screen and keyboard and accesses a resident library on a mass storage device. The separate microprocessor asset controllers have software to control individual functional circuit cards called for by the Test Executive. Programs are written in a variety of languages, including FORTRAN, PASCAL, and assembly language.

All operational TPS software used by a particular station configuration at a site are stored in the resident library and may be drawn down on call by the operator to run a test on a UUT or may be transferred to other stations via the external ethernet. All OTPS is written in the DOD standard test language known as ATLAS.

CASS uses self-maintenance software to perform continuous on-line monitoring and calibration of station and TPS interface circuits simultaneously with UUT testing. It controls calibration standards and fault detection and isolation within CASS, plus any line loss parametric compensation requirements. The self-maintenance software monitors over 9,200 station test points for fault detection and isolation. [Ref. 8]

The Intermediate Maintenance Operations Management System (IMOM) performs automated test data collection and storage and is the system which establishes the communication with NALCOMIS via the external ethernet. The IMOM system continuously collects data reflecting station status, operational availability, failed station hardware that was isolated using the self-maintenance function, station usage, operator identification, and the results of UUT testing. [Ref. 19]

The Operational Management System (OMS) aids I level maintenance personnel with management of production, manpower and material control. This includes assigning UUTs to particular workcenters to balance workload and minimize turn around time by projecting/simulating shop performance under different constraints, workloads, conditions and operating policies. OMS software contains applications utilities such as network protocol handlers, input/output functions, and mathematical and statistical packages. Working together, the IMOM and OMS systems are designed to create a completely automated ATE shop. [Ref. 2]

CASS support software is used to assist in the design, development, testing, and support of station software, self-maintenance software, IMOM and OTPS. Many TPS development software tools are part of the CASS station deliverables.

D. ACQUISITION STRATEGY

CASS is managed by NAVAIR with a program organization (PMA-260) rather than by the support equipment acquisition staff (AIR-552) as has been done for all previous ATE acquisitions. This management organization was directed by SECNAV during the pre-FSED phase in March 1985, when CASS was designated the standard ATE for the Navy. [Ref. 12] This direction reflects the facts that CASS' scope and acquisition strategy resemble that of a major weapon system far more than a support equipment system. The key features of its acquisition strategy are: [Ref. 2]

- A single firm fixed price (FFP) contract with GE for FSED and three years of production options for 327 stations, which NAVAIR may change up or down by 50% to meet introduction requirements and funding constraints.
- A contract awarded based on performance specifications and equally weighted technical, acquisition/life cycle cost and logistic support factors.
- Military standard logistic support analysis (LSA).
- A dual manufacturing source, Martin Marietta Technical Services Company (MMTSC), to ensure head-to-head competition for the life of the program.

- Full data rights and validated level III engineering drawings.
- The contractor must demonstrate full performance (DT-IIC and OT-IIB) prior to acceptance of the first production article.
- A performance warrantee for four years after government acceptance of each end item.

The warrantee clause in the CASS FSED and initial production contract covers design and manufacturing requirements, defects in material and workmanship, technical/logistic performance, and reliability and maintainability (R&M). R&M requirements are mean time between failure (MTBF) of 148 hours, mean time to repair (MTTR) of 2.0 hours, 100% BIT detection, and 95% BIT isolation to one SRA. The OMS system will be used to collect performance data, and will be used to enforce technical, logistic, and R&M performance. [Ref. 15:p. 6]

1. Acquisition History

The initial conceptual phase of the program began in 1978 with small studies designed to augment the Marcy Report by clarifying ATE problems in procurement, management, operation and future test requirements. Acquisition Phase 0 began in August 1980, when CSS was approved as an ACAT III project by a Navy decision coordinating paper (NDCP). On 31 December 1981, five contracts were competitively awarded for concept exploration and definition. Contractors included GE, General Dynamics, Sperry, Grumman and Harris, chosen from 135 companies who responded to the request for proposal (RFP). Their studies were completed in September 1983 and encompassed system requirements analysis, determination of appropriate performance and logistic support specifications, systems engineering tradeoff analysis, and creation of computer models to simulate the performance of their proposed systems.

During Phase I, Concept Demonstration/Validation (then called pre-FSED), two industry design teams competed for the FSED contract. These teams were headed by Grumman (with GD and Hughes as partners) and GE (with Honeywell, Northrup, and Astrosystems as partners). [Ref. 20] GE won the contract in December 1986.

Soon after that, SECNAV approved Milestone II entry into FSED in a February 1987 Program Decision Memorandum (PDM). [Ref. 15:p. 1]

2. Full Scale Engineering Development

NAVAIR awarded GE the contract for FSED based on equal weighting of technical, logistics and cost criteria in the evaluation. As prime contractor, GE awarded a subcontract to Martin Marietta as the dual manufacturing source (DMS) in December 1988. Under this contract, GE and Martin Marietta will share production of the first 327 CASS stations with a 60/40% split. As an incentive to ensure full DMS qualification, GE payments are contingent on Martin Marietta's on-time delivery of exact copies (verified through PCA and operational testing). The two companies will then go into head-to-head competition for the remainder of the life of the system, with each guaranteed at least 40% of the award. Distribution will be based on price and past performance. [Ref. 15:p. 4] Currently, 91 Martin Marietta employees are integrated with GE employees at their Huntsville site for training in co-assembly. Martin Marietta is constructing a 32,000 square foot production facility in Americus, Georgia. [Ref. 16:p. 4]

3. Logistic Support Elements

Because most of the problems identified by the fleet in the Marcy Report concern supportability issues, logistic supportability has been a major CASS program goal since its inception. Heavy emphasis was placed on the logistic support analysis (LSA) process to ensure that support continually influenced design through an iterative process. Additionally, the usual concept of phased support during system introduction was abandoned during negotiation for the FSED contract. Instead, all logistic support elements were priced into the development and production contract, including development of training, maintenance publications and all other data requirements, eliminating the need for interim support from the contractor.

The CASS program has also pursued several other logistic support initiatives. CASS was developed using concepts of the DOD Computer-Aided Acquisition and

Logistic Support initiative (CALS) for automated digital interchange of technical information between contractors and NAVAIR. CALS was created in an effort to reduce costs and improve quality and integration of information used for design, manufacture and ILS.

The most noteworthy product of this effort in the CASS program is digitized technical manuals (paperless publications). Known as the Automated Technical Information (ATI) System, all of the many volumes of technical manuals are stored on 5.25 inch erasable optical disks, which are FSED phase deliverables. Some of its features include menus, help files, a mouse/cursor, icons, multi-windowing, browse features, electronic bookmarks, and automated technical publication deficiency reports (TPDRs).

There are many advantages to this paperless publication system, including increased operator efficiency, faster updates, and reduced storage requirements and transportation costs. It also allows efficient use of other CALS tools, such as computer aided design and the LSA process, used in the creation and quality control of ATI publications. [Ref. 16:p. 3]

As noted above, the CASS FSED contract requires full data rights and delivery of all technical data (in both manual and digitized formats) including level III engineering drawings, sufficient for future competitive reprocurement of end items and spare parts (with the exception of some embedded commercial test equipment (CTE)). All data and publications must be delivered after they are validated during OPEVAL, no later than the physical configuration audit, which is well before fleet delivery. [Ref. 12:p. 13]

Formal training courses will also be evaluated at OPEVAL, then updated to correct problems identified prior to delivery to the Naval Training Group (NAMTRAGRU). Courses and personnel classifications have been created for CASS operator/maintainer and maintenance technician. An embedded training module is also available on the ATI system to support and augment the formal instruction which allows on-call interactive refresher training for operators and maintainers. A CASS innovation is the development of a CASS supervisor course which includes use of the OMS, IMOMS, ethernet LAN, ATI, and embedded training systems. Manpower planning is an iterative process driven by the introduction plan which is supported by the Navy Training Plan (NTP) scheduled for approval in August 1990. [Ref. 2]

The CASS program is also the prototype for a new approach to supply support transitioning, intended to allow CASS to achieve ASO material support concurrent with IOC and be fully supportable before it hits the fleet. This ASO/NAVAIR joint venture aims to provision spares in one third the normal time by paralleling provisioning events. Rather than following a sequential process of ordering end items, data analysis and file loading, and finally spares procurement, spares will be delivered by GE concurrently with CASS end items. This will achieve economies of scale as well as eliminate interim contractor support. The danger of this approach is that the first spares procurement is right in the middle of test and evaluation, before the CASS configuration is frozen. As a result, GE will accept the risk for configuration control of both the CASS station and spares as per the FSED contract. [Ref. 21]

4. Streamlining and Costs

Acquisition streamlining initiatives in the CASS program resulted in 48% savings in the FSED contract with GE. In the approved CASS NDCP of 18 April 1986 NAVAIR estimated a cost of $341 million for FSED during fiscal years 87-91. The firm fixed price offer from GE for FSED and initial production was $164.4 million, which is $176.8 million less than the estimate. The CASS program subsequently received a number of awards in recognition of this cost savings, including the OSD Acquisition Streamlining Excellence Award. Streamlining initiatives were: [Ref. 22]

- Converted from design specifications to performance specifications.
- Reduced first tier specifications from 126 to 95.
- Converted all 3,000 second tier specifications to guidance only.
- Reduced the contract data requirements list (CDRL) from 359 to 258.
- Eliminated the engineering development model (EDM).
- Eliminated test requirement data (TRD) for support of support (SOS) TPS.

- Eliminated interim contractor support by making the material support date (MSD) and Navy support date (NSD) concurrent with initial operating capability (IOC).
- Required the contractor to propose additional CALS initiatives.

Among the most important features of the CASS acquisition are use of a firm fixed price development and production contract containing performance rather than design specifications, with all logistic support elements priced in. They were the key to these streamlining achievements.

E. CASS INTRODUCTION PLAN

The CASS Program Office (PMA-260) and the Support Equipment Division (AIR-552) work jointly to define the actions and milestones necessary to successfully introduce CASS to the fleet. This effort requires identifying existing and emerging testing requirements and setting priorities to establish the sequence in which they will receive CASS support. From this plan, the transition team schedules TPS development and CASS station delivery to each site in the right quantities and configurations. This process is iterative, and will continue throughout the CASS life cycle.

The following paragraphs examine the criteria for selecting weapon systems to be introduced or transitioned to CASS, and summarizes the first-round CASS introduction plan, the process for determining site-specific CASS requirements, and the TPS acquisition strategy.

1. Weapon System Selection Criteria

Systems to be transitioned or introduced to CASS will be identified based on the following NAVAIR policy, established in 1987 to halt development of any new ATE systems and to establish CASS as the standardized ATE for all avionics systems of the future: [Ref. 23]

- All electronic systems requiring ATE support with IOC dates during FY-92 or beyond will be supported on CASS.
- All existing electronic systems will be transitioned to CASS as they are modified or upgraded.

- All electronic systems with an IOC during FY-90 through FY-92 will receive interim support until supported by CASS. (For example, the F-14D will be supported by RADCOM until CASS is ready to accept its testing requirements.)
- Testing that is presently done on obsolete ATE which can no longer be economically supported will be off-loaded to CASS based on fleet support priorities and economic analysis.

2. Summary of Introduction Plan

Figure 9 is the product of this policy. It identifies the weapon systems scheduled to be introduced or transitioned to CASS support through fiscal year 1999. [Ref. 24] CASS 'introduction' applies to new weapon systems never before supported, while 'transition' applies to existing ATE that will off-load their testing of WRAs and SRAs to CASS and then be retired.

Appendix A shows the schedule for these introductions and transitions (with the weapon and ATE systems listed in alphabetical order) in a series of six bar charts. Many of the weapons systems will require some form of interim support if they reach IOC before CASS and CASS TPS are available. These periods are shown as shaded bars; the beginning of the full clear bars indicate the start of full CASS support. For example, the "F-14D Misc" WRAs and SRAs will be supported by RADCOM and other existing testers from the first quarter of 1991 until the second quarter of 1995, when CASS will begin to accept some of the testing load. Full CASS support will begin in the second quarter of 1998.

The AAM-60 electro-optical station will be the first to be transitioned (beginning in 1994), chosen because it is obsolete and difficult to support. It tests WRAs for the A-6E forward looking infra-red (FLIR) and laser system. VAST will follow later in 1994, so all the F-14A and S-3 WRAs and SRAs it supports must be offloaded. VAST has a high priority to undergo transition because it must be removed from carriers to make room for CASS. An already approved Ship Alteration calls for replacing one

Weapon System
Introductions:

A-12	CAINS II	JTIDS I/D
AAAM	EA-6B AIP	MARK XV DEPOT
AIWS	EA-6B AN/ALQ-149	MARK XV WRA
AMRAAM LOT 1	EA-6B RPG	MINI-DAMA
AMRAAM LOT 2	F-14D AN/APG-71	MMR/ARN-138
AN/AAS-33A	F-14D Misc.	P-3C UPDATE IV
AN/ALE-47	F-14D SMS	PHOENIX LOT 1
AN/ALE-50	GPS/ARN-151	PHOENIX LOT 2
AN/ALQ-126B	GPWS/TRANSPORT	SAHRS
AN/ALQ-156	HARM LOT 1	SCS
AN/ALQ-165	HARM LOT 2	SH-60F
AN/ALR-67 ASR	HELO/GPWS	SH-60F/ALFS
AN/APS-137	HNVS	SIDEARM II
AN/ARC-210	IRSTS	SPARROW
ATARS F-18	JTIDS	TOMAHAWK

ATE Transitions:

AAM-60 (A-6)	RADCOM (A-6E)
AAM-60 (S-3)	RADCOM (E-2C)
ASM-614 (EA-6B)	RADCOM (EA-6B)
ASM-614 (S-3)	TMV (F-14A+)
EETS (AV-8B)	VAST (F-14A)
HATS (S-3)	VAST (S-3)

Figure 9. CASS Candidate Programs, FY-90 to FY-99.

VAST with one CASS. The AAM-60 station and the ASM-614 station for the EA-6B will also be one-for-one replacements. [Ref. 16:p.3] A total of 19 CASS stations are expected to be required on an average carrier to support the full workload. [Ref. 1:p. 5-5]

3. Site Planning

The goal of the CASS introduction plan is to optimize the CASS testing resources at each site. To do this, planners must select the right weapon system UUTs to be introduced or transitioned, and then deliver tailored CASS configurations to handle the workload for the least cost.

The process of optimizing the support resources at each site will be managed using three computer models collectively known as the System Synthesis Model (SSM). The first is a mapping model that identifies CASS configurations able to support each UUT. These are determined by matching UUT parametric requirements, such as power, signal stimulus and measurement, to the CASS assets that provide these necessary functions.

The second model is a workload planning model that determines CASS quantities and configurations required for each site. The key input parameters are CASS operational availability, the configurations specified by the mapping model, and UUT induction rates. Induction rates are based on projected aircraft flying hours and MTBF of each UUT. This model is discussed in greater detail in Chapter V. [Ref. 24:p. 11]

The third model is a queuing simulation which analyzes the sensitivity of the workload model output to changes in input parameters. The simulation will be used before NAVAIR makes final decisions on the quantity and configuration of CASS stations to deliver to each site. [Ref. 25]

These three models are vital for accurate determination of site requirements. The dynamics of the decision process are very complex for a number of reasons. First, thousands of UUTs will ultimately be supported by CASS. Second, TPS transportability allows many UUTs to be tested on multiple configurations. Third, the workload at each site will undergo constant changes as transition progresses and as weapon systems come and go, forcing stations to be periodically reconfigured.

CASS site planning must also deal with significant constraints which may upset plans after they are finalized, such as the availability of funds for CASS production and TPS procurement, the production output of GE and Martin Marietta, and the performance of TPS yet to be developed. These constraints may affect repair throughput and alter projected site workloads. [Ref. 24:p. 7]

The CASS introduction plan is particularly vulnerable to slippages in TPS development. For example, NAVAIR calculated the impact of slipping F-14D TPS development, which is the top CASS requirements driver. (The A-12 program is the next major driver.) Expenditure of $7.7 million in funding budgeted for this effort in FY-90 is at risk of being deferred until FY-91, which would delay F-14D initial organic capability by 12 months. This slippage would increase AVDLR costs by approximately $30 million to sustain interim support beyond the F-14D MSD. Because it would also delay the offload of VAST and RADCOM, this slippage would disrupt planning for the introduction of other new weapon systems because CASS cannot be installed aboard space-constrained carriers until these other ATE stations are removed. This example is intended to show the how a host of interdependent factors must be orchestrated to achieve an orderly CASS introduction. [Ref. 26]

4. TPS Acquisition Strategy

The key elements of the NAVAIR (AIR-552) TPS acquisition strategy are: [Ref. 27]

- Development contracts will be firm fixed price, sole source with the weapon system prime contractors.
- Production contracts will be openly competed.
- The government will provide to contractors two sets of UUTs for each TPS, CASS stations and TPS development tools as government furnished equipment (GFE).
- The government will provide maintenance and spares for the CASS station and UUT.

Thirty months is the targeted lead time for TPS delivery, from identification of a requirement using the process described above until the date it is needed in the fleet. [Ref. 28:p. 5] To enhance this effort, GE has delivered a suite of TPS development tools as part of the FSED contract. These include ATLAS language compilers, translators, editors, FORTRAN debugging programs, automatic test program generators (ATPGs) and a CASS Test Executive simulator. GE has prepared a 20 volume TPS developers' guide and is preparing a TPS development training course.

The standard interface environment with CASS, combined with the Test Executive simulator (which runs on any VAX computer), allows early design, development and testing of TPS programs, interconnection devices and cabling without a CASS station. GE demonstrated this capability by completing most of the A-6E FLIR/laser TPS development and fabrication before the first pre-production station was available. A similar approach is intended for the huge development effort that lies ahead to reduce dependence on GFE which is a critical cost and schedule driver. [Ref. 16:p. 3]

IV. THE AVIONICS REPAIR PROCESS INVOLVING I LEVEL ATE

Many of the historical ATE problems the CASS program was created to solve are rooted in the repair process. This chapter describes the supply/AIMD repair cycle using existing testers to clarify the functional role of ATE and lay a foundation for the comparative evaluation of CASS in the next chapter.

A. REPAIR PROCESS EFFECTS ON SPARES REQUIREMENTS

Intermediate and depot level repair is intended to fill supply shelves, not holes in aircraft, so the repair process is intimately related to weapon system spares requirements. This section explains that relationship.

The I level maintenance cycle normally begins when squadron technicians fault isolate an aircraft system failure to a specific WRA. The maintenance concept for aircraft typically requires that O level technicians perform all on-equipment work. Any component that is not repairable on the aircraft is removed and turned in to the local supply department and a replacement is requested. This requisition is ideally filled 'off the shelf,' while the failed component is sent to the local AIMD for repair.

The AVCAL (aboard ship) or SHORECAL (ashore) includes thousands of WRAs and SRAs stocked to meet the local demand for spare repairable and consumable parts. The fast movers receive special handling and are kept in locations close to their squadron or AIMD customers to speed their delivery. These fast movers are kept in the rotatable pool (for WRAs), module pool (for SRAs) or pre-expended bin (for consumables).

The full AVCAL is a level of safety stock designed to provide 90% protection against stockout for three months without resupply. Its range is dependent on the number of types of aircraft and the commonality of WRAs among aircraft aboard the carrier, and its depth is dependent on expected demand (failure rates) during the three-month period without resupply. In the case of I level repairables, carrying a full three-month supply can be avoided by repairing WRAs on the ship. Thus, the 90% protection level for these items need only protect for the repair turn-around time (TAT) for the I level activity. Additional units are needed, however, to accomodate the beyond capabilty of maintenance (BCM) rate. Thus, an attrition demand level is also provided to cover the three-month deployment assumption.

The Aviation Supply Office (ASO) computes the size and composition of the AVCAL using "ASO manual rules." The average AVCAL quantity of each repairable item is calculated by multiplying its average repair TAT by the average number of removals per day. Calculations are typically based on Navy-wide averages for removals per flight hour. Removals per day equals:

(Removals/Flight Hour) * (Flight Hours/Aircraft/Day)
* (Number of Aircraft)

This average is used in the Poisson probability distribution to determine the number of units of an item which are needed to provide 90% protection over TAT. There is also a special consideration for low demand items which would otherwise have zero allowance under these rules.

Figure 10 shows AVCAL levels for various TATs and removal rates and assuming no BCMs (thus no attrition) calculated by the Center for Naval Analysis. [Ref. 29:p. 19] It illustrates that the higher the removal rate for a component, the greater will be the potential for decreases in TAT to cause large AVCAL reductions, with corresponding percentage reductions in weapon system life cycle costs. For example, given a component with 0.7 removals per day and TAT of 20 days, reducing TAT to 10 days would reduce the AVCAL allowance for this item from 20 to 11.

The BCM rate also has an important effect on sparing requirements. Table II shows the average quantities of a component in the off-ship repair/resupply pipeline for various values of BCM rate, assuming one removal per day, a five-day TAT, and a three-month

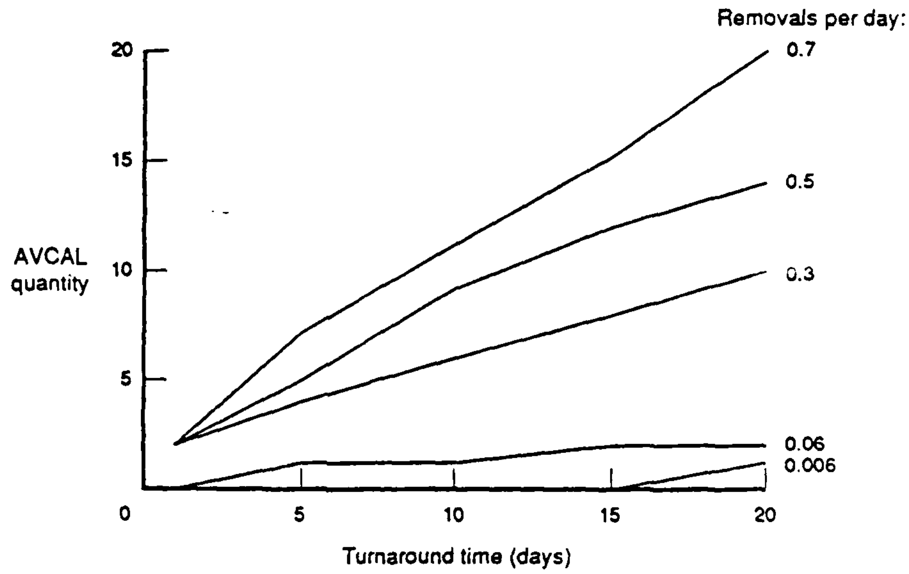

Figure 10. AVCAL Levels for Various TAT and Removal Rates (BCM rate = 0)

support period without resupply. These data were determined by the Center for Naval Analysis. [Ref. 30:p. 5] The table shows that the average number of units needed to cover attrition drops quickly with decreases in BCM rate, while the number of units needed to cover the repair TAT stays fairly constant over the typical range of BCM rates between 0 and 0.3. For example, reducing BCM rate from 0.2 to 0.1 decreases the number of units in the resupply pipeline from 18 to 9 and increases units in the repair pipeline from 4.0 to 4.5.

These relationships have profound implications for the repair process and ATE; any improvements in equipment or process which reduce TAT or BCM rates can significantly reduce the quantity and cost of weapon system spares required to achieve the same protection against stockout during a deployment.

Table II. Average Number of Units in Repair/Resupply Pipelines

BCM Rate	Repair	Resupply	Total
.0	5.0	.0	5.0
.1	4.5	9.0	13.5
.2	4.0	18.0	22.0
.5	2.5	45.0	47.5
.8	1.0	72.0	73.0
.9	.5	81.0	81.5
1.0	.0	90.0	90.0

B. THE REPAIR PROCESS: INDUCTION AND SCREENING

A WRA enters the AIMD repair cycle as a component awaiting maintenance (AWM) and joins the repair queue, or backlog. The aviation material screening unit (AMSU) of the AIMD screens the WRA by part number to determine whether the AIMD has repair capability. If it does not, the WRA is returned to supply for shipment to depot maintenance as a BCM component. If full or partial capability exists, the WRA is sent to the appropriate shop for induction into the shop's repair queue.

Once shop technicians receive the WRA it is screened again and is either inducted into the shop repair queue or returned to supply (with Production Control approval) as a BCM. If inducted by an ATE shop, technicians call it a UUT since WRAs, SRAs, and ATE station repairables all intermingle in the same queue.

At the same time that a component is received by the shop, data (paper or electronic) about the induction passes through Production Control (PC). PC assigns a work priority for running WRAs and SRAs on ATE based on two rules: criticality of need, followed by the first come, first served rule. In assigning a status based on criticality of need, expeditious repairs (EXREPS) are priority 1, 'pool critical' and 'pool zero balance' assets are priority 2, and all others are priority 3. [Ref. 6:p. 8-12]

EXREP status occurs when a replacement for a failed repairable part that downs an aircraft is not on the shelf for immediate issue. The repair pipeline must therefore work to fill the aircraft 'hole,' instead of the supply shelf. Pool critical status is assigned to an inducted component when its stocking level drops to a certain percentage of the allowance, and pool zero balance status is assigned when there is a stockout. Toward the end of a deployment, this should occur 10% of the time with the standard 90% protection level.

An additional priority status exists at shore AIMDs, which typically support carriers between at sea periods by repairing all components that were in the carrier's repair pipeline at the time the ship pulled into port. As the carrier's deployment date approaches, these 'repair and return' inductions compete against EXREPS from the shore squadrons for priority 1. The overall effect of the priority system is to create a lumpy demand for high priority repairs.

C. ATE SETUP AND TESTING

Components inducted to the ATE shop are set up for testing by connecting the UUT to the ATE station by means of the TPS. Setup operations are broken down into external setup, performed off-line while other UUTs are running on the station, and internal setup, performed on-line with the station idle. All internal operations are 'dead time' for the station. External operations include collecting the necessary TPS, such as cables, active power supplies, the ID and test program disk, and setting it all up with the UUT on a roll-around cart. Internal operations involve plugging it all in to the station, installing the TPD, and downloading the program. Station self-test and calibration are also internal operations if they cannot be performed while the station is running another program.

The setup often contributes to UUT backlog, because many operations can only be performed internally when the station is idle. As each site typically has an allowance for only one TPS and one ID of each type, the individual component is serviced by a single channel queuing system (one server) regardless of the number of ATE stations. One ID may also be shared between multiple TPS, adapting to the ATE station on one side and to one of several TPS cable sets and UUTs on the other. UUTs which share a common ID cannot be run concurrently regardless of their priority.

Once set up, the test program is downloaded and started. Numerous operator interventions are typically required during the course of the test to answer programmed questions, manually adjust ID power supplies, or operate switches on the UUT.

D. FAULT ISOLATION AND REPAIR

TPS software by design does not provide 100% fault isolation to a single SRA. This is done in an attempt to reduce TPS development costs and program run time (PRT). An ATE/TPS system's fault isolation capability for a particular UUT is instead expressed as the probability that faults can be isolated to an 'ambiguity group' of a certain size. For example, there may be a 95% probability of isolation to an ambiguity group of three SRAs.

The size of the ambiguity group may affect the quantity of SRAs and WRAs needed in the AVCAL. If repair is performed off-line (after disconnecting the UUT from the ATE), all SRAs in the ambiguity group would require replacement, even though it is likely that only one has a fault. If repair is performed on-line (while the UUT and ATE are still connected), the ambiguity group affects elapsed maintenance time (EMT) because SRAs will normally be replaced sequentially; if three SRAs are 'called out,' three cycles must be made through the program. The EMT that results from this process is a primary component of TAT and so affects WRA sparing. Ideally, cost-benefit analysis should be used to tradeoff the cost of TPS fault ambiguity group size against the cost of AVDLR and AVCAL allowances. If such a tradeoff were made, 95% isolation to three SRAs is expected to be the lower limit of acceptable TPS performance. [Ref. 31]

Figure 11 is a flow chart for the testing, fault isolation and repair process in an I level ATE shop. [Ref. 6:Chapters 8, 13 and 14, and Ref. 10:p. C-3] The chart shows the steps required to transform components inducted for repair into ready for issue (RFI) or beyond capability of maintenance (BCM) WRAs and SRAs.

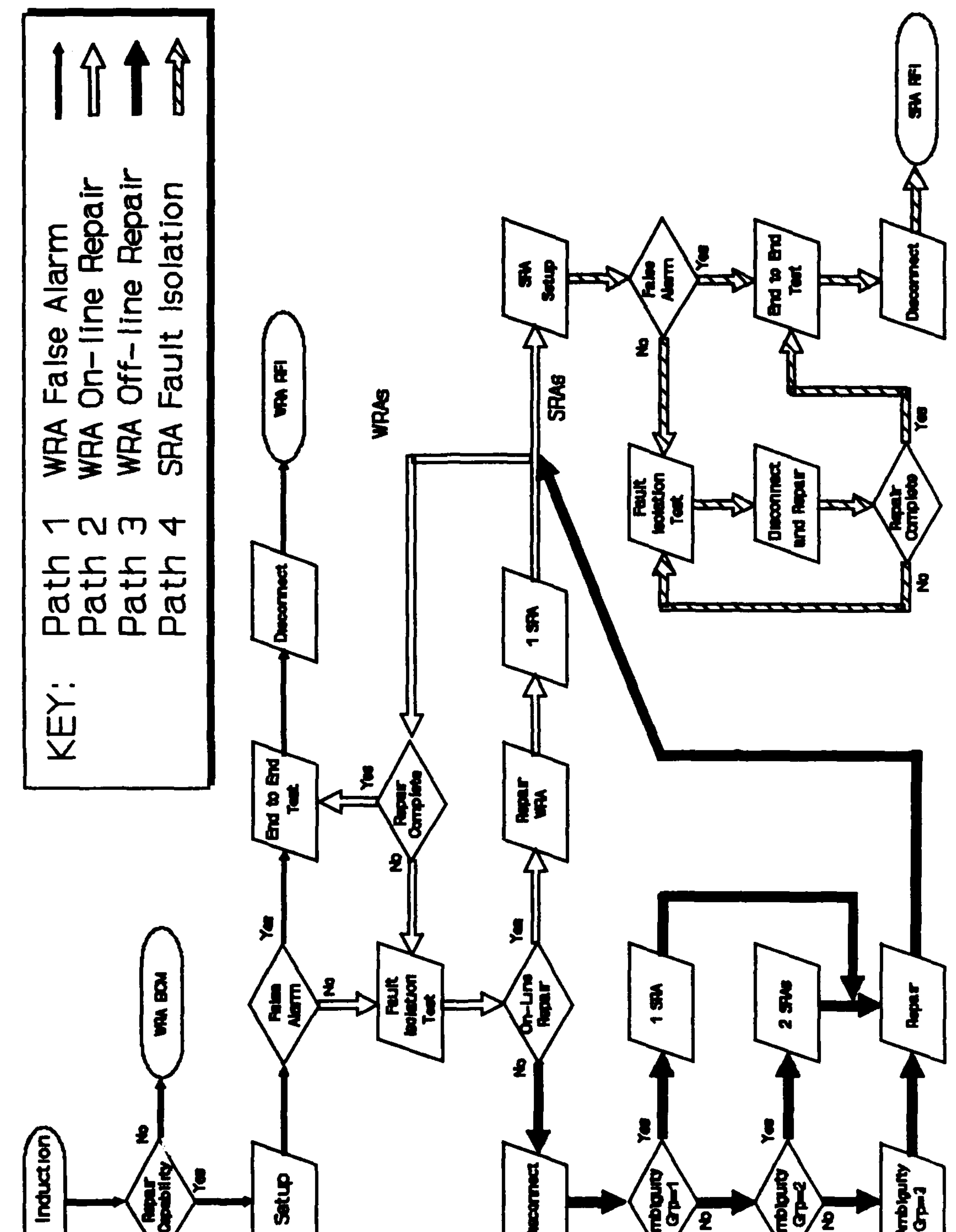

Figure 11. Repair Process Flow Using I Level ATE

The shortest path through the shop is the case of a 'false alarm,' which occurs when the WRA runs 'end to end' (from the beginning to the end of the test program) with no fault detected. This is path 1 in the figure and leads to a quick RFI if there are no other known faults and the WRA is not a 'Y code' (meaning a squadron has rejected it after a previous repair attempt).

Path 2 is the case of a WRA with a confirmed failure which is repaired on-line. The ATE isolates the fault and SRAs are replaced sequentially with multiple cycles though the program if the ambiguity group is greater than one. The WRA is retested end to end after the repair is complete to ensure it was successful. If there are multiple failures, the retest will branch into another fault isolation and repair cycle. Thus testing, fault isolation and repair operations are performed iteratively during on-line repair; testing is not a discrete step in the repair cycle.

Path 3 is the case of a WRA repaired off-line. Each cycle through the repair process results in an on-station time delay for disconnecting and reconnecting the WRA. The size of the ambiguity group does not affect EMT but does affect the number of SRAs which must later be tested (some of which are false alarms).

Path 4 is the case of an SRA tested on ATE but completely repaired off-line. When identified by the ATE as failed subcomponents of a WRA, they make a loop from the ATE shop to supply and are re-inducted to AIMD for repair. They may be manually tested by a specialized component repair shop or enter the same or another ATE queue right along with WRAs. (For example, many WRAs tested on RADCOM have SRAs that are tested on the CAT IIID station.) In either case, the tester identifies failed circuit card components which are then repaired or replaced by technicians in a separate micro-miniature (2M) repair shop. Just as WRA repair shops are not intended to fill holes in aircraft, SRA repair shops work to fill supply shelves, not holes in the next higher assembly.

WRAs are normally repaired on-line because off-line repair results in higher SRA spares requirements. To enable sequential replacement of SRAs in an ambiguity group during on-line repair, special SRAs known as Maintenance Assist Modules (MAMs) are kept on hand in the ATE shop. MAMs are standard SRAs in every way, but are procured for high failure rate SRAs specifically to enable fault isolation using ATE. After the test is complete, they must be removed and replaced with standard SRAs obtained from the supply department. When an SRA that is called out as a possible failure has no MAMs available because the needed MAMs have failed or are not stocked, an operator typically cannibalizes known good SRAs from awaiting parts (AWP) WRAs held by the supply department or even from the other WRAs in the AWM queue. The operator may do this with permission or even illegally in order to finish the test before breaking down the TPS setup. Cannibalized SRAs are generally not removed once installed in contrast to MAMs, so the repair step is completed during fault isolation.

The frequency of the program entry points for re-running portions of the test and the number of operator interventions it requires are critical determinants of the time needed to complete these iterations. Together, they determine how long it takes to return to the point at which the failure was detected to verify its correction and then continue the test. If the design of the ATE allows it, experienced operators will often temporarily re-program the software to create entry points closer to the portion that must be re-run, reducing the time for each iteration by tens of minutes.

E. ATE AND TPS TROUBLESHOOTING

Test program strategies typically assume that all interconnecting wires in the TPS and WRA are good and that WRA failure modes do not include multiple or intermittent faults. If any of these assumptions are wrong, or there are software errors, the test program may generate erroneous SRA failure callouts. The operator may suspect this if a UUT will not pass a portion of the test after multiple replacements of an SRA.

This happens quite frequently with certain ATE/TPS combinations. For example, NAS Norfolk AIMD at one point in 1988 documented an average of 50 manhours per day troubleshooting failures in the many hundreds of interface pins between TPS and the RADCOM and CAT IIID stations. These were unreliable and very vulnerable to damage from power fluctuations. [Ref. 32]

The operator must troubleshoot the entire ATE/TPS/UUT system using ATE and TPS off-line self-test capabilities or through the process of elimination. Self-test capabilities typically consist of an ATE survey self-test which checks the instuments used for that test, an ID confidence check, and a signature identity test, used to ensure all the correct equipment is installed. The success of these checks in discriminating between ATE, TPS and UUT faults is dependent upon their comprehensiveness, which is frequently not sufficient to avoid using manual troubleshooting methods. [Ref. 31]

If self-testing does not isolate the fault, ATE station failures may be ruled out through the process of elimination, starting by breaking down the whole setup and moving the TPS and UUT to another of the same type of station if there is one at the site. If the station is ruled out as a failure, TPS failures must be ruled out by substituting a known good UUT. (Because there is normally only one TPS of each type per site, it cannot be substituted.) Alternately, the operator/maintainer may turn to manual troubleshooting using probes, ATE and TPS hardware schematics, program listings and test diagrams that lay out the software flow contained in the (often unofficial or bootleg) TPS supplementary data packages. There is a formal training track for this troubleshooting process only for VAST technicians; all others must learn on the job.

If the long process of troubleshooting the ATE/TPS/UUT system rules out station, TPS and SRA problems, the shop will typically declare the UUT beyond capability of maintenance (BCM).

This description of the repair process is important for understanding the factors which influence ATE effectiveness. The next chapter is the evaluation of CASS. It draws on this and each of the foregoing chapters in comparing CASS to the existing family of testers to determine its ability to solve the most pressing ATE problems.

V. COMPARATIVE EVALUATION OF CASS

A. CRITERIA

The CASS Acquisition Plan presents the operational goals for the program which are the basis for evaluation criteria used in this chapter. They are: [Ref. 12:p. Add. A, p. 2]

- Achieve a 100 percent improvement in testing throughput capability over existing ATE.
- Provide a sustained test capability with higher reliability and potential for reconfiguration to satisfy different test requirements.
- Reduce proliferation of ATE and improve logistics supportability and maintainability through standardized hardware and software.
- Reduce ATE and avionic system life cycle costs.

These goals are interrelated. For example, reliability, maintainability, and logistic supportability are key determinants of throughput. However, the cost of ATE stations must be traded off against the cost of avionic system spares in the AVCAL/SHORECAL. Many of these relationships were illustrated in describing the repair process in the last chapter and are further clarified in this chapter.

CASS is evaluated against the following three criteria:

- Turnaround time (the reciprocal of throughput);
- Expandability to accept emerging testing requirements;
- ATE system life cycle costs.

These criteria encompass all four of the above goals. The remainder of this analysis evaluates expected CASS performance against the criteria in comparison with the family of testers.

B. TURNAROUND TIME

To achieve the CASS goal of 100% improvement in throughput, turnaround time (TAT) must be reduced by 50%. Evaluation of the ability of CASS to achieve this goal requires analysis of the ATE attributes that influence it, and comparison of CASS to existing testers with respect to these attributes.

TAT of weapon system components through the local I level repair process is the total time from removal of a suspected failed WRA from an aircraft, or SRA from a WRA, until the WRA/SRA is RFI. When the repair process employs ATE systems, TAT is built up from several components:

- Program Run Time (PRT): The time required for a no defect end-to-end test, including programmed operator interventions.
- Elapsed Maintenance Time (EMT): The total time that a UUT occupies a station. It includes PRT, troubleshooting time (while swapping MAMS or isolating station/TPS failures), time spent looking for parts to use in troubleshooting, and repair time (while replacing SRAs or making adjustments).
- Logistics Delay Time (LDT): Time spent in the ATE backlog waiting for station availability, in a supply awaiting parts locker, and in the supply transportation and administrative processing pipeline.

The key ATE system attributes affecting these times include the test strategy and computer capabilities (which affect PRT and EMT), logistic supportability (which affects EMT and LDT), and the number of ATE stations (which affects LDT). The following sub-sections compare CASS and members of the FOT in these attributes.

1. Test Strategy

CASS TPS development plans call for use of functional test strategies rather than the parametric test strategies now used in most TPS (although CASS is capable of both). [Ref. 33] Parametric testing checks all input and output signals from a UUT sequentially to determine if they comply with specifications. It is a strict test that requires the UUT be restored to essentially factory condition to be declared RFI, regardless of whether a detected deviation from specification caused the failure reported by the squadron. Functional testing, on the other hand, screens the component only for failures that inhibit its proper operational performance. It is in many ways a 'confidence check' or quick verify routine that checks most-likely-to-fail functions first, and then tests in progressively greater depth to fault isolate to an ambiguity group. [Ref. 30:p. 1]

A functional test strategy is faster than parametric in both PRT and time required for fault isolation and results in lower BCM rates because it does not require the component to meet factory specifications. It may gain further speed and program simplification by monitoring the BIT circuits within a WRA for fault detection and isolation. It may, however, cause shorter mean time between removal (MTBR) of WRAs because the test may fail to detect true faults that would be detected by parametric testing, and result in issue of WRAs that will not work well in the aircraft. Functional testing will reduce weapon system spares allowances in the AVCAL/SHORECAL to the extent that it reduces components in the repair cycle (through shorter TAT) and resupply pipeline (through lower BCM rates) without an offsetting increase in spares due to their reduced reliability. [Ref. 30:p. 1]

The Intermediate-Level Avionics Fault Tree Analyzer (IAFTA) ATE system used to support the F-18 aircraft employs functional test strategies analogous to what are planned for CASS TPS development. Comparison of IAFTA to the Avionics Test Set (ATS) it replaced, which uses a traditional parametric strategy, shows the potential impact on TAT of replacing other parametric testers with CASS.

A study conducted by the Center for Naval Analysis compared the TAT, BCM rates and MTBR of 14 F-18 WRAs using IAFTA and ATS. Data was collected primarily from two shore sites which had one of each tester. These were used almost equally to repair the 14 WRAs. Their results are summarized in Table III. Total TAT using IAFTA was less than half the TAT using ATS (averaging 6.5 days compared to 2.5 days), as shown in the second column. BCM rates using IAFTA dropped to a fraction of those achieved on ATS (averaging 10% compared to less than 1%), as shown in the third column. Some components tested on IAFTA showed slightly reduced reliability, indicated by the increased WRA removal rates shown in the forth column.

Table III. Comparison of the Effects of Functional Versus Parametric Test Strategies (IAFTA vs ATS).

WRA Nomen.	TAT ATS/IAFTA		BCM % ATS/IAFTA		Removal Rate ATS/IAFTA		# Spares ATS/IAFTA	
ADC	6.5	3.5	2.5	0.0	.089	.307	2	2
RPYC	6.4	2.9	3.2	1.2	.158	.477	4	6
DataLink	2.0	2.3	0.0	0.0	.113	.062	1	0
SDC	6.3	5.4	5.4	2.4	.269	.737	3	5
SDR	8.2	5.5	8.6	0.0	.551	.630	8	5
CSC	6.1	2.8	4.8	0.0	.328	.481	3	3
HI	7.0	3.1	30.5	1.2	.551	.690	15	3
DDI	7.0	2.7	17.3	0.4	.568	.572	10	3
HUD	5.5	3.6	12.1	5.0	.458	.259	6	2
SMP	6.6	2.1	8.0	0.0	.193	.113	2	1
Gun e/d	6.2	3.4	6.5	0.0	.169	2.23	10	8
Wing e/d	8.2	1.8	20.8	0.0	.243	.132	6	1
Fus e/d	4.9	2.8	11.8	0.0	.240	.136	4	2
Pyln e/d	6.9	2.3	13.7	0.0	.193	.410	4	2
Total # Spares							78	43
Tot Cost ($ Mil)							$6.2	3.1

The analysis used the ASO sparing model discussed in the last chapter to calculate the change in AVCAL spares that resulted from the combination of these three factors. The fifth column shows AVCAL spares quantities by WRA using IAFTA and ATS, and totals the quantities and spares costs at the bottom. To support 14 F-18 aircraft aboard a carrier, cost of spares for the 14 WRAs tested on IAFTA dropped by 50%, from $6.2 million to $3.1 million.

In analyzing these results to make predictions about the performance CASS will achieve, several points must be considered. First, the study controlled for variables such as LDT, which may substantially affect TAT, but did not break out PRT or EMT as separate measures. As a result it is difficult to specify all the causes of the 50% reduction in TAT. Differences in reliability and maintainability of IAFTA and ATS may have contributed to the change (although the BCM rate reduction can be tied directly to the functional test strategy since no other variables are likely to affect it). Second, it is not clear that these results can be extrapolated to predict results for the whole range of WRAs and SRAs that CASS will test. These may have BIT capabilities and levels of complexity that vary substantially from the 14 F-18 WRAs.

Despite these questions which cloud the analysis, this study leads to the conclusion that using a functional test strategy with CASS is likely to reduce TAT, BCM rate and cost of weapon system spares for at least some complex UUTs or those with extensive BIT circuits.

2. Computer Capability

Improvements in computer capabilities between earlier generations of ATE and CASS may significantly reduce the time required for several testing and management functions. These capabilities include significantly expanded computer processing power, which allows both faster testing and simultaneous performance of several operator controlled tasks, and management tools never before available, such as the OMS and IMOMS systems.

The influence of computer processing power on testing time is shown through comparison of VAST and RADCOM. While the shift to a software orientation in test programs between VAST development in the late 1960s and RADCOM in the late 1970s greatly improved the ease with which programs can be updated, PRT increased for many UUTs. For example, the PRT for the E-2C main display unit (MDU) averaged 20 minutes on VAST, but 45 minutes on RADCOM. One reason for this is that RADCOM digital analysis is performed by the station computer, which consequently becomes easily bogged down and cannot perform any other task at the same time. VAST, by contrast, performs most digital analysis within its digital sub-system, freeing its station computer for overall test control. The resulting difference in computer speed may become significant in terms of EMT when a complete test or portion of a test must be repeated numerous times during on-line WRA repair (using the process illustrated by the flow chart in the last chapter). [Ref. 32]

CASS, like VAST, frees its station computer for overall test control by incorporating the series of microprocessor sub-systems known as asset controllers. CASS also benefits from advances during the 1980s in computer and communications technology, including faster computer chips, increased memory and the internal and external ethernet. These improvements give CASS processing power which will allow many simultaneous computer controlled functions.

The CASS operator directs these functions through a 'multi-tasking windows interface' rather than the 'single-tasking test based interface' used in earlier systems. [Ref. 31] A multi-tasking interface may increase station utilization by moving many UUT setup and teardown functions from internal (performed with the station idle) to external, which may keep the station engaged in actual testing for more of its available operating time.

This multi-tasking capability may be illustrated by considering a CASS station with three UUTs to be run. The operator sets up the first UUT and starts its testing, then enters data for the next UUT. While performing the first test, the station prepares for the second by calling down the TPS software and maintenance publications from its own memory or that of another CASS station in the local area network (LAN). As soon as the first test is complete, it is physically disconnected and the second UUT is connected and the test is started. The IMOM system automatically collects and stores test data on the first UUT, which the operator can then enter on the paper maintenance action form, type it into the NALCOMIS terminal, or uplink it in electronic form to NALCOMIS.

While performing these tasks, the station can prepare for testing the third UUT. When there are more than three UUTs to be run, the station and operator may engage in a continuous process of simultaneous pre-test, test and post-test operations. [Ref. 19]

While performing the testing and data management functions for the three UUTs, the computer may also be used for embedded training of technicians, self-calibration using built-in standards, and continuous, automatic self testing/diagnostics. Together, these automated systems are likely to reduce EMT by increasing operator efficiency and capability during testing.

Finally, the IMOMS and OMS systems together have the capability to make AIMDs of the future fully automated avionic repair facilities. If the OMS network of CASS stations is linked to a minicomputer in production control (either using NALCOMIS or a specialized ATE network computer able to provide software storage and a communication node), the ATE shop supervisor or production chief may determine in real time or by a report: [Ref. 19]

- The availability rate and fault/calibration status of every station and TPS.
- CASS station utilization rates, for use in distributing workload.
- The status of any in-work UUT.
- Details of repair actions, PRT and EMT of any UUT or type of UUT from a library of test logs within the OMS data base management system.
- Which stations are most efficient at running a particular type of UUT.

These management tools may substantially increase the efficiency and flexibility of CASS production managers in responding to increased operating tempo or to unexpectedly large volumes of UUTs inducted into some shops (while leaving others idle). In contrast to existing systems which have little such surge flexibility and consequently often have large backlogs and long TATs, the transportability of TPSs across a CASS network managed using the IMOMS and OMS systems allows workload to be evenly distributed and effectively controlled, minimizing logistic and administrative delays.

3. Supportability

Supportability is the degree to which an ATE system can be supported, in terms of characteristics of the prime test equipment, such as reliability and maintainability, and the effectiveness of the elements of its logistic support. [Ref. 34:p. 16] Because the majority of the problems identified in the Marcy Report concern supportability issues, supportability became a cornerstone of CASS. The first Navy ATE system to fully benefit from the Logistic Support Analysis (LSA) process, CASS was developed with heavy emphasis on both the iterative process of designing for supportability from the earliest stages of the program, and on delivery of total organic support by the IOC date. This section will evaluate the likely results of that emphasis in terms of reducing TAT.

ATE and TPS supportability affect repair TAT in two ways. First, the reliability and self-test capability designed into the ATE system affects EMT because, to complete a test, operators must fault isolate not only the UUT but any station and TPS failures that occur. Second, ATE reliability, maintainability and logistic support affect ATE system availability, which influences UUT backlog and the LDT portion of TAT. The following paragraphs analyze these two effects.

a. Supportability Effects on EMT

CASS may significantly reduce EMT in comparison to existing testers because of its continuous on-line self test capability. Members of the FOT have only off-line self test programs used during start-up or when a problem is suspected, and generally have limited TPS fault detection capability. The significance of this difference is clarified by recalling the description of current ATE/TPS troubleshooting practices presented in the last chapter.

When replacing an SRA does not fix a UUT failure identified by a test program, the operator must determine whether the problem is in the UUT (perhaps in the wiring rather than an SRA), the TPS or the ATE. Often this requires extensive manual troubleshooting which is very dependent upon availability of ATE and UUTs for substitution, operator skills and the adequacy of maintenance manuals. Increased reliability of ATE and TPS will reduce the frequency of this testing interruption while self-testing capability improvements may reduce their length.

An example of the impact of supportability factors on EMT is illustrated by Table IV, which shows that EMT increased for several high failure rate E-2C components when they were offloaded from VAST to RADCOM at NAS Norfolk AIMD. [Ref. 32] For example, EMT for the HARS-SDC (a signal data converter) tripled, increasing from 8.1 hours on VAST to 24.4 hours on RADCOM (three full shifts of station time).

Table IV. Comparison of VAST and RADCOM EMT.

WRA Nomenclature	VAST EMT Hrs	RADCOM EMT Hrs	Change Factor
MDU	5.4	7.5	1.4
HARS-SDC	8.1	24.4	3.0
UMD	2.1	11.4	5.4
ADC	5.5	9.8	1.8

Differences in test programs cannot account for the large increases in EMT because RADCOM TPSs are virtually identical to those for VAST. Nor are differences due to computer speed because, although PRT increased between VAST and RADCOM for some UUTs, these increases are measured in minutes while EMT increases are measured in hours. For example, the PRT of the E-2C main display unit (MDU) shown in Table III increased from 20 to 45 minutes when it transitioned from VAST to RADCOM support. (PRT did not increase by a consistent percentage for all UUTs, however.) [Ref. 32] Such PRT increases may have a multiplied effect on EMT when all or part of the program must be repeated several times during sequential replacement of SRAs. However, the single most important factor in the dramatic increases in EMT was lack of TPS supplementary data needed by the operator to discriminate between ATE, TPS and UUT faults, and then isolate and repair them. Such documentation was available for VAST TPSs but was not delivered for RADCOM TPSs until several years after their introduction to the fleet (after the data in Table III was collected). [Ref. 32]

CASS should have improved ability to discriminate between station, TPS and UUT faults, resulting in decreased EMT for the same UUTs. It is designed and warranted to continuously monitor station and TPS interface status and automatically indicate all faults to the operator, detecting 100% of the faults within five minutes and isolating them to a single CASS SRA within 15 minutes 95% of the time (as detailed in Chapter III). As soon as a CASS fault is detected that affects the particular test being performed, the operator may disconnect the set up and move to an 'up' station, with no additional on-line troubleshooting required.

However, TPS troubleshooting time has historically been a large contributor to EMT [Ref. 32], and may continue to be a problem using CASS, depending on the comprehensiveness of TPS self-test capability and supplementary data. CASS TPSs are likely to be more reliable and maintainable than existing TPS for the same UUT because all needed instruments are intended to be inside the station, enabling use of simple passive IDs, perhaps containing only a junction box and cables. But there are already many known exceptions to use of passive IDs. For example, CASS will require a 'power head' (an active ID with a high frequency signal processor) for UUTs needing radio frequencies above 40 Ghz because it was technically impractical to put these instruments in the station. [Ref. 35] Many digital WRAs will require IDs containing digital multiplexers while many electro-optical, pneumatic and radar UUTs will require IDs with liquid coolant and extensive mechanical devices. Designing comprehensive self-testing capability into such IDs may be prohibitively expensive.

Some individuals involved in TPS development believe that TPS performance, reliability and maintainability goals are not affordable for a large percentage of TPSs. [Ref. 31] NAVAIR considers TPS development an area of high risk which they are attempting to control through development of a standard TPS contracting vehicle to be used for each of the thousands of TPS to be developed. The technical approach to TPS acquisition now being considered by a 'Red Team' of NAVAIR and field activity personnel emphasizes performance specifications calling for 100% fault detection and isolation to an ambiguity group of six, 95% fault isolation to an ambiguity group of two, an MTBF of 2500 hours and MTTR of 60 minutes, plus a tradeoff analysis to optimize TPS cost, ID complexity and PRT. These goals have been achieved for already developed support of support (SOS) TPS for CASS station components. [Ref. 50]

Another critical factor affecting TPS reliability and maintainability is the way TPS developers deal with new instrumentation requirements for emerging weapon systems. If CASS does not contain all needed instruments, they may be added to the station through engineering change proposals (ECPs) or pre-planned product improvement (P^3)I, or they may be placed in active IDs for the UUTs that need the function. Many existing ATE systems have been upgraded to accept new testing requirements using active IDs rather than station modifications because it is often cheaper and more manageable in terms of configuration control. Similar reasoning by decision makers involved in CASS TPS development could lead eventually to fielding of many complex IDs to support new weapon systems.

Consideration of each of these factors leads to the conclusions that CASS station self-testing capability will tend to reduce EMT overall, but the EMT of each UUT will be highly dependent upon the tradeoffs made during TPS development between cost and TPS performance, reliability, maintainability and self-testability.

b. ATE Availability Effects on TAT

Operational availability (A_o) is the probability that a system, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. [Ref. 34:p. 65] ATE operational availability affects the LDT portion of TAT through its effect on backlog.

A study by the Center for Naval Analysis demonstrated this relationship between operational availability and TAT (given a constant number of ATE stations at a site) for four ATE stations: VAST, the Avionics Test Set (ATS), the Hybrid Test Set (HTS) and CAT IIID. The study compared the actual ATE availability and repair TAT achieved by these stations during a 1987 USS Constellation deployment to the TAT that would have been achieved given 100% ATE availability. The likely effects of 100% ATE availability on queue length and TAT were determined using a queuing simulation called the Aviation Logistics Model (ALM) developed by CNA. [Ref. 29]

The study found that the actual average TAT for VAST was 9.7 days, but fell to 7.1 days when the station was assumed to be always available. For ATS it fell from 4.8 days actual average TAT to 4.0 days assuming 100% availability. Using ASO manual rules, the shorter TAT reduced the cost of AVCAL spares allowances by 7.9% for VAST and 11% for ATS. TAT and sparing differences turned out to be slight for HTS and CAT IIID, probably because they had greater excess capacity than VAST and ATS and so were less sensitive to changes in availability.

It is important to note that even very low levels of ATE availability may have little effect on TAT if a site has sufficient stations to compensate for it. For this reason, if all else is held constant, improving ATE A_o will either reduce the number of stations required or reduce TAT, as in the above study. (The workload model used to compute station requirements at a site based on a given A_o and other key input variables is considered in the next section.)

To make comparison of A_o for CASS and FOT meaningful, common assumptions and methodology must be used in the A_o calculation. The following paragraphs establish this common base and then compare the computed values of A_o for CASS versus three members of the FOT.

A critical assumption in calculating A_o is what constitutes a 'down' station. The CNA study reported above avoided this definition problem by using documented downtime of individual components of each station rather than A_o of the entire station. Different UUTs require different station 'building blocks;' some components are core requirements needed for testing all UUTs, but others are required for only a few UUTs. A further complication is that a station component may be partially down, but can still be used to test a subset of UUTs.

To overcome these problems, the CASS development specification for A_o is based on the assumption that any failure downs the entire station. Much less conservative (and difficult to compare) assumptions are commonly used in calculating A_o for members of the FOT, resulting in published values close to 0.90. [Ref. 36] The 1984 NAVAIR methodology used for calculating the targeted CASS A_o was based on the standard Navy policy for calculating the A_o of weapon and support systems. [Ref. 37] It used the following equation: [Ref. 38]

$$A_o = \frac{MTBF * k}{(MTBF * k) + MDT_u}$$

$$\text{and } k = \frac{T_c}{T_o},$$

where T_c = Period of calendar time over which A_o of the system is to be measured;

T_o = Operating time of the system during T_c;

and MDT_u = Mean unscheduled downtime (ignoring scheduled maintenance);

= MTTR + MLDT + MDT_o;

MTTR = Mean time to repair;

MLDT = Mean logistic delay time;

MDT_o = Mean downtime for other delays (outside assistance, training, documentation, etc.).

CASS used 1984 VAST data as the baseline for estimating many of these values. The k factor is introduced in this methodology to convert MTBF (which assumes continuous operating time except during repair) into units of continuous elapsed calendar time (which includes those time periods when the system is not operating and, therefore, will not fail) so that all elements of the equation will be in common units. If the station is always in active use, k is equal to 1. However, when there are long periods of station inactivity (because the ATE shop does not work around the clock) k is greater than 1. It equals the ratio of T_c/T_o which represents the calendar time to operating time relationship over the long run to account for all active and inactive phases. [Ref. 37:p. A-13] The weighted average actual operating time (T_o) for all VAST sites in 1984 was 343.5 hours/station/month (out of 720 total calendar hours/month). The k factor for VAST (and assumed for CASS) is therefore:

$$k = \frac{T_c}{T_o} = \frac{720 \text{ hours/station/month}}{343.5 \text{ hours/station/month}} = 2.096.$$

MLDT for VAST was 80.9 hours. To account for the initial supply system learning curve that will probably increase the CASS MLDT, NAVAIR increased this value by 50%, to 120 hours.

The CASS reliability and maintainability specification values given in Chapter III are derived from inherent, or laboratory, values which were derated to reflect operational values expected to be achieved during initial fleet introduction. A reliability derating factor of 2.7 was chosen on the basis of a Rome Air Development Center study of avionic systems which determined the typical ratios of $MTBF_i/MTBF_o$ are between 2.5 and 2.7. MTTR was doubled to account for the initial maintenance learning curve. If the following terms are defined:

$MTBF_i$ = inherent MTBF;

$MTBF_o$ = operational MTBF;

$MTTR_i$ = inherent MTTR;

$MTTR_o$ = operational MTTR;

then

$$MTBF_o = \frac{MTBF_i}{2.7} = \frac{400 \text{ hours}}{2.7} = 148 \text{ hours};$$

$$MTTR_o = MTTR_i * 2 = 1 \text{ hour} * 2 = 2 \text{ hours}.$$

Using an assumed value for MDT_o of 10 hours, CASS A_o is calculated as follows:

$$A_o = \frac{MTBF * k}{(MTBF * k) + MTTR_o + MLDT + MDT_o}$$

$$= \frac{(148 * 2.096)}{(148 * 2.096) + 2 + 120 + 10} = 0.70.$$

Sensitivity analysis demonstrated that the three principal drivers of A_o are T_o, MLDT and MTBF; a 10% change in any of one these parameters (up or down) results in only a 3% change in A_o. This is an indication of the sensitivity of the results to errors in estimating the input values. It is notable that A_o is not overly sensitive to small errors in individual input values, but even small errors in multiple input values are cumulative and can strongly affect the A_o prediction.

NAVAIR lowered the contractual value for A_o from 0.70 to 0.68 because the latter is the CNO goal for weapon system availability. To provide adequate support for these weapon systems CASS should be able to achieve at least this level of availability. [Ref. 39]

Table V shows the estimated A_o and its components for CASS VAST, CAT IIID and RADCOM calculated using the above methodology. A value for k of 2.096 and MDT_o of 10 hours was assumed for all four ATE systems. All other FOT input data was obtained from the Naval Air Engineering Center which compiled it by validating and cleaning up the notoriously inaccurate 3M data base. They used a representative sample of stations from sea and shore sites, including 31 VAST stations, 16 RADCOMs, and 19 CAT IIIDs, for the period April 1985 to February 1990. (Note that the data for VAST in Table V differs from the 1984 VAST data used in the above analysis.) [Ref. 40]

Table V. Comparison of A_o for CASS vs Members of the Family of Testers.

Parameter	VAST	CAT IIID	RADCOM	CASS
MTBF	122	457	341	148
MTTR	1.782	6.92	7.917	2.0
MLDT	200	655	744	120
MDT_O	10	10	10	10
A_o	.547	.588	.484	.70

(All times are given in hours)

The comparison indicates that if NAVAIR assumptions are correct, upon initial fleet introduction CASS may be less reliable than RADCOM and CAT IIID, but more reliable than VAST (indicated by MTBF for each system). Its reliability is expected to grow during its initial 'burn-in' period, however. CASS may be far more maintainable than RADCOM and CAT IIID and about the same as VAST (indicated by MTTR). Overall, CASS A_o is significantly higher than the A_o of the three FOT stations, given the assumptions discussed above.

The CASS assumption for MLDT of 120 hours is most open to challenge. It is much lower than the MLDT for any of the FOT systems, even though CASS must use the same supply system and faces many of the same logistic delays. If the CAT IIID MLDT value of 655 hours is substituted in the equation for the assumed CASS MLDT of 120 hours, CASS A_o drops from 0.70 to 0.317. Even using the current VAST MLDT (which at 200 hours is significantly better than CAT IIID MLDT) the CASS A_o would be 0.59, which is only a slightly higher value for A_o than the three FOT systems. The conclusion drawn from this comparison is that CASS availability will not be better than the availability of existing ATE unless its MLDT is significantly lower than that of the three FOT systems.

c. *Influences on ATE Supportability*

RADCOM and CAT IIID have much higher MTTR and MLDT than VAST because changes in the architecture of these newer testers limit their ability to be organically repaired and spares allowances have not adequately covered the long TAT for commercial depot repair.

The architectural approach used in most ATE developed since VAST employs predominately off-the-shelf (non-developmental) hardware to 'rack and stack' the needed functional components. As much as 80% of the circuitry is typically made up of embedded commercial test equipment (CTE). Testers may be assembled from different combinations of about 40 standard commercial instruments (such as RF generators, vector voltmeters and signal analyzers) to provide input signals and response measurement. These are joined with a station computer, software and a small set of contractor developed equipment (CDE) to provide power and functions such as interface with the ID and the operator. [Ref. 13:p. 5-6]

The advantages of an ATE acquisition strategy emphasizing CTE are that it is the fastest way to build test equipment and it has low up front costs and technical/schedule risks compared to using CDE as was the case in the older VAST. Most CTE have proven high levels of reliability in commercial applications and most have performed similarly well in ATE, as reflected in the relatively high levels of reliability of RADCOM and CAT IIID shown above.

This acquisition strategy causes many supportability problems, however, including reliance on primarily non-organic depot maintenance and short obsolescence cycles. The phased support concept has also induced supportability problems during introduction of new ATE. The following paragraphs explain these problems and compare the alternative approaches used in CASS development.

Intermediate level maintenance support for testers employing CTE is very limited because NAVAIR policy restricts maintenance of all embedded CTE to depot repair activities. This decision was made in 1987 in an effort to improve configuration control of commercial instruments. CTE manufacturers continually update their products by discontinuing product lines (and their repair parts) and by making frequent design changes in current production instruments to improve them and keep up with state of the art. While many companies such as Hewlett Packard (used extensively in ATE) pledge to support their product for seven years, it is nonetheless difficult for Navy repair sites to maintain the right spare parts and publications, especially at intermediate level. [Ref. 41]

Despite this policy, experienced I level maintenance technicians or technical representatives often perform needed repairs to CTE. When they cannot, technicians must ship the CTE to the depot even when only minor adjustments are required. This has seriously affected RADCOM and CAT IIID MLDT and availability. Due to a commercial depot repair backlog approaching two years for the CTE in these testers, there were over 600 parts awaiting induction by Grumman as of 23 January 1990. [Ref. 42] Of these, 119 were holding stations down. Much of this delay arose during the transition from prime contractor support by Grumman to Navy support after MSD in 1988, which occurred without adequate spares on hand to meet the demand. A snapshot of the resulting Atlantic fleet ATE status on 26 January 1990 reveals that 9 of 25 RADCOM stations and 8 of 27 CAT IIID stations were down for parts ordered from off the ship or station. With one third of fleet RADCOM/CAT IIID assets typically down (as on this day), type commanders have kept deployed carrier ATE stations up by cannibalizing station parts from shore AIMDs and pierside carriers. [Ref. 43]

The short obsolescence cycles of CTE (averaging seven to fourteen years) also creates ATE supportability problems. Because the government generally does not buy level III engineering drawings for these instruments, spare parts procurement becomes costly after the contractor stops supporting them. For example, 29 repairable RADCOM circuit cards made by HP are currently obsolete and must be reprocured in FY-91 from other sources using inadequate level II drawings. These parts will require significant reverse engineering to attain the same form, fit and function as the original parts. The redesign may also significantly change their repair processes. [Ref. 44]

Use of phased support plans is at the root of many supportability problems associated with the introduction of new ATE systems. For example, the RADCOM IOC date was September 1982 and the introduction is now almost complete, yet many RADCOM publications were not ordered from Grumman until 1986 and many have not been delivered. [Ref. 44] Maintenance Assist Modules (MAMS) needed for station troubleshooting were not delivered until 1988. Many operator and maintainer courses were overloaded until 1989 so, until recently, less than half of the RADCOM operators at many shore sites were formally trained. Sea and shore AIMDs experienced significant problems supporting their stations (reflected in the MTTR, MLDT and A_o data above) during the several years' wait for the logistic 'tail' to catch up.

The negative consequences of a phased support concept include: [Ref. 11]

- ATE systems must often be nurtured and micro-managed until all logistic elements are in place.
- Support of ATE cannot be tested during development, so poor design for logistic supportability may be discovered only by fleet users.
- Few incentives exist for the contractor to design for minimum life cycle cost and adequately perform logistic support analysis (LSA).
- Few incentives exist to pay for a logistic support tail once a system is operating because ATE deficiencies can be compensated for by higher expenditures for weapon system spares and depot repairs (which may increase total life cycle costs).

CASS is likely to eliminate most of these supportability problems affecting existing ATE systems for a number of reasons. Most importantly, CASS will have no phased support. All logistic elements including spares are under development concurrently with the prime equipment, will be provided organically, will be delivered up front, and will be tested during TECHEVAL and OPEVAL. Second, maintainability will be improved by the high degree of commonality between tester configurations and by the 'function on a card' approach that eliminates most CTE instruments. It should have faster repairs due to its extensive self-testability, modularity, automated technical information system and embedded training capability. The MTTR is warranted not to exceed 2.0 hours, compared to the 6.9 and 7.8 hours for CAT IIID and RADCOM. It has a power conditioning system and battery backup sufficient to overcome many of the reliability problems experienced by current testers due to power transients.

There are, however, several areas of technical risk that could impact supportability. Perhaps the most significant is the high forced air cooling requirement of CASS which exceeds the current capabilities of carriers to provide. An adequate and reliable cooling system is of vital importance to ensure CASS is more supportable than existing systems. The current plan to solve this problem is to deliver a portable air chiller along with each CASS station. This chiller will require a water line, power and an additional four square feet of deck space. [Ref. 35] The supportability issues are, first, that the chiller must also have organic logistic support, and second, that because it will form a series system with CASS it will reduce total reliability of the test system by a factor equal to the chiller's reliability. The chiller may be more reliable than facility air conditioning on which ATE now depends, but it is sure to increase CASS' demand for electrical power which is constrained by the inability of ships to meet ever growing requirements. The significance of these power and air problems is illustrated by a recent Coral Sea cruise in which RADCOM technicians reported an average of 1.6 hours down each day due to facility power and cooling problems. [Ref. 45]

In the event that CASS overheats, among the first components likely to be damaged is the RF subsystem, which contains the few items of CTE in CASS (other than the VAX computer). They will not be organically supported, and the government has no level III drawings. They are an improvement over present CTE in terms of supportability, however, because they are modular cards rather than complete instruments and the manufacturer (HP) has contracted to provide support for 20 years. [Ref. 35]

The key to reducing MLDT from the 600+ hours experienced by RADCOM and CAT IIID to the 120 hours targeted for CASS is to have up front delivery of organic intermediate and depot level support. This will significantly reduce the repair TAT of CASS SRAs in comparison to the TAT of SRAs for non-organically supported testers. Adequate spares must also be stocked. To achieve the CASS goal for A_o of 0.68, NAVAIR has therefore set the policy that A_o will drive CASS SRA sparing. The Aviation Supply Office (ASO) will use a 'readiness based sparing model' known as 'ARROWS' to compute AVCAL/SHORECAL allowances for a site. CASS is the first support equipment system to use this model (until now ARROWS has been used only for weapon systems). If it works as intended, sufficient spares will be stocked to achieve the targeted A_o value of 0.68 given CASS' forecast reliability. [Ref. 39]

A fundamental problem remains unsolved, however, because there is still no adequate measure of availability that accounts for partially capable CASS stations that can test some UUTs and not others. Achieving an A_o of 0.68 does not mean the station has a 68% probability of being able to perform satisfactorily when called upon. Because NAVAIR assumes that any fault (however minor) downs the station, its probability of being able to perform satisfactorily (able to test some but not all UUTs) may be considerably higher than its measured value of A_o.

4. Workload Analysis

The number and type of ATE stations delivered to a site are the final key determinate of TAT. Providing too few ATE stations to a site results in unplanned levels of backlog (which is a principal cause of weapon system LDT) and drives up AVCAL/SHORECAL allowances. An accurate workload model, on the other hand, facilitates tradeoff analysis between cost of ATE and cost of weapon system spares to achieve a given level of customer service and enables decision makers to compensate for low ATE A_o or long EMT of individual UUTs.

Inputs which must be considered in workload analysis include:

- UUT induction rates;
- EMT of each UUT;
- Facility operating hours;
- Station A_o;
- Desired ATE utilization rate;
- Desired level of customer service;
- Queue discipline;

To adequately account for these factors in determining the correct number of stations to install at a site, a queuing simulation should be used. The CASS System Synthesis Model (SSM) contains such a model (as discussed in Chapter III) but it is still under development. Once accepted by the government from GE it will be used to compute CASS station requirements at each site. Station requirements up until now have been computed with a linear algebraic workload model which uses average values for inherently random parameters such as EMT and UUT inductions. It attempts to account for the effects on a repair queue of random surges in UUT inductions and variations in EMT by setting the CASS station utilization to some value less than one. [Ref. 46] A similar model has been used for determining requirements for earlier ATE systems without benefit of a far more accurate queuing simulation (as CASS should eventually have). As a result, too few ATE stations have been procured for many members of the FOT to achieve the desired level of customer service or minimize total weapon system support costs. The early problems with VAST workload are a typical example of this, as discussed in the summary of ATE evolution in Chapter II. RADCOM is another example, as will be demonstrated below.

This section compares two studies of RADCOM workload to illustrate the effects of different assumptions and input values on the linear algebraic model's calculation of the number of stations required. It also indicates the degree of risk the CASS introduction team faces as they forecast CASS station requirements using this model and predicted input values. The CASS SSM model is reviewed in more detail at the end of this section.

The basic linear algebraic model used for RADCOM workload analysis is as follows:

$$\text{Stations required} = \frac{\text{TOT WKLD HRS REQ}}{\text{StAV}};$$

TOT WKLD HRS REQ = WKLD/M summed over all UUT_j in each $aircraft_i$ for each site;

$$WKLD/M_{ij} = PFH/M_i * WKLD/FLTH_{ij};$$

$$StAV = SLF * A_o * HRWD * DPM;$$

where

TOT WKLD HRS REQ = Total expected workload hours required per month for the site;

$WKLD/M_{ij}$ = Expected workload/month for the i^{th} aircraft and the j^{th} UUT;

PFH/M_i = Peak flight hours/month (highest flight hours expected in any month) for the i^{th} aircraft;

$WKLD/FLTH_{ij}$ = Total expected workload/flight hour for the i^{th} aircraft and j^{th} UUT;

StAV = Station availability;

SLF = Surge loading factor;

HRWD = Hours of work/day;

DPM = Days/month.

WKLD/FLTH is a unitless value calculated as the sum of EMT/MTBF for each UUT_j in each $aircraft_i$ to be tested on the ATE system. For example, the radar data converter for the A-6E aircraft has an MTBF of 39 hours and EMT of 4.19 hours. WKLD/FLTH for this WRA is thus 4.19/39, or 0.10743. [Ref. 47] This value is computed for the remained ATE-supported A-6E UUTs to obtain a total A-6E WKLD/FLTH. This is added to the totals computed similarly for the other aircraft types to obtain the overall WKLD/FLTH for the site.

The surge loading factor is equivalent to the desired station utilization rate. It is less than 1.0 to protect against surges in operating tempo and the effects of randomness in the distributions of inductions and EMT which could cause undesired levels of backlog if a station is loaded to full capacity.

This model was used in RADCOM workload studies conducted by the Pacific Missile Test Center (PMTC) [Ref. 47] and by Grumman Aerospace Corporation (under NAVAIR contract). [Ref. 48] It is also the basis for the workload module of the CASS SSM developed for NAVAIR by General Electric. Although the three organizations called some of the variables by different names, the models they used are all essentially as shown above (which is based on the PMTC study). The following paragraphs compare the results and input values of the 1985 Grumman study (which considered E-2C RADCOM support requirements) and the 1989 PMTC study of the full RADCOM workload.

The Grumman study underestimated EMT and overestimated station A_o in predicting site requirements for RADCOM stations to support the E-2C. PMTC determined that 150 RADCOM stations are needed Navy wide, compared to the 122 that were procured based on this Grumman analysis (as well as other similar Grumman studies of RADCOM quantities needed to support the A-6E and EA-6B). Even before the PMTC study, NAVAIR (AIR-552) recognized that the first calculation of site requirements was too low and in 1986 delivered an extra station for many sea and shore AIMDs. [Ref. 43] In 1988 COMNAVAIRLANT and COMNAVAIRPAC urged that quantities be further increased above planned deliveries in order to reduce backlog, recommending quantities at major sea and shore AIMDs very close to PMTC's later calculations. [Ref. 43]

Grumman determined the values of EMT for each UUT based on 1981-1982 3M data compiled very early in the RADCOM program. EMT for new UUTs never before supported were based on estimates by systems engineers, using the relative complexity of components and comparisons to similar systems. The EMT values for UUTs offloaded from VAST were reduced by 20% based on the expectation that RADCOM would reduce VAST EMT by that amount (an expectation which was not realized, as shown by the comparison of VAST and RADCOM EMT earlier in this chapter). From these EMT values the study calculated a mean station workload/flight hour (WKLD/FLTH) of 0.619 using the method shown above.

PMTC recalculated this value and found it to be 0.99884 after RADCOM had been in the fleet for several years and more accurate and complete 3M data on EMT was available. The increase in station WKLD/FLTH, with everything else held constant, results in a 61% increase in RADCOM station requirements to support the E-2C aircraft.

The Grumman overestimate of RADCOM A_o (contained in the denominator of the above equation) appears in a factor they called "workload efficiency," which is equivalent to the portion of the model PMTC labeled "A_o * SLF." Whereas Grumman used 0.8 for this value, PMTC calculated the value based on a more complex analysis which used the values of A_o and SLF for various types of sites. These values are shown in Table VI.

The A_o values of 0.746, 0.777 and .842 for carriers, shore AIMDs and depots, respectively, were computed from 3M data. The SLF values were derived from a multiple server queuing model that attempted to account for the varying levels of surge protection needed at sites with different numbers of ATE stations to achieve the same level of customer service. Queuing theory predicts that at a site with two stations, UUTs will have a significantly lower waiting time to be serviced than if there is one station, while each additional station installed at the site reduces waiting time by an ever decreasing amount. PMTC made a 'first pass' estimate of station requirements for each site and used these values in the queuing analysis to compute the SLF. For example, large shore AIMDs (such as AIMD Oceana) which are assumed to need four RADCOM stations have an SLF equal to 0.78. Shore AIMDs assumed to need only two stations to support their smaller workload need greater surge protection; their SLF therefore drops to 0.72. The workload efficiency for a large shore AIMD is thus computed as:

Table VI. PMTC Calculation of RADCOM Workload Efficiency.

Type of Site	Station Qty	A_o	SLF (from Station Qty)	Workload Efficiency (A_o * SLF)
Carrier AIMD	4	.746	.78	.58
Shore AIMD	4	.777	.78	.56
Shore AIMD	1	.777	.62	.48
Depot	2	.842	.72	.61
Depot	1	.842	.62	.52

$$\text{Workload Efficiency} = A_o * SLF$$
$$= 0.777 * 0.78 = 0.56.$$

The workload efficiency factor for the other types of sites were computed similarly. This process is iterative because the quantity of stations finally calculated using the model must be the same as the first pass estimate that feeds into it.

It is not at all clear what the 'correct' value is for A_o given the difficulties in defining its meaning, but the PMTC results (based on the higher EMT and lower values for A_o * SLF) come nearer to reflecting actual station quantity requirements. The model is very sensitive not only to errors in predicting values such as A_o and EMT, but to assumptions concerning the surge loading factor and number of hours worked per day. When PMTC recalculated total station requirements using a surge loading factor of 1.0 (100% utilization) for all sites, total RADCOM station requirements dropped from 150 to 125. This quantity is not significantly higher than the 122 that were actually procured. Station requirements dropped from 150 to 127 when PMTC assumed that all AIMDs work 24 hours per day rather than the more typical 16 hour workday ashore and 24 hour workday at sea.

The Naval Air Engineering Center, which manages the CASS SSM model, confirmed the sensitivity of their version of the model to EMT, A_o and surge loading factor. They ran a sensitivity analysis of the workload model of the CASS SSM at the author's request for this thesis research, using assumed input values and six hypothetical UUTs. The results show that doubling the average EMT doubles the quantity of stations required at a site. An 18% decrease in either A_o or the surge loading factor (which the SSM calls "desired station utilization") produce 18% increases in the number of stations required. Thus it is simple to predict changes in this algebraic model output as inputs are varied because they are linearly related. They are not so simply related in a queuing model. [Ref. 49]

These relationships demonstrate the implications of errors in assumptions and predictions for the CASS introduction. If too few CASS stations are initially delivered to handle the assigned testing load, as occurred in both the RADCOM and VAST programs, the results may be unplanned backlogs, a reduction in the level of customer service provided by the AVCAL/SHORECAL (at least temporarily until allowances are raised), and a disruption of the introduction/transition schedule. [Ref. 50]

This schedule disruption may occur if, first, NAVAIR must redistribute CASS stations to increase their allowances at critical sites, or second, NAVAIR must retain FOT testers at some sites as backups to CASS even after their TPSs are offloaded. As an example of the latter response to overloaded ATE stations, the type commanders and A-6 Assistant Program Manager for Logistics (APML) decided to retain Mini-SACE stations (used to support the A-6E) aboard some carriers (such as Ranger) as backups after Mini-SACE UUTs were supposed to have completed transition to RADCOM because there are not enough RADCOMs in place to handle the full testing load. [Ref. 51] and [Ref. 52]

The task of estimating CASS station requirements is far more complex than the introduction of earlier ATE systems because the program has a significantly larger scope and because the high degree of commonality between CASS stations permits UUTs to be run on several different station configurations.

As noted in Chapter III, the SSM was developed to optimize the number and mix of stations at a particular site, using mapping, workload and simulation models. Figure 12 shows the process used for determining an optimized site profile using the model. [Ref. 46] The workload (as shown in the first block) is determined by first reading from a computer data base the weapon system complement of a site, the WRAs in each weapon system, and the SRAs in each WRA. Induction rates are calculated using the quantity and MTBF of each WRA/SRA and the appropriate weapon system planning documents (WSPDs) containing projected combat/peacetime operational hours per platform. The output of this process is the potential CASS workload at the site if it is able to test all WRAs/SRAs. The Mapping model is used to perform UUT-to-station mapping to indicate which UUTs may be tested by which station configurations (and also which UUTs cannot be tested by CASS).

The second and remaining steps shown in the figure are performed using the workload model in conjunction with a linear programming model that considers all possible UUT to station type assignments and minimizes the unconstrained objective function:

$$Z = \text{sum}\,(\text{rank}(i) * \text{quantity}(i));$$

where

i = index to each station type required;

rank = user specified desirability rank for each station configuration;

quantity = number of each station type.

The desirability rank is based on either the relative cost or space requirements of each station type. For example, the hybrid configuration is the cheapest and the smallest (because it has no sixth rack), so will have the highest rank (smallest number). The requirements of a specific site will dictate whether space or cost is the most important ranking criterion.

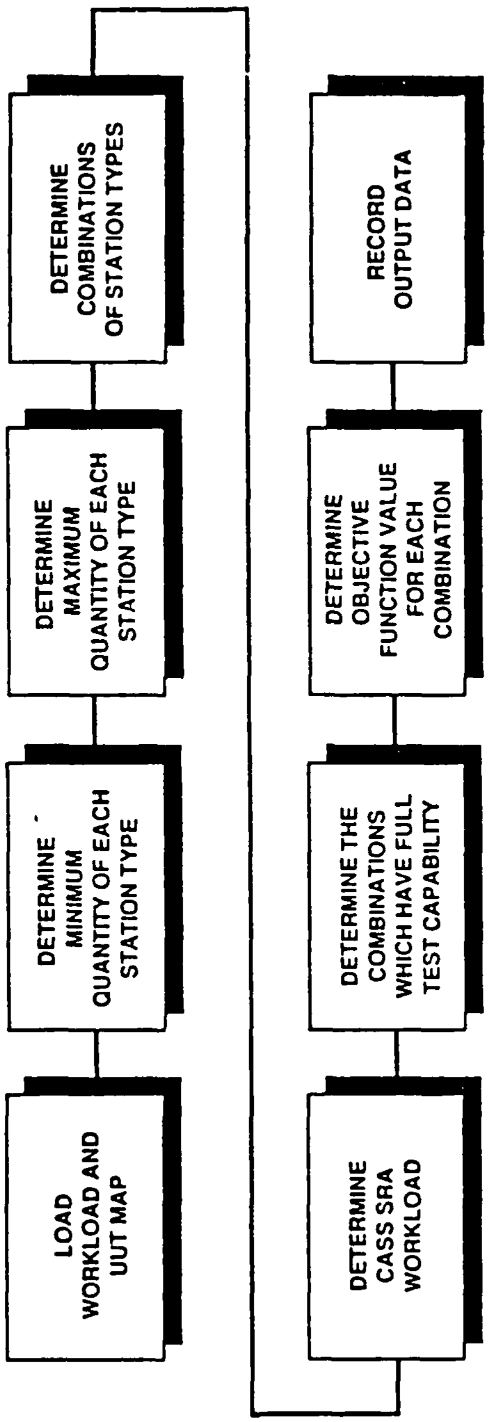

Figure 12. Process for Determining an Optimized Site Profile of CASS Stations Using the System Synthesis Model (SSM).

The minimum quantity of each type required at a site (shown in the second block of the figure) is computed using the workload model. Inputs include the A_o and desired utilization for each station configuration plus the induction rates and EMT of all UUTs which can be tested on that station type only. The maximum number of each station type (shown in the third block) is computed similarly, but considers the induction rates and EMT of all UUTs that may feasibly be tested on that station type. Table VII is a hypothetical example of minimum and maximum UUT maps showing three CASS configurations with different sets of UUTs that may be mapped to them. For example, the CNI station is the only configuration that will test UUTs 1, 2, and 7 (which sets minimum CNI station quantities) but it will also test UUTs 4, 5, 6, and 10 (which sets maximum CNI station quantities if these UUTs are included in its workload). The actual number of CNI stations placed at a site will be some quantity between these values determined by the linear programming model.

Table VII. System Synthesis Model Mapping of UUTs to CASS Station Configurations

CASS Configuration	UUTs with a Single Station Map	Total UUTs Mapped to Each Station
CNI	1,2,7	1,2,4,5,6,7,10
Radar	3,8	3,4,6,8,10
DDS	9	5,6,9

All possible combinations, or profiles, of station configurations are determined using this process, including their resulting CASS self-repair SRA inductions. Those profiles which cannot meet the total workload requirements (determined by the workload model) are eliminated from consideration. The linear programming model then calculates the objective function of each remaining profile, ranks them by their level of merit and prints them as the final output of the SSM. The profiles with the lowest level of merit (there will likely be ties) are optimal. [Ref. 46:p. 44]

The CASS SSM model is still under development and has not been used extensively for determining site requirements in the initial introduction plan. The queuing simulation model must ultimately be integrated with the mapping and LP models before site requirements can be determined with a high degree of confidence in the results. It will likely be used in place of the linear workload model for determining minimum, maximum and optimal station profiles following the process shown in Figure 12. The identities of UUTs to be tested on CASS at each site must also be determined, as well as accurate values for their EMT. The SSM may be used at the current stage of planning only for estimating gross station requirements suitable for scheduling funding requirements.

Until input data is more accurate and the simulation model is ready, NAVAIR is attempting to err on the side of scheduling too many stations at a site. Nevertheless, a low initial guess of station requirements made several years ago resulted in inclusion of too few stations in the Program Objectives Memorandum (POM) and a shortfall in station procurement funds through FY-94 totaling $543 million. [Ref. 50] To make up for it, NAVAIR is now considering several plans, including:

- Slipping the transition schedule of selected programs. Many programs that are critical to the introduction of CASS aboard CVs are protected from slippage, however, including the offload of existing testers such as VAST, AAM-60 and HATS (because they must be removed from CVs to make room for CASS), and emerging systems such as the F-14D and A-12. [Ref. 50]
- Creating a centralized test and integration facility (CTIF) located at one of the NADEPS, which TPS developers would use for the integration phase of development instead of using government furnished CASS stations in their own contractor facilities as originally planned. This is expected to produce a 20% savings in station quantity requirements, reducing TPS development stations from 51 to 41. [Ref. 53]

The planned operational testing of CASS and all CASS TPSs before fleet introduction is a critical step in minimizing risk in many aspects of the CASS introduction plan. TPSs have never before had thorough testing prior to their fleet introduction. [Ref. 25] As a result, fleet users have experienced many problems with the TPS for existing

ATE systems, such as problems with equipment supportability and software accuracy, and workload analysis has been conducted using inaccurate EMT and A_o values.

Workload analysis is, in the end, the deciding factor on whether or not the CASS program achieves its goal of 100% improvement in throughput. Decision makers may opt to abandon this goal, however, if the reduced cost of weapon system spares resulting from doubling throughput is less than the procurement and support costs of the CASS stations needed to achieve it. Such economic tradeoff analysis is beyond the scope of current detailed planning but should be a critical element of future CASS introduction planning.

It is important to note that CASS will not significantly improve weapon system readiness or availability even if it does improve throughput by 100%. In the long run, when ASO rules are used to compute spares allowances, all improvements in CASS TAT and supportability will be reflected in reduced requirements for weapon system spares. This reduction in spares will cancel out most improvements in customer support that result from the introduction of CASS. Because of its flexibility in spreading workload over many redundant CASS stations, CASS will, however, improve customer support when there are short run surges in UUT inductions at a site. Present ATE systems, with only a few stations of each type and no transportability of TPS, only build backlog.

C. PROPOSED METHODS FOR CALCULATING CASS AVAILABILITY

The previous section showed the importance of the measures of CASS availability for workload analysis and for determining CASS SRA spares allowances using a readiness based sparing model. Both of these requirements for measures of availability call for a site-wide computation of average availability. However, there are two significant problems with using the standard A_o formula for ATE in general and for CASS in particular. These problems are, first, the standard A_o formula fails to account for 'partially up' stations that can test some assigned UUTs but not others. If one assumes that any failure downs the station, the actual probability that CASS can perform its mission when called upon is underestimated. Second, the problem of measuring CASS availability is complicated by the commonality of CASS circuit cards across configurations and the transportability of CASS TPSs.

For example, assume that a CASS EO station has a fault in a 'core' circuit card that is not needed to test the EO UUTs (those that are mapped only to the EO configuration) but causes the station to lose its capability to test some UUTs normally run by the hybrid station. Should this degradation impact the EO station's measure of availability until it is repaired? If so, by how much? At what point is the station 'down': when the first UUT testing capability is lost, or only when there is no redundant capability at the site to test that UUT? Some UUTs will have many redundant CASS stations able to support them (so loss of capability in one station may not be a significant problem) while others will have few or none. Redundant capability among CASS stations causes many complex interactive effects on site-wide CASS availability that should be considered in workload analysis and sparing, but are not accounted for in a simple average A_o computation.

AIMD production managers and aircraft operational decision makers also need a more meaningful 'snapshot' measure of CASS availability than the standard A_o formula or than a simple labeling of stations as 'up' or 'down,' especially in situations that demand a realistic understanding of a ship or shore AIMD weapon system support posture. Managers will be concerned not only with the degree of redundancy if a station loses the capability to test a particular UUT, but with the expected induction rate of the UUT. From a readiness perspective, degradation or loss of capability to test a UUT with a high failure rate is of much greater concern than a UUT that is seldom inducted by the AIMD.

To better satisfy these diverse requirements for measuring CASS availability (for planning and for control purposes) the remainder of this section explains a proposal for alternate methods of computing CASS availability. The first part considers the problem of establishing adequate control measures of availability and the second part considers the problem of finding a planning measure useful for workload analysis and sparing. The CASS OMS system should be capable of providing input data for the calculations. These proposals are based on interviews with and notes from Professor T. P. Moore. [Ref. 54]

1. Measures of Effectiveness for Control Purposes

Two MOEs for management control are proposed. The first is a point availability measure labeled A_p. Its purpose is to provide a snapshot of the overall availability of the CASS station repair capacity (weighted by demand repair rates) at the shore or carrier AIMD. The purpose of the second, labeled A_M, is to provide a snapshot of the worst (minimum) UUT repair capability at the site to indentify where the most degraded capability lies.

a. Point Availability (A_p)

A_p is computed by the following equation:

$$A_p = \frac{\sum_{i=1}^{m} \frac{\lambda_i x_i}{n_i}}{\sum_{i=1}^{m} \lambda_i},$$

where:

λ_i = Failure rate of the i^{th} UUT for the given deckload and flying hour program;

x_i = Number of CASS stations able to repair the i^{th} UUT at the time of the snapshot;

n_i = Number of CASS stations able to repair the i^{th} UUT if all functions are 'up' on all stations that are supposed to have repair capability for this UUT (determined by the SSM mapping model);

m = Number of types of UUTs.

The value x_i/n_i represents, for the i^{th} UUT, the fraction of the AIMD's intended repair capability that is available. The λ_i's can be viewed as weights in the A_p computation (i.e., A_p is a weighted average of the x_i/n_i values). The sum of the λ_i's in the denominator is the normalization factor which makes the weights sum to 1. The weights give greater emphasis to the status of CASS repair capability for UUTs that fail more often.

Thus A_p is a function of the status of the CASS station functional capabilities, the aircraft deckload and the operating tempo.

b. Minimum Availability (A_M)

There are two approaches to this 'snapshot' measure. The first is to compute it as follows:

$$A_M = \min \{ \frac{x_1}{n_1}, \frac{x_2}{n_2}, \frac{x_3}{n_3}, \ldots \frac{x_m}{n_m} \}.$$

This simply identifies the UUT type with the worst case status in terms of the fraction of its intended CASS repair capability that is actually available.

The second approach is to combine the first idea with the 'importance' of the need to repair a UUT provided by the λ_i's. In this case, A_M is computed as follows:

$$A_M = \max \{ \lambda_i (1 - \frac{x_i}{n_i}) \mid \textit{for all } i = 1, \ldots, m \}.$$

Note that $(1 - x_i/n_i)$ is the unavailable fraction of the repair capacity for UUT_i. If duplicate TPSs for certain high failure rate UUTs are procured to enable simultaneous testing on multiple stations (one TPS per station able to support these UUTs), the fraction of failures of the i^{th} UUT that could not be repaired due to downed station capability is represented by $\lambda_i(1 - x_i/n_i)$.

c. *Example Computations*

Table VIII shows example λ's for three UUTs and the status of four CASS configurations used to test them. Shaded blocks represent lack of repair capability for a particular UUT as determined by the SSM mapping model. For example, station B is intended to have the capability to repair UUT 2 and 3 but not 1. 'Up' and 'down' indicate the actual functional status of the capability within a station at the time of the snapshot. For example, station C has a 'down' status for repair of UUT 1 caused (perhaps) by a failed circuit card that has not yet been removed and replaced. Given this information, A_p and A_M are computed as follows:

Table VIII. Example 'Snapshot' Data for Computing A_p and A_M

UUT	Sta A	Sta B	Sta C	Sta D	λ	x_i/n_i
1	UP		DOWN	UP	.002	2/3 = .6667
2		UP		DOWN	.005	1/2 = .5000
3	DOWN	UP	DOWN	DOWN	.003	1/4 = .2500

(Shaded blocks indicate no repair capability)

$$A_p = \frac{.002\ (.6667) + .005\ (.5000) + .003\ (.2500)}{.002 + .005 + .003} = .4583$$

A_M, using method 1, is

$$A_M = \min\ \{.6667,\ .5000,\ .2500\} = .2500.$$

UUT 3 has the minimum value of x_i/n_i and is thus the most critical one identified by this method.

A_M, using method 2, is

$$A_M = \max \{.002(1 - .6667), .005(1 - .5000), .003(1 - .2500)\}$$
$$= \max \{.6667, 2.500, 2.250)\} = 2.500.$$

UUT 2 has the maximum value and is thus the most critical one identified by this method.

2. Measures of Effectiveness for Planning Purposes

a. Average Availability (A_{avg})

The proposed MOE for planning such as workload analysis and sparing will be called A_{avg}. It is computed by the following series of equations:

$$A_{ij} = \frac{MTBF_{ij}}{MTBF_{ij} + MDT_{ij}},$$

where

A_{ij} = Operational availability of the capability to repair UUT_i on CASS $station_j$;

$MTBF_{ij}$ = Mean time between failure of the repair capability for UUT_i on CASS $station_j$;

MDT_{ij} = Mean downtime for the specific functional capability to repair UUT_i on CASS $station_j$;

Next, define a matrix,

$B = [b_{ij}]$,

where

$b_{ij} = A_{ij}$ if CASS $station_j$ is supposed to have capability (determined by the mapping model) to repair UUT_i;

$b_{ij} = 0$ otherwise.

and another matrix M,

$M = [m_{ij}]$,

where

$m_{ij} = 1$ if CASS $station_j$ is supposed to have capability to repair UUT_i;

$m_{ij} = 0$ otherwise.

The demand weighted average availability is then:

$$A_{avg} = \frac{\lambda \, B \, I}{\lambda \, M \, I},$$

where

λ = A vector of λ_i values;

λ B I = The weighted sum of the $\lambda_i A_{ij}$'s for all UUTs and CASS stations;

λ M I = The sum of $\lambda_i m_{ij}$ for all UUTs and CASS stations.

b. Example Computations

Table IX shows the three UUTs and four CASS stations presented above with values of A_{ij} for the capability to repair UUT_i using CASS $station_j$. Given the values of availability for each repair capability, the site-wide average availability (A_{avg}) is computed. Note also that average availability can be computed for an individual CASS station and for an individual UUT repair capability (across the CASS stations).

Site-wide average availability is:

$$A_{avg} = \frac{[.002\,(.74 + .81 + .70)] + [.005\,(.77 + .65)] + [.003\,(.67 + .75 + .69)]}{(.002 * 3) + (.005 * 2) + (.003 * 3)} = .72.$$

Table IX. Example Data for Computing Average Availabilty (A_{avg})

UUT	Sta A	Sta B	Sta C	Sta D	λ
1	.74		.81	.70	.002
2		.77		.65	.005
3	.67	.75	.69		.003

(Shaded blocks indicate no repair capability)

UUT average availabilities are:

$$A_{UUT\,1} = \frac{.74 + .81 + .70}{3} = .75;$$

$$A_{UUT\,2} = \frac{.77 + .65}{2} = .71;$$

$$A_{UUT\,3} = \frac{.67 + .75 + .69}{3} = .70.$$

CASS station average availabilities are:

$$A_{CASS\,A} = \frac{(.002 * .74) + (.003 * .67)}{.002 + .003} = .70;$$

$$A_{CASS\,B} = \frac{(.005 * .77) + (.003 * .75)}{.005 + .003} = .76;$$

$$A_{CASS\,C} = \frac{(.002 * .81) + (.003 * .69)}{.002 + .003} = .74;$$

$$A_{CASS\,D} = \frac{(.002 * .70) + (.005 * .65)}{.002 + .005} = .66.$$

D. EXPANDABILITY

The second criteria for evaluating CASS in comparison to existing ATE systems is its ability to accept emerging testing requirements without the need for major hardware and software changes. This expandability has become a critical requirement for CASS as a result of quantum leaps in the technology used in weapon systems now under development which have resulted in new frequencies, power levels and functional parameters that exceed current testing capabilities. Advanced technologies which CASS must support in the future include: [Ref. 13:p. 5-11]

- Digital technology using very high speed integrated circuits (VHSIC).
- Advanced electro-optic systems such as high energy CO_2 lasers and focal plane array technology.
- Millimeter wave technology for electronic warfare systems using very high frequencies.
- Advanced radar and data transmission systems using spread spectrum technology to achieve high frequencies and bandwiths.
- Fiber-optics interface systems that will replace existing data transmission cables.

Past ATE systems have not been able to expand to keep pace with changes in technology. The result has been obsolescence cycles of seven to fourteen years. The FOT was created to reduce the proliferation of testers, yet the inflexibility of these systems to accept new technology has resulted in the continued need for peculiar support equipment. The Navy ATE inventory today is a mixture of more than 300 PSE testers and 24 ATE systems. Whenever a new test requirement emerges, weapon system program managers look at the existing inventory and try to adapt an FOT tester to fit the need, either through station modifications or development of complex IDs that contain the missing instruments. If neither of these are feasible, NAVAIR buys another PSE tester. [Ref. 9]

A 1987 cost-benefit analysis conducted for NAVAIR by Prospective Computer Analysts (PCA) estimated the extent and cost of FOT modifications needed to accommodate projected requirements through the year 2010. It identified seven members of the FOT capable of receiving new instrumentation to provide the needed capabilities and eliminate most PSE. These include HTS, CAT IIID, RADCOM, RADCOM-Radar Interface Unit (RIU), EWTS, TMV and IMUTS II. The existing electro-optics tester cannot be modified to accept the new requirements and a new one will be needed. The conclusions of this study were that development and procurement costs of this 'augmented' FOT far exceeded the costs of CASS (to be discussed further in the next section) even though the FOT systems chosen are mature and would require only replacement of instruments. They would also require considerably more facility space; an average carrier would require 34 augmented FOT (AFOT) stations compared to 19 CASS stations. [Ref. 1:p. 5-5]

There are many factors which limit the growth capability of commercial test equipment (CTE) based testers. Among the most serious constraints are: [Ref. 55]

- Space: New instruments must fit physically into existing racks.
- Heat: New instruments must not exceed the existing air conditioning capacity of facilities.
- Speed: New instruments may drive changes in the ATE operating system, test executive or application software.
- Calibration: New instruments must not exceed existing calibration accuracy.

CASS must overcome these problems to achieve its goal of a 20-year life cycle and a halt in the proliferation of PSE. The CASS approach to these goals is termed "flexible and open-ended architecture" centering around the functions-on-a-circuit-card described in Chapter III. This approach is intended to enable adding functions to meet new testing requirements simply by inserting an additional card or replacing an existing one. Because CASS separates the hardware from the application software with intermediate microprocessor asset controllers, functions may change or move around within the tester without impact on the TPS and station computer software. Any change requires only a new address within the asset controller software. Functional assets may also be combined by the asset controllers to create large functional test suites of stimulus and response capabilities required for complex testing strategies. [Ref. 28:p. 2]

Armed for the first time with a test system capable of low cost expansion to meet new technologies, NAVAIR has established the policy that CASS will always be modified in response to emerging requirements rather than acquiring PSE. At least thirty months before a new testing capability is needed in the fleet, NAVAIR (AIR-552) will match the attributes of CASS to the technical test requirements of the new weapon system using the SSM mapping model. If the requirement cannot be matched to an existing CASS functional asset, one of two actions will be taken. If the test requirement falls within the scope of the CASS performance specification, an engineering change proposal (ECP) will be initiated using support equipment procurement funds. If the requirement falls outside the CASS scope, a change will be initiated under the preplanned product improvement (P^3I) program using R&D funds.

As site-specific testing requirements and workload change over time with the phase-in and phase-out of weapon systems, CASS stations will not only be modified to meet new functional requirements but will be reconfigured to maintain an optimal workload. For example, if a site has three hybrid testers and one EO tester and additional EO testing requirements emerges, one of the three hybrid testers could be reconfigured into a second EO tester by adding the needed circuit cards, EO rack and ancillary equipment. The new EO tester would be technically able to support the new requirement plus the full set of UUTs previously supported by the hybrid tester. [Ref. 28:p. 4] Through these approaches, CASS should hopefully be able to meet the challenge of new technology and remain the Navy's standard general purpose tester.

E. ATE SYSTEM LIFE CYCLE COSTS

The final criterion for evaluating CASS is the extent to which it reduces ATE system life cycle costs. For this criterion CASS must be compared, not to existing systems, but to an Augmented Family of Testers which is the only feasible alternative to CASS for the expected twenty year life of the program.

Table X presents the conclusions of the 1987 PCA cost-benefit analysis. [Ref. 1:p. 1-3] They determined that the 20 year costs of procuring an augmented FOT of eight testers, matched instrument-by-instrument to current CASS testing capabilities, would exceed the costs of CASS by $2,022 million.

Table X. 1987 Cost-Benefit Analysis of Procurement of CASS versus AFOT

Cost Catagory	Augmented FOT	CASS
ATE Development	227	164
ATE Production	3,777	1,178
TPS Procurement	8,291	9,202
Storage/Transport	367	96
Total	12,662	10,640

(Costs are in $ Millions)

This study ignored support costs, and considered only the costs of development and production of ATE stations and TPS plus storage and transportation during phase-in. It also computed relative cost, schedule and performance risks for each alternative, which it found to be roughly equivalent. Its most significant assumptions were:

- ATE station costs: CASS development and production costs are based on the FSED contract price. AFOT development and production costs are based on vendor catalogue costs for CTE and complexity factors and standard engineering labor hour costs for CDE.
- TPS procurement: Costs per UUT are equivalent for CASS and AFOT. Total CASS TPS costs exceed those of AFOT by $911 million due solely to the costs of transitioning existing testers to CASS.
- Workload analysis: The number of CASS stations required was based on the rough estimates computed by NAVAIR early in the full scale development phase. The number of AFOT stations was based on the current throughput and UUT load of the seven testers that would be augmented, assuming a proportional increase in stations required to support the added workload of UUTs from off-loaded testers and new weapon systems.
- Costs are computed in 1987 dollars with no discounting of future dollars to present values.

The overall effect of these assumptions is an underestimation of the cost advantages of CASS. TPS development and production costs for CASS will almost certainly be less than for development of the same TPS for augmented versions of existing testers because CASS will require fewer complex and costly IDs than would the less flexible augmented FOT. CASS TPS development tools (discussed in Chapter III) also offer cost advantages. NAVAIR has not quantified the resulting reduction in TPS development costs but considers it to be significant. The study also ignored the significant advantages of CASS compared to the FOT in such areas as TAT, supportability, flexibility, TPS transportability, and expandability, and assumed that a tester matched functionally to CASS is equivalent in performance. This is not a valid assumption, and results in further underestimation of the benefit/cost ratio of CASS. [Ref. 56]

NAVAIR also conducted a cost benefit analysis of CASS that includes many of the operation and support costs neglected in the PCA study. Table XI compares the February 1990 NAVAIR estimates of the 20 year life cycle costs of CASS versus a "future" FOT and PSE combination. [Ref. 57] This analysis estimated CASS life cycle costs to be $8,069 million less than the alternative.

Table XI. 1990 Life Cycle Cost Comparison for CASS versus a Future FOT

Cost Catagory	Future FOT	CASS
ATE Development	653	180
ATE Production	8,452	1,312
Operation/Support	2,066	1,440
P^3I	-	170
Total	11,171	3,102

(Costs are in $ Millions)

These estimates are in undiscounted 1989 dollars, and include all operation and support costs except manpower. The expected costs of CASS P^3I are also included. They do not, however, include the costs of TPS.

The 1987 PCA study estimated CASS development and production costs to be $2,662 million cheaper than AFOT, while the 1990 NAVAIR study estimated these CASS costs to be $7,613 million cheaper than a future FOT. The differences in their conclusions are due primarily to different assumptions regarding hardware requirements for the non-CASS alternative. Both analyses, however, agree that CASS is the cheaper alternative by a significant margin.

Because CASS is also cheaper in TPS and operation and support costs, it is clearly the least cost alternative for satisfying NAVAIR automatic testing needs throughout its life cycle.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

CASS will enter operational service in fleet AIMDs beginning in mid-1993. This thesis attempted to answer the questions most in the minds of fleet users who will have to live with CASS, for better or worse. Will it solve the host of ATE problems that currently plague the fleet? What is NAVAIR's strategy for solving them, and how does it differ from past strategies? Will CASS make a difference in terms of weapon system support?

To lay the groundwork for answering the research questions, the thesis introduced ATE by describing its place in the Naval avionics maintenance concept, ATE maintenance facilites and architecture. It then summarized ATE evolution to show the problems and initiatives that led up to CASS. It next described the CASS program goals, system, acquisition strategy and introduction plan. Because achieving these goals and solving current ATE problems are rooted in the avionics repair process, the thesis described this process and its relationship to weapon system support and spares allowances. Finally, the thesis evaluated CASS in comparison to the existing family of testers using three criteria: throughput, expandability and test equipment life cycle cost.

B. CONCLUSIONS

The primary conclusion of this analysis is that CASS is technically capable of achieving its program objectives and solving or alleviating virtually every significant problem faced by AIMDs in operating and supporting the current family of ATE. Its objectives are first, to improve throughput 100% in order to improve weapon system operational availability, readiness and capability to meet combat sortie requirements; and second, to standardize ATE hardware, software and support in order to reduce the cost of ownership of both avionic systems and support equipment. These objectives address the most significant ATE problems facing the fleet today: those related to ATE supportability and its affects on weapon system readiness and support costs.

The CASS acquisition strategy, support philosophy and equipment design are significant improvements over those of most existing ATE systems in terms of supportability and life cycle costs. CASS is a model development program in many respects. However, there are still many areas of risk remaining in the program. CASS' success in the fleet is critically dependent on decisions that will be made during TPS development and introduction planning. The areas of risk with the most damaging consequences are:

- Funding shortfalls for CASS station procurement or TPS development which may disrupt the sequence of introductions and transitions, result in less than optimal profiles of quantities versus configurations of CASS stations delivered to individual sites, result in less than optimal TPS fault isolation or maintainability performance, and lead ultimately to greater weapon system life cycle support costs. Slippages in the introduction and transition schedule are likely to result in increased interim support costs and cause a ripple effect in other programs. A one year slip in F-14D TPS development, for example, would increase F-14D support costs by *approximately $30 million and disrupt the carrier transition schedule.*
- Inaccurate workload analysis of site-specific station requirements. If this analysis results in delivery of too few CASS stations it may, like funding shortfalls, lead to weapon system supportability problems and higher than optimal weapon system support costs.

The following paragraphs summarize the conclusions of the study in greater detail with regard to the three evaluation criteria.

1. Throughput

As a result of a number of attributes, CASS is likely to substantially improve throughput in comparison to existing testers. CASS attributes which favorably influence throughput include use of a functional test strategy, expanded computer capabilities, and improved supportability. Use of a functional test strategy is likely to reduce TAT. BCM rate and cost of weapon system spares for at least some UUTs, especially for newer weapon systems having extensive BIT capability.

Advances in computer capabilities between the family of testers (FOT) and CASS may significantly reduce the relative time required for several testing and management functions. These capabilities include expanded computer processing power, which allows both faster testing and simultaneous performance of multiple tasks, and management tools such as the Operational Management System (OMS) and Intermediate Maintenance Operations Management System (IMOMS). Coupled with the transportability of many weapon system TPS between different CASS configurations, these management tools offer the capability to efficiently and flexibly manage a network of CASS stations. This flexible network is a key to minimizing backlog and improving weapon system support because it enables the CASS testing load to be evenly distributed across many avionics shops. Existing ATE systems have little such flexibility and redundant testing capability. As a result, they commonly build up backlog during periods of increased operating tempo or even due to random variations in induction rates.

Improvements in CASS supportability will work to increase throughput in two primary ways. First, better self-testability and maintainability will reduce elapsed maintenance time (EMT) because less time will be lost troubleshooting station and TPS faults during on-line UUT testing and repair. TPS maintainability is UUT specific, however, so it is still an unknown element (although NAVAIR has established tentative guidelines for TPS development which would lead to satisfactory levels of maintainability). It is a function primarily of the comprehensiveness of TPS self-testing capability (which improves maintainability) and the amount of active circuitry they contain (which reduces it). Because TPS maintainability affects throughput and weapon system spares costs, TPS development should seek an optimum (least total weapon system support cost) tradeoff between total TPS costs and total spares costs. This tradeoff must also be considered in any decision to develop active interconnection devices rather than modify the CASS stations to attain the capability to support new technology.

The second way that CASS supportability can increase throughput is by improving CASS station operational availability. The analysis did not provide an unequivocal answer on whether CASS will have a higher level of availability, however.

It is likely that CASS stations will be far more maintainable (measured by mean time to repair) than many existing testers such as RADCOM and CAT IIID because CASS minimizes the use of commercial test equipment and provides extensive self-testability, modularity and improved operator support aids such as an automatic technical information system (ATI) and embedded training. CASS may be less reliable than these same testers, at least upon initial fleet introduction, if its comparatively low mean time between failure assumptions are accurate. Its reliability is likely to grow during operational service, however, and should eventually match or exceed the reliability of existing testers. The CASS requirement for a portable chiller for station cooling may negatively impact its reliability.

The most significant factor affecting ATE operational availability is mean logistics delay time (MLDT). The conclusion of this analysis is that CASS will substantially improve MLDT in comparison to existing testers because it will have an organic repair capability and all logistic support will be delivered up front and tested during OPEVAL rather than phased in. Because of this, CASS operational availability will likely be higher than that of existing testers.

Given a particular value for CASS operational availability and the EMT of each UUT, workload analysis facilitates additional tradeoff decisions to achieve the optimal total weapon system support cost. Attaining the CASS program goal of a 100% increase in throughput may not be desirable because throughput is intimately related to many factors, including the number and cost of stations at a site, the cost of CASS SRA sparing, the cost of weapon system sparing and the cost of TPS procurement. The CASS System Synthesis Model (SSM) is under development to enable consideration of at least some of these many complex relationships in calculating optimal combinations of CASS stations at each site. Its use is hampered at the present stage of introduction planning, however, by the lack of solid data on TPS EMT, difficulty in calculating a value for CASS availability that accounts for partially capable stations and the interactive effects of redundant testers at a site, and the SSM's lack of a queuing simulation model for workload analysis. The linear programming model currently used in the place of such a simulation model is far less accurate and could lead to substantial errors in site planning, as has occurred in past ATE programs using such a model, and could result in many of the negative consequences highlighted at the start of this section. Operational testing of CASS and CASS TPSs will substantially reduce the risk in measuring these input parameters and is critical to the program's success.

2. Expandability

Expandability to accept emerging testing requirements is a critical requirement for CASS to be able meet the challenge of new technology and remain the Navy's standard tester throughout its intended 20 year life. The conclusion of this thesis is that CASS is clearly far more able than existing testers to keep pace with changes in technology. It achieves this expandability because it separates the hardware from the software and because of its flexible 'function-on-a-card' approach that enables functions to be added by inserting new cards or replacing existing cards. Rather than procuring a new tester, as has often been done in the past when a new testing requirement emerged, NAVAIR can initiate a change to the CASS station using the engineering change proposal (ECP) or preplanned product improvement (P^3I) processes. CASS stations can also be reconfigured from one functional type of station into another as site-specific testing requirements and workload change over time. These capabilities of functional expansion and reconfigurability should enable each AIMD site to maintain an optimal set of testers to minimize the total weapon system life cycle cost.

3. ATE Life Cycle Cost

Two studies were reviewed which showed that CASS has substantially lower 20-year life cycle costs than an upgraded FOT. A 1987 cost benefit analysis performed by Perspective Computer Analysts (PCA) compared CASS to an 'augmented' family of testers (AFOT) composed of seven existing testers plus a new electro-optical (EO) tester. These eight testers would take over virtually all avionics testing from the other common ATE and peculiar support equipment (PSE) and meet new technology requirements envisioned through the year 2011. The study found the cost of developing and producing such an AFOT would exceed the costs of CASS by $2,022 million. The study included the costs of TPS procurement, and found that CASS TPS would exceed the cost of the AFOT TPS by $911 million as a result of the requirement to transition many existing TPS to CASS support. The study assumed individual new CASS TPS development costs would be similar to typical costs for current TPS, which is probably an invalid assumption since CASS is intended to have less complex interconnection devices. As a result, new CASS TPS are likely to be substantially cheaper than would TPS for an AFOT (rather than more expensive as the PCA study concluded). The study did not consider operation and support costs.

The second cost benefit analysis, performed by NAVAIR, included operation and support costs (except manpower) but not TPS costs. It found CASS development and production costs to be $7,613 million cheaper than a 'future' FOT, and total 20-year life cycle costs to be $8,069 million cheaper than the alternative. Although the conclusions of the two studies differ in many cost categories as a result of differing assumptions, both agree that CASS is the cheaper alternative by a significant margin.

C. RECOMMENDATIONS

The following recommendations are made based on the above conclusions:

1. NAVAIR should continue to fund the CASS program at 100% of requirements to maintain the emerging introduction and transition schedule and the optimal (minimum weapon system support cost) level of TPS performance. The introduction plan should be developed and justified through rigorous economic cost analysis. Efforts to reduce current outlays by slipping the schedule or reducing TPS performance will most likely lead to far greater expenditures in the out years.

2. Expedite completion of development of a queuing simulation and integrate it into the System Synthesis Model (SSM) for determination of CASS station quantities/configurations to be delivered to each site. Expand the model (perhaps by modifying the existing linear programming portion of the workload model) to consider the full range of inter-related factors that should be traded off to optimize weapon system support costs at each site. Additional factors not presently

included in the SSM include the costs of procuring and holding weapon system spares, the costs of procuring multiple TPS for high failure rate UUTs, the costs of CASS spares and their effects on CASS availability, measures of CASS availability that account for partial capability and the interactive effects of redundant stations, variations in UUT inductions and the effects of multiple server queuing on EMT and TAT.

D. FOLLOW-ON RESEARCH

The thesis proposed new methods for calculating CASS availability for management control and introduction planning. Additional research is needed, ideally by the Naval Air Engineering Center since they maintain the SSM, to validate the usefulness of these measures for solving some of the current problems involved in using measures of CASS operational availability (A_o) for sparing and workload analysis. If these measures are found to be useful, research is also needed to validate the ability of the IMOMS/OMS systems to collect the necessary data. If their ability is found to be inadequate, these systems should be modified.

APPENDIX A: CASS INTRODUCTION AND TRANSITION SCHEDULE FOR FISCAL YEARS 1990-1999

This appendix presents the current schedule for introduction of new weapons systems to CASS support and transition of existing ATE systems to CASS. It is taken from a May 1990 unpublished draft version of the *CASS Introduction Plan* prepared by the Naval Air Engineering Center for NAVAIR. [Ref. 57] Weapon and test systems are listed in alphabetical order. The shaded areas represent periods of interim support required prior to availability of CASS stations and TPS to support a particular weapon system. Split bars indicate a period of dual CASS and interim support. Various notations indicate the type of weapon system interim support that is planned, such as contractor warrantees, commercial factory test equipment (FTE) or 'repair of repairables' (ROR), organic depot support, existing PSE testers or existing ATE systems such as the RADCOM, CAT IIID or ASM-614.

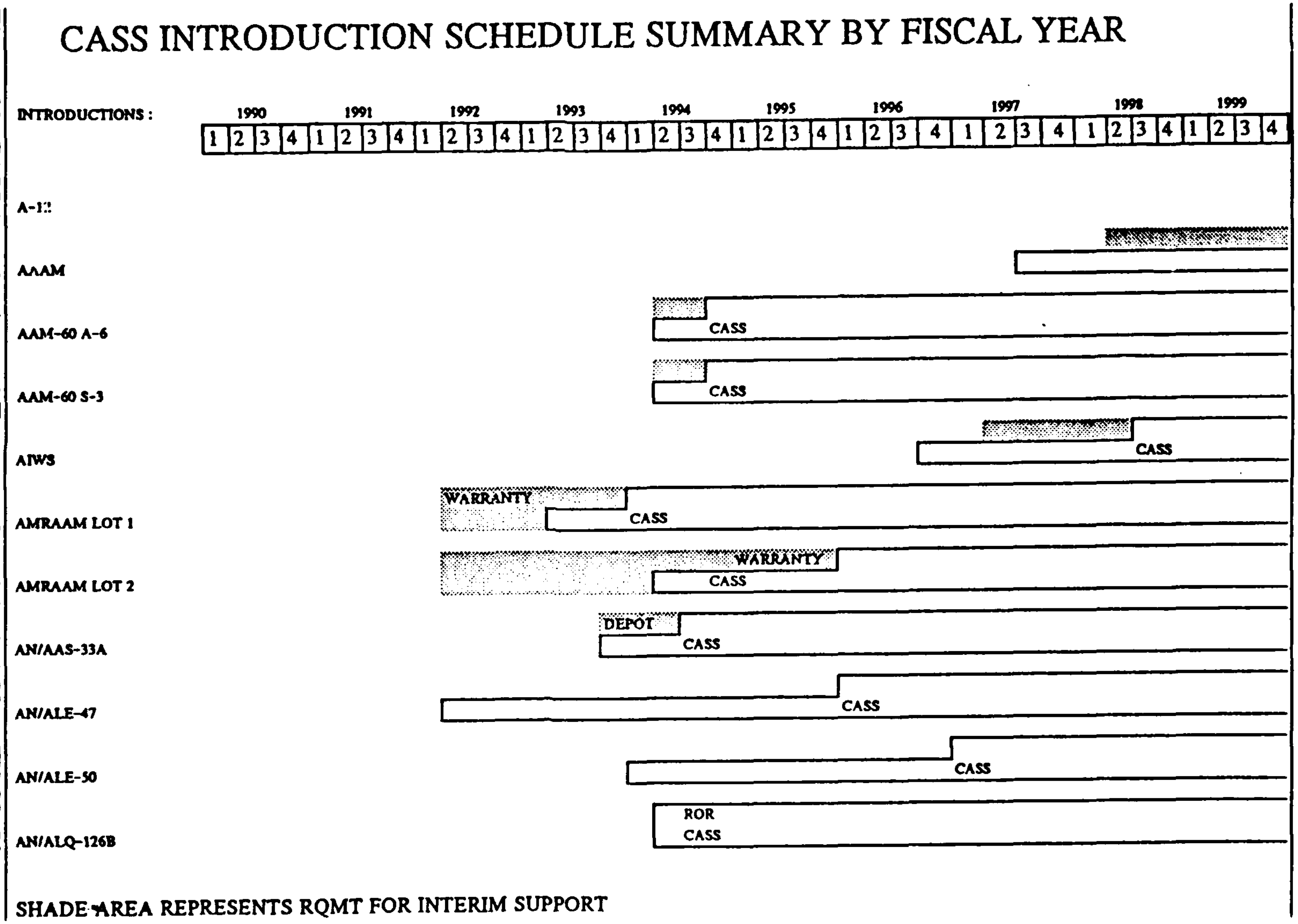

Figure 13. CASS Introduction and Transition Schedule, FY-90 to FY-99, Plate A

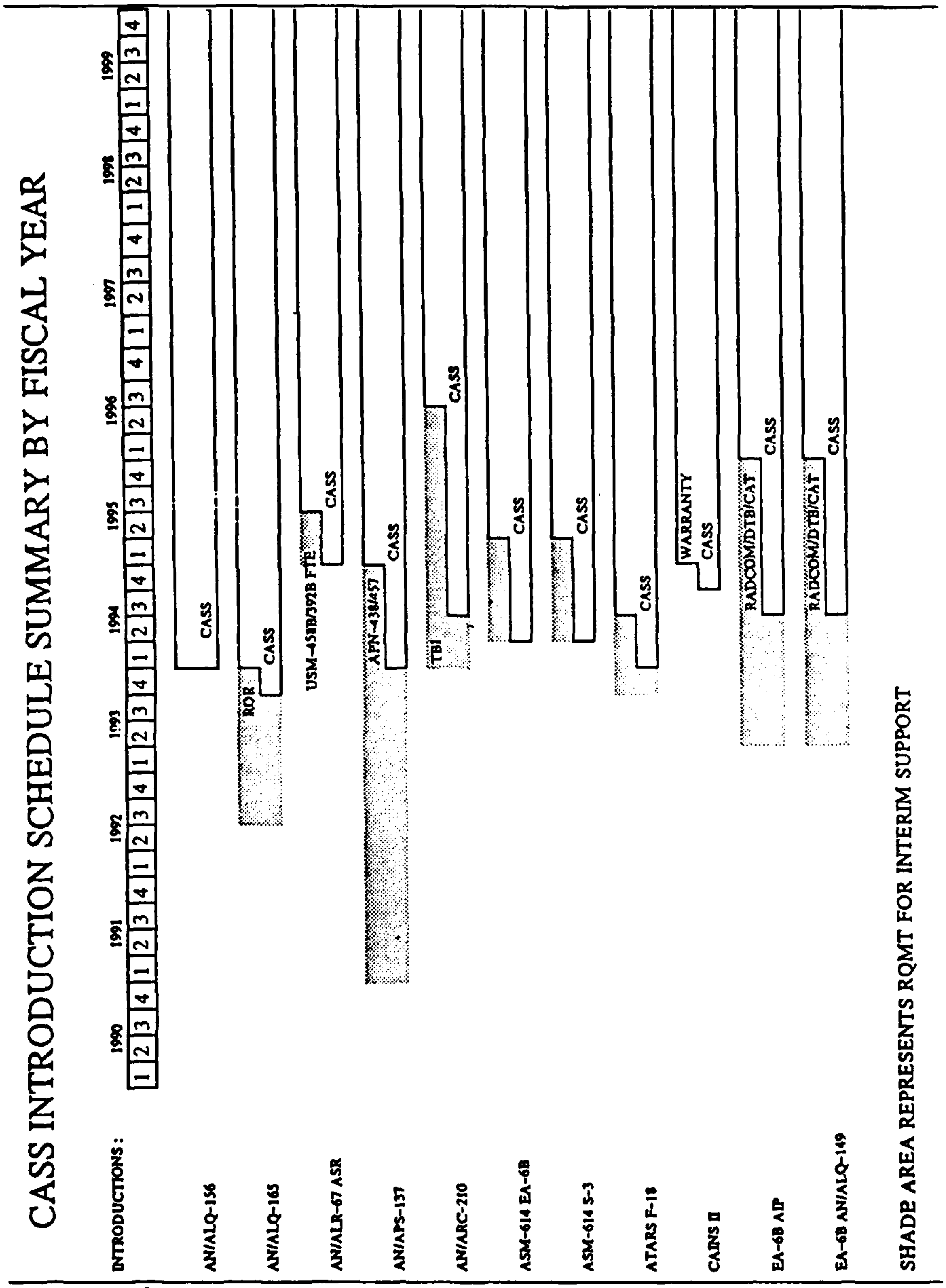

Figure 13. CASS Introduction and Transition Schedule, FY-90 to FY-99, Plate B

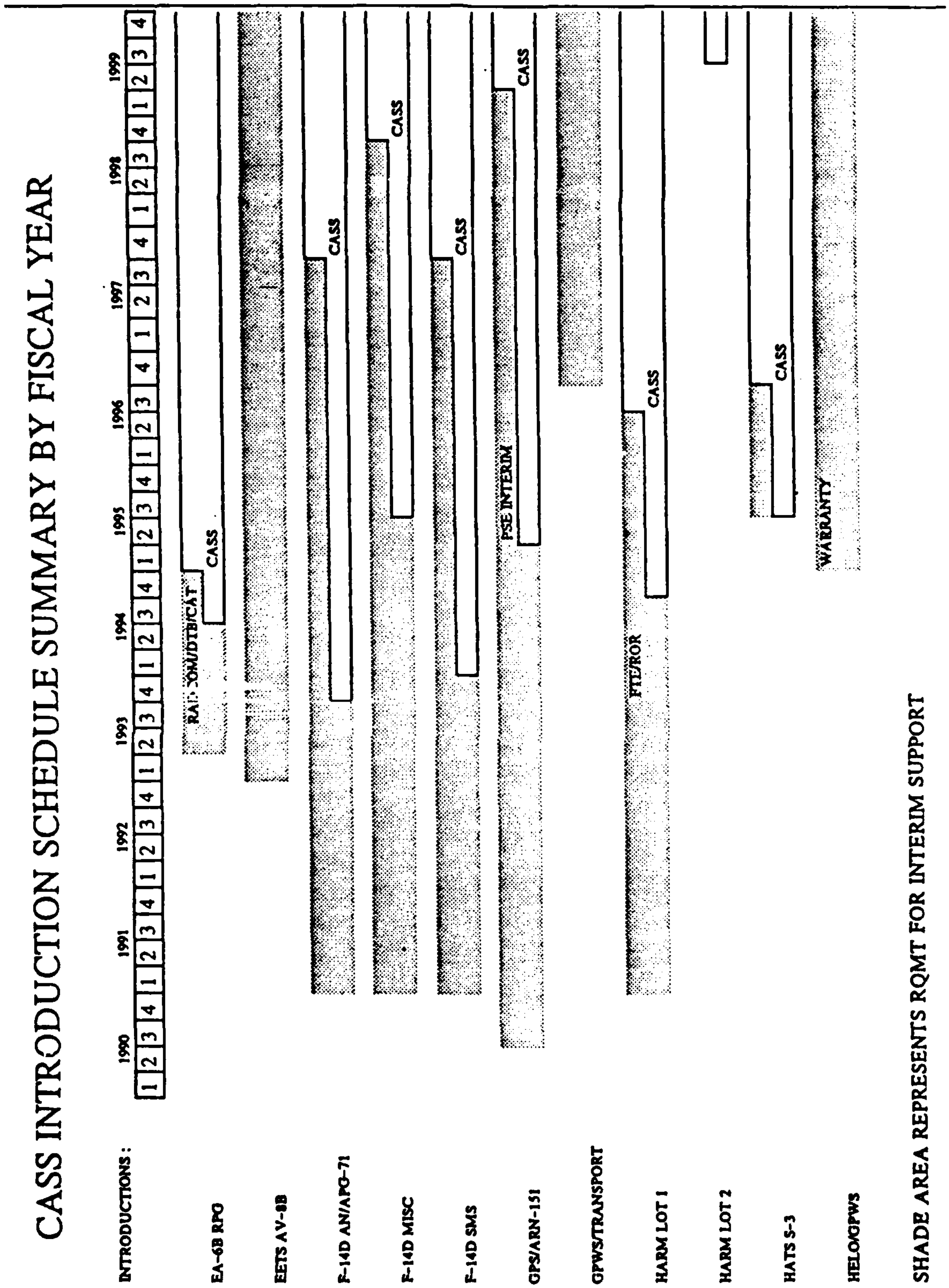

Figure 13. CASS Introduction and Transition Schedule, FY-90 to FY-99, Plate C

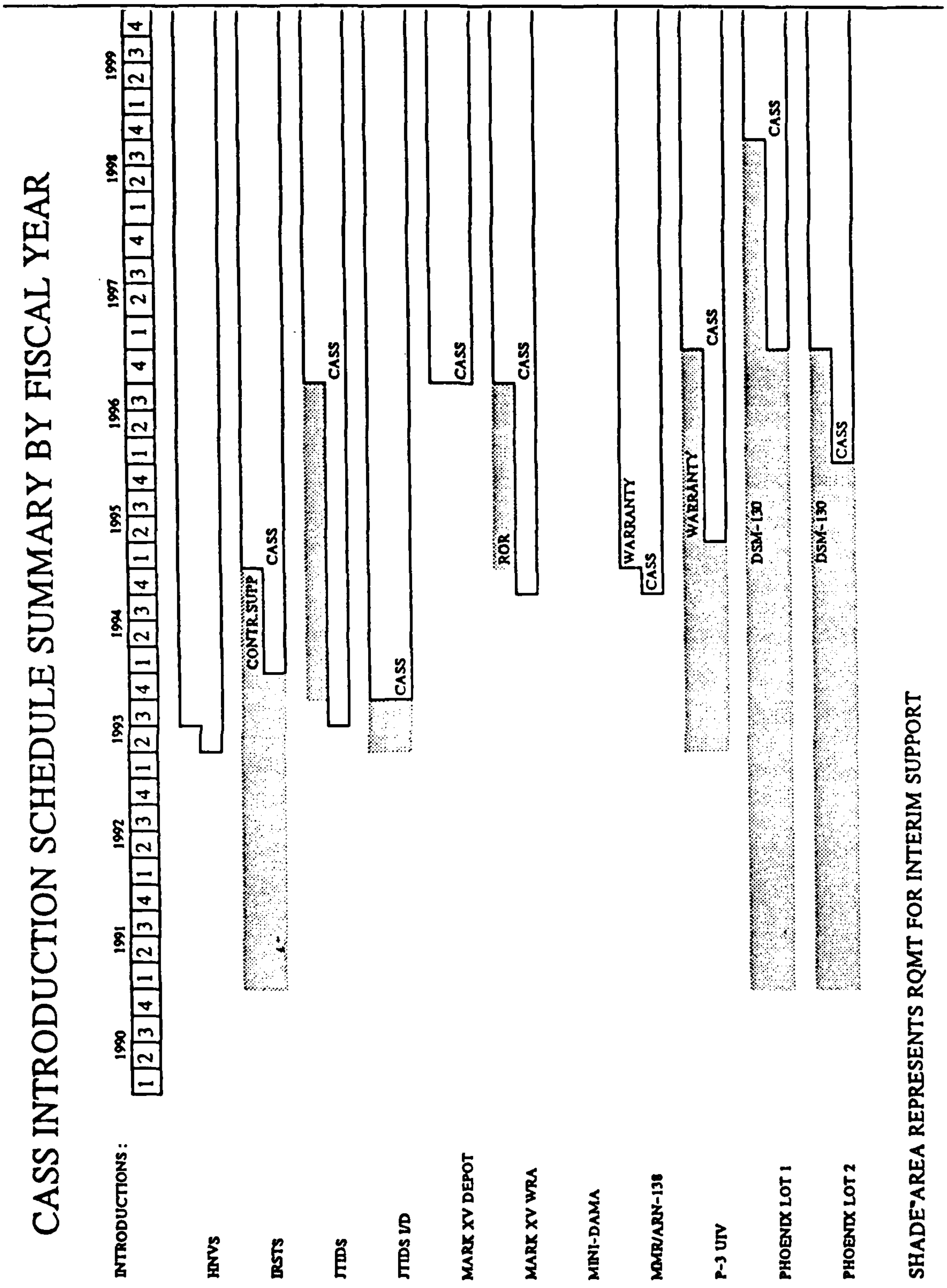

Figure 13. CASS Introduction and Transition Schedule, FY-90 to FY-99, Plate D

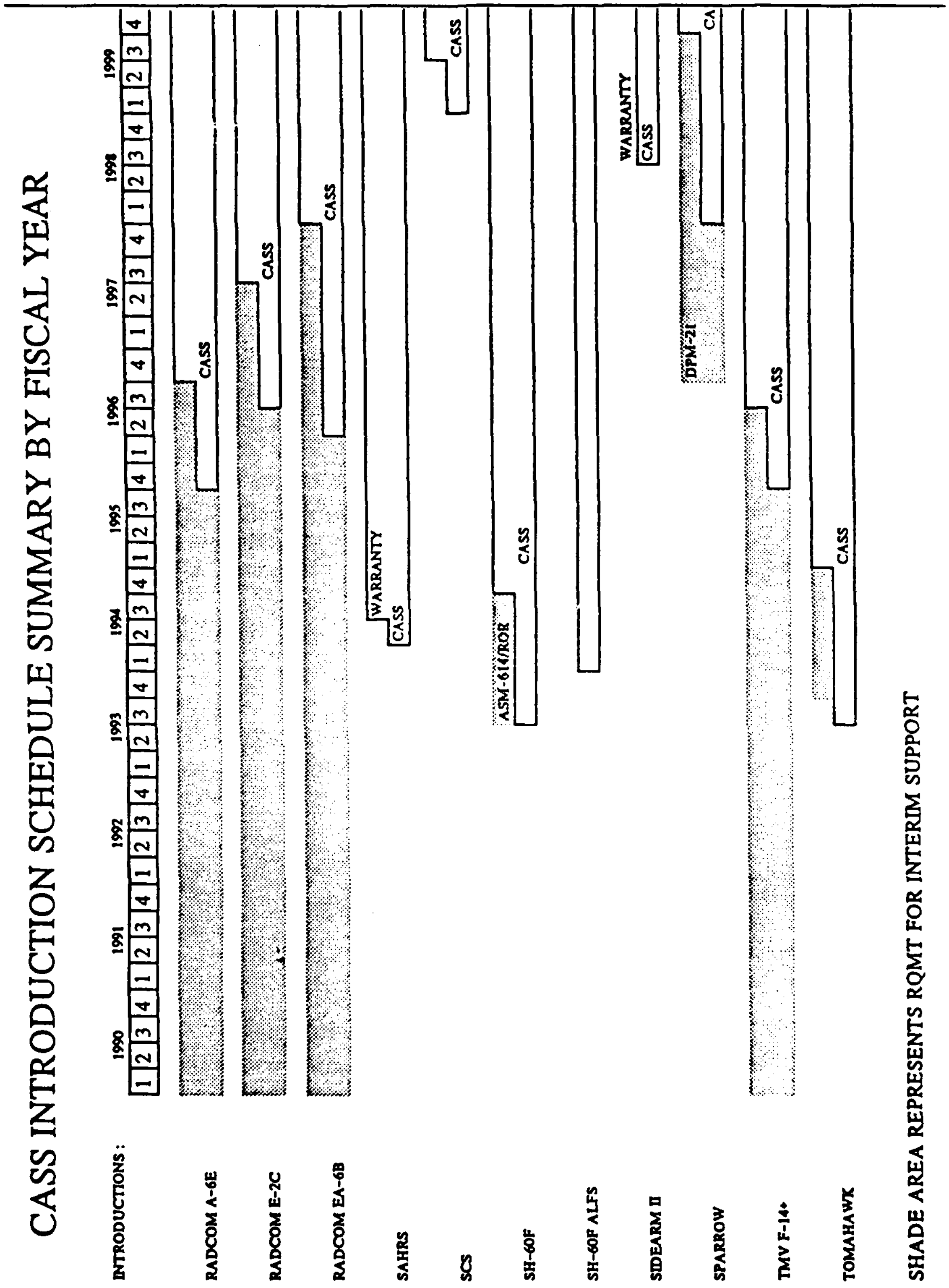

Figure 13. CASS Introduction and Transition Schedule, FY-90 to FY-99, Plate E

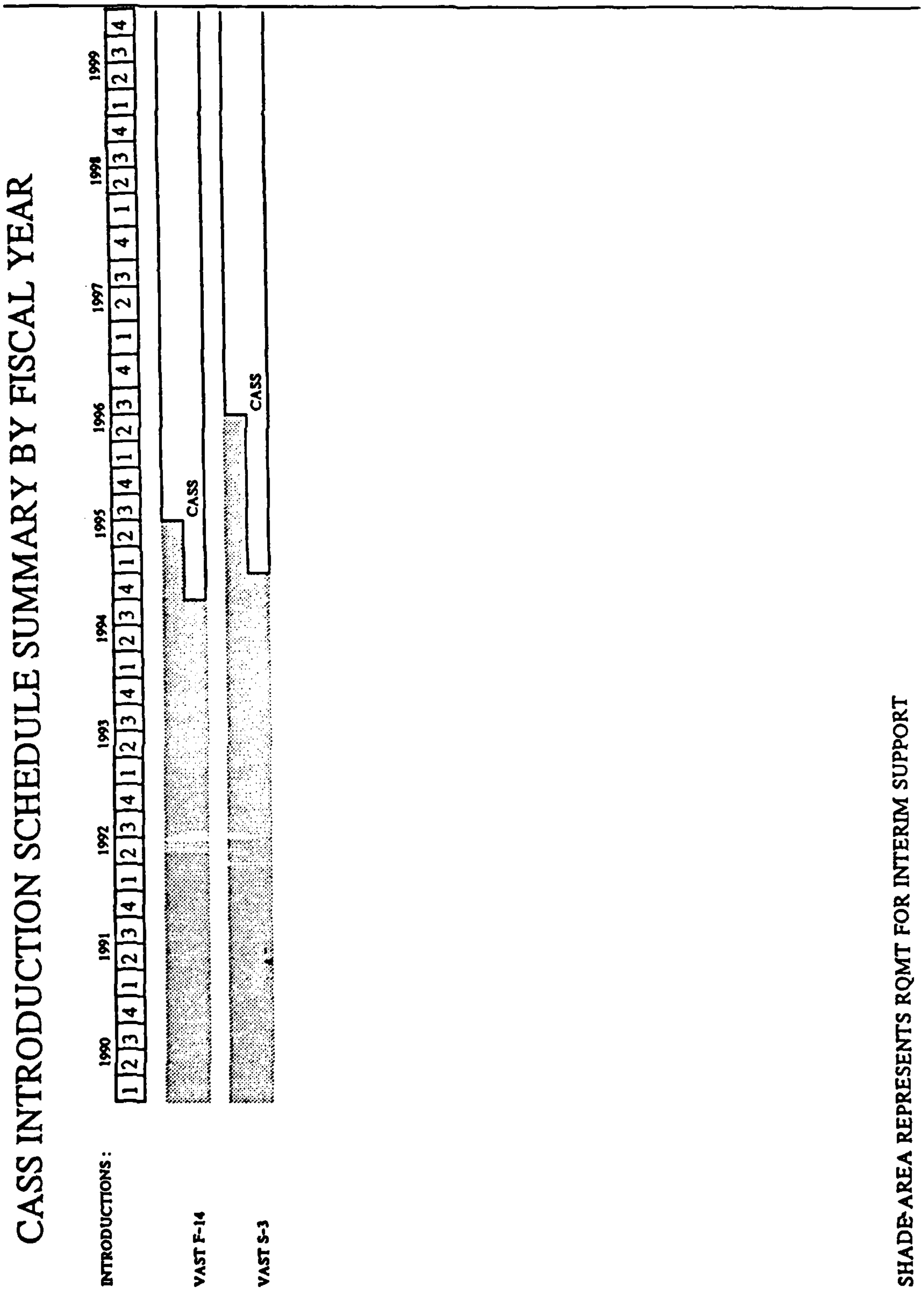

Figure 13. CASS Introduction and Transition Schedule, FY-90 to FY-99, Plate F

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