IDA PAPER P-2917

INVESTMENT STRATEGY FOR DoD AUTOMATIC TEST SYSTEMS

Volume I: Summary and Analyses

Robert M. Rolfe, *Task Leader*

Herbert R. Brown

January 1994

Prepared for
Weapons Support Improvement Group
Office of the Assistant Secretary of Defense for Production and Logistics

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

DEFINITIONS

IDA publishes the following documents to report the results of its work.

Reports

Reports are the most authoritative and most carefully considered products IDA publishes. They normally embody results of major projects which (a) have a direct bearing on decisions affecting major programs, (b) address issues of significant concern to the Executive Branch, the Congress and/or the public, or (c) address issues that have significant economic implications. IDA Reports are reviewed by outside panels of experts to ensure their high quality and relevance to the problems studied, and they are released by the President of IDA.

Group Reports

Group Reports record the findings and results of IDA established working groups and panels composed of senior individuals addressing major issues which otherwise would be the subject of an IDA Report. IDA Group Reports are reviewed by the senior individuals responsible for the project and others as selected by IDA to ensure their high quality and relevance to the problems studied, and are released by the President of IDA.

Papers

Papers, also authoritative and carefully considered products of IDA, address studies that are narrower in scope than those covered in Reports. IDA Papers are reviewed to ensure that they meet the high standards expected of refereed papers in professional journals or formal Agency reports.

Documents

IDA Documents are used for the convenience of the sponsors or the analysts (a) to record substantive work done in quick reaction studies, (b) to record the proceedings of conferences and meetings, (c) to make available preliminary and tentative results of analyses, (d) to record data developed in the course of an investigation, or (e) to forward information that is essentially unanalyzed and unevaluated. The review of IDA Documents is suited to their content and intended use.

The work reported in this document was conducted under contract MDA 903 89 C 0003 for the Department of Defense. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
January 1994

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Investment Strategy for DoD Automatic Test Systems. Volume I: Summary and Analyses

5. FUNDING NUMBERS
MDA 903 89 C 0003
Task T-B5-490

6. AUTHOR(S)
Robert M. Rolfe, Herbert R. Brown

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses (IDA)
1801 N. Beauregard St.
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-2917

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OASD(ES)
WSIG
The Pentagon, Room 2B322
Washington, DC 20301-8000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, unlimited distribution: March 28, 1994.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (Maximum 200 words)

This paper reports the results of an investigation into investment strategies for DoD automatic test systems (ATS). The study was chartered by the Assistant Secretary of Defense for Production and Logistic, and was conducted by a DoD and IDA team under the guidance of an Office of Secretary of Defense/Joint Service Executive Steering Group. This paper documents the results, methodology, and conclusions of the detailed technical analyses conducted in conjunction with this effort. Fifteen weapon systems were selected as representative of Defense-wide programs for in-depth ATS data collection and analysis. Selected ATS were evaluated for technical capabilities and their ability to meet multiple weapon system applications. The resulting data provided a baseline for characterizing Defense ATS acquisition costs and investment focus. Future benefits of an improved ATS investment strategy were compared with present ATS acquisition approaches used by the Services. The study concluded that Defense-wide use of standard ATS families provides the best approach to meet automatic testing needs at the lowest possible cost. Volume I contains a summary and high-level analyses of the results; Volume II contains the supporting data.

14. SUBJECT TERMS
Automatic Test Systems (ATS), Automatic Test Equipment (ATE), Test Program Set (TPS), Weapon Systems, Acquisition.

15. NUMBER OF PAGES
214

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

UNCLASSIFIED

IDA PAPER P-2917

INVESTMENT STRATEGY FOR DoD AUTOMATIC TEST SYSTEMS

Volume I: Summary and Analyses

Robert M. Rolfe, *Task Leader*

Herbert R. Brown

Accesion For		
NTIS CRA&I		☒
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Dist: ibution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

January 1994

INSTITUTE FOR DEFENSE ANALYSES

Contract MDA 903 89 C 0003

Task T-B5-490

UNCLASSIFIED

PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) under the Task Order, Integrated Diagnostics, and fulfills an objective of the task, to "provide analytic support for a DoD sponsored forum to develop an implementation approach for an investment strategy for DoD automatic test systems." The work was sponsored by the Director of the Weapon Support Improvement Group (WSIG), Office of the Assistant Secretary of Defense for Production and Logistics (ASD(P&L)).

On February 7, 1992, the ASD(P&L) chartered a DoD team to develop a recommended DoD automatic test system investment strategy, and tasked IDA to perform in-depth technical and economic analyses in support of this effort. The effort was directed by a joint Executive Steering Group composed of personnel from the Office of the Secretary of Defense (OSD) and the Departments of the Army, Navy, and Air Force. The results of the IDA analyses presented in this paper were provided to the DoD study team and Executive Steering Group, which had the broader responsibility to consider recommendations and implementation. This paper comprises two volumes: Volume I, Summary and Analyses, and Volume II, Supporting Data.

The overall study team consisted of (in addition to the authors of this paper) the following personnel from OSD, the Services, and IDA: Ms. Christine Fisher (DoD Chairperson of the Study Team), Mr. Michael Bloom, Mr. Bill Darling, Mr. Steven Freschi, CMSgt Terry Lambert, Mr. Jonathan MacMillian, Mr. Wesley McElveen, Ms. Kate O'Sullivan, Mr. Bill Ross, CDR Gus Scalia, LCDR Jim Seveney, Mr. Howard Sterling, Maj Steve Topper, and Mr. Perry Trolinger. This team worked full time for 4 months and, along with more than 80 representatives of DoD and industry, participated in over 100 hours of technical interchange meetings. Follow-on activities of the team continued for another eight months, with support provide by the Services as required.

The following IDA research staff members were reviewers of this document: Dr. Brian Cohen, Mr. Waynard Devers, Mr. Robert Eberhard, Dr. Harlow Freitag, Dr. Richard Ivanetich, and Dr. Richard Wexelblat. Additional document reviews for technical content, accuracy, and completeness were conducted by Mr. Bill Ross, U.S. Navy; Mr. Patrick Stevens, U.S. Army; and Mr. Terry Lindemann and CMSgt Terry Lambert, U.S. Air Force.

EXECUTIVE SUMMARY

Automatic test systems (ATS) are used to test weapon electronics in manufacturing and maintenance. The Assistant Secretary of Defense for Production and Logistics requested a study to characterize the scope of current ATS investments and to characterize mission, technical, and economic benefits of an improved ATS investment strategy. The Institute for Defense Analyses (IDA) found that the Department of Defense (DoD) invested an estimated $35 billion in ATS inventory from 1980-1992, with an additional $15 billion estimated for associated ATS support. Based on acquisition programs and FY93 Program Objectives Memorandum (POM) funding levels, DoD will spend an estimated $11 billion across FY93-99 for additional inventory ATS development and procurement.

Furthermore, the analyses showed a strategy using common ATS to meet cross-weapon systems requirements is technically feasible and meets DoD-wide testing requirements. Analyses also demonstrated that this strategy will reduce logistics, improve operational interoperability, and significantly reduce ATS acquisition costs.

Approach

In-depth data were collected on ATS supporting 15 weapon systems considered representative of DoD-wide programs. Separate analyses were conducted to evaluate technical capabilities of modern ATS, to identify acquisition and mission support opportunities, and to evaluate economic benefits of an improved investment strategy. Feasibility assessments of meeting cross-weapon system and cross-Service test requirements with standard ATS families were carried out based on technical capability reviews of several current DoD ATS. ATS acquisition and support opportunities were assessed based on technical reviews of factors affecting ATS technology development and evolution. A macro ATS investment strategy model was developed in conjunction with these analyses and was used to estimate ATS acquisition costs. Estimates of potential ATS investment strategy savings were based on several analyses: (1) the collection of representative historical ATS cost data for the 15 weapon systems, (2) case study analyses that evaluated different ATS investment strategy benefits, and (3) a macro assessment of DoD cost avoidance opportunities.

Conclusions

The specific conclusions are addressed from three perspectives: Investment Approaches, Requirements and Capabilities, and Long-Term Opportunities.

Investment Approaches

1. **DoD is making duplicative investments in ATS within and across weapon programs and depots.** The majority of DoD's ATS are acquired separately to meet individual user requirements. For the 15 weapon systems reviewed, over 100 unique ATS types were identified with total test equipment numbers exceeding 2,300. From another perspective, production quantities averaged less than 25 ATS for each unique ATS type. Assessments show that the technical testing capabilities of these unique ATS have a high degree of overlap.

2. **A strategy applying DoD selected standard ATS families will reduce ATS development and production costs and provide operation and support benefits.** A macro ATS investment strategy model was developed as part of this study and used to estimate DoD total ATS acquisition costs. This model was based on total projected weapon system budgets and historical ratios of ATS acquisition to weapon system costs. Although "system-specific" savings were not addressed by this modeling approach, the analyses identified potential overall ATS cost reductions of between $1.5 and $1.9 billion across FY93-99 weapon system acquisition budgets based on FY93 POM funding projections. This assessment assumed the strategy was implemented at the outset of FY93. The following factors were identified as the principal causes for these ATS investment savings:

    a. Development costs shared across multiple applications,

    b. Increased tester work-loading efficiency by replacement of multiple unique ATS,

    c. Economies of scale permitted by consolidation of ATS requirements and production learning, and

    d. Stable product base for ATS production, spares, and modifications.

Requirements and Capabilities

3. **Existing ATS standard families, IFTE and CASS, meet DoD automatic testing technical requirements today and will handle nearly all projected testing requirements through the next decade with only modest improvements.** The Army and Navy respectively have designated the Integrated Family of Test Equipment (IFTE) and the Consolidated Automated Support System (CASS) as their standard families of ATS. Analysis of DoD's most modern ATS shows the CASS tester meets the broadest range of testing capabilities. No other tester evaluated covered the same depth and breadth of testing capabilities. IFTE was a close second and adds the additional dimension of a highly mobile single ATS. Both testers were evaluated against potential future testing requirements, and analysis results showed that both testers will accommodate projected testing needs over the next decade with only modest ATS family improvements. CASS and IFTE use industry standard architectures that promote easy incorporation of instruments. Consequently, they may be updated relatively easily to meet future test needs.

4. **Appreciable size reductions of modern general purpose ATS are achievable only by eliminating test system capabilities or by introducing highly tailored design solutions.** Central to this conclusion are two critical findings: (a) the frequently used term "downsized tester" addresses a concept of reducing ATS size, and this term has little meaning outside the context of specific applications with existing ATS, and (b) tester downsizing approaches are technology limited and directly define tester application limits by trading off capability for smaller size.

5. **Built-In-Test (BIT) will not substantially change ATS requirements for off-equipment repair over the next decade.** BIT will not eliminate off-equipment (weapon system) testing needs. BIT provides a valuable fault detection function; however, it does not have the same accuracy and range of testing capability for fault detection, fault isolation, and repair verification as a modern ATS. In fact, current BIT technologies are either limited or not available for many subsystem testing domains. Analysis indicated that total off-equipment ATS work-loads will not change substantially because total ATS work-load requirements are determined by the reliability of the systems to be tested.

Long-Term Opportunities

6. **Cost-effective test software engineering and rehosting require new standards and development and support environments for test information and software.** Although hardware represents the dominant research and development (R&D) and production ATS costs, test software development, acquisition, and rehosting still represent significant costs. Analyses indicated that the development and implementation of a common ATS software development and support environment would reduce total weapon system ATS acquisition cost by 8 to 10%.

7. **Applying a standard ATS families acquisition strategy will not adversely affect DoD's ability to acquire test resources from industry.** DoD ATS R&D and production expenditures are spread across a large number of contractors, with a small fraction, typically less than 10%, of the ATS market in any one firm. Critical test technical and engineering capabilities will continue to reside in the commercial sector.

8. **Standard ATS families will promote the purposeful reuse of test equipment and test software across factory, depot, and operational maintenance.** Standard general purpose ATS were found to facilitate and promote the reuse of test equipment and test software. Also, when used at multiple maintenance levels, common ATS families tend to improve the relative diagnostic accuracy of testing results.

Table of Contents

List of Figures

List of Tables

PART I
INTRODUCTION

1. INTRODUCTION

1.1 PURPOSE

The purpose of this study was to determine the economic and technical factors essential in the development and support of a Department of Defense (DoD) automatic test systems (ATS) investment strategy. The study, requested by Assistant Secretary of Defense for Production and Logistics (ASD(P&L)), set out to characterize the scale and scope of current ATS investments and to characterize economic, technical, and mission benefits of an improved ATS investment strategy. Underlying objectives of the study were as follows:

- To evaluate ATS investment strategy options that meet both individual weapon system and joint Service needs in a cost-effective way,
- To characterize technical capabilities of current automatic test systems, and
- To project needed future capabilities.

1.2 BACKGROUND

The DoD invested an estimated $35 billion in ATS inventory from 1980 to 1992, with an additional $15 billion estimated for associated ATS support. Furthermore, based upon the current planned acquisition programs, DoD will spend an estimated $11 billion across FY93-99 for additional inventory ATS development and procurement. If Defense factory test equipment investments are included, the total may be over $100 billion. Yet historically DoD ATS acquisition and management activities have not been well coordinated across DoD. Applied investment strategies have principally focused on individual system requirements, often at the expense of shared development resources, production economies of scale, and lost opportunities for common mission and logistics support use.

On February 7, 1992, the ASD(P&L) chartered a DoD team to develop a recommended DoD ATS investment strategy, and sponsored the Institute for Defense Analyses (IDA) to perform an in-depth technical and economic analysis. The effort was directed by a joint Executive Steering Group composed of Office of the Secretary of Defense (OSD) and Army, Navy, and Air Force personnel. A principal study team of 12 people worked full time for 4 months, and more than 80 representatives of DoD and industry participated in over 100 hours of technical interchange meetings. Follow-on investigation and analysis continued with a team ranging from four to seven people for another eight months, with support provided by the Services as required. Summaries of the data collected and results of the IDA technical and economic analyses are presented in this paper.

1.3 GLOSSARY

Automatic Test System (ATS): Automatic test system is defined to include the automatic test equipment (ATE) hardware and operating software, test program sets (TPS) that include the hardware connectors and software programs to test individual weapon electronic items, and the associated ATS software development environments. Figure 1 illustrates the principal ATS elements and includes listings of sample functions.

Automatic Test Equipment (ATE): Automatic test equipment includes the operating system or executive software that runs on the main computer and a range of hardware components. ATE hardware components consist of items such as the main computer within the test equipment, operating system, stimulus and measurement instruments, signal control and switches, and needed interfaces such as heating and cooling sources and structural supports.

Test Program Sets (TPS): Test program sets consist of interface test adapters (interface devices), test program software, and test program documentation and data. The test program set provides necessary resources and information to test an item on an automatic test equipment. Development and production of a specific interface from automatic test equipment to the unit under test (UUT) are performed as part of test program set development and production. Test programs are generally written for each unit under test. The test program set must provide all additional resources not available in the designated automatic test equipment, but which are necessary to test the unit under test.

ATS Software Development Environment: The test program set development environment includes the descriptions of the ATE and related equipment architectures and interfaces, programming and test specification languages, compiler, and provisions for capturing and using design test requirement and test strategy information concerning the unit to be tested.

General Purpose Automatic Test Equipment: Automatic test equipment is general purpose when it is designed to meet a broad spectrum of electronics testing (direct current (DC) to light, large frequency ranges, large power ranges, etc.). Furthermore, to be

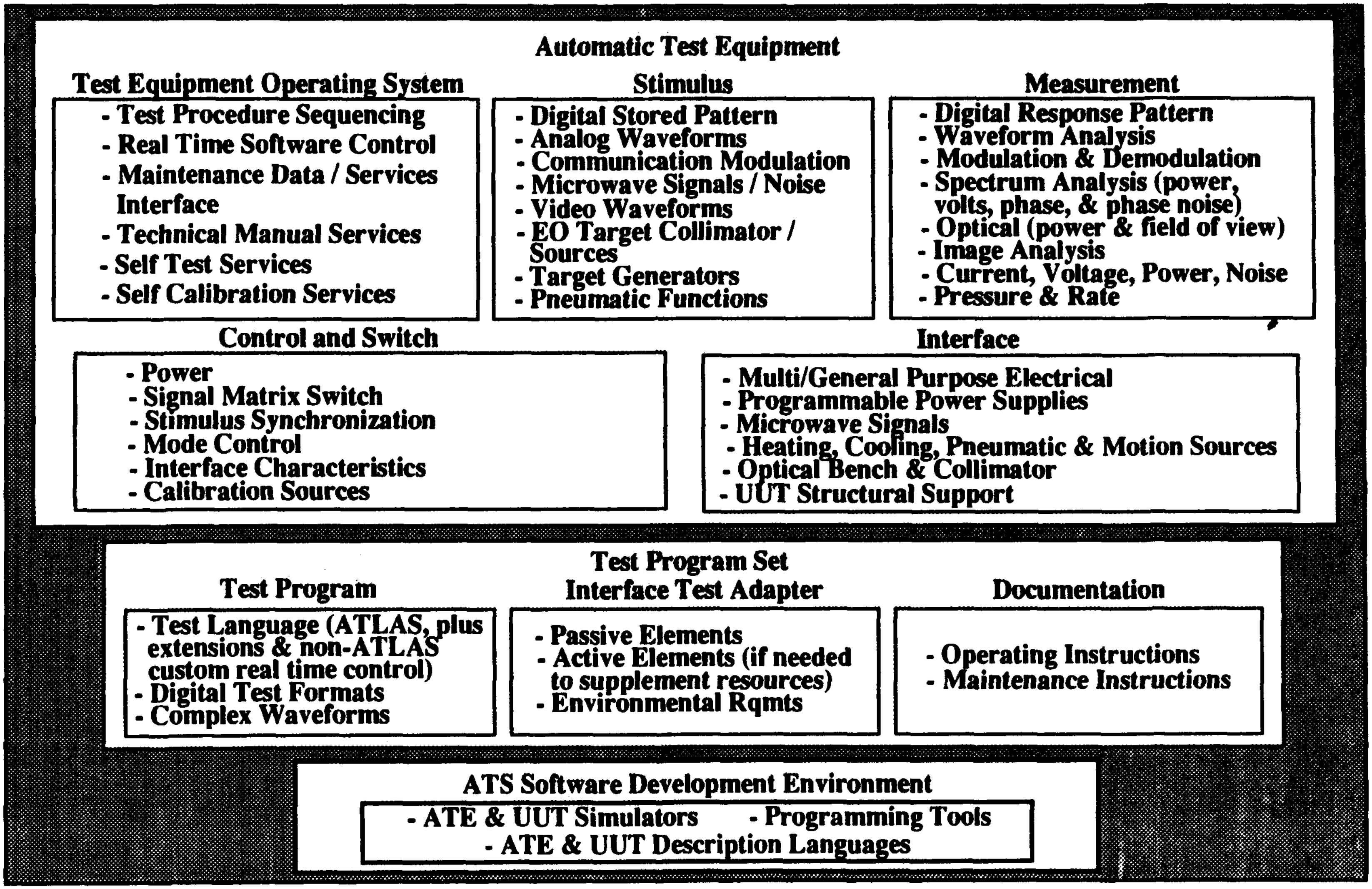


Figure 1. Automatic Test System (ATS) Principal Elements

general purpose, the automatic test equipment must be capable of testing multiple types of full systems and subsystems including black-boxes and circuit cards, and must provide fault detection and fault isolation capabilities down to a board and component level.

ATS Applications: DoD automatic test systems are used to test weapon system repairable items by aiding in the tasks of (1) identifying the replaceable component, (2) adjusting a repairable item to technical order specifications, and (3) assuring a repaired item is ready for issue. Automatic test systems are used in DoD field and depot electronics maintenance environments to reduce troubleshooting times, to augment the skills of technicians, and to test electronics technologies that are difficult or impossible to test manually. Automatic test systems are also used in manufacturing for in-process and acceptance testing of electronics related products.

DoD Standard ATS Family: Within the context of this paper, a DoD standard ATS family is an automatic test system with general purpose capabilities that meet the testing needs of multiple DoD systems, and has been designated by one or more of the Services as a common automatic test system for multiple weapon system testing applications. Within this context, DoD has identified two existing ATS standard families: the Army Integrated Family of Test Equipment (IFTE) Base Shop Test Facility (referred to as IFTE throughout this paper unless an exception is specifically cited), and the Navy Consolidated Automated Support System (CASS). Both of these automatic test systems were proposed for designation as *initial* DoD standard ATS families for immediate application throughout DoD. A formal process for identifying requirements and adding other automatic test systems to this designated list of DoD standard ATS families was not established during the study period. Other potential family candidates include commercial testers used for some depot applications, testers for special application areas such as electronic warfare, and DoD-developed automatic test systems.

1.4 REPORT ORGANIZATION

This report is arranged as four major sections (Parts I, II, III, and IV) which have been divided into two volumes. The first three sections are in Volume I, and the last section, along with the References, Bibliography, and List of Acronyms, are in Volume II.

VOLUME I: Summary and Analyses

a. Part I: *Introduction* provides a very brief introduction, including purpose, report organization, glossary, and background.

b. Part II: *Conclusions* provides a short summary list of the primary conclusions and follows with a more detailed discussion of each.

c. Part III: *Analyses* provides summaries of data collected during the study and analyses that support the primary conclusions presented in Part II. Secondary findings and conclusions are also documented within sections that discuss the following:

   1. baseline data analysis,
   2. ATS investment strategy option case study analysis,
   3. DoD ATS investment analysis,
   4. analysis of DoD and Service ATS management policies and organizations,
   5. assessment of ATS requirements and applications, and
   6. assessment of ATS technology development and evolution.

VOLUME II: Supporting Data

d. Part IV includes weapon system profiles, ATS baseline data summaries, summaries of selected ATE comparisons, definitions of ATS investment strategy options, and lists of study participants.

PART II
CONCLUSIONS

2. DISCUSSION OF CONCLUSIONS

DoD-wide use of standard ATS families provides the best opportunity to meet automatic testing needs at the lowest possible cost. The study investigated automatic test systems principally used to test weapon system electronics related products. Analyses revealed significant acquisition cost avoidance, and logistics savings and improvements are possible if DoD components meet their ATS needs by selecting from designated standard ATS families. The eight specific conclusions address ATS from three perspectives: Investment Approaches, Requirements and Capabilities, and Long-Term Opportunities. These conclusions are discussed in greater detail, with supporting findings, in the following sections of this chapter. The in-depth analyses from which these conclusions are drawn are presented in Part III, Sections 3 through 9.

Investment Approaches

a. DoD is making duplicative investments in ATS within and across weapon programs and depots.

b. A strategy applying DoD selected standard ATS families will reduce ATS development and production costs and provide operation and support benefits.

Requirements and Capabilities

c. Existing ATS standard families, IFTE and CASS, meet DoD automatic testing technical requirements today and will handle nearly all projected testing requirements through the next decade with only modest improvements.

d. Appreciable size reductions of modern general purpose ATS are achievable only by eliminating test system capabilities or by introducing highly tailored design solutions.

e. Built-In-Test (BIT) will not substantially change ATS requirements for off-equipment repair over the next decade.

Long-Term Opportunities

f. Cost-effective test software engineering and rehosting requires new standards, and development and support environments for test information and software.

g. Applying a standard ATS families acquisition strategy will not adversely affect DoD's ability to acquire test resources from industry.

h. Standard ATS families will promote the purposeful reuse of test equipment and test software across factory, depot, and operational maintenance.

2.1 DOD DUPLICATIVE ATS INVESTMENTS

DoD is making duplicative investments in automatic test systems within and across weapon programs and depots.

2.1.1 ATS Duplication

The development costs for standard automatic test systems which meet multiple applications are typically the same as those for a single weapon ATS. Figure 2 compares ATE development cost profiles for a limited application and two multi-application automatic test systems over their respective lifecycles. Large repeated development investments for each single system application go principally for hardware and software integration: consequently the same testing capability is duplicated on each new automatic test system. This is illustrated by the fact that large percentages of current ATS are using previously developed, commercially available, components (e.g., for Consolidated Automated Support System (CASS) and Integrated Family of Test Equipment (IFTE) approximately 65%) many of which provide the same capability. These duplicative investments also extend over the ATS life cycle.

The F-16 Avionics Intermediate Shop (AIS) is a weapon-unique intermediate maintenance ATE that was developed specifically for the F-16 aircraft. The F-16 AIS initial development costs, at $178 million, approached CASS development costs at $220 million (both FY93$). However, CASS is currently targeted for some 30 weapon systems/subsystems, while the initial F-16 AIS only supported the avionics of the A/B series F-16 aircraft. IFTE initial development costs were $70 million; present IFTE fielding plans are in place for 14 weapon systems/subsystems. While the $70 million accurately reflects the Army's initial development funding for IFTE, additional development resources, both Government and contractor, were expended against the IFTE concept when Grumman was

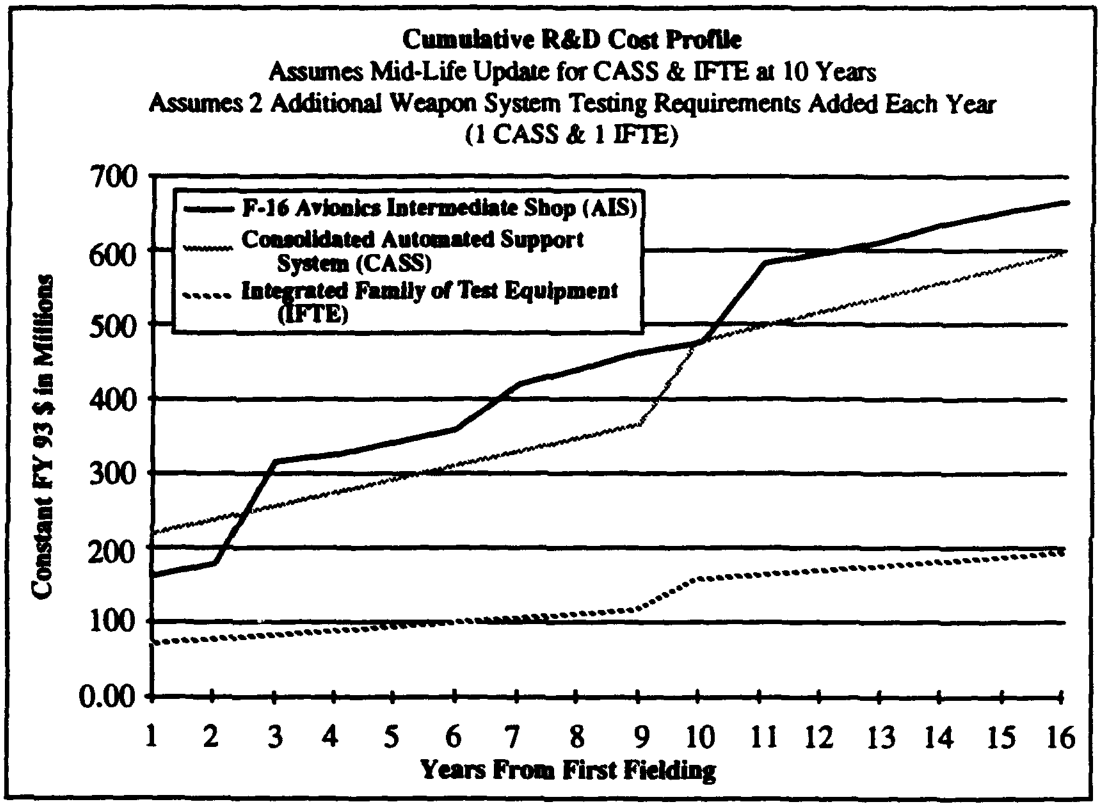


Figure 2. Development Cost Profile Comparisons of a System Unique (F-16) and Two Multiple System Application ATE (CASS & IFTE)

in head-to-head competition with General Electric to win award of the CASS development and production contracts.

These initial ATS developments are followed by longer term developments of ATS improvements and updates that usually approach the initial costs. Automatic test systems require system maturation and technology modifications over their lifecycle. For example, automatic test systems, historically, experience mid-life upgrade if employed for more than 8 to 10 years. In the case of the F-16, later AISs that were design evolutions of the original A/B AIS automatic test equipment supported the avionics of the C/D series aircraft. The F-16 AIS automatic test equipment over its life required a total development/modification design investment of nearly $700 million (FY93$). The same development/modification design investment (approximately $700 million) is projected for CASS over a similar lifespan. However, in contrast to the F-16 AIS series of testers, CASS may support as many as 45 different weapon systems/subsystems (the original 30 plus the addition of 1 new weapon system per year as illustrated in Figure 2).

Analyses revealed a proliferation of ATS types, many of which had duplicative capabilities. For example, 47 unique automatic test systems (plus 1 additional development under current consideration) were identified for the F-18, M-1, F-16 and F-15 weapon systems. The 47 ATS types were split between field (intermediate or "I") and depot level applications.

For the 15 weapon systems reviewed, over 100 unique ATE types were identified with total equipment numbers exceeding 2,300. Table 1 summarizes the types and quantities observed. Since the study focused on direct weapon system electronics test equipment, other related weapon system items (e.g., munitions, electronic warfare (EW) pods) are not included in these tables. ATS experts at technical interchange meetings (TIMs) concluded that there existed, within the operational life of each ATS type identified by weapon system in Table 1, multiple general purpose automatic test equipment that met or exceeded 95% of the technical testing requirements of these systems. In other words, the ATE capabilities such as measurement, stimulus, timing, and loading would accommodate the test needs of the weapon system in excess of 95% of all specified technical testing requirements. These observations are supported for current generations of general purpose testers by detailed comparisons of testing capabilities summarized in Appendix D, *ATE Comparisons*.

Table 1. Summary of ATE Types and Quantities by Weapon Systems

NAVY			ARMY			AIR FORCE		
Weapon System	ATS		Weapon System	ATS		Weapon System	ATS	
	Types	Qty		Types	Qty		Types	Qty
A-12	1	62	ABRAMS	4	202	ACM	4	16
AMRAAM *	2	27	BRADLEY	2	230	C-17	2	12
F-18	9	453	APACHE	6	47	F-15	24	402
MK-50	1	10	MLRS	5	14	F-16	10	444
SQQ-89	5	14	AVENGER	3	48	F-22 (est.)	25+	338
* Joint Air Force/Navy program. Air Force is lead service; however, Navy collected data for this study.								

Examples of ATS proliferation and duplicative development and acquisition are illustrated by the many F-18 automatic test systems. If CASS had been available at the outset of the F-18 program, the requirements for over 350 automatic test systems of 8 different types could have been met with only 64 CASS stations. In another example, two Services test the same prime equipment, yet use different automatic test equipment (e.g., the Air Force and Navy use different ATS to test the AIM-9L/M Sidewinder Missile Guidance and Control Section).

These findings of duplicative investments correlate with the findings of earlier studies reviewed in the course of this investigation. ATS proliferation and duplicative developments documented in a study of automatic test equipment sponsored by the Secretary of the Navy in 1976, lead to the cost benefit analysis (CBA) and competitive development of CASS. In the past year, DoD ATS management has been the subject of 4 DoD Inspector General (IG) audits, three General Accounting Office (GAO) audits, and most recently a House Armed Services Committee (HAC) special investigation. These have all reflected the lack of a DoD policy or coordinated approach to automatic test systems (to be discussed in the next section), and have criticized the resulting ATS proliferation.

2.1.2 Decentralized ATS Management

Decentralized ATS management, within and across Service and functional lines, is viewed as a major contributing factor to duplicative ATS investments. Historically, DoD ATS investment decisions have been made predominately in a decentralized fashion by individual weapon program and depot managers.

The Army and Navy have begun to implement centralized ATS management strategies and organizations, and the Air Force has a dispersed management strategy giving ATS acquisition process and standardization implementation authority to individual weapon system program offices. The Army and Navy are making progress with partial implementation of Service-level polices to use ATS families. The Air Force, during the course of this study, was undergoing a reorganization that combines the Systems and Logistics Commands. In addition, at the outset of this study the Air Force was proposing to establish an ATS management office identified as an Integrated Weapon System Management (IWSM) office; and, as the study was concluding, the Air Force formalized its ATS management approach by establishing an ATS Product Group Manager (PGM).

Even with current Service management initiatives targeted towards improving ATS acquisition processes, approximately 70% of all ATS funds are spent on unique ATS requirements. Opportunities to consolidate requirements and reduce the percentage of unique, and often duplicative, ATS are lost due to the decentralized ATS policy and decentralized management applied across the Department of Defense. Table 2 summarizes the decentralized conditions found during this study.

The Army and Navy have several early generations of ATS families (e.g., EQUATE & Versatile Avionics Shop Test (VAST) System), with their most current being IFTE and CASS respectively. Partial centralized management implementations for both the Army

Table 2. ATS Policy and Management Summary

	DoD	Army	Navy	Air Force*
Policy	None **	Service Level	Service Level	System/Logistics Command Level
Acquisition Control & Standardization	ATLAS ***	Common Family (IFTE)	Common Family (CASS)	Standard Specification Set (MATE Guides)
TPS Development & Process Control	None	Varies by Program (AMC Guidance)	CASS-Related Control (NAVAIR Mgmt)	Varies by Program (MATE Guides)
ATS R&D Organization	None	Service Wide	Limited Service & CASS Wide	Program Specific & MATE Stds
ATS Management Organization	None	Service Wide (PM TMDE)	CASS Wide (NAVAIR)	Program Specific & MATE Stds (Prog Off/ALC)

* Air Force proposing changes (reflects status at time of study).

** DoD Directive 4151.18, Maintenance of Military Material, was published August 12, 1992 (requires ATS be standardized among the DoD components).

*** Abbreviated Test Language for All Systems (ATLAS) allowed in lieu of Ada programming language by DoD Instruction 5000.2.

Acronyms not previously defined: Air Logistics Center (ALC); Army Material Command (AMC); Modular Automatic Test Equipment (MATE); Naval Air Systems Command (NAVAIR); Program Manager, Test, Measurement, and Diagnostic Equipment (PM TMDE).

and Navy were considered primary motivating forces for common ATS acquisitions. Naval Air Systems Command (NAVAIR) reduced duplicative ATS investments with a central organization that consolidates common requirements and then funds common needs with budget category Aircraft Procurement Navy (APN)-7 funding for common support equipment. This funding policy approach applies to NAVAIR, but not to surface and submarine programs. No similar funding approach was observed elsewhere in the Navy. The Army Program Manager, Test, Measurement, and Diagnostic Equipment (PM TMDE) authority is invoked by a waiver process. Army study personnel reported that waivers are often submitted late in the acquisition process, and the study found that all early automatic test system decision authority resides with individual weapon system program offices.

The Air Force delegates decisions to dispersed weapon and depot program managers. The Modular Automatic Test Equipment (MATE) Program was the Air Force's attempt to reduce proliferation and reduce ATS costs. The failure of MATE to have a significant influence on these two areas (ATS proliferation and costs) was attributed to a lack of implementation authority and support at the weapon system program manager and weapon system prime contractor. Of 323 potential programs, less than half (126) followed MATE procedures, only 45 were MATE baselined programs, and only about half of this number went on contract (24). At present the Air Force is reported to be pursuing new ATS acquisition programs for the F-22, the F-15 (downsized tester), and the F-16 (downsized intermediate tester). None of these new acquisition programs require use of the same automatic test system; yet the bulk of the development work involves the duplicative integration of already existing capabilities: stimulus, measurement, signal switching, interface buses, and general purpose computing.

Finally, no DoD-level policy nor management structure limiting ATS acquisition decisions was identified during the study. The lack of mechanism and policy to foster cross-Service ATS applications was found to be a major impediment to consolidating DoD-wide ATS requirements and investments. Reduction of duplicative investments can be achieved more effectively with DoD-level ATS acquisition policy and centralized ATS management structures. Use of the common ATS families across systems does not limit a weapon system program manager's flexibility to acquire and support unique test programs to meet weapon system specific test requirements and mission profiles.

2.2 AN IMPROVED ATS ACQUISITION STRATEGY

A strategy applying DoD selected standard ATS families will reduce ATS development and production costs and provide operation and support benefits.

2.2.1 Development and Production Costs

Case study results showed that a DoD acquisition strategy based upon wide application of standard general purpose ATS families will reduce total DoD expenditures. Extending this analysis across projected DoD weapon system acquisition budgets revealed cost avoidance opportunities that ranged into the billions of dollars.

The case study analysis, based on historical DoD ATS costs data, compared investment strategy options:

- No change in strategy
- Adopting common ATS specifications
- Adopting common ATS families
- Adopting common software environment

The case studies evaluated the relative ATS investment expenditures (development and production) for the F-18, M-1, F-16, and F-15 weapon systems over a 20-year period. Analysis results showed that a standard ATS family acquisition approach could produce an average ATS acquisition savings of 25 to 35% or more for each weapon system. The potential DoD ATS acquisition savings that could have been realized for these systems alone was conservatively estimated in excess of $2.35 billion. The common ATS family investment strategy option produced the greatest savings for each of the weapon system case studies, yet additional savings of lesser magnitude were possible with the common ATS specifications and common software environment strategies (more details follow in Section 5). Case study sensitivity analyses of the common ATS family acquisition strategy approach revealed that less conservative assessments produced estimates of even greater savings. For example, a less conservative analysis based on the F-16 ATS case study identified additional savings of $373 million over the $2.35 billion.

The analysis was extended beyond these 4 weapon system case studies to the full DoD weapon system acquisition budget. The evaluated investment strategy was a composite of the ATS common family and the common software environment strategies, with the principal benefits coming from the family approach. This extended analysis across projected DoD weapon system acquisition budgets identified ATS cost avoidance opportunities of 1.5 to 1.9 billion dollars, estimated for a period from FY93 through FY99. The assessment was based on the assumption that the strategy had been implemented at the beginning of the FY93 budget year. These potential savings are summarized in Table 3.

Table 3. Potential ATS Acquisition Strategy Savings

	Average Per Weapon System	DoD Wide
ATS Acquisition (Development & Production) Savings	25% to 35%	$1.5 to 1.9 Billion (over 6-Year Period)
Reasons	• Share Development Costs • Share Production Overhead (Economies of Scale) • Benefit from Production Learning • Increase Tester Work-Load Efficiency • Benefit from Stable Product Base	

The following paragraphs help to illustrate several of the reasons presented in Table 3. The benefits of shared development costs are presented as Research and Development

(R&D) cost avoidance. The benefits of reduced ATS type proliferation are presented as production unit cost reductions. The benefits of increased tester work-load efficiencies are presented as reduced ATS production quantities. More details follow in Section 6.

R&D Cost Avoidance. A DoD ATS standard family strategy avoids duplicative development efforts because the general purpose testing capabilities of existing ATS family members meet multiple system applications. Comparisons of weapon system testing needs to the general purpose testing capabilities of CASS and IFTE showed these ATE can, with minimal modifications, meet most (over 95% on average) of DoD's technical testing requirements for the next ten years. There is virtually no need for new unique ATS developments in this period. Further analysis of multiple DoD ATS types in many field and depot locations shows the costs to develop a general purpose family ATS is of the same relative magnitude as the cost to develop ATS for a single unique system application.

Figure 3 illustrates R&D cost avoidance opportunities when weapon system unique ATE developments are avoided by requiring the use of a general purpose standard tester. Each time a new ATE development is initiated, the cost is at 100%, the starting point of the

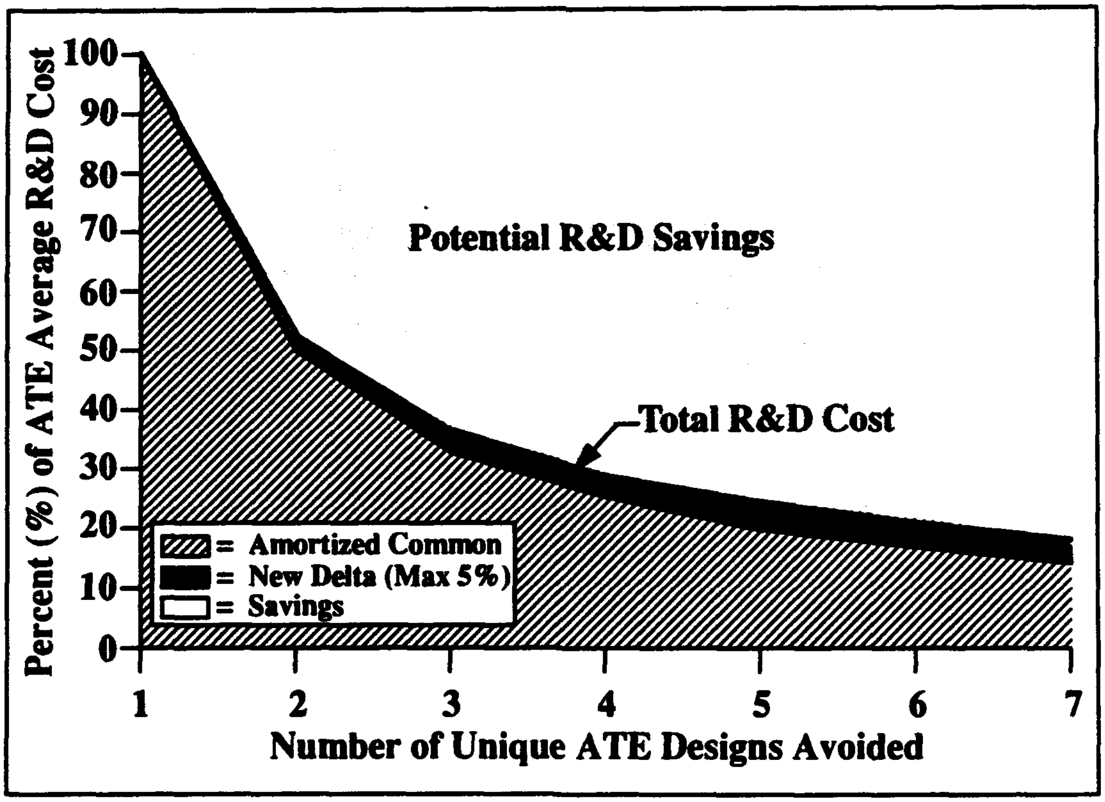


Figure 3. Summary of ATE R&D Cost Avoidance Opportunities

curve. The total R&D cost line shows that R&D costs are amortized when a single ATS is used in multiple applications: the current R&D amortization point for ATE such as CASS or IFTE, already planned for application to dozens of weapon programs, is far to the right off of this chart. The Total R&D line includes the cost for additional ATS R&D needed to meet additional new (unique) weapon system testing needs: the "New Delta" R&D area in this figure relates to the average 5% testing capability additions that are expected to be required for subsequent weapon system applications.

Production Unit Cost Reductions. ATS production unit cost reductions can be achieved by larger order quantities. Classically, production unit costs are quantity dependent due to two principal cost categories: recurring and non-recurring costs. The recurring costs are directly associated with the time and materials needed to actually manufacture an item. Improvements in manufacturing efficiencies, which result from accumulated experience as additional units are produced, tend to reduce the recurring cost in a consistent pattern (production/manufacturing learning curve theory). Larger and more stable order quantities for materials can also lead to cost reductions. The non-recurring costs include fixed expenditures associated with doing business (i.e., sustaining engineering, facilities, overhead). Pro-rating these fixed costs across greater quantities results in reduced production unit costs due to economies of scale. Consequently, as production quantities increase, the opportunities to decrease production unit cost increase.

Historical data for the 15 weapon systems reviewed shows DoD "unique type ATE" procurements have average total production quantities of 23 each. By contrast, currently planned production quantities for IFTE and CASS are approximately 200 and 500 (through FY 99) respectively. ATS manufacturers of both IFTE and CASS estimated that average unit production costs will decrease by 30% when ATS quantities increase from 50 to 500.

Reduced ATS Production Quantities. General purpose DoD ATS standard families have the capabilities to meet a wide range of test applications. This allows reduced ATE quantities by replacing multiple ATS types at each maintenance location and loading the maintenance workload more efficiently on the testers. Examples of the quantity reduction impact of using general purpose standard ATS is summarized in Table 4.

Table 4. Potential ATE Quantity Reductions

SYSTEM	ATE QUANTITY REDUCTIONS
F-16 (ATS STUDY ANALYSIS)	50%
F/A-18 (NAVY ACTUALS)	82%
F-15 (SEPARATE AF/ARMY ANALYSES)	72%

- **F-16.** As a part of the ATS study analysis, an evaluation of the F-16 testers technical capability and workloading was performed. This analysis showed that use of a general purpose tester CASS to accommodate workloading could result in reducing tester quantities by approximately 50% over the current quantity of testers required.
- **F/A-18.** The Navy is currently replacing 6 different F-18 ATS with the CASS. The improved workloading that will result allows the F-18 to reduce from 356 total testers to 64 CASS testers, a quantity reduction of 82%. The 356 number represents F/A-18 testers that evolved over time for which there exist some duplication and overlapping capabilities that the Navy did not eliminate.
- **F-15.** Separate analyses (performed by both the Army and Air Force outside of this ATS study) have shown the potential to replace at least 6 (and potentially 8) of the current F-15 testers with the IFTE. The workload realignment associated with the 6 to 1 replacement would lead to a 72% reduction in tester quantities over the number currently required.

2.2.2 Operation and Support Benefits

The Services do not collect complete operation and support (O&S) information as it relates to automatic test systems; therefore, the analysis and conclusions in this area relied on ATS-specific anecdotal information. Although a rigorous cost analysis was not possible given the available data, previous studies performed by the Army and Navy clearly show that ATS support is more effectively provided with common general purpose family versus application specific (peculiar or unique) ATS. Examples of O&S benefits were collected for the five areas presented in Table 5.

Table 5. Examples ATS Family Support Benefits

O&S Category	Examples of Benefits
Technical Publications	CASS will reduce the total technical manual requirements for 5 current automatic test systems from 367 to 13. Technical manual information will be on optical disks which will further improve efficiency over traditional paper control and change management.
Support of ATS	Each type of ATS requires a unique set of between 80-200 line items of support equipment. CASS requires 135 items across its four configurations, thus reducing a comparable number of line items for each duplicative ATS type eliminated.
Manpower, Personnel & Training	CASS estimated personnel savings of 40% and training cost reductions of 75%. IFTE estimated personnel savings of 42% and training cost reductions of 52%.
Supply Support	Navy projected that the total number of ATS related spare parts could be reduced from 30,000 to 3,800 per aircraft carrier by replacing automatic test systems with CASS.
Facilities	Navy estimated that facility space could be reduced by approximately 5,000 square feet on a typical aircraft carrier by replacing existing automatic test systems with CASS.

Although the exact benefits could not be quantified, the authors observed that common ATS families would allow flexibility of tester work loading, and possibly reduce total ATS requirements. Of the ATS acquisition strategy options evaluated, the common ATS families strategy was the only option that had the potential to increase flexibility of weapon system support, reduce deployment logistics tails, and permit more flexible use of maintenance personnel.

2.3 ATS FAMILY CAPABILITIES

Existing ATS standard families, IFTE & CASS, meet DoD automatic testing technical requirements today and will handle nearly all projected testing requirements through the next decade with only modest improvements.

Test requirements analyses of existing and future complex weapon systems (F-15, F/A-18, AH-64, F-22, and A-12) showed that IFTE and CASS exceeded 95% of technical test requirements. CASS test stimulus and measurement capabilities *at the front panel* *interface* were specified (in 1986) to take advantage of anticipated 1992 test instrument capabilities. These CASS specification requirements represented an aggressive design challenge to attain anticipated 1992 test instrument stimulus and measurement capabilities out at the front panel interface to items being tested concurrent with the CASS design completion. All of the instruments developed in the downsized Modular Measurement System (MMS) instrument packaging standard for the CASS were designed and developed during the last three years. The currency of this set of general purpose test resources cannot be exceeded in fielded equipment today.

The IFTE Base Shop Test Facility (BSTF) is a general purpose ATS and in addition meets the Army's high mobility requirements. The current IFTE automatic test system is size (weight and volume) competitive with paper designs coming off drawing boards today. The proposed DoD-designated ATS family members (IFTE and CASS) together represent the forward, leading edge of testing technology capabilities in inventory today for highly mobile, intermediate level, depot, and factory acceptance testing.

Analysis of DoD's most modern ATS shows the CASS tester meets the broadest range of testing capabilities. No other tester evaluated covered the depth and breadth. IFTE was a close second and adds the additional dimension of a highly mobile single ATS system.

The broad capabilities of these two testers are illustrated by the large numbers of items to be tested on each. Over 1250 units under test (UUTs) have been funded or projected for the Navy CASS Introduction Plan (CIP) [AIR 552, 30 April 1993] which includes off-load or new program start-ups. Furthermore, nine existing ATS station types are being replaced by the CASS ATS. The Army has funded or projected 239 units under test for the near-term (Fiscal Years (FY)93-95) IFTE BSTF laydown plan [PM IFTE]. The IFTE BSTF will replace two existing Army ATS types.

2.3.1 IFTE and CASS Technical Capabilities

IFTE and CASS were developed as general purpose automatic test systems and designed to be configured into broad coverage ATS families. The Army, Navy, and Marines performed extensive mission and test requirements studies including assessment of the capabilities of fielded ATS and future mission and test requirements across many weapon systems. These studies resulted in a new test capability requirements envelope for general purpose ATS. The ATS development programs for the IFTE and CASS met or exceeded the advanced test requirements envelope defined by these studies [NAEC-MISC-82-0147, PM IFTE Test Reqts. Analysis] as well as mission deployment requirements.

Tables 6 to 10 summarize current IFTE and CASS capabilities and identify the type and range of projected testing requirements that may be desired over the next decade. These tables address how to meet potential requirements and what the ATS impacts might be. Impacts are categorized as none, minor, modest, and major:

- No new requirements over this period or the requirements will not impact the automatic test systems (*none*).
- A *minor* impact is defined as a change or extension of test operation software and the addition or exchange of a few test resources that will not affect the overall ATE footprint.
- A *modest* impact is defined as the addition of new chassis resources which may lead to extension of the ATE footprint after a few test resources are implemented.
- A *major* impact is defined as a new configuration with an enlarged footprint of 20% or more.

The ATS family capabilities are summarized against five of the primary ATE elements identified in the introduction: interface, stimulus, measurement, control and switch, and test operating system. One modest, no major, and a range of minor impacts were identified.

2.3.2 Ability to Use and Extend IFTE and CASS Capabilities

An analysis of cross-weapon and cross-Service ATS requirements demonstrated that IFTE and CASS exceed most technical test requirements. More importantly, since IFTE and CASS use flexible industry standard architectures that promote modularity and partitioning (e.g., MMS, VME, Ethernet), they may be updated relatively easily. As significant performance enhancing technologies become available, the families can incorporate the improvements without disturbing basic architectures. Changes to IFTE or CASS to achieve new testing capabilities may be accommodated with only modest impact. For example, the Navy is funding an Air Force managed joint Service initiative to add full-up-round radar guided missile testing capabilities to the CASS with only modest changes.

The cross-weapon and cross-Service review compared F-18 to IFTE, F-22 to CASS, and Apache to the F-16 ATS. The Army and Navy were asked to select assemblies

Table 6. Summary of DOD ATS Family Capabilities of Interface Elements

CAPABILITIES	FUTURE REQUIREMENTS	IMPACT
Virginia Panel - 1,486 total connectors, 1,500 V/pin, 210 low freq, 64 coax, 448 digital, 76 power.	Digital pin count may exceed 512 I/O Pins.	**Minor** - Reassign some unallocated interface pins.
Gold Dot - 3,200 total connectors, 200 V/dot, 274 low freq., 224 digital, 200 power, 1,718 dots unallocated.		
EO air shutter.	None	
All standard power supplies and loads available.	High power, linear power (Full up round, radar guided missile test).	**Modest** - part of current CASS Missile Test Set baseline.
All power supplies are programmable and switchable.	None	
115/200 VAC 400 Hz feed through.	None	

that represent a challenge for other automatic test systems. Since actual test requirements for an F-22 system have not been determined yet, the F-22 Common Automatic Test System (CATS) preferred equipment list was used as a comparison baseline. Three F-18 weapon replaceable assemblies (WRAs) were evaluated against the IFTE Base Shop Test Facility.

Finally, to gain insight into the capability of existing automatic test systems to support cross-Service testing requirements, three Apache line replaceable units (LRUs) were evaluated against the F-16 Improved Avionics Intermediate Station (IAIS). Comparisons results are presented in Table 11. The "Exceptions" in this table are grouped as none, minor, modest, and major (same definitions used in Section 2.3.1 now applying to *exceptions*). Few minor and no modest nor major exceptions were identified.

Additional comparisons of DoD tester capabilities are presented in the Appendix D. *ATE Comparisons*. Based on the analyses from these comparisons, only minor tester capability technical improvements to ATS families will be required over the next decade.

Table 7. Summary of DOD ATS Family Capabilities of Stimulus Elements

CAPABILITIES	FUTURE REQUIREMENTS	IMPACT
Arbitrary waveforms to 200 mbits/sec (CASS), 50 mbits/sec (IFTE).	None	
Digital - all logic families 336 IO to 40 mbit (CASS) 224 IO to 50 mbit (IFTE).	Digital pins approximate 512 range, data rates to 50 mbit, clock rates to 100 MHz.	**Minor** - Near-term CASS expandable to 432 I/O at 40 mbit. **Modest** - IFTE expandable to 1,024 I/O at 50 mbit, 1/2 rack. **Minor** - TPS portability must be managed. **Minor** - Develop a procurable specification for a next generation digital test unit (DTU) replacement subsystem common for all DoD designated ATS.
Analog functions - 0.01 -> 25 MHz.	None	
Communications waveforms available include standard AM (ILS,VOR), TACAN, Linear Pulse, FSK, MSK, BPSK, QPSK, OQPSK (GPS), generic spread spectrum hardware (IFTE).	Improve programmability of spread spectrum resources and ATLAS integration.	**Minor** - Upgrade existing test resources to achieve higher programmability.
Synthesizers to 40 GHZ (CASS), 22 GHz (IFTE) fast switching to 18.4 GHz (CASS), 2.3 GHz (IFTE).	Extended synthesizer range (Navy).	**Minor** - Extended range synthesizers. will be integrated as COTS items replacing existing instrument assets. No footprint change.
EO collimator 0.5 -> 5.0 inch Wavelength 1.064 um and IR, visual targets and tracker stimulus.	EO Aperture to 17 inch (Apache).	**Minor** - Assess & develop EO apertures, standard EO interface to simulate larger aperture.
	Extended laser frequencies to far IR (Army).	**Minor** - Procure other laser frequencies; hardware & software already supports laser exchange in field use.
	Advanced target generators (Missiles).	**Minor** - Develop advanced, programmable target generators, modify existing EO tester target generation.

Table 8. Summary of DOD ATS Family Capabilities of Measurement Elements

CAPABILITIES	FUTURE REQUIREMENTS	IMPACT
Digital (see Stimulus Elements in Table 7; all capabilities are bidirectional).	(See Stimulus Elements).	**Minor** - (See Stimulus Elements).
Synchro/resolver 360 degree, 130Vrms.	None.	
Multimeter to 1000V (CASS), 200V (IFTE).	None.	
Frequency to 0.0001Hz (IFTE), 0.001 Hz (CASS), to 200 MHz (CASS), 100MHz (IFTE).	None.	
Digitizer to 500MHz (CASS), 50 MHz (IFTE).	None.	
Demodulators for standard AM (ILS,VOR), TACAN, Linear Pulse, FSK, MSK, BPSK, QPSK, OQPSK (GPS), generic spread spectrum hardware.	Improved abstraction level for test software interface (lower cost TPS rehost to designated ATS).	**Minor** - Communications: develop/ maintain DoD common, higher level test libraries. This will lower recurring TPS engineering cost.
RF Power -70 to +44 dbm 50 GHz RF Vector voltmeter to 1 GHz RF Peak power to 26.5 GHz RF Network analysis to 26.5 GHz.	Increased precision phase noise measurement.	**Minor** - Phase noise measurement option based upon COTS instruments, possible 1/5 rack addition.
EO collimator 0.5 -> 5.0 inch Wavelength 1.064 um & laser detector, RS 343, RS170, Raw Video to 40MHz.	None.	

Table 9. Summary of DOD ATS Family Capabilities of Control and Switch Elements

CAPABILITIES	FUTURE REQUIREMENTS	IMPACT
Full complement signal matrix.	None	
All standard buses and ATLAS statements.	New Joint Integrated Avionics Working Group (JIAWG) specialty buses.	**Minor** - Develop ATLAS software extensions, minimal impact to ATS software. **Minor** - Develop common new bus instruments as required, 1/5 rack max.
All calibration standards built-in.	None.	

Table 10. Summary of DOD ATS Family Capabilities of Test Equipment Operating System Elements

CAPABILITIES	FUTURE REQUIREMENTS	IMPACT
ATLAS, Non-ATLAS modules in Ada or Fortran. ATLAS Complex RF waveform extensions.	Add ATLAS 1989/1994 capability (Operational Commonality).	**Minor** - ATLAS TPS portability must be managed through concurrent support of multiple standards, software maintenance on designated ATS.
Teradyne IEEE WAVES interface. LASAR V6 or Teradyne binary file format for digital. Maintenance data interface. Interactive technical manual interface and functions.	ABBET and ATLAS compatibility (to lower cost of TPS development).	**Minor** - Develop ABBET specifications and demonstrate tool suites on designated ATS.
Built-in test concurrent and on-demand, automatic calibration.	Multiple, concurrent test programs execution. Advanced built-in-test interfaces.	**Minor** - Develop and demonstrate on designated ATS ATLAS extensions for concurrency and built-in test interfaces.
	Real time test control interface (Missile Test).	**Minor** - Provide real-time test control software with missile ATS.

Table 11. Results of ATS Cross-System Comparisons

SYSTEMS	ITEMS COMPARED	EXCEPTIONS
F-18 WRAs to IFTE	Radar Set Receiver-Exciter.	**None** -Full capability exists.
	Radar Target Data Processor.	
	FLIR Receiver & Optics Stabilizer.	**Minor** -Stimulus and measurement requirements within capabilities. - IR/EO testing needs HW fixturing augmentation. - Optics stabilizer needs HW augmentation for vibration test stand and motor-powered mechanical interface.
F-22 CATS Preferred Equipment List to CASS	VXI Instruments.	**None** - Comparable capabilities.
	Radio Frequency Equipment.	**None** - Technical capabilities comparable, CATS large rack & stack equipment, CASS downsized MMS based.
	EO Equipment.	**None** - Capabilities: CATS limited, CASS broad based.
Apache LRUs to F-16 IAIS	PNVS Electronic Unit Assembly.	**None** - Full capability exists.
	PNVS Night Sensor Assembly.	**None** - Stimulus and measurement requirements exist, holding fixture augmentation needed.
	Day Sensor Assembly.	**None** - TPS augmentation of a transformer (on qualified parts list-QPL) needed.
	TADS Night Sensor Assembly.	**None** - Temperature probe, voltage divider and variable temperature target source required for TPS interface adapter.
Key to acronyms: Common Automatic Test System (CATS), Consolidated Automated Support System (CASS), Electro-Optical (EO), Forward-Looking Infrared Radar (FLIR), Integrated Family of Test Equipment (IFTE), Hardware (HW), Improved Avionics Intermediate Shop (IAIS), Infrared (IR), Line Replaceable Unit (LRU), Modular Measurement System (MMS), Pilot Night Vision System (PNVS), Target Acquisition and Designation System (TADS), Test Program Set (TPS), VME Extended for Instruments (VXI), Weapon Replaceable Assembly (WRA)		

2.4 DOWNSIZED TESTER APPROACHES

Appreciable size reductions of modern general purpose ATS are achievable only by eliminating test system capabilities or by introducing highly tailored design solutions.

Two critical findings are central to this conclusion: (1) the term "downsized tester" addresses an amorphous concept with little meaning outside of the context in which it is used, and (2) tester downsizing approaches are technology limited and directly define tester application limits by trading off capability for smaller size. The following paragraphs present the context that the term "downsized tester" is used within DoD, provide details of tester downsizing approaches, and summarize the consequences of tester downsizing.

Downsized Tester. There exists no clear or consistent definition of a downsized tester. The term "downsized" is not technically defined, and so is meaningless if taken out of context. Within DoD, the term *downsized tester* most often represents an ATS with one or more of the following attributes: reduced volume, reduced weight, and reduced deployment load relative to another tester or group of testers that meet some predetermined set of testing needs.

For example, the Air Force F-15E Mobile Electronic Test Set (METS) has been referred to as a downsized tester. This tester was acquired as an alternative to three existing F-15 aircraft ATE that deploy with the aircraft: Computer Test Station; Communication, Navigation and Identification (CNI) Test Station; and Indicators and Control (I&C) Test Station. The F-15E METS alternative, although it has less functional testing capability than the three individual testers, is 21,000 pounds lighter, 4,000 cubic feet smaller, and requires 7 fewer pallets to transport than the other three test stations.

From another perspective, a tester is "downsized" if it reduces the total deployment loads, usually aircraft pallets, needed to transport full system testing capabilities. In this context, IFTE could be used to further reduce the full ATS deployment burden of the F-15. IFTE is a highly mobile van tester that requires only 2.5 pallets. With only modest modification, IFTE would exceed testing capabilities of the existing METS, and at the same time could replace other F-15 tester requirements for electronic warfare (EW).

Tester Downsizing Approaches. Given the current state of test technology, a downsized tester is nearly always synonymous with limited range testing capabilities. This reduced tester functionality manifests itself from two perspectives: (1) the physical elimination of testing capabilities that would have been present in a more general purpose tester, and (2) the unique design of special purpose testing functions with limited testing performance capabilities. These may be applied separately, or in combination, to produce a tester that meets testing needs of only a limited class of items. The apparent shrinking of a tester's size is almost always achieved by a combination of three methods:

- **Reduction of Tester Functionality**. Reduction of functionality achieves the greatest potential for physical tester size reductions by eliminating or excluding ATE elements. However, this method tends to inhibit consolidation of multiple tester requirements and tends to increase total weapon system tester-related deployment burdens (i.e., greater weight and volume, and multiple application specific testers versus a single general purpose tester). The IFTE and CASS programs both avoided this method, and specifically designed general purpose testers that address a broad spectrum of functional requirements.
- **Packaging UUT unique test resources in active IDs**. The packaging of test resources in an active interface adapter reduces a tester's physical size, but tends to increase total tester deployment weight and volume burdens. The size difference for ATS element resources, whether installed in the tester or ID, is minor. However, total tester deployment burdens increase when element resources are replicated in multiple ID types. The IFTE and CASS tester designs incorporate a broad range of test resource capabilities specifically intended to minimize this duplicative packaging concern.
- **Application of Newer Technology**. The physical size of a tester may be reduced by applying new technology ATS elements that take advantage of more densely packaged components (i.e., advanced microelectronics devices, advanced device packaging approaches, and new reduced form factor architectures). IFTE and CASS make extensive use of advanced, state-of-the-art, technologies to meet design requirements. For example, no further downsizing of instrument back-plane interfaces used on IFTE and CASS are on the horizon in the electronics industry. However, this downsizing approach may have negligible influence on ATS size reductions for the immediate future, because these new instrument back-plane interfaces have become the predominately preferred architecture in both military and commercial tester applications. No other near term tester size reductions, driven solely by the application of newer technology were identified during this study.

Consequences of Downsizing. The consequences of downsizing ATS are less general purpose functionality, reduced system performance, higher costs (development, production, and support) per functionality, and greater obsolescence potential. Figure 4 presents a summary of design trade-offs that influence the size of automatic test systems. The design alternatives for reducing ATS size have a tendency towards design solutions indicated by the arrows in this figure. The design trade-off examples are discussed in the following paragraphs.

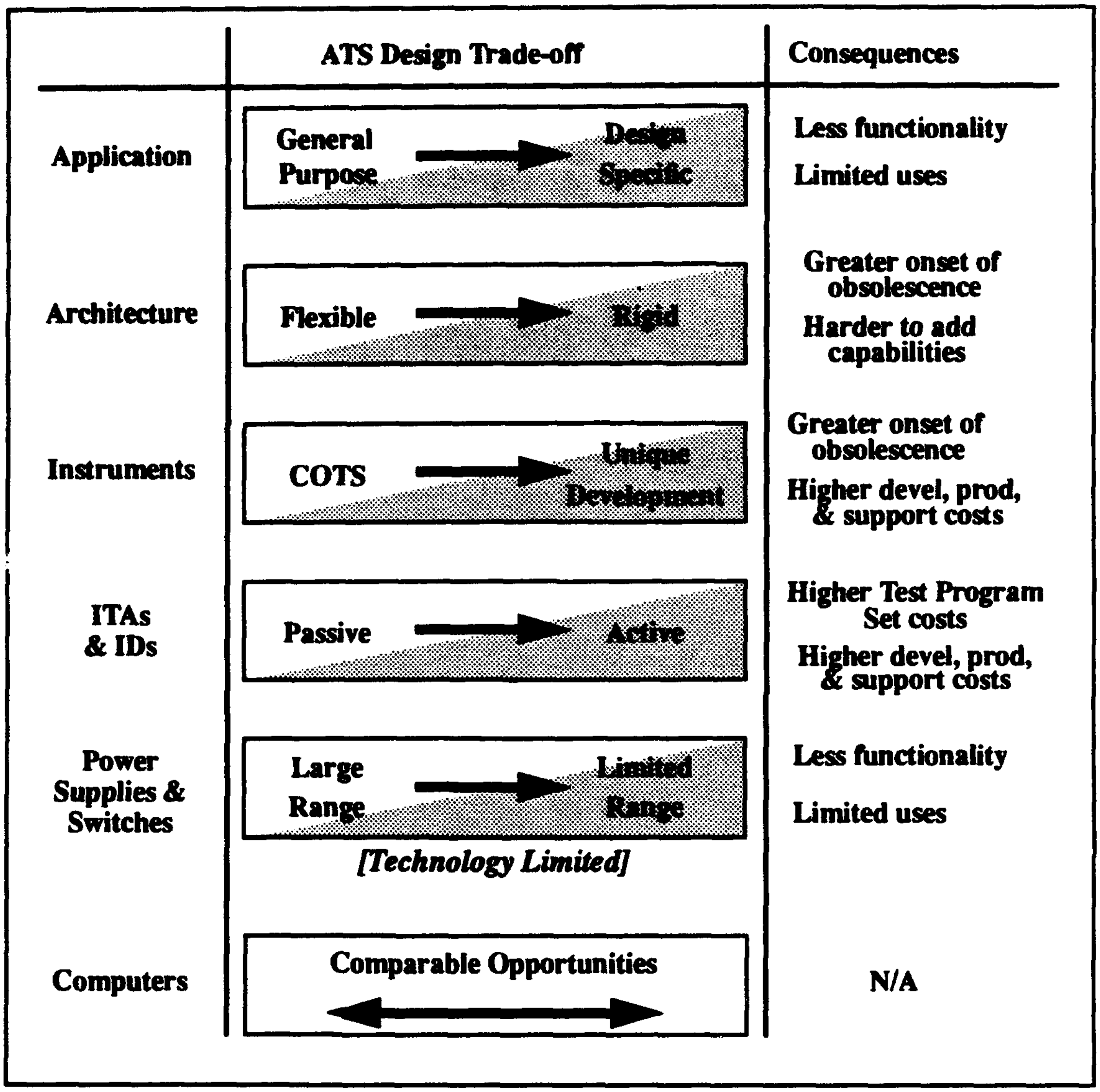


Figure 4. Design Alternatives for Reducing ATS Size

- **General Purpose versus Design Specific.** The physical size of the F-18 Intermediate Avionics Test Set (IATS) was downsized by using UUT-specific stimulus and measurement functions in place of general purpose instruments. This approach limited fault detection and fault isolation capabilities. Furthermore, this approach limited upgrade capability to accommodate changes resulting from evolving avionics systems. The F-18 IATS applied testing process used fault trees and nominal input/output stimuli that simulated functional applications in order to identify sets of probable faults. This resulted in ambiguity groups of potential failed items that were further isolated manually by switching and installing maintenance assist modules (MAMs) that represented known "healthy" examples of the suspect units under test. The difference in applied functionality is further illustrated by comparing the F-15E Mobile Electronic Test Set (METS) downsized automatic test system with the Navy CASS. The difference in applied functionality is several orders of magnitude: the F-15E METS tests 22 line replaceable units (LRU) relative to current estimates of over 1,250 subsystems and assemblies to be tested by CASS.

- **Flexible versus Rigid Architecture.** New, more rigid architectures will be required if smaller form factors than may be accommodated by either VXI or MMS are desired. VXI stands for VME-bus Extension for Instruments, and MMS stands for Modular Measurement System. These smaller form factors require unique design solutions with tailored architectures that use non-standard protocols and non-standard mechanical and electrical interfaces. Tailored architectures tend to restrict the flexibility of the ATS to accommodate new testing functions since the number of available instruments, especially COTS, is substantially reduced. Consequently, there is a greater potential for obsolescence due to diminishing manufacturing sources as production quantities decline. Furthermore, unique, non-standard architectures tend to complicate design and modification processes.

  VXI & MMS buses are examples of the most recent developments of flexible instrument interface architectures. This level of technology is found in both IFTE and CASS. At present these two instrument interface standards represent the smallest general purpose form factor available. Their flexibility is derived principally by the wide-range of commercial off the shelf (COTS) instruments available and compatible with these architectures. No further downsizing of these or other instrument back-plane interface architecture standards are on the horizon. According to key DoD suppliers, the industrial base has not recovered the R&D that went into these downsizing improvements, and therefore, development resources to support further downsizing are unlikely. Furthermore, they perceive that the need does not exist to further reduce the integrated ATS form factor at this time.

- **COTS versus Unique-Developed Instruments.** Instruments that meet rigid architectures or special limited (non-general purpose) stimulus, measurement, power, or load ranges are generally not available as COTS products. Non-standard and uncommon specifications require unique developments with commensurate higher development, production and support costs. Uniquely specified products tend to be more expensive because non-recurring costs are not amortized across multiple applications. The causes for a greater rate of obsolescence both for the individual instruments and the integrated ATS are the same as those described in the prior paragraph.

  The dominant test equipment technical and engineering capability resides with the commercial tester and instrument manufacturers. As an example, instrument vendors have delivered COTS resources that were developed within the last three years to CASS. The vendors observed that the currency of the general purpose test instrument resources packaged in MMS for CASS represents the performance limits available either as COTS instruments or as uniquely developed instruments. In general, COTS instruments meet or exceed the technical performance requirements and possess less cost and programmatic risks than presented by the development of specialized ATS instruments.

- **Active versus Passive ITAs & IDs.** Smaller (downsized) ATS form factors have often been achieved by placing functional capabilities of principal ATE elements in active interface test adapters (ITA) or interface devices (ID). For example, additional functional capabilities, such as an extra RF interface, might be needed at a unit to be tested. Consequently, the ID must incorporate the corresponding instruments needed for each functional capability not provided by the ATE.

  A general purpose ATE design does not preclude requirements for active IDs to meet each and every test requirement. However, the tendency is for a general purpose tester to meet more of required testing functionality than a downsized tester, since greater range and depth of the functional testing capabilities are incorporated as elements of the general purpose ATE.

Data collected shows that test program sets are more expensive for uniquely tailored downsized testers with active interface test adapters. The cost for TPS development and ITA production was found to be approximately two times as high for downsized testers than for full sized general purpose automatic test systems (e.g., F-18 IATS vs. F-18 MV).

- **Large Range versus Limited Range Power Supplies and Switches.** IFTE and CASS incorporate a large range of UUT programmable power supplies and loads. Both were designed to meet a wide range of power and switching requirements that are found across multiple weapon systems. In general, as the range of power supply and switching features shrink, there is a corresponding limit to the testing applications.

  CASS incorporates power conditioning features that regulate and control input power. Also, CASS has backup power features that ensure if power is lost, the station will orderly shut down and save data under controlled conditions. These power features makeup over 20% of the core CASS station. Power-related features could be removed, provided by facility sources, or tailored to meet UUT specific testing needs. However, if removed, CASS would lose some of its current testing capabilities. Similarly, the range of ATS stimulus and measurement capabilities may be limited by selectively deleting building block components, instruments, or other principal ATS elements. In the case of the IFTE, the weight and volume of the generators (or an equivalent power source) must be accounted for in the total IFTE form factor for operational applications.

These design trade-offs are illustrated by the following. Recently the Marine Corps outlined requirements for a downsized automatic test system. Their initial perception was that the form factors of IFTE and CASS were excessive relative to operational requirements. However, upon in-depth review of testing requirements, all of the CASS general purpose capabilities were required. Furthermore, packaging all of these capabilities in multiple ATE would have would have duplicated common ATE elements, and resulted in a larger total ATE volume. Therefore, the Marines decided to install the CASS stations in vans for mobile use. Since CASS was to be repackaged, the Marines discussed the feasibility of deleting some levels of testing functionality in order to achieve a reduced form factor. The Marine Corps decided they needed full specified functionality to meet mission requirements. Therefore, a single composite CASS station occupying 6 racks, plus another half rack for EO, will be used to meet their mobile ATS requirements. This provides an example of the flexible architecture benefits to accommodate change, yet permit the retention of a common ATS standard family.

Further downsizing of any full range general purpose tester, including the IFTE and CASS automatic test systems, without reducing testing functionality, would require substantial technology breakthroughs in areas such as power supplies, and switches. Conversely, as requirements to add testing functionality to a given downsized ATS grow broader, either the physical size of the tester begins to approximate a full function (e.g., general purpose) tester or the combined volume of the tester and the required additional active interface test adapters approximates or exceeds that of a full function tester.

2.5 IMPACT OF WEAPON SYSTEM BUILT-IN-TEST

Built-in-Test (BIT) will not substantially change ATS requirements for off-equipment repair over the next decade.

Built-in-Test will not eliminate off-equipment testing needs. Built-in-Test provides a valuable function as one of several tools for detecting and analyzing system faults; however, it does not have the same accuracy and range of testing capabilities as modern general purpose automatic test systems when used for off-equipment testing.

The capability of Built-in-Test to identify and isolate problems is limited and highly system dependent. Where BIT technology is most mature, most notably digital applications, there are still significant fault coverage limitations. These limitations generally fall in two categories: (1) performance verification over the broad range of environment and signal timing excursions is not practical with current digital BIT technologies, and (2) the standards needed are not widely nor universally applied.

The first category is due to size and complexity limitations. Implementing capabilities equivalent to a digital test unit (DTU) of similar complexity and performance as found on the CASS at multiple BIT nodes within a system is neither practical nor feasible. Therefore, BIT applications are limited to assessing some level of performance around a nominal threshold while operating under normal conditions.

The second category is due to the lack of widely applied standards. Effective digital Built-in-Test requires architectures that permit dedicated fault detection and fault isolation interface and communication with chips, multi-chip carriers, modules, circuit boards, interface busses, and system protocols. Review of the F-22 aircraft advanced avionics revealed that close to a quarter of its microcircuit devices may be commercial or militarized commercial products (i.e., meet extended temperature, environmental, and reliability constraints) that do not incorporate BIT interface features. Consequently, major portions of critical F-22 avionics circuitry must either be void of BIT or must be redesigned to incorporate BIT capabilities such as boundary scan and diagnostic bus interfaces.

BIT capabilities that fall outside the digital domain present an even greater challenge. The ability of current BIT technology to detect and diagnose to a unique faulty replaceable unit or component rapidly degrades as the testing spectrum broadens to mixed signal, analog, radio frequency, and electro-optics (EO). For example, requirements for high radio frequency (RF), and microwave exceed most current BIT technical capabilities. Yet future weapon systems, as illustrated by technology distribution projections for new aircraft avionics in Table 12, will have a majority of subsystems that fall in the domains where Built-in-Test is either limited or impossible at this time.

Table 12. Technology Distribution for Advanced Avionics Subsystems

Aircraft	Digital	Analog and Mixed Signal	RF and EO
F-22	24%	43%	33%
A-12	42%	33%	15%

Built-in-Test is advocated as the dominate approach for future fault detection and fault isolation of advanced ground electronic and avionic systems. The principal target of BIT designs is on-equipment detection of faulty removable units. While this may lower the number of Cannot Duplicates (CND) seen between organizational-level, intermediate-level, or depot maintenance, it does not address the testing requirements for off-equipment automatic test systems. In fact, proper diagnosis and repair of systems incorporating Built-in-Test requires increased automatic test system complexity with special test features and buses for built-in-test hardware.

Even where technically possible, extensive BIT implementation may not be feasible. Built-in-Test is difficult to incorporate because it requires custom engineering for each item. Furthermore, it increases costs, reduces reliability, and adds additional weight and power use. Built-in-Test is subject to the same system engineering trade-off analysis as any other system function in a complex system. With ever improving reliability, on-equipment Built-in-Test, other than for performance assessment, will often be deleted in an overall system performance or economic trade-off analysis.

Off-equipment work load is anticipated to decrease because of increased item reliability. Continuing design complexity growth is resulting in decreasing fault isolating capability of Built-in-Test for off-equipment testing. This condition is increasing the engineering complexity of off-equipment test program set development and ATS.

2.6 TEST SOFTWARE DEVELOPMENT & SUPPORT ENVIRONMENT

Cost-effective test software engineering and rehosting requires new standards, and development and support environments for test information and software.

Software development, acquisition, and rehosting represent major costs for ATS systems. Although hardware still represents the dominant R&D and production ATS cost category for field or intermediate-level maintenance applications, newer systems are showing a trend towards increasing software percentages. At depots, the test program software costs as a percentage of total ATS acquisition costs were generally higher because of the favorable utilization that depots can achieve by concentration of test resources. The depot test software costs often averaged 50% of the total acquisition costs. Selected examples are summarized in Table 13.

Table 13. Software Costs as a Percentage of Total ATS Acquisition Costs for Selected Applications

ATS APPLICATION	SOFTWARE COSTS (Percentage of Total ATS Acquisition)
F-18	20%
F-22	32% to 35%
Depots	~ 50%

Costs for software become important in the ATS life cycle beyond acquisition. As an ATS ages, it often must be replaced with more modern equipment because of hardware obsolescence and non-availability, or new capability requirements. The cost of rehosting software often becomes the deciding factor. At present, the Navy is investing over $800 million in rehosting software from six aviation testers onto the standard Navy tester, CASS. Although this price tag is high, it represents an overall cost avoidance relative to what the total costs would have been if the Navy had continued to modify and support the six old testers rather than off-loading to CASS.

Analysis of TPS development and support expense categories were conducted, and against each of these categories, potential cost reductions for the software environment were estimated. The estimates were formulated around potential technology improvements and software environment standards yet to be developed. Therefore, the cost reduction estimates were divided in to near- and long-term opportunities. Table 14 summarizes these results. If a mature, long-term capability was available and applied against the projected TPS rehosting burden from obsolete automatic test systems to CASS as planned by the Navy, the cost savings would exceed $500 million.

Table 14. Test Software Development and Support Environment Cost Benefits

TIME FRAME	POTENTIAL TPS DEVELOPMENT COST REDUCTIONS
Near Term (5 - 10 years)	17%
Long Term (10 - 20 years)	70%

Case studies revealed that the development and implementation of common ATS software development and support environment would reduce total weapon system ATS acquisition costs by 8% to 10%. (Note that this represents additional acquisition savings over and above potential savings that are due to an ATS family acquisition strategy.)

Without the development of new common standards for software development and support environments, the only currently available technical solution to achieve operational commonality across ATS applications is for each ATS to have 100% identical assets.

2.7 IMPACT ON INDUSTRY

Applying a standard ATS families acquisition strategy will not adversely affect DoD's ability to acquire test resources from industry.

DoD ATS research and development and production expenditures are spread across a large number of contractors, with a small fraction, typically less than 10%, of the ATS market in any one firm. Critical automatic test technical and engineering capability resides in the commercial sector instrument manufacturers, and more recently for critical automatic test technical and engineering capability for test subsystems resides with commercial sector ATS providers. In no case do DoD sales exceed 50% of the sales of major commercial ATS and instrument providers. Furthermore, many of the instruments and ATS subsystems required for DoD automatic test equipment are widely required in the telecommunications and computer industries.

Only a few companies have automatic test systems as their principal business, and their technical capability is in the systems integration business. The most recent ATS development programs are relying heavily on commercial instruments and subsystems, and the value added has been in the design integration, system packaging, and software environment.

The dominant software standard, ATLAS, has been co-developed with the commercial airline industry. There are numerous test software environment development companies, many of which are small businesses. These conditions are summarized in Table 15.

Table 15. Availability of ATS Component Sources

ATS COMPONENT	SOURCE
Test instruments	Multiple COTS Sources
TPS software	Broad set of competitive sources
Test operating software	A few emerging commercial suppliers
Test development environment	Commercial CAE companies and a few emerging integrated test environment commercial suppliers
ATS	Prime weapon or subsystem providers

Looking at total acquisition quantities for DoD versus the commercial sector and across the broad sets of ATS element sources, the authors concluded that a DoD ATS family strategy will not adversely impact ATS industries. Although the actual amounts are proprietary, and therefore not presented here, the test equipment and instrument vendors interviewed observed that DoD constitutes only a small percentage of their market. For example, the world market test instrument sales are over $6 billion annually. The delta to these world wide test instrument sales attributed to the DoD ATS estimated savings would average less than 1% per year.

From another perspective, the combined 1992 sales of VXI and MMS instruments represent less than 2% of the total instrument market. If adjusted for comparable product market share, this percentage increases to approximately 16%. Assuming test instruments and other test resources represent about 50% of the anticipated savings identified by the analyses in this study, the potential impact of a DoD ATS family investment strategy will be less than 8% of this specific market.

TPS software is supplied by a broad set of contractors in highly competitive procurements. Consolidation on common automatic test equipment would improve TPS quality by providing a smaller set of target ATE systems to focus TPS development process and third-party tool development. ATS common operating software and TPS development software are developed by a broad set of computer-aided engineering (CAE) vendors to both commercial and defense contractors.

The authors observed that ATS expenditure reductions of the relative magnitude identified in this study might be attributable solely to DoD budget reductions. An ATS family investment strategy was found to provide the means to (1) compensate for potential budget resource reductions and (2) meet weapon system ATS needs, both without adversely affecting operational ATS capabilities nor adversely affecting ATS industry.

2.8 PURPOSEFUL REUSE OF ATS RESOURCES

Standard ATS families will promote the purposeful reuse of test equipment and test software across factory, depot, and operational maintenance.

Standard general purpose ATS were found to facilitate and promote the reuse of ATE and TPS elements. Also when used at multiple maintenance levels, common ATS families tend to improve the relative diagnostic accuracy of testing results.

The opportunities to purposefully reuse test equipment and test software are many and varied. Automatic test systems for factory in-process and acceptance testing are typically developed and controlled by the contractor. The authors observed that the entire area of factory automatic test systems might prove to be a fruitful area for future investigation because of the large dollar amounts involved. For example, AMRAAM acquired 350 test stations of 190 types for 24 factory-level locations, mostly special purpose with unique software. The Joint Air Force and Navy Advance Medium Range Air-to-Air Missile (AMRAAM) program reported approximately $350 million for special test equipment (STE), of which around $70 million was Government furnished equipment (GFE) special test equipment. DoD currently has listed GFE special test equipment valued at $10.5 billion. Due to the limited availability of factory ATS data, conclusive observations on the benefits of common in-process factory automatic test systems were not possible. To be consistent with other categories of collected and summarized data, this factory information was not included with the weapon systems ATS summary data.

Early selection and fielding of an ATS standard family will help to avoid costly interim support over the lifecycle of the weapon system. Early selection (i.e., by the start of the EMD phase) ensures that an automatic test systems will be available for factory acceptance testing and permits sound concurrent engineering practices to be followed in the design and implementation of system, diagnostic, and support capabilities elements. Frequently the same testing capabilities and requirements that are needed for factory acceptance are also required in Service depot and intermediate maintenance level testing.

ATS for intermediate and field testing requirements have historically been specified and developed late in the EMD or production phase. Consequently automatic test systems (and especially the test program sets) are delivered late, relative to operational need. When this occurs, interim contractor support is used to compensate for the lack of testing capability. If an ATS family is designated early, the tester may be used for factory acceptance, thereby permitting early maturity of organic depot and field ATS maintenance capabilities. A Center for Naval Analysis (CNA) case study, analyzing F/A-18 aircraft test and support requirements, estimated an interim support cost avoidance of around $900 million would have been possible had the required automatic test systems been deployed concurrent with the weapon system. The Navy stated that concurrent ATS deployment with a weapon system is now a standard goal and expects to use this approach extensively with CASS.

The purposeful reuse of test equipment and test software across factory, depot, and operational maintenance is tied directly to three ATS design factors: Test Strategy, Data Transportability, and ATS Flexibility. Using the designated ATS families at multiple application levels reduces potential limitations for reuse of TPS. In addition, the greater the flexibility of the ATS, the greater the potential of reusing test equipment and test software across factory, depot, and operational maintenance.

ATS flexibility describes an ability of the testing system to adapt to different UUT test requirements. In general, it is easier to transport TPS elements from one automatic test system to another of equal or greater flexibility provided they both have, or may incorporate, capabilities to cover the same testing requirements spectrum. The effect of ATS flexibility on the ease of transporting TPS elements may be addressed from several perspectives: the ability of the automatic test systems to accommodate new requirements at flexible physical interfaces, the ability to accommodate the same range of stimulus and measurement performance properties across ATE versions, and the degree to which a TPS specification language will accommodate common syntax and common testing methods.

Reuse of TPS elements is severely impeded when target automatic test systems are neither identical nor incorporate features that foster ATS flexibility.

The standard ATS approach avoids the need to account for differences because the equipment is identical at all levels. Since it is unlikely that total standardization could (or should) be achieved, highly flexible architectures that accommodate a wide range of general purpose testing needs are most desirable. The advantages of standard ATS families and flexible general purpose tester architectures are both available with CASS and IFTE.

PART III
ANALYSES

3. ANALYSES OVERVIEW

Analyses were conducted in conjunction with the DoD Automatic Test System Investment Strategy Study. Reviews of ATS costs, use, policies, processes, and organizations were conducted, involving over 100 hours of technical interchange meetings (TIMs) and OSD/Service Executive Steering Group (ESG) meetings between February and November 1992. Data were collected and analyses performed by a study team of 12 full-time team members, with support from more than 80 representatives of DoD and industry. IDA continued collecting data and performing analyses through March 1993.

The study was partitioned and organized as several separate analyses. The following provides an overview of each analysis and highlights their interrelationships.

Section 4, Baseline Data. ATS data from 15 weapon systems were collected and subjected to detailed analysis. Principal results included summaries of ATS costs and quantities, percentages of ATE and TPS development and production costs, and ratios of ATS to weapon system production costs by system type. Results were used to establish a baseline for subsequent analyses.

Section 5, Alternative ATS Investment Strategies. ATS investment strategy options were evaluated in this section. Principal results included an economic payoff analysis that was based on four weapon system case studies. Baseline data from Section 4 were used extensively to develop the individual case study scenarios. A common ATS family investment strategy was found to have the greatest economic benefits.

Section 6, DoD Investment Assessment Analysis. This analysis characterizes total DoD ATS investments, and projects the savings that will result from a new DoD common ATS family based investment strategy. This section describes in detail the evaluated investment strategy, the model used to conduct the evaluation, and the range of savings that may be realized if the new ATS investment strategy is adopted. This analysis makes extensive use of ATS baseline data (Section 4) and ATS investment strategy evaluation results (Section 5).

Section 7, Policy, Process, Funding and Organizations. This section summarizes the principal ATS policies, and describes the predominant ATS management process and funding flow for DoD organizations found to be involved with ATS acquisitions. Analysis addresses dispersed investment decisions, both within as well as across Service and weapon program lines, and describes how distributed ATS management has been a major contributing factor to DoD ATS proliferation.

Section 8, ATS Capabilities and Applications. This section describes the capabilities of DoD designated ATS standard families, and demonstrates the technical feasibility of following the investment strategy evaluated in Section 6. ATS test capability envelopes and selected weapon system testing requirements are compared.

Section 9, ATS Technology Development and Evolution. This section of the report provides an analysis of ATS technology development and evolution influences that have a direct affect on ATS used by the Services. Development and evolution are addressed from six different perspectives: ATS industry, standardization, TPS development and support environment, vertical testability, Built-In-Testing (BIT) applications, and DoD unique ATS needs.

To help manage the study work load and scope, the ESG selected 15 weapon systems as representative of DoD-wide programs for ATS data collection and in-depth analysis. Data collected from these 15 systems were used to establish a baseline that characterizes ATS acquisition costs, scale, and investment focus. The team also complied a comprehensive library of ATS related information from previous studies, DoD and industry technical perspectives, and Service policies and standards.

This information was used to characterize and assess the magnitude of DoD's ATS investments, to evaluate selected investment options, and to characterize economic, technical, and mission benefits of an improved DoD ATS investment strategy. The following sections (Sections 4 - 9) describe the major findings and conclusions in the context of the specific analysis where they were observed. Unique analysis details, background discussions, and study constraints are described where they are pertinent to the respective analysis section.

4. BASELINE DATA

4.1 BACKGROUND DISCUSSION

The initial phase of this study effort was dedicated to the collection of data necessary to characterize the scale and scope of current ATS investments. The intent of this initial phase was to characterize relationships of various cost elements in the acquisition of ATS. This data was considered fundamental to the study and formed the baseline for all investment related analyses. Because of the broad expanse of these topic areas, the ESG directed the study team to use existing data and previous studies to the maximum extent practical, and to focus new data collection on the 15 selected weapon systems shown in Figure 5.

• Abrams (M-1) *	• Avenger *	• F-16
• ACM	• AX (A-12) *	• F-18 *
• AMRAAM *	• Bradley *	• F-22 *
• AN/SQQ-89	• C-17 *	• MK-50
• Apache/Longbow *	• F-15 *	• MLRS

* In Depth History/Projection

Figure 5. Weapon System List for ATS Study

The Executive Steering Group included the new Navy AX aircraft on the weapon system list, and suggested that data from the cancelled A-12 program might be used to supplement incomplete information. To simplify references to the Apache/Longbow and the AN/SQQ-89, they are generally referred to as the Apache and SQQ-89 respectively throughout this paper. References to the M-1 and Abrams tank are used interchangeably throughout the paper.

Five technical interchange meetings (TIM) were conducted during 1992. The TIMs were used to present the data requirements and to support the data collection. Service representatives at these meetings were asked to coordinate the collection and delivery of detailed information on specific ATS types used or planned for each of the designated weapon systems. Copies of the charts used to identify the baseline data requirements at the TIMs are included in Appendix A, *Data Request Formats and Details*. To narrow the scope of the data collection work load, the ESG identified systems within this group as the most representative of current DoD ATS needs. These systems are marked with an asterisk in Figure 5, and the study team attempted to obtain in-depth historical data as well as detailed projected ATS requirements for each system.

The TIM agenda was structured around the overall data requirements, and each TIM covered a different set of ATS topic areas:

- TIM#1: March 13 - ATS Organizational/Managerial Baseline & Common ATS Baseline
- TIM#2: March 25 & 26 - Technology & Related Commonality Issues/Trends
- TIM#3: April 9 & 10 - ATS Acquisition Process & Factory Testing Issues
- TIM#4: April 21 & 22 - Field & Depot ATS Commonality Issues
- TIM#5: May 4 & 5 - Test Requirements & Test Development Environments

4.2 ATS BASELINE COST SUMMARIES

Tables 16, 17, and 18 summarize the baseline cost data collected. More detailed charts are presented in Appendix E, *ATS Data Summaries*. In general, the study team found ATS acquisition and support data were not easily collected. This was principally because complete libraries of ATS acquisition and support data were not found in the Services. Since this may represent the best source of DoD ATS related acquisition and support data, the following paragraphs summarize the study teams perception of its quality and completeness.

Once collected, most of the ATS related acquisition (R&D and production) data was very complete and was very consistent in form and substance from the different sources. The three exceptions where the data are not complete are marked with a single asterisk in Tables 16 and 18. The study team was unable to obtain reliable TPS information for the MK-50. All of the data collected on the SQQ-89 was considered questionable and incomplete by the study team. The C-17 weapon system acquisition strategy includes the development of ATS as part of a support capability package, and as such, the ATE R&D was not separately priced. The acquisition data reflected what the DoD paid for the products developed and delivered. The populations of weapon system ATS examples for which data were collected must inevitably include acquisition instances of buy-ins, over-runs, sole-sources, etc. No attempt was made to differentiate should-cost estimates from actual expenditures. The authors felt this was a reasonable approach, since the objective was to evaluate several ATS investment strategy options and assess relative benefits rather than determine absolute costs.

The form and substance of the support data varied widely. In general, the ATS related support costs were not complete and could not be used except to indicate trends. The collected depot and factory ATS information focused primarily on electronic subsystems and was also incomplete. Characteristics of the collected baseline data are discussed in more detail in the next section.

Table 16. ATS Summary for Selected Navy Weapon Systems

WEAPON SYSTEM	ATS TYPES/ QTY	TPS R&D ($M)	TPS PROD ($M)	ATE R&D ($M)	ATE PROD ($M)
A-12	1 / 62	183.6	96.5	24.8	155.2
AMRAAM	2 / 27	62.8	18.1	13.8	58.4
F-18	9 / 453	205.5	203.4	142.8	759.8
MK-50 *	1 / 10	not avail	not avail	17.4	19.7
SQQ-89 *	5 / 14	0.2	not avail	not avail	1.7
* Indicates data not complete					

Table 17. ATS Summary for Selected Army Weapon Systems

WEAPON SYSTEM	ATS TYPES/ QTY	TPS R&D ($M)	TPS PROD ($M)	ATE R&D ($M)	ATE PROD ($M)
ABRAMS	4 / 202	11.9	31.9	9.1	182.7
BRADLEY	2 / 230	13.6	32.4	10.6	209.8
APACHE	6 / 47	15.0	33.5	26.7	239.9
MLRS	5 / 14.2	19.0	5.4	3.4	25.8
AVENGER	3 / 48.2	9.3	1.5	17.2	108.8

Table 18. ATS Summary for Selected Air Force Weapon Systems

WEAPON SYSTEM	ATS TYPES/ QTY	TPS R&D ($M)	TPS PROD ($M)	ATE R&D ($M)	ATE PROD ($M)
ACM	4 / 16	27.4	5.1	16.3	11.9
C-17 *	2 / 12	135.0	32.5	0.0	50.1
F-15	24 / 402	703.6	366.7	172.9	1398.9
F-16	10 / 444	251.9	277.0	431.9 **	1074.7
F-22 (est.)	UNK / 338	150.4	51.2	39.3	206.2

* Indicates data not complete.
** Plus additional $338 million product improvement development concurrent with production and fielding.

4.3 BASELINE CHARACTERISTICS

The following sections discuss in detail the issues and findings uncovered during the data collection and baseline data analysis.

4.3.1 DoD ATS Proliferation

Analyses revealed proliferation of ATS types within DoD, and subsequent analyses in this paper show that many of these ATS had duplicative capabilities. The effects of this proliferation on increasing total DoD costs have been recognized by multiple sources. A report, requested by the Assistant Secretary of the Navy in 1976 [ATE 1976], highlighted many proliferation concerns. The results of the report lead to a cost benefit analysis (CBA) and competitive development of CASS. The MATE program was the Air Force's attempt to reduce proliferation and reduce ATS costs. In the past year, four DoD IG audits, three GAO audits, and a HAC special investigation all criticized ATS proliferation found in the Services.

For the 15 weapon systems reviewed, over 100 unique ATS types were identified with total equipment numbers exceeding 2,300. Tables 16, 17, and 18 present summaries of the types and quantities observed. Since the study focused on direct weapon system electronics test equipment, other related weapon system items are not included in these tables. For example, the baseline data focused primarily on onboard system electronics and did not include testing requirements for other equipment such as F-16 pods which have their own unique ATS (i.e., ATS for the LANTIRN and EW - AN/ALQ131). In another example, two Services test the same prime equipment, yet use different automatic test equipment (e.g., the Air Force and Navy use different ATS to test the AIM-9L/M Sidewinder Missile Guidance and Control Section).

Recognizing that some of the ATS data for these selected systems reflect future or projected quantities, four of the Services' current front line weapon systems were assessed separately. Forty-seven unique ATS were identified just for the F-18, M-1, F-16, and F-15 weapon systems alone. The 47 ATS types were found to be used in field (intermediate or "I") and depot level tester applications, and in some cases were found to be used in both applications.

4.3.2 ATS Acquisition Cost Factors

ATS costs are dominated by ATS hardware development and procurement. For example, test equipment and interface device hardware R&D and production costs for the F-18 are over 80% of the total F-18 ATS acquisition cost. This was typical of the weapons evaluated. Emerging programs such as the F-22 projected higher software percentages (approximately 32 to 35%) but are still dominated by hardware costs.

The magnitude of this dominance is illustrated in Table 19. Columns two through five are percentages of principal R&D and production cost categories to the total ATS acquisition costs. The last column summarizes the approximate percentage of hardware costs.

Table 19. ATS Acquisition Cost Factors for Selected Weapon Systems

WEAPON SYSTEM	TPS R&D / ATS ACQ (%)	TPS PROD / ATS ACQ (%)	ATE R&D / ATS ACQ (%)	ATE PROD / ATS ACQ (%)	HW (%)
ABRAMS	5	14	4	77	95
BRADLEY	5	12	4	79	95
APACHE	5	11	8	76	95
F-18	16	16	9	59	85
F-15	26	14	7	53	77
F-16	12	14	21	53	87

Production percentages in this table (both TPS production and ATE production) account for recurring engineering tasks that are almost totally hardware related. The ATE R&D percentages include a mix of hardware and operating system software costs. Nominally, software and hardware ATE R&D percentages are approximately 10% and 90% respectively. For example, the F-16 AIS development costs associated with the control and support software was 9% or $13.5M of $146.9 (FY93$) [MATE 1990]. The TPS R&D percentages also include a mix of hardware and software costs; however, the relative percentages are almost reversed. Data from both the Navy [TPS DEVEL 1992] and General Dynamics [ATE HISTORY] imply that the software costs are approximately 87% of the total TPS R&D. These relative percentages were used to estimate the hardware (HW) percentage column.

Weapon system ATS acquisition cost factors were also evaluated for the F-16 and F-15 intermediate level and depot level maintenance equipment. The hardware costs were still dominant; however, the software cost share increased significantly for the depot cases as shown in Table 20. This condition was found to be ATE quantity dependent and attributed to the fact that greater numbers of each ATE type are found at the intermediate level (I-level) maintenance than found at the depot.

Table 20. ATS Acquisition Cost Factors for Selected Maintenance Locations

WEAPON SYSTEM & MAINT. LEVEL	TPS R&D ATS ACQ (%)	TPS PROD ATS ACQ (%)	ATE R&D ATS ACQ (%)	ATE PROD ATS ACQ (%)	HW (%)
F-15 I-Level	21	16	5	58	81
F-15 Depot	37	7	13	43	67
F-16 I-Level	8	14	22	56	91
F-16 Depot	50	9	19	22	55

A relatively strong grouping was observed for different ATS cost component ratios of similar weapon system applications. Figures 6 and 7 illustrate the grouping of these ratios, first for tactical fighter aircraft avionic systems and second for Army systems. The inference from these tight groupings was that the relative distribution of principal ATS costs was strongly influenced by the complexity and application of the weapon system being tested.

The ATS baseline data for "real" (i.e., not projected) systems were then grouped by six weapon system category types: Weapons Carrier/Tracked Vehicle (WCTV), Missile-

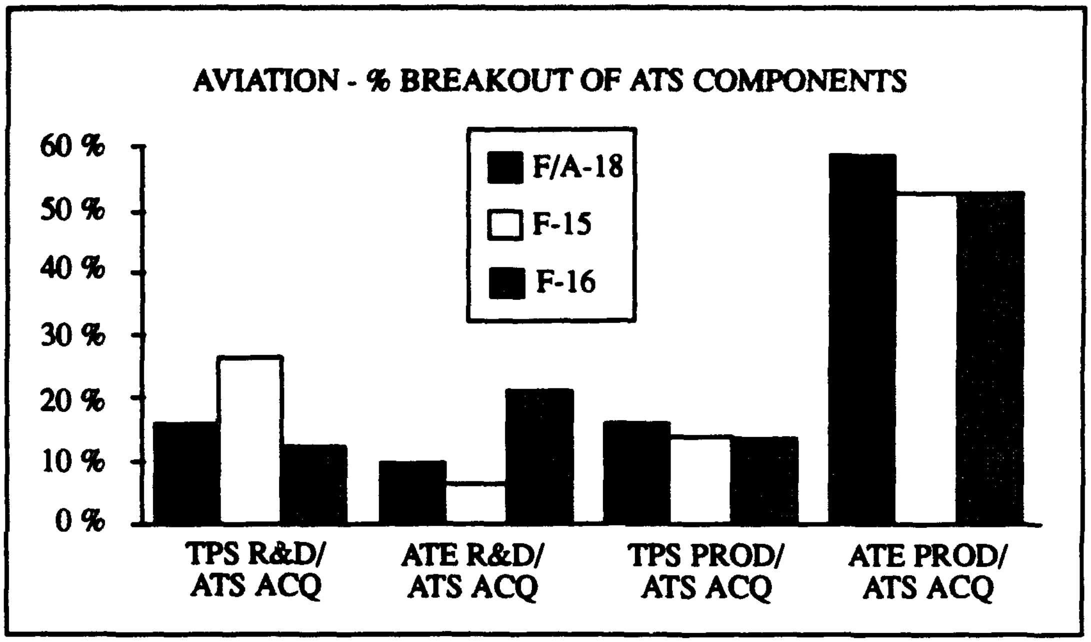


Figure 6. ATS Cost Component Ratios for Selected Aircraft Avionics Systems

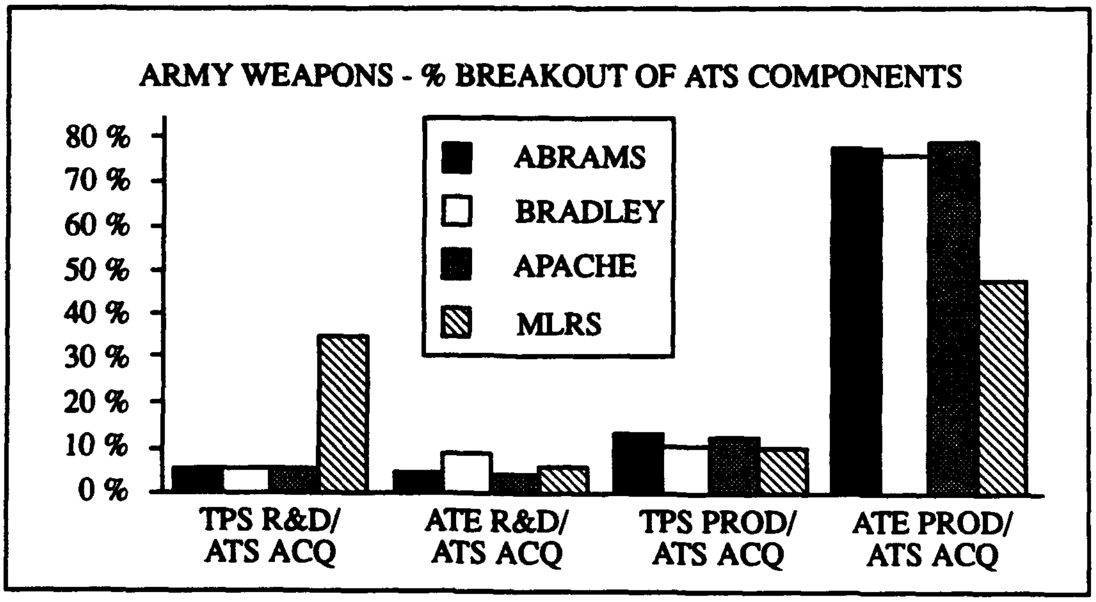


Figure 7. ATS Cost Component Ratios for Selected Army Systems

Terrestrial, Missile-Air Launch, Air-Army, Air-Air Force, and Air-Navy. Table 21 summarizes the results of this analysis.

Table 21. ATS Cost Apportionment Ratios

WEAPON SYSTEM TYPE	TPS DEVEL / ATS ACQ	ATE DEVEL / ATS ACQ	TPS PROD / ATS ACQ	ATE PROD / ATS ACQ	ATS ACQ / ATS PROD
WCTV *	0.068	0.057	0.119	0.756	1.154
Missile Terrestrial	0.148	0.108	0.0367	0.707	1.375
Missile Air Launch	0.375	0.182	0.108	0.335	2.257
Air - Army	0.048	0.085	0.106	0.762	1.153
Air - AF	0.204	0.129	0.139	0.528	1.500
Air - Navy	0.158	0.096	0.157	0.589	1.341
* Weapons Carrier/Tracked Vehicle					

Procurement data for each of the 15 selected weapon systems also was collected and analyzed against the total ATS production costs for each of the weapon system category types. Ratios of total ATS production costs against total weapon system procurement costs were developed for each of the six categories. The results are summarized in Table 22. The ratios in Tables 21 and 22 were used to estimate DoD ATS investments in subsequent analyses which are discussed in more detail in Section 6, DoD ATS Investment Analysis.

Table 22. Ratios of ATS Production Costs To Weapon System Production Costs

Missiles		Aircraft			WCTV*
Terrestrial	Air Launch	Army	Navy	AF	
0.031	.006	0.026	0.027	0.043	0.017
* Weapons Carrier/Tracked Vehicle					

4.3.3 Annual ATS Support Related Costs

Insufficient data was available to rigorously assess ATS operating and support costs. However, for the few systems where data was accessible, the O&S costs were substantial. The best data acquired implied that the annual intermediate level ATS operations and support related costs exceed $40M and $80M for the F-18 and F-16 weapons systems respectively. Data for the other systems was far less complete. Table 23 illustrates the level of accessible data. The large A's and small s's indicate whether the information collected is believed to represent *all* or *some* of each expense category.

O&S data collection was hampered by multiple factors, the most significant being that this type of data was not purposefully collected by any of the Services. Further, the form and substance of the data across support related expense categories varied by Service and sometimes by application. The spares costs for the Navy F-18 were considered accurate and complete because of additional accounting and resource tracking capabilities implemented to handle stock funding of depot level repairables. The service reports and sustaining engineering expense categories for both the F-16 and the F-18 were also considered accurate since there were actual expenditures available for Service review. The F-16 and F-18 data reflects the average funds paid to General Dynamics and Navy Cognizant Field Activities respectively. All of the other data was based on models or algorithms developed by the Services.

Although not well represented by Table 23, all of the technical experts representing the Services at the TIMs indicated that costs for software are important in the ATS life cycle beyond acquisition. As an ATS "ages" it often must be replaced with more modern ATS; the cost of rehosting test software often dominates this decision. The Navy is investing over $800 million in rehosting software from six aviation testers onto the CASS. Although this was determined to be cost effective because of the cost of supporting and updating six different testers over time instead of one (CASS), it illustrates the need for reducing the cost of rehosting software across hardware types. The Navy has developed a CASS O&S cost model that is based upon earlier analysis work and historical data. It is being used to project new as well as rehosting TPS costs, including projected sustaining requirements. Although the accuracy of the model was not assessed, the authors observed that the cost categories were very comprehensive and included all of the categories identified in this study.

4.3.4 Depot ATS

The ATS baseline acquisition data for depots of the selected systems varied in terms of accuracy and completeness. Information was received on depot tester types, their capabilities, and the commercial versus DoD-developed ATS demography. In general, all depots reported some degree of common use of ATS to support multiple electronics items. The custom-built ATS were found to be dominant in the depots (75% custom ATS for most electronics items), many of which were targeted to one weapon or system. This was further sup-

Table 23. Annual ATS Support Related Costs in Constant FY93$(Millions)

Support Related Expense Category / ATS by Weapon System	Operations	Spares & Repair of Repairables	Operational Maintenance	Technical Manuals	Training	Modifications	Service Reports	Sustaining Engineering Maintenance	Hardware Sustaining Engineering	Software Sustaining Engineering	Annual Total Costs Data Identified
ABRAMS			15.4			s	–	–	s	5.8	21.2
ACM	–	–	–	–	–	s	s	s	s	s	4.5
APACHE			18.4			s	–	–	s	1.4	21.4
AMRAAM	–	A	–	A	–	–	A	A	A	A	5.0
BRADLEY			17.2			s	–	–	s	4.4	23.0
F-15 (I-level)	–	–	–	–	–	s	s	s	s	s	16.1
F-16 (I-level)	–	37.8	22.8	0.1	–	0.4	1.4	5.8	14.0		82.3
F-18 (I-level)	–	28.8	–	–	–	–			11.3		40.1
MLRS			2.3			s	–	–	s	1.7	4.0

A = All s = Some – = Not Included = Model Based = Actual Data ported by the realization that much of the depot automatic test systems is refurbished automatic test equipment that has made a transition from the factory.

The relatively small depot commercial tester percentage (only 25%) came as a surprise to the technical experts at the TIMs. The general perception, until viewing the data, had been almost the reverse. This perception difference was attributed to the fact that the custom-built automatic test equipment were generally targeted to sets of unique subsystem testing needs that did not have the visibility afforded many of the general purpose commercial testers that were in frequent demand. However, these representatives did cite numerous examples of common testing requirements that were best met with COTS automatic test equipment, some of which are from common families (or extensions of a family) in the commercial sector. The Army cited a recent example where common testing requirements were consolidated, and a COTS tester was competitively acquired as a common tester for general digital testing needs across multiple systems.

The Navy and Army were found to have more depot-common automatic test systems because of the wide use of VAST and EQUATE, their two previous generations of common ATS families. For the data reviewed, the greatest reuse of intermediate level ATS in the depot was found in the Navy. This high level of reuse was attributed to the fact that the Navy generally tends to move their repair forward (towards the operational weapon system) as much as possible. Therefore, the ATS testing requirements are very similar and these requirements are being met with the same tester. This information was provided at the TIMs or as a result of TIM action items [AF DEPOT], [ARMY DEPOT 1992], [NAVY DEPOT].

4.3.5 Factorv ATS

The study team was unable to obtain accurate accounting of factory ATS investments for the selected systems. However, there is evidence that the DoD investments are sizeable. Over $10 billion in GFE factory test equipment are accounted for in DoD records [GFE ATE 1991]. Furthermore, the bulk of factory ATS is contractor developed or provided, paid for by the Government, but is not included in this GFE accounting.

ATS for factory manufacturing in-process and acceptance testing are typically developed and controlled by the contractor. Federal Acquisition Regulation (FAR) Part 45 directs that equipment to perform contracts is provided by the contractor; however "special test equipment" (STE) may be developed under a contract when "advantages to the Government" [FAR 1992]. In application, many large programs pay a sizeable STE bill. For example, the AMRAAM program is procuring approximately $350 million in STE; about $70 million of their STE is provided as GFE [AMRAAM 1992]. Historically "STE" is specialized enough that it is often retained in the factory. This large STE base is in place across the DoD industry.

5. ALTERNATIVE ATS INVESTMENT STRATEGIES

The authors performed in-depth analyses of alternative DoD ATS investment strategy options. Five investment strategy options were defined, and are summarized in Table 24. Complete option definitions are presented in Appendix C, ATS Investment Strategy Options.

Table 24. Investment Strategy Option Definitions

OPTION	DEFINITION
I	NO CHANGE: No unified or coordinated DOD policy, strategy, or investments. Some minimal coordination in ATE test language area.
II	COMMON ATS FAMILIES: A DoD-wide policy, strategy, and related investments to apply common ATS families.
III	COMMON ATS SPECS: A DOD-wide policy, strategy, and related investments to apply a common ATS specification set.
IV	COMMON SW ENVIRONMENT: A DOD-wide policy, strategy, and related investments to apply a common software environment.
V	WEAPON SYSTEM ENGINEERING APPROACH: A DoD-wide policy, strategy, and related investments for testability based on a weapon system engineering approach

Five evaluation categories for each option were selected by the study team and approved by the Executive Steering Group at the onset of the analyses:

- Economic Payoff,
- Operational Commonality,
- Technological Feasibility,
- Programmatic Risk, and
- Depot Efficiency.

Information available for evaluating the ATS investment strategy options under the Economic Payoff category was quantitative in nature and included ATS development, production, and support cost data. In contrast, information available for evaluating each of these strategy options under the remaining categories was more qualitative or subjective in nature.

Therefore, the analyses presented in this section of the paper are divided into two independent analyses: Section 5.1, Economic Analysis, and Section 5.2, Qualitative Analysis.

5.1 ECONOMIC ANALYSIS

The economic analysis was based on ATS acquisition and O&S cost data. The ATS acquisition costs include all costs associated with development, production, and major modifications. The ATS O&S cost data collected and presented here are less complete and include ATS operation, maintenance, training, and spares cost information. Due to these data completeness differences, the economics analysis is divided into two sections: ATS Acquisition Costs, and Operations and Support Costs.

5.1.1 ATS Acquisition Costs

This section summarizes a major analysis effort conducted in conjunction with the study. Due to its complexity, it is divided in three major sections:

- Case-Based Analysis Approach,
- Cost Factors for ATS Investment Strategy Options, and
- ATS Acquisition Case Studies.

The first section provides an overview of the approach used to assess ATS acquisition cost differences for the selected investment strategy options. The second section summarizes the rationale that went into the selection of option cost factors used in the case studies. The third section describes four weapon system ATS case studies used to compare the ATS investment strategy options.

The first four investment strategy options were compared: Option I (Baseline-No Change), Option II (Common ATS Families), Option III (Common ATS Specifications), and Option IV (Common Software Environment). Since technology advances are needed before the full advantages of Option IV may be realized, this option was evaluated from both near- and long-term perspectives.

The investment strategy described as Option V (Weapon System Engineering Approach) proposes to selectively apply aspects of the other four options. No consistent approach for applying Option V cost factors could be defined. Without a consistent approach across each scenario, there was no basis for when to apply and when not to apply a cost factor. Since results would be suspect and open to broad and inconsistent interpretation of each application assumption, Option V was not separately evaluated. However, details presented in this economic analysis section show syntergistic benefits of combining acquisition strategy elements of Options II and IV. Therefore, the strategy evaluated in Section 6.0 of this study selectively applies aspects of other options, and is similar to some aspects of Option V.

The case study analyses showed, in every weapon system scenario examined (F-18, F-16, F-15, and M-1), that a sizable acquisition cost avoidance is possible by eliminating multiple unique ATS developments and procurements and instead using or modifying a selected set of standard tester families. As reflected in Table 25, projected acquisition savings averaged 25 to 35%. The savings were attributable to significant reductions due to shared development costs, production economies of scale, and increased tester work load efficiencies. The details of this analysis are provided in the following three sections.

Table 25. Case Studies ATS Development and Production Costs (Constant FY93$ in Millions)

SYSTEM CASE STUDY	OPTION I (Baseline - No Change)	OPTION II (Common ATS Families)	OPTION III (Common ATS Specs)	OPTION IV (Common SW Environment) Near Term [Long Term]	
F/A-18	$1,321	$577	$1,184	$1209	[$1129]
M-1	$394	$300	$364	$390	[$383]
F-16	$2,374	$1,716	$2,161	$2,316	[$2,140]
F-15	$2,501	$1,602	$2289	$2,381	[$2,012]

5.1.1.1 Case-Based Analysis Approach

A two-step approach was used to assess the four selected investment strategy options.

- Step 1: ATS investment strategy options were analyzed and assigned ATS cost factors.
- Step 2: These ATS option cost factors were then applied to specific weapon system life cycle case study scenarios.

Step 1: Generic ATS expense categories were selected for ATS development and production. The effects on each ATS expense category by investment strategy Options II, III, and IV were assessed and compared against the Option I (Baseline). The result was a matrix of option cost factors for each ATS expense categories. These cost factors were each computed as a ratio against its respective baseline expense category that had been assigned the value of 1.0. This produced cost factors all normalized relative to the baseline option. Step 1 is described in the next section, Cost Factors for ATS Investment Strategy Option.

Step 2: Four weapon system ATS acquisition life cycle scenarios were developed for use in case-based analysis. The four weapon systems used for these case studies were the F-15, F-16, F-18, and M-1. The scenarios for the weapon systems ATS were derived from the collected baseline data. Actual expenditure data was used where possible throughout the analysis. The option cost factors developed in step 1 were applied to the ATS acquisition life cycle scenarios for each of the weapon systems. Four basic assumptions were applied consistently across the case studies.

- The baseline data accurately summarizes a nominal 20-year life cycle for weapon system ATS.
- Technology risk factors were applied to case studies in order to normalize scenarios.
- Applying sets of cost factors for each option across a system specific scenario compensates for common costs that were not determined, and neutralizes the effects of different maintenance concepts, missions, reliability, and O&S needs.
- The capabilities or benefits of each option were assumed to be available at the onset of the case study and to have existed throughout a system-specific scenario.

These assumptions are discussed in more detail in the next section, Cost Factors for ATS Investment Strategy Options.

By restricting analysis to a single weapon system in each scenario, the effects of component reliability and applied maintenance concepts were minimized across each ATS acquisition strategy case-based analysis. The approach permitted the analysis to focus on the effects of the respective options for each expense category independently, while holding the weapon system design and its maintenance and support concepts fixed. This approach provided a process for evaluating ATS development, acquisition, and support strategies for different options fairly and objectively for each individual weapon system scenario.

Because of the number of assumptions and because there are other details over an ATS life cycle that might be overlooked, the resulting costs should not be considered representative of actual total costs. What is important is this approach provides a very good comparison of the relative cost benefits across ATS investment strategies relative to Option I (Baseline-No Change).

5.1.1.2 Cost Factors for ATS Investment Strategy Options

Eight ATS expense categories were selected for this analysis: ATE Development, ATE Acquisition, TPS Development, TPS Acquisition, ATE Support, TPS Support, TPS New Equipment Re-Host, and TPS Updated Equipment Re-Host. Each of these categories are explained in more detail below. Individual cost factors were developed and applied against each of these ATS expense categories.

The current ATS acquisition and support approach was defined as the case study baseline (Option I-No Change). All baseline ATS factors were assigned the value of 1.0, with the exception of TPS Updated Equipment Re-host. The rationale for this difference is presented in paragraph a. below.

The individual cost factors in Table 26 reflect identified expense category cost deltas (or fractional portion) attributed to the respective options relative to Option I. The assumptions, rationale, and source data behind the derived cost factors are described in the following paragraphs (a. through j.).

a. **TPS Updated Equipment Re-host.** The ATS expense category of TPS Updated Equipment Re-host was defined as a special category, and was to be assigned a value relative to the TPS Development factor within the respective option category. Since all of the TPS documentation and the coding for the same basic design would be available, the non-recurring engineering work load reduction relative to re-hosting on totally new equipment was assumed to be 66.6%. This value was assigned based on a review of the percent of time classically found allotted to the various TPS development cycle elements (discussed later in paragraph e.(3) of this section). Therefore, the ATS Updated Equipment Re-host cost factor for Option-I was assigned a value of 0.33 (1.0 - 0.67) relative to TPS Development. If actual expense information was available under Option I, the factor was assigned the value of 1.0 and actual data was used.

Table 26. ATS Option Cost Factors

EXPENSE CATEGORY	OPTION-I (Baseline - No Change)	OPTION-II (Common ATS Families)	OPTION-III (Common ATS Specs)	OPTION-IV (Common SW Environment) Near Term [Long Term]	
ATE Devel	1.00	0.05	0.87	1.00	[1.00]
ATE Prod	1.00	0.85	0.93	1.00	[1.00]
TPS Devel	1.00	0.90	0.90	0.83	[0.31]
TPS Prod	1.00	0.85	0.93	1.00	[1.00]
ATE Sup	1.00	1.00	1.00	1.00	[1.00]
TPS Sup	1.00	1.00	1.00	0.66	[0.40]
TPS Re-Host (New Eq)	1.00	1.00	1.00	0.25	[0.25]
TPS Re-Host (Updated Eq)	0.33	0.33	0.33	0.20	[0.20]

b. **Option II Cost Factors.** All of the Option II (ATS standard families) factors were applied against typical ATE family costs. The nominal costs of CASS or IFTE were used.

c. **ATE Development Costs (Options II-IV).** Expenses in this category include the development costs of both test equipment and the operating system software.

(1) Under Option II, almost all of the ATE Development costs were assumed to have been previously allocated to other system(s). In other words, there is a large percentage of these development costs that are shared across multiple weapon system applications. The prorated share of these development cost could have been included under this category. However, for this analysis approach they were included in the case studies by applying a common charge to each of the Service-specific case studies that used family ATS in a scenario. This will be discussed in more detail in Section 5.1.1.3, ATS Acquisition Case Studies. The basis for this assumption is inherent in the common family investment strategy, and is also representative of the technical data collected on the CASS and IFTE ATS family applications in the respective Services. To account for any unique or special development requirements needed in this (or other future system testing requirements), an

additional 5% of the original ATE family development cost was assigned to this expense category. The 5% was based on an estimate of the necessary costs associated with an assessment of testing requirements coverage and capabilities, the identification of testing enhancement needs, and the equivalent of a tax against future test equipment users for Pre-Planned Product Improvement (P^3I) engineering and design. Therefore, the ATE development option cost factor was assigned the value of 0.05 against the original ATE development costs and thereby being representative of the actual ATE design complexity.

(2) Based on historical data in the *MATE Effectiveness Evaluation Report* [MATE 1990], the common ATS specifications associated with the MATE concept permitted approximately 90% operating system code reuse and approximately 4.1% hardware design reuse for new ATE developments.

The test equipment hardware design reusability percentage was derived from an assessment in the report that described test module reusability. The report documented an average MATE module development cost of $190.2K (FY90$). The report went on to show an average of 19 modules per test station, for which approximately 23% were non-MATE modules requiring new development (versus available off-the-shelf MATE modules), and approximately 18% of all the modules were reused. Combining these observations revealed that approximately 79% of the modules are not redesigned per ATS. Based on the average module development cost, the report estimated $150K (FY90$) cost avoidance per ATE development, or when related to the total development costs, the 4.1% savings.

This information was then combined with the estimate that the test equipment hardware and the operating system software respectively represent approximately 90% and 10% of the total ATE development costs. The cost share distribution was based on Air Force data for the F-16 AIS. The combination of this information produced a cost avoidance percentage of 12.7 (90% x 4.1% + 90% x 10%) which translates to an Option-III ATE development option cost factor of 0.873 (1.00 - 0.127).

(3) The common software environment approach under Option-IV was assessed to have minimal effect on the ATE development costs; therefore, the option factor was assigned a value of 1.0.

d. **ATE Production Costs (Options II-IV).** Expenses in this category include the recurring engineering and production costs to acquire the hardware and any embedded system software.

(1) Given the near 100% ATE design reusability across test systems for Option-II, the potential for applying a recurring engineering learning curve was assessed as high. Both GE and Grumman reported that by around the 500th unit, DoD could anticipate an estimated 30% cost reduction attributed to a production learning curve. This translates to a 96% learning curve:

Rate of reduction applied at 2^{-b} or double the quantity, where
$y=a*i^{-b}$
y=cost of unit,
a=cost of 1st unit,
i=number of units, and
b=rate of reduction

After the first year of CASS and IFTE, the current planned production will have moved along this learning curve sufficiently to realize 15% or greater savings. This was assessed as a low estimate of potential savings, since learning curves of around 90% are common for electrical and mechanical commodity assembly. Although actual learning curves for the CASS and IFTE have yet to be determined, the F-16A/B AIS ATS experienced a production learning curve of 71% [CAIG]. Combining this 15% with the near 100% reusability across applications results in the assignment of an ATE acquisition Option-II cost factor value of 0.85 (1.0 - 0.15).

(2) The *MATE Effectiveness Evaluation Report* [MATE 1990] documented that "manufacturers are building MATE testers made up of about 31% of the modules being used on other programs." The authors assessed that this percentage could have climbed to at least 50% with a more aggressive MATE implementation approach. Applying the same value used in paragraph d.(1) above that produced a 15% savings over similar production quantities to this 50% value results in a projected 7.5% unit cost savings that may be applied across the full analysis. Therefore, the ATE acquisition Option-III cost factor was assigned a value of 0.925.

(3) The common software environment approach under Option-IV was assessed to have minimal effect on the ATE Acquisition costs; therefore, the option factor was assigned a value of 1.0.

e. **TPS Development Costs (Options II-IV).** Expenses in this category include the non-recurring engineering and analyses costs to develop TPS software, interface test adapter (ITA) hardware, integration and testing, and operating documentation and instructions.

(1) The *MATE Effectiveness Evaluation Report* [MATE 1990] identified a total savings of 9.7%. This TPS development savings was attributed to three primary areas: MATE station interface commonality, MATE Control and Support Software Standard, and the standard ATLAS language commonality. Therefore, the TPS Development Option-II cost factor was assigned a value equal to that of Option-III or 0.903.

(2) By their very nature, each of the three primary areas discussed in paragraph e.(1) above would be completely standardized under an ATS family concept. Therefore, for this study, the TPS Development Option-II cost factor was assigned the same value (or 0.903).

(3) Since a common ATS software development and support environment does not exist, and since some development efforts will be required to achieve benefits or savings, both near- and long-term sets of option cost factors were developed. The near term was designated within 5 to 10 years, while the long-term was 10 to 20 years. The data provided by the Navy [TPS DEVEL 1992] describing the percent of development time allotted to individual steps of the TPS development cycle were assumed to be representative (Table 27). This assumption was in agreement with information provided by General Dynamics [ATE HISTORY] describing TPS development productivity.

Table 27. Percent TPS Development Time Allotted to Tasks

TPS DEVELOPMENT CYCLE ELEMENT	DEVELOPMENT TIME
UUT Analysis	2%
ATE Analysis	2%
Functional Flow	10%
Detailed Test Design	15%
ID Design	13%

Table 27. Percent TPS Development Time Allotted to Tasks (Continued)

TPS DEVELOPMENT CYCLE ELEMENT	DEVELOPMENT TIME
Coding/Compiling	10%
Integration	46%
Acceptance	2%

The following paragraphs provide the assumptions and rationale for the potential near- and long-term cost avoidance benefits against each of the development cycle elements.

UUT Analysis: Improvements in product data capture coupled with improved analysis tools are estimated to reduce the UUT analysis work load by 25% in the near term and by over 50% in the long term.

ATE Analysis: Same as UUT Analysis above.

Functional Flow: A standardized software environment such as ABBET will provide improvements in documentation standards that facilitate the transport of UUT design functional flow characteristics. The development of improved tools for partitioning functional flow characteristics in useful formats will also support fault isolation and fault detection requirements analysis. Near-term improvements in the range of 50% are assumed practical for digital testing, with overall long term TPS development benefits in excess of 75% for all testing domains.

Detailed Test Design: Automated test design capabilities are evolving; however, major benefits will be dependent upon standard environments and new tools that are designed to benefit from these standards. The authors assumed that the detailed test design element work load will decrease by approximately 33% in the near term and by as much as 66% in the long term. This growing trend is supported by the idea that standard libraries of tests will be developed and available for reuse.

Interface Device (ID) Design: The authors assumed that a standard software environment will have minimal influence in the near term; however, the growth of standard test libraries were expected to promote greater ID commonality and design reuse. These observations lead to the assumption that the long-term benefits will be in the 50% range.

Coding/Compiling: For the near term, the authors assumed that the needed tools and libraries would not be in place. Therefore, the near term coding benefits of approximately 10% would result from the improved electronic availability of source data and the limited automated TPS generation for some digital tests. However, major benefits in the range of 75% would be available in the long term. These benefits are expected to be the result of future automated tools capable of electronically receiving the detailed test design and producing reliable reusable code.

Integration: For the near-term, this area will continue to constitute a major TPS development work load driver. Since the benefits in this area will be the direct results of the progress and implementation made in the preceding development cycle elements, the near-term benefits were assumed to be in the 10% range. However, over the long-term, the authors assumed that the work load associated with this area will decrease substantially because of the improvements made to the entire TPS development process. Long-term benefits are projected to range around 75%.

Acceptance: Same as Integration above.

Summary of Option-IV TPS Development Benefits: The TPS Development Option-IV cost factor was assigned a value of 0.832 for the near term and 0.305 for the long term. Table 28 summarizes the approach used to produce these option factors.

Table 28. Near and Long Term Option-IV TPS Development Benefits

TPS Development Cycle Element	Development Time	Near-Term Benefits	Long-Term Benefits
UUT Analysis	2%	x 25% =0.5%	x 50% = 1%
ATE Analysis	2%	x 25% = 0.5%	x 50% = 1%
Functional Flow	10%	x 50% = 5%	x 75% = 7.5%
Detailed Test Design	15%	x 33% = 5%	x 66% = 10%
ID Design	13%	x 0% = 0%	x 50% = 6.5%
Coding/Compiling	10%	x 10% = 1%	x 75% = 7.5%
Integration	46%	x 10% = 4.6%	x 75% = 34.5%
Acceptance	2%	x 10% = 0.2%	x 75% = 1.5%
TOTAL	**100%**	**16.8%**	**69.5%**

f. **TPS Production Costs (Options II-IV).** Expenses in this category include the recurring engineering and production costs to acquire the interface devices (ID) or ITA hardware and TPS software and instructions.

(1) The primary benefits for Option-II under this expense category would fall under potential recurring engineering production learning curves similar to the those identified in paragraph d.(1) which addressed ATE Production Costs. Therefore, the TPS Production Option-II cost factor was assigned the same value or 0.85.

(2) Similarly, the primary benefits for Option-III under this expense category are related to production learning curves as identified in paragraph d.(2). Therefore, the TPS Production Option-III cost factor was assigned the same value or 0.925.

(3) The common software environment approach under Option-IV was assessed to have minimal effect on the TPS Production costs; therefore, the option factor was assigned the value of 1.0.

g. **ATE Support (Options II-IV).** Expenses in this category include direct and indirect logistics and sustaining engineering support of the ATE hardware and any embedded operating software. The differences between the ATE support costs for Options-I, -II, -III, and -IV were assessed to be minimal. Therefore, all ATE Support cost factors were assigned the same value: 1.0.

h. **TPS Support (Options II-IV).** Expenses in this category include direct and indirect software support of the of the TPSs and the ID/ITA hardware.

(1) The differences between the TPS support costs for Options-I, -II, and -III were assessed to be minimal. Therefore, TPS Support cost factors were assigned the same valuc: 1.0.

(2) The common software environment approach under Option-IV was projected to reduce the sustaining engineering and software analyses by 50% for all continuing support efforts. New testing capabilities on existing equipment were assessed to be of similar work load complexity as original TPS development or approximately 17% for the near term and 70% for the long term as presented in paragraph e.(3). During one of the Technical Interchange Meetings (TIM), the Air Force assessed the work load split between these two tasks to be approximately equal. Combining this information results in a projected work load reduction of 34% (50% x 50% + 17% x

50%) for the near-term and 60% (50% x 50% + 70% x 50%) for the long-term. Therefore, the TPS Support Option-IV cost factor was assigned a value of 0.66 for the near-term and 0.4 for the long-term.

i. **TPS New Equipment Re-Host (Options II-IV).** Expenses in this category include the reverse engineering and development of replacement TPSs that are re-hosted on replacement or alternate ATE which represents a substantial change from the original hardware and/or operating system configuration.

(1) The differences between the TPS Re-Host costs for transferring to totally new ATE hardware under Options-I, -II, and -III were assessed to be minimal. Therefore, TPS New Equipment Re-Host cost factors were assigned the same value: 1.0.

(2) The common software environment approach under Option-IV was assessed to reduce the reverse engineering and analyses work load by 75% for all TPS being re-hosted on new equipment. This percentage was based on the conclusion that all of the critical information will be in electronic form and that the standardized software environment will permit tools that will highly automate the re-hosting effort including the integration and acceptance tasks. Therefore, TPS New Equipment Re-Host cost factor was assigned a value of 0.25.

j. **TPS Updated Equipment Re-Host (Options II-IV).** Expenses in this category include the reverse engineering and development of replacement TPSs that are re-hosted on updated ATE which represent relatively minor configuration changes to the original hardware and/or operating system.

(1) The differences between the TPS Re-Host costs for transferring to updated ATE hardware under Options-I, -II, and -III were assessed to be minimal. Therefore, TPS New Equipment Re-Host cost factors were assigned the same value: 0.33

(2) The common software environment approach under Option-IV was assessed to further reduce the reverse engineering and analyses work load beyond the baseline factor of 0.33. Since the re-host for new equipment was assigned a factor of 0.25, the TPS New Equipment Re-Host cost factor was chosen to be slightly less, or 0.20.

5.1.1.3 ATS Acquisition Case Studies

The following sections describe the general approach used to model and evaluate each of the weapon system case study scenarios, provide detailed discussions and results of four weapon system case study scenarios (F-18, F-16, F-15, and M-1), and provide analysis of the case study sensitivity to several selected assumptions used.

Table 29 identifies the four weapon systems and provides an overall comparison of the case study results. This table was presented earlier as an overview to this analysis area and is repeated here for continuity in this section (previously Table 25).

Table 29. Case Studies ATS Development and Production Costs (Constant FY93$ in Millions)

SYSTEM CASE STUDY	OPTION I (Baseline - No Change)	OPTION II (Common ATS Families)	OPTION III (Common ATS Specs)	OPTION IV (Common SW Environment) Near Term [Long Term]	
F/A-18	$1,321	$577	$1,184	$1,209	[$1,129]
M-1	$394	$300	$364	$390	[$383]
F-16	$2,374	$1,716	$2,161	$2,316	[$2,140]
F-15	$2,501	$1,602	$2289	$2,381	[$2,012]

5.1.1.3.1 Case Study Approach

Four models that represented each weapon system case study scenario were developed using data collected earlier. The models were intended to reflect the actual ATS requirements for a weapon system over a 20-year period (e.g., actual expenditure data collected and budgeted/funded cost projections). These models were used as the baseline or Option-I, No Change scenario. The 20-year period was selected as a representative life cycle for the purposes of the case studies. The other options were evaluated relative to this baseline. The option cost factors, developed in the previous section, were then applied to appropriate expense categories to determine the relative costs for each option.

The following assumptions were used to construct the four weapon system case study scenarios. Assumptions used to build the scenarios were based upon factual sources except as specifically noted. These four systems were selected because they are representative of the major DoD weapon systems and because sufficient historical ATS acquisition data were available to construct representative pictures of their ATS life cycles.

a. The baseline data was assumed to accurately summarize a 20-year life cycle. The information used to construct the life cycle scenario was from the respective system ATS data provided by the Services and included actual expenses, budgeted requirements, and known projected costs as reflected in the Five-Year Defense Plan (FYDP). This expenditure data was considered very representative of actual costs. The same data was used across each option evaluation for a specific case study scenario to ensure that potential data omissions or errors would not invalidate the relative differences ultimately computed.

b. One or more families of testers were assumed to be available and suitable to meet testing and mission requirements at the onset of the specific weapon system (used in Option-II, Common ATS Families). Additional factors to compensate for any differences in capabilities and tester quantities are addressed in the next paragraph.

c. The quantity of family test stations, required to meet specific testing requirements, was based on known (or projected) test station requirements for a replacement family of testers today (1992). To compensate for any ATS technology differences today relative to the capabilities that might have been available at the start of the specific weapon system program, a technology risk factor was applied. The technology risk factor compensated for technology differences by adjusting the earlier test station quantities upward linearly up to 25% over a 13-year period. This additional cost risk was reflected as a delta procurement cost for an additional quantity of ATE (used in Option-II, Common ATS Families). The authors recognized that the technology adjustment could be accommodated from two perspectives: (1) increase the unit acquisition cost or (2) increase the quantity of testers needed to perform the same testing throughput. The second approach was selected because ATS technology improvements have permitted greater throughput capabilities and because this approach permits graphical representation. Therefore, as applied in this study, the 25% was based on a subjective estimate of potential testing throughput differences. Further evaluation of this estimate, described in the Section 5.1.1.3.6, Sensitivity Analysis, revealed acquisition cost differences of less than 5% relative to Option II and 2% relative to the baseline for the F-18 case study.

d. Sets of specification standards were assumed to be in place throughout the life cycle of the ATS systems represented by the baseline analyses. Option cost factors for Option-III, Common ATS Specs., were then applied directly to each expense category of the baseline (Option-I). Similar to the situation in the Option II evaluations, these standards are not in place nor are they defined to represent the entirety of standards needed for DoD ATS acquisition.

e. A standard ATS software development and support environment was assumed to be in place throughout the life cycle of the system as presented in the baseline analyses. The option cost factors for Option-IV, Common SW Environment, were then applied directly to each expense category of the baseline (Option-I). The near-term results are based on an assumption that the near-term benefits were in place throughout the weapon system life cycle, the long-term results are based on an assumption that the long-term benefits were in place through the weapon system life cycle. The existence of these assumptions permit the evaluation of this option, in an approach similar to that used in Options II and III.

f. A prorated share of a standard ATS family development cost ($60 million) was assigned to scenarios that used a tester from a family. This $60 million value was based on a very conservative assumption that an ATS family of the complexity of CASS would be used to meet 3 weapon system testing needs. This area is also discussed further in Section 5.1.1.3.6, Sensitivity Analysis.

g. In several cases, the actual reported TPS development and acquisition for the baseline did not distinguish between the relative costs for circuit cards (also referred to as shop replaceable units or assemblies (SRU or SRA)) and modules (also referred to as line replaceable modules or units (LRM or LRU), or as weapon replaceable assemblies (WRA)). Therefore, module TPSs were assigned a relative cost of approximately 10 times that of cards. This factor was used in the models to compute weighed TPS development and acquisition costs. This relative difference in card to module cost was well supported throughout the TIMs.

h. For the ATS development costs under Option II (Common ATS Families), the option cost factors were applied to the actual development cost of an ATS family candidate that met the basic technical testing requirements. This was an exception to the earlier rule that cost factors were applied to baseline expense categories. This approach change was justified for two reasons: (1) by applying the 5% factor to the original development, the cost more closely reflected the design complexity of the ATS, and (2) the total development cost for the ATS family candidate was higher (yet distributed across multiple systems) than the unique ATS systems in each scenario.

5.1.1.3.2 F/A-18 Scenario

The F/A-18 A/B and later the C/D aircraft are supported by over 350 ATS made up of 8 unique types. The Navy plans to support the new F/A-18 E/F unique avionics with 31 CASS ATS stations. Approximately 4 years later the Navy intends to off-load work of the 8 older ATS stations and rehost TPSs on 64 additional CASS stations. The ATS information used to formulate the baseline is presented in Table 30. This information was collected by Navy personnel and provided specifically in support of this study. A representation of the no change (Option-I) scenario is illustrated in Figure 8.

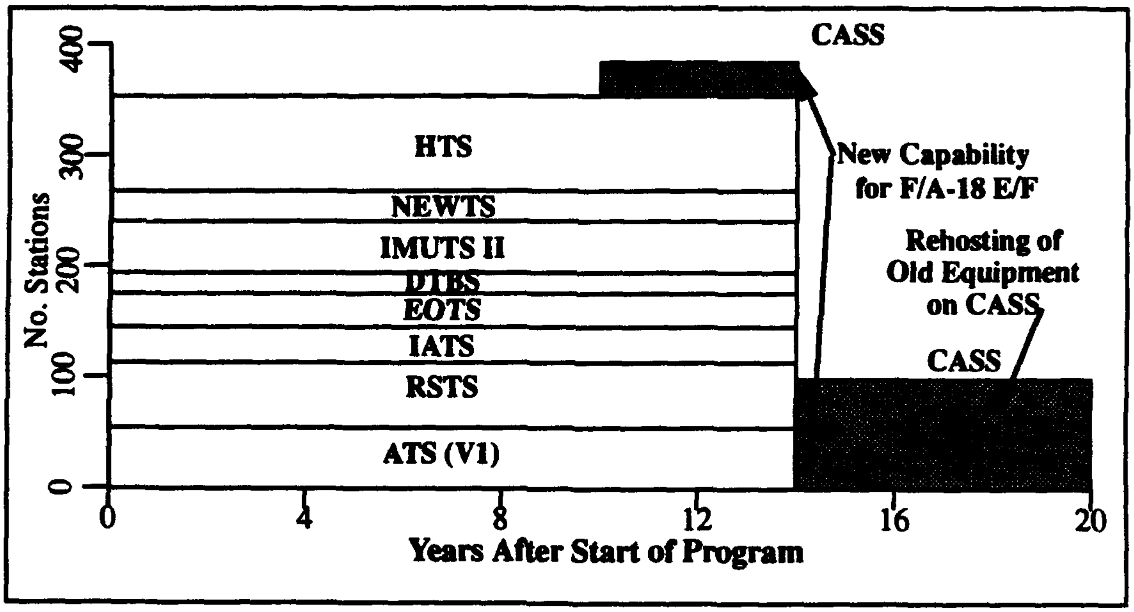


Figure 8. Option I, No Change Scenario for the F/A-18 Weapon System

This scenario representation of Option I in Figure 8 shows the current and planned implementation of ATS to support the F/A-18. Although this baseline scenario includes a Navy ATS family (CASS), it is not representative of a case study scenario that implemented an Option II (Common ATS Family) at the onset of the 20-year life cycle.

Table 30. F-18 Baseline Scenario Information

ATS Name	QTY	Cards	Modules	ATE Devel ($M)	ATE Acq ($M)	TPS Devel ($M)	TPS Acq ($M)	No. ITAs/ AIS	Off-Load ITAs
AN/USM-470 ATS (V1)	58.0	0	43	39.3	290.7	25.8	21.9	27	9
AN/USM-446 RSTS	55.0	21	6	10.0	130.8	20.0	35.3	27	8
AN/ASM-686 IATS	31.0	0	27	11.3	30.4	32.9	16.0	27	0
AN/USM-629 EOTS	34.0	0	11	21.5	50.0	5.6	12.4	11	0
AN/USM-392 B DTBS	14.4	18	0	10.7	5.6	4.1	1.1	18	4
AN/ASM-608 V IMUTS II	49.0	0	3	4.0	22.8	5.0	4.0	3	3
AN/USM-458 C NEWTS	28.2	0	7	14.3	14.4	6.9	7.4	7	4
AN/USM-484 HTS	88.0	44	1	3.3	45.7	8.1	23.0	39	0
AN/USM-636 CASS RF	31.0	106	16	9.3	59.8	41.1	28.1	21	N/A

The Option-II scenario is based on the assumption that an ATS family existed at the onset of the F/A-18 program. The algorithm for determining the number of ATS family stations required at the start of the program was based on the fact that 64 CASS stations are programmed by the Navy to handle the F/A-18 A/B and C/D testing work loads after the ATS off-load. This number was then adjusted to 80 by adding in the 25% technology risk factor discussed in the model assumptions from the previous section. At mid way through the 20-year scenario, the ATS family was assumed to under go a mid-life update. At that time the number of CASS stations required to support the F/A-18 A/B and C/D was readjusted downward to the actual number of CASS stations needed (64). The Option-II scenario model includes the cost of updating the old CASS (the 80 stations assumed to meet testing needs at the start of the program) to the 64 current CASS stations. The cost to reconfigure and update to the current CASS configuration was assumed to be 25% of the production costs for the 64 stations. Figure 9 illustrates this scenario.

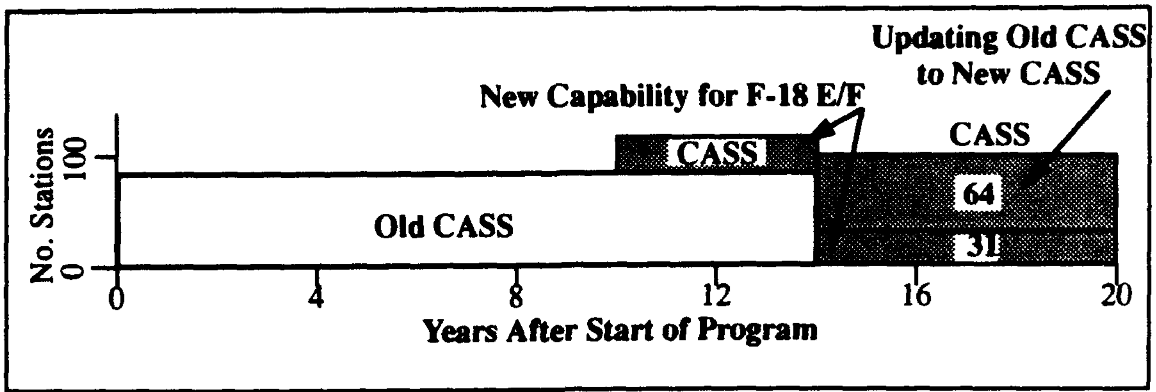


Figure 9. Option II, ATS Family Scenario for the F/A-18 Weapon System

Both Options III, Common ATS Specifications, and Option IV, Common Software Environment, were based on the assumption that all benefits would be derived from either the common ATS specifications or the common software environment respectively. Therefore, both of these scenarios are based on the assumption that at the mid-life update, the ATS would be totally replaced one-for-one. Figure 10 illustrates the scenarios for both options.

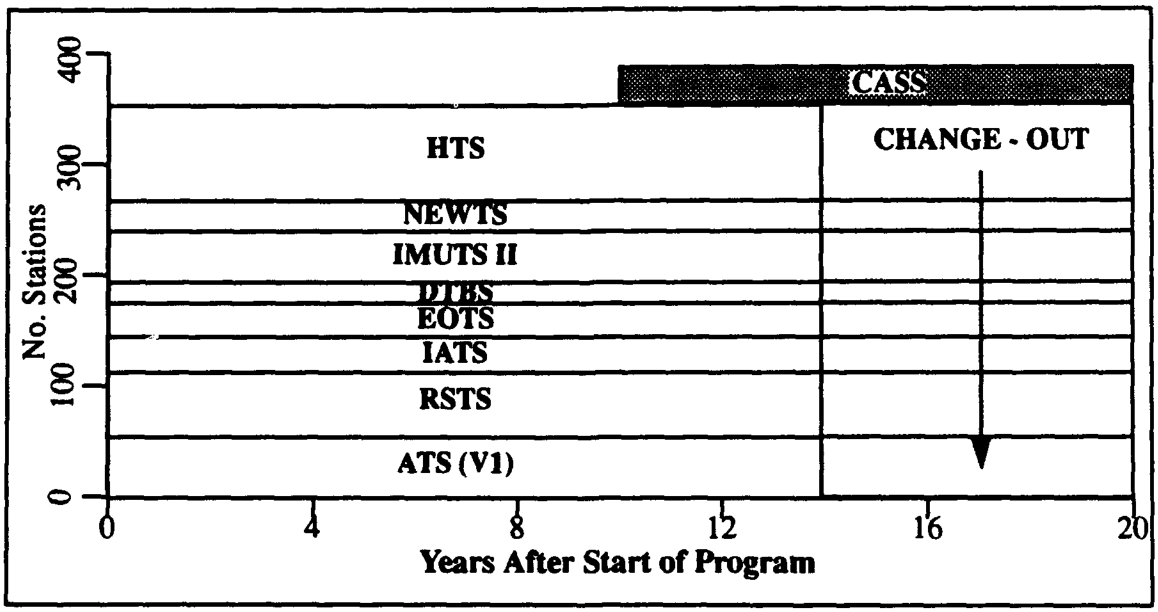


Figure 10. Option III, Common ATS Specs and Option IV, Common SW Environment Scenarios for the F/A-18 Weapon System

The relative costs for all ATS changes (developments, acquisitions, additions, updates or change outs) are computed based on the relative quantities of testers needed according to the developed scenario and the costs as adjusted by the option factors. Summary of the F/A-18 case study are presented in Table 31. The several of the expensed categories listed in this table are composite summaries of the ATE and TPS development and production costs for the event identified under the heading: ATE Mid-Life Addition, TPS (New Dev & Prod), ATE Mid-Life Update, and ATE Change-Out.

To preserve the integrity of the case studies and for consistency across scenarios, the authors decided to err on the conservative side. For example, one could argue that the computed TPS production cost under Option-II of $102.9 million is too high and would be more representative of projected costs if reduced to $25 million. The value in Table 31 was derived by multiplying the TPS acquisition factor from Table 26 (0.85) with the baseline value ($121.1 million). This approach neglects the fact that the number of ITAs dropped down from 8,298 (the actual total number identified for the baseline, Option-I used on 8 ATE types at multiple locations) to 1680 for the Option II. The $25 million value was computed based on the reduced number of ITAs.

In another example, the assigned prorated share of ATS family development costs was $60 million. This would imply that an ATS family of the complexity of CASS will only be used on approximately three weapon systems. Although it makes little difference in the F/A-18 set of scenarios, this assumption represents further savings in the other weapon system case studies to be discussed in the next section.

5.1.1.3.3 F-16 Scenario

The F-16 weapon systems are supported by four generations of ATS at the intermediate maintenance level. The four ATS generations are closely tied to the aircraft series as indicated by their names and these ATS were acquired as the weapon system series evolved: A/B Avionics Intermediate Shop (AIS), C/D AIS, Advanced Computer AIS, and Improved AIS (IAIS). Several different specialized depot ATS were also acquired over the life of the weapon system. Figure 11 illustrates the quantities and time frame that the different F-16 ATS were introduced. The conditions illustrated in this figure represent Options I, III, and IV weapon system scenarios (No Change, Common ATS Specs, and Common SW Environment respectively). The baseline scenario information used to develop this figure is presented in Table 32.

Table 31. F-18 Case Study Summary (FY93$-Million)

EXPENSE CATEGORY	OPTION-I (No Change)	OPTION-II (Common ATS Family)	OPTION-III (Common ATS Specs)	OPTION-IV (Common SW Environment) Near Term / Long Term	
ATE Development	114.4	8.9	99.9	114.4	114.4
ATE Production	590.3	131.2	546.0	590.3	590.3
TPS Development	108.4	97.9	97.9	90.0	33.1
TPS Production	121.1	102.9	112.0	121.1	121.1
SUBTOTAL	**934.2**	**340.9**	**855.8**	**915.8**	**858.9**
ATE Mid-Life Addition	69.1	59.7	59.8	65.5	65.5
TPS (New Dev & Prod)	69.2	61.0	33.3	32.0	17.7
SUBTOTAL	**138.3**	**120.7**	**93.1**	**97.5**	**83.2**
ATE Mid-Life Update	-	22.6	-	-	-
TPS Rehost	-	32.3	-	-	-
SUBTOTAL	**0.0**	**54.9**	**0.0**	**0.0**	**0.0**
ATE Change-Out	132.1	-	110.2	120.0	120.0
TPS Rehost	64.6	-	65.2	15.2	6.8
SUBTOTAL	**188.0**	**0.0**	**175.4**	**135.2**	**126.8**
Prorated Share of ATS Family	60.0	60.0	60.0	60.0	60.0
TOTAL	**1,320.5**	**576.5**	**1,184.3**	**1,208.5**	**1,128.9**

In contrast with the F/A-18 case-based analysis, one figure is required to represent these three option scenarios rather than two. This is attributable to the fact that Options-III and IV of the F/A-18 analysis represented a special situation that made it necessary to build a separate set of scenarios where a common ATS family would not be replacing the eight existing automatic test systems. For this F-16 case-based analysis, however, the representative cost factors for Options-I, III, and IV are all applied to the same quantity of ATS.

To develop an Option-II scenario, an ATS family candidate that was consistent with the assumptions used for the F/A-18 case study and met the basic technical testing require-

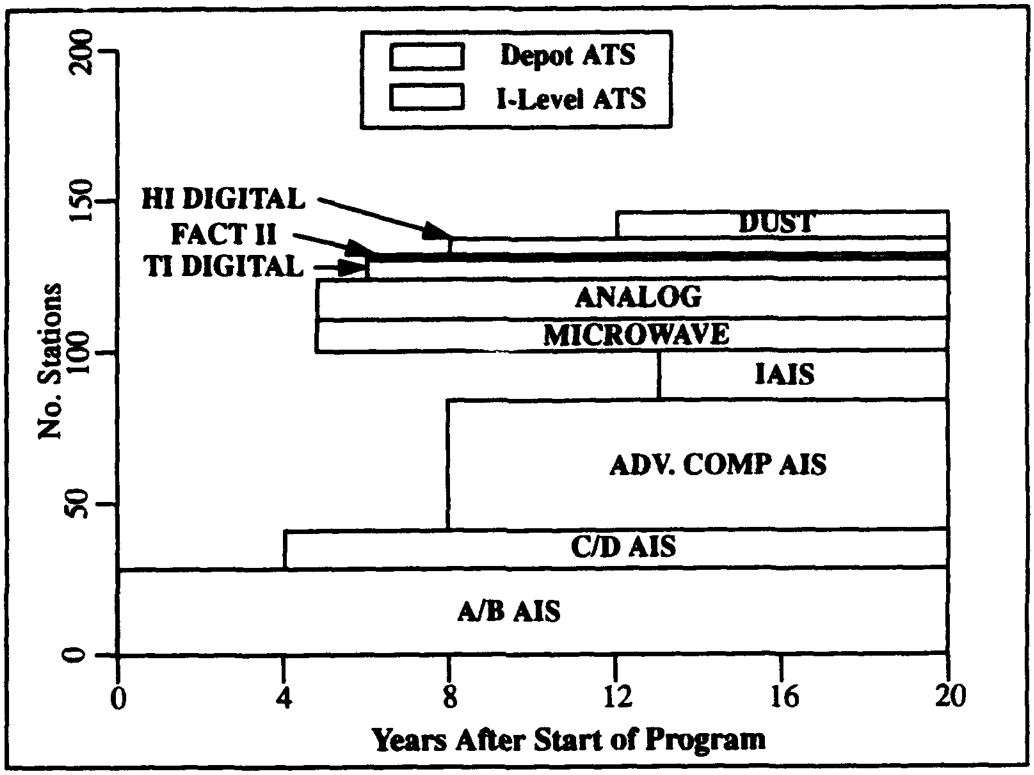


Figure 11. F-16 Weapon System ATS Evaluation Scenario for Options I, III, and IV

ments of the F-16 systems needed to be selected. CASS RF (Radio Frequency) station type, augmented with an electro-optical testing (EO) capability, was chosen as the family candidate. The F-16 AIS consists of 4 different station types: Computer Inertial, RF, Display Indicator, and Processor/Pneumatic. Four CASS RF stations plus 1 EO augmentation were assumed to meet testing throughput requirements of the full F-16 AIS. Therefore, for the purposes of this scenario option, the ATS family candidate was priced at $9.25 million (FY93$) or 4 times the cost of the CASS RF station ($2.06 million) plus $1 million for the EO augmentation. This assumption was justified, since other analysis revealed that 2 or 3 CASS RF stations would more than adequately handle the current F-16 AIS (4 stations) testing work load (e.g., a station reduction of 1 or 2 per location).

The technology risk factor was used to adjust the quantity of candidate family ATS intended to replace the A/B AIS, C/D AIS, Advanced Computer AIS, and Depot ATE (lineally prorated by the number of years proceeding the current CASS based technology). Since the F-16 IAIS was a significant departure from the other AIS, it was treated in the scenario as a new ATS family "downsized tester" candidate. Figure 12 illustrates the F-16

ATS family (Option-II, Common ATS Families) scenario used to evaluate the acquisition costs.

Table 32. F-16 Baseline Scenario Information (FY93$-Millions)

ATS Name	QTY	Cards	Modules	ATE Devel ($M)	ATE Acq ($M)	TPS Devel ($M)	TPS Acq ($M)	No. ITAs/ ATS
A/B AIS	26	0	52	146.9	267.5	71.2	57.0	42
C/D AIS	18	0	69	129.7	235.9	20.4	61.8	52
Advanced Computer AIS	40	0	76	29.4	425.1	20.8	112.9	52
IAIS	16	0	22	89.4	102.4	41.3	27.5	18
TI Digital	6	224	0	1.1	5.3	25.5	5.8	132
Analog	13	218	0	17.1	2.9	33.2	5.6	125
Microwave	11	42	0	6.7	21.5	12.1	3.0	27
Hi Digital	5	107	0	11.5	11.8	22.6	1.9	36
Fact II	1	116	0	0.0	0.2	4.1	0.3	54
Dust	8	46	0	0.1	2.1	0.7	1.2	46

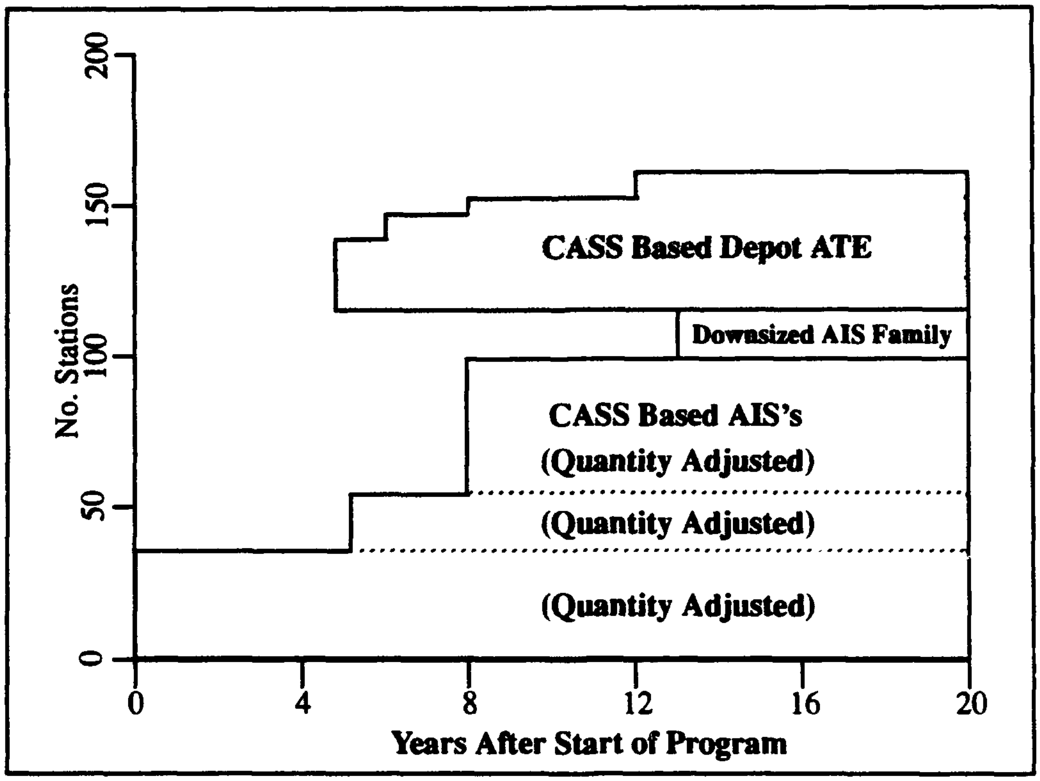


Figure 12. Option II, ATS Family Scenario for the F-16 Weapon System

The F-16 case study summary is presented in Table 33. The approach used throughout the scenario was identical to that used for the F/A-18; however, the presentation of the information differs slightly. The F-16 depot ATS information was identified separately on this table. The information is displayed differently because of the maintenance concept differences and in order to reflect the mid-life additions. For example, the Air Force and Navy concepts for levels of repair and maintenance are different. At the I-level maintenance shop, the Air Force generally fault isolates to a failed SRU by testing LRUs. The suspect SRUs are returned to the depot for further fault isolation and repair. Whereas, the Navy generally provides testing down to the equivalent of the SRU (called SRA by the Navy). This results in different Air Force ATS to meet depots and field testing needs.

Due to the time phasing of the ATS to meet the evolving aircraft series testing requirements, it was convenient to separate out the various ATS mid life additions.

Since CASS was used as the ATS family candidate, the F/A-18 average computed TPS development and production costs for cards, modules, and ITAs were used for consistency. These were the same values used in the F/A-18 case study scenario. This approach was conservative because the Navy includes a greater share of the O&S related fielding tasks under the acquisition cost of the TPS (i.e., training, documentation, manuals, etc.).

The prorated cost share for ATS families (Option-II, Common ATS Family) under the F-16 scenario was greater than that for the F/A-18. In the F-16 scenario, the authors assumed there were two sets of different ATS families used over the life cycle: (1) the AIS replacement and (2) the downsized tester. Therefore, the prorated share assigned was to be 2 times $60 million or $120 million.

The data in Table 32 includes the results of extensive discussions regarding how to address the additional F-16 weapon system production funds (Air Force budget category 3010 - aircraft production funds) paid to the ATS contractor for a range of P^3I equivalent efforts over the ATS life cycle. An agreement was reached by the F-16 System Program Office (SPO) and the authors that these funds fell in the following three categories: service reports, sustaining engineering, and maintenance.

Service Reports (SRs). Service reporting is the process by which users identify problems or deficiencies with fielded systems to the procuring activity prior to system program management responsibility transfer (PMRT). For the F-16 SPO, service reporting is a separate Contract Line Item Number (CLIN) under the AIS multiyear contracts that requires General Dynamics (GD) Fort Worth to maintain a system for receipt of SRs, con-

Table 33. F-16 Case Study Summary (FY93$-Million)

EXPENSE CATEGORY	OPTION-I (No Change)	OPTION-II (Common ATS Family)	OPTION-III (Common ATS Specs)	OPTION-IV (Common SW Environment) Near Term / Long Term	
ATE Development-A/B	146.9	8.9	128.3	146.9	146.9
ATE Production -A/B	267.5	255.6	247.4	267.5	267.5
TPS Development -A/B	71.2	72.3	64.3	59.1	21.7
TPS Production -A/B	57.0	40.1	52.7	57.0	57.0
SUBTOTAL	**542.6**	**376.9**	**492.7**	**530.5**	**493.1**
ATE Mid-Life Addition					
C/D	365.6	174.0	331.4	365.6	365.6
Adv Computer	454.5	364.1	418.9	454.5	454.5
IAIS	191.7	134.8	172.7	191.7	191.7
TPS (New Dev & Prod)					
C/D	82.2	58.0	75.5	78.8	68.0
Adv Computer	133.7	89.9	123.2	130.1	119.2
IAIS	68.8	41.2	62.8	61.8	40.1
SUBTOTAL	**1,296.5**	**862.0**	**1,184.6**	**1,282.5**	**1,239.1**
Depot ATS					
ATE Devel	36.5	53.4	31.9	36.5	36.5
ATE Prod	43.8	77.2	40.5	43.8	43.8
TPS Devel	98.1	104.7	88.6	81.5	29.9
TPS Prod	17.7	121.7	16.4	17.7	17.7
SUBTOTAL	**196.1**	**357.0**	**177.4**	**179.5**	**127.9**
Prorated Share of ATS Family	0.0	120	0.0	0.0	0.0
P^3I Sustaining Eng.	338.3	0.0	306.7	323.9	279.5
TOTAL	**2,373.5**	**1,715.9**	**2,161.4**	**2,316.4**	**2,139.6**

duct analysis to identify the cause of the SR problem, and suggest a corrective action. SR costs are apportioned equally between TPSs and the ATE.

Sustaining Engineering. Sustaining engineering is the vehicle for implementing corrective actions recommended by SR investigations. It is also a separate CLIN, and includes activities such as engineering change proposal preparation, software coding, integration, software reproduction, Technical Change to Technical Order (TCTO) preparation, and semi-annual updates to station control and support software. These costs are also evenly split between TPSs and ATE.

Maintenance. Maintenance covers all the direct and indirect costs involved with maintenance and repair of GFE ATE and TPSs in the care of the contractor. GD Fort Worth currently maintains one of each configuration of the F-16 AIS, three pre-production version A/B AISs, and a large number of TPSs. These items are used for sustaining engineering, modification integration and testing, and aircraft production line check-out. Maintenance is also a separate CLIN.

A summary of the sustaining engineering and SR costs used to estimate the Option-I P^3I sustaining engineering line of Table 33 are presented in Table 34. For Option-II the authors assumed no contractor sustaining engineering, and for Options-III and IV the authors applied the average of the appropriate cost factors to the baseline (Option-I) value. Data was provided by the F-16 SPO for years 1980 to 1995: years 1980 through 1985 represent estimated totals, years 1986 through 1989 are actual costs, years 1990 through 1993 are prenegoatiated costs, and years 1994 and 1995 are estimated costs. To address a full 20-year ATS life cycle, averages were computed. The P^3I development and production sustaining engineering was assumed to include all of the reported sustaining engineering column and half of the maintenance.

The results of this case study clearly indicate that the ATS family scenario acquisition strategy produces the greatest savings under the stated assumptions. Given these results, the authors decided to expand this case study evaluation to compare the baseline life-cycle development costs of the F-16 ATS with similar development costs for multiple applications of a CASS and IFTE ATS families. This expanded evaluation was based on the assumption that two additional weapon system testing needs would be added each year to the ATS family candidates (one for each CASS and IFTE). Only ATE development costs were included in this expanded evaluation.

Table 34. Summary of (Actual and Projected) F-16 Aircraft Production Resources Used to Fund Continuing ATS Development (FY93$-Millions)

Year	Sustaining Engineering	Service Reports	Maintenance	Equivalent Continuing P^3I
1980	16.7	1.7	4.2	18.8
1981	11.6	1.2	4.6	13.9
1982	7.3	1.0	5.1	9.9
1983	7.0	0.7	5.6	9.8
1984	10.2	1.0	6.1	13.2
1985	13.1	2.0	7.2	16.7
1986	28.9	3.8	8.8	33.3
1987	14.7	2.0	5.2	17.2
1988	19.3	2.5	8.3	23.4
1989	10.7	1.3	5.1	13.3
1990	14.9	0.8	4.5	17.1
1991	13.9	0.8	4.4	16.2
1992	14.7	0.8	5.1	17.3
1993	17.5	0.8	6.0	20.5
1994	14.5	0.9	6.1	17.6
1995	9.4	0.8	6.1	12.4
Subtotal (16yr)	**224.4**	**21.9**	**92.4**	**270.7**
Avg Per Year	14.0	1.4	5.8	16.9
4-Year Delta	**56.1**	**5.5**	**23.1**	**67.6**
Est. 20 Year Total	**280.5**	**27.4**	**115.5**	**338.3**

The same 5% of the original development cost for each new tester application would be applied. In addition, the need for a mid-life update at the 10 year point, with an adjustment to the development cost by an additional 25%, was assumed. Results are illustrated in Figure 13 and show that the combined ATE development costs of over 30 ATS family applications may cost less than the development of the F-16 automatic test equipment that supported two basic system types (A/B, and C/D). Both the CASS and IFTE in this example are assumed to support the core systems for which they were originally developed plus 16 additional systems at the conclusion of the 16 years.

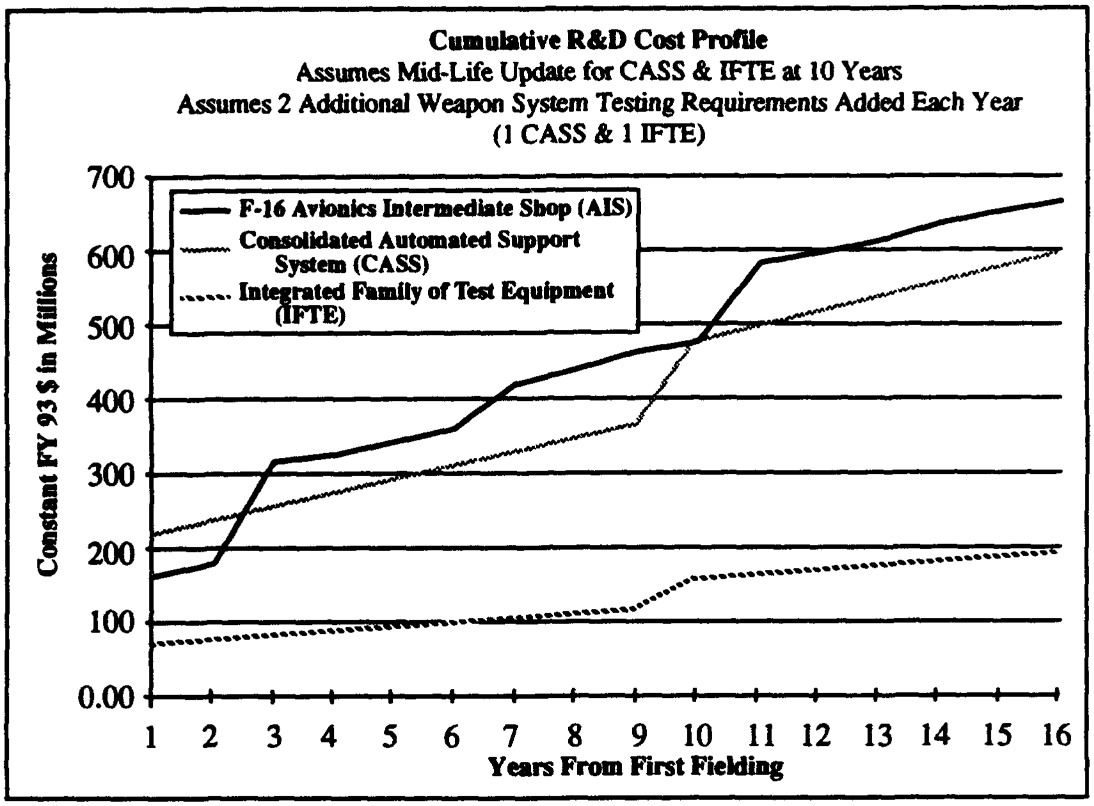


Figure 13. Development Cost Profile Comparisons of a System Unique (F-16) and Two Multiple System Application ATE (CASS & IFTE)

5.1.1.3.4 F-15 Scenario

The F-15 weapon systems, at the intermediate maintenance level, are supported by a combination of ATS that spans the life of the aircraft and several generations of new ATS. The newest ATS generation included as a part of this case study is a proposed "Downsized Tester" (DST) that is in source selection as the study continues. Like the F-16 weapon system, several different specialized depot ATS were also acquired over the life of the weapon system. Figure 14 illustrates the quantities and time frame that the different F-15 ATS were introduced. The conditions illustrated in this figure represent Options-I, III, and IV weapon system scenarios (No Change, Common ATS Specs, and Common SW Environment respectively). The baseline scenario information used to develop this figure is presented in Table 35 and Table 36.

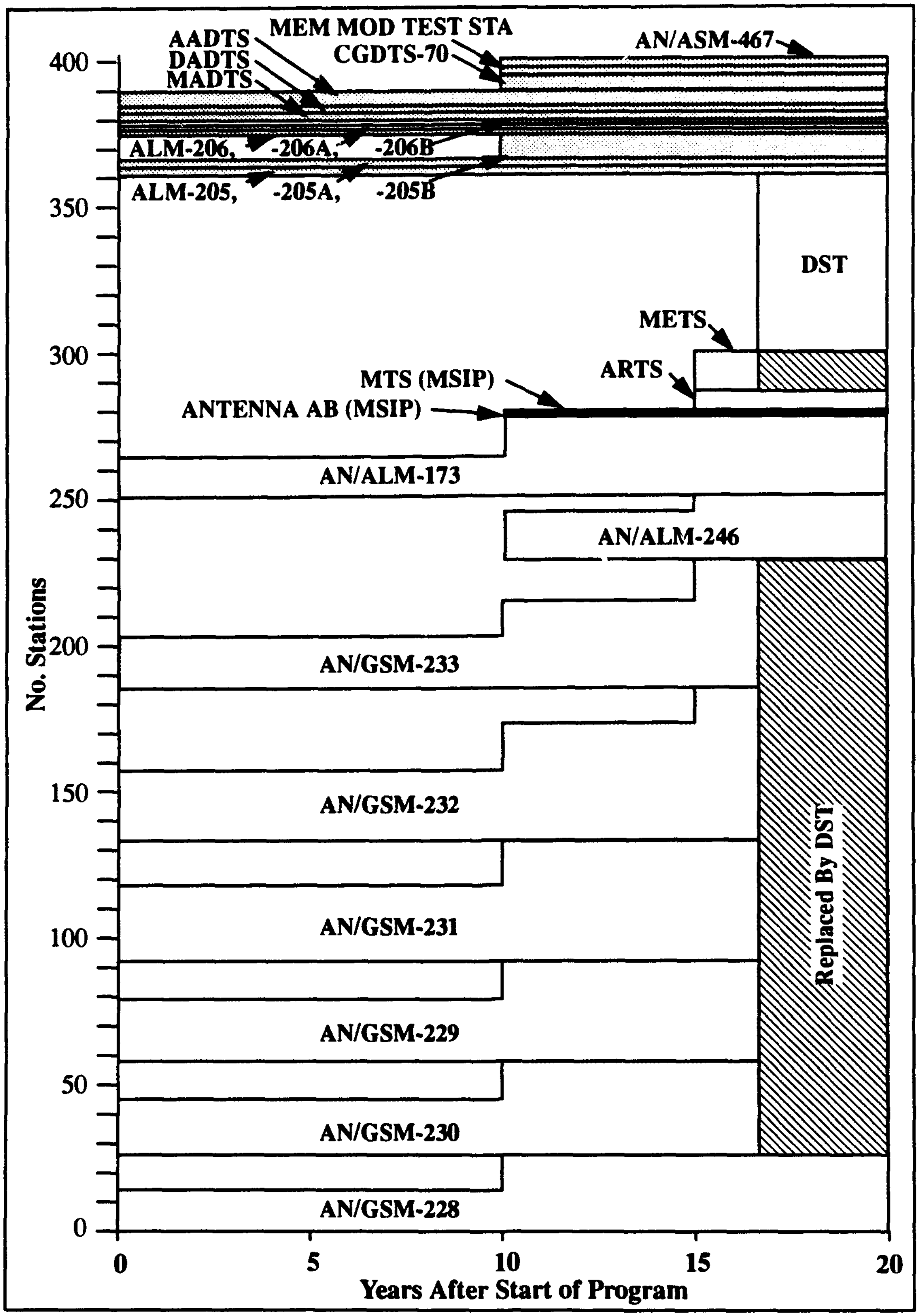


Figure 14. F-15 Weapon System ATS Evaluation Scenario for Options I, III, and IV

Table 35. F-15 Baseline Scenario Information for I-Level (FY93$-Millions)

NAME	QNTY	CARDS	MODULES	ATE Devel	ATE Prod	TPS-C Devel	TPS-M Devel	TPS-C Prod	TPS-M Prod	No. ITAs
AN/GSM-228	14 (A/B) 12 (C/D)	-	3	7.5	49.0 36.8	-	3.0	-	19.7	3
AN/GSM-230	19 (A/B) 13 (C/D)	-	15	6.2	44.3 30.3	-	5.7	-	17.1 10.5	15
AN/GSM-229	21 (A/B) 13 (C/D)	-	20 +3	5.4	38.7 23.9	-	7.0 0.4	-	25.2 2.1	20 +3
AN/GSM-231	26 (A/B) 15 (C/D)	5	24	3.8	89.4 51.6	4.0	19.1	1.0 1.3	10.7 6.2	29
AN/GSM-232	25 (A/B) 15 (C/D) 12 (E)	-	14 +6	10.6	95.2 57.1 45.7	-	86.2 12.6	-	17.9 15.3 8.6	14 +6
AN/GSM-233	18 (A/B) 15(C/D) 12 (E)	-	5 +2	3.8	48.6 40.5 32.4	-	14.0 0.7	-	12.1 17.1 8.0	5 +2
AN/GSM-246	2 (A/B) 14 (C/D) 7 (E)	-	14 +9	- 12.1	9.5 66.2 33.1	-	- 70.1	-	3.6 24.9 11.7	14
AN/GSM-173	16 (A/B) 11 (C/D)	9 +4	9	14.2	110.8 76.2	31.2	107.3	5.5 3.8	12.3 8.5	18
ANTENNA AB	1 (MSIP)	-	3	7.9	3.1	-	-	-	0.5	3
MTS	1 (MSIP)	-	9	-	2.9	3.5	-	-	1.4	9
ARTS	6 (E)	-	3	10.1	24.8	-	0.1	-	0.9	6
METS	12 (E)	-	22	0.4	10.0	-	0.6	-	13.2	12
DSTS (est.)	61 (all)	-	97	2	84.9	-	82.3	-	45.4	62

Table 36. F-15 Baseline Scenario Information for D-Level (FY93$-Millions)

NAME	QNTY	CARDS	MODULES	ATE Devel	ATE Prod	TPS-C Devel	TPS-M Devel	TPS-C Prod	TPS-M Prod	No. ITAs
ALM-205	3 (A/B)	39	-	17.0	15.1	16.3	-	4.9	-	39
ALM-206	2 (A/B)	21	-	5.7	4.0	6.4	-	2.6	-	21
ALM-205A	3 (A/B)	88	-	9.4	11.9	30.8	-	5.8	-	88
ALM-206A	2 (A/B)	49	-	3.1	3.4	12.0	-	3.2	-	49
ALM-205B	8 (C/D) + (E)	78 +14	-	9.7	43.7	21.0 3.2	-	6.5 1.9	-	78 +14
ALM-206B	1 (C/D&E)	13	-	1.4	2.5	3.5	-	1.1	-	13
MADTS	3 (A/B)	20	-	3.0	16.0	6.0	-	1.3	-	16
DADTS	3 (A/B)	57	-	3.7	15.3	17.4	-	2.5	-	46
AADTS	5 (A/B) + (C/D) + (E)	160 +170 +68	-	13.7	72.2	42.5 30.9 13.1	-	3.1 3.3 1.7	-	105 - 61
CGDTS-70	5 (C/D) + (E)	48 14	-	4.0	41.4	9.2 1.9	-	1.2 0.1	-	40 14
Mem Mod Tester	3 (C/D) + (E)	26 37	-	1.4	30.9	8.3 10.9	-	1.2 1.8	-	21 34
ASM-467	3 (C/D)	21	-	16.0	37.3	22.6	-	2.5	-	8

To develop an Option-II scenario, the authors needed to identify F-15 ATS testing requirement sets that might be grouped, and thereby, addressed by one or more families of testers. Five of the F-15 A/B tester types were assumed to be replaced by 2 sets of family testers. This was based on two observations: (1) the Air Force plans to replace testing capabilities of the AN/GSM 229, 230, 231, 232, and 233 with the DST, and (2) the METS replaced AN/GSM 229, 230 and 231 testers. That left two other ATS family groupings: antenna and electronic warfare (EW) testing. The final ATS family candidate was a downsized tester to meet the operational requirements that led the Air Force to consider the METS and DST. Considering the level of technology available at the beginning of the F-15 life cycle, 5 sets of ATS families were selected for this scenario. The scenario applied ATS mid-life additions (updates) to accommodate new F-15 C/D testing needs for the MTS, MSIP antenna, and the TISS. The requirements for the METS were assumed to have been accommodated by the introduction of a DST family earlier.

Finally, the authors noted that the general purpose ATS candidates would meet a range of depot testing needs, yet other depot testing needs were probably very specialized. Therefore, the ALM-206's and ALM-205's were assumed to be accommodated by several of the candidate I-level ATS families, and the rest would be unique as before. Figure 15 illustrates the F-15 ATS family (Option-II) scenario used to evaluate the acquisition costs.

The technology risk factor (discussed earlier in Section 5.1.1.3.1, subparagraph c.) was also applied to the tester quantities similar to the earlier scenarios. Since a very conservative scenario approach (that resulted in identifying five families over the life cycle and added to this the technology risk factor) was adopted, a more appropriate prorated share of sunk costs of $60 million was assumed. As indicated in Table 37, the ATS family option scenario reduced the acquisition costs by $898 million or a 35% saving. If the more conservative approach that applied the prorated share of $60 million for 5 testers were used, the results would still have produced a 26% savings.

The single application of the prorated share of development costs ($60 million) was further justified by the fact that this cost exceeded the total $51.6 million development expenditures required for all seven of the F-15 A/B weapon system intermediate level testers at the start of the program.

Table 37. F-15 Case Study Summary (FY93$-Millions)

EXPENSE CATEGORY	OPTION-I (No Change)	OPTION-II (Common ATS Family)	OPTION-III (Common ATS Specs)	OPTION-IV (Common SW Environment) (Near Term)	(Long Term)
ATE Development-A/B	51.6	35.6	45.0	51.6	51.6
ATE Production-A/B	485.5	185.3	449.1	485.5	485.5
TPS Development-A/B	277.4	146.6	250.5	230.2	84.6
TPS Production-A/B	125.1	82.9	115.7	125.1	125.1
SUBTOTAL	**939.6**	**450.4**	**860.3**	**892.4**	**746.8**
ATE Mid-Life Addition					
C/D	408.7	246.8	377.0	408.7	408.7
E	45.4	31.7	41.4	45.4	45.4
DST	86.9	81.1	80.2	86.9	86.9
TPS (New Dev & Prod)					
C/D	195.8	219.4	179.2	180.9	135.1
E	14.8	10.8	13.7	14.7	14.3
DST	127.7	112.9	116.3	113.7	70.5
SUBTOTAL	**879.3**	**702.7**	**807.8**	**850.3**	**760.9**
A/B C/D, E Depot					
ATE Devel	88.1	88.3	76.9	88.1	88.1
ATE Prod	293.7	71.9	271.7	293.7	293.7
TPS Devel	255.8	128.4	231.0	212.3	78.0
TPS Prod	44.6	100.8	41.3	44.6	44.6
SUBTOTAL	**682.2**	**389.4**	**620.9**	**638.7**	**504.4**
Prorated Share of ATS Family	0.0	60.0	0.0	0.0	0.0
TOTAL	**2,501.1**	**1,602.5**	**2,289.0**	**2,381.4**	**2,012.1**

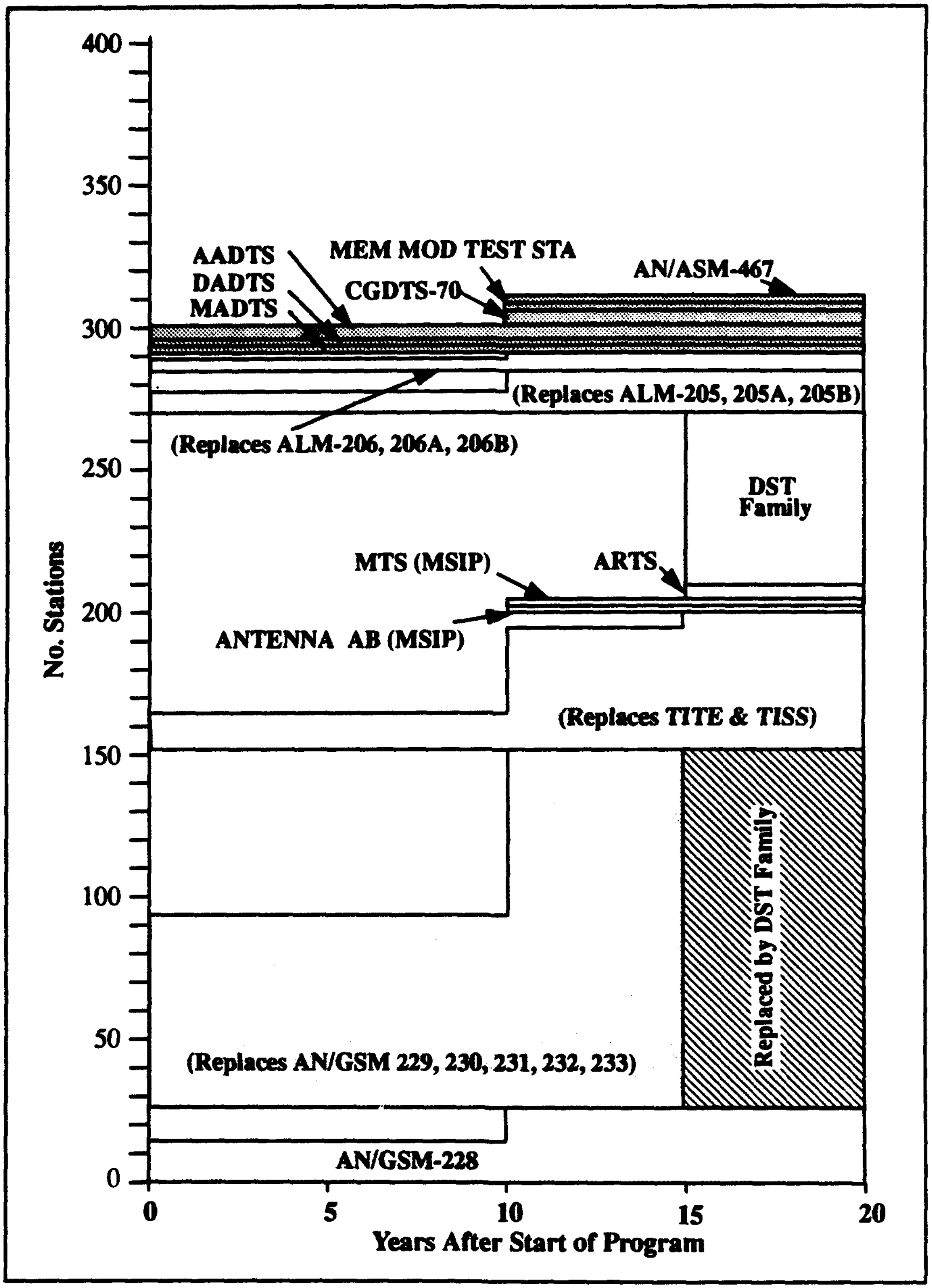


Figure 15. Option II, ATS Family Scenario for the F-15 Weapon System

5.1.1.3.5 Abrams (M-1) Scenario

The Abrams Tank designated as the M-1 weapon system is already supported with families of ATS: the STE and DSESTS in the field and the USM-410 in the depot. The Army plans to replace and augment the STE fault detection and diagnostic capabilities with the contact test set (CTS) plus the electro-optical assembly (EOA). The Army has identified plans to either update or replace the aging DSESTS. For Option I (No Change), Option III (Common ATS Specs), and Option IV (Common SW Environment) the authors assumed a mid-life update to the DSESTS. Figure 16 illustrates the quantities and time frame that the M-1 ATS were introduced for these acquisition strategy scenarios..

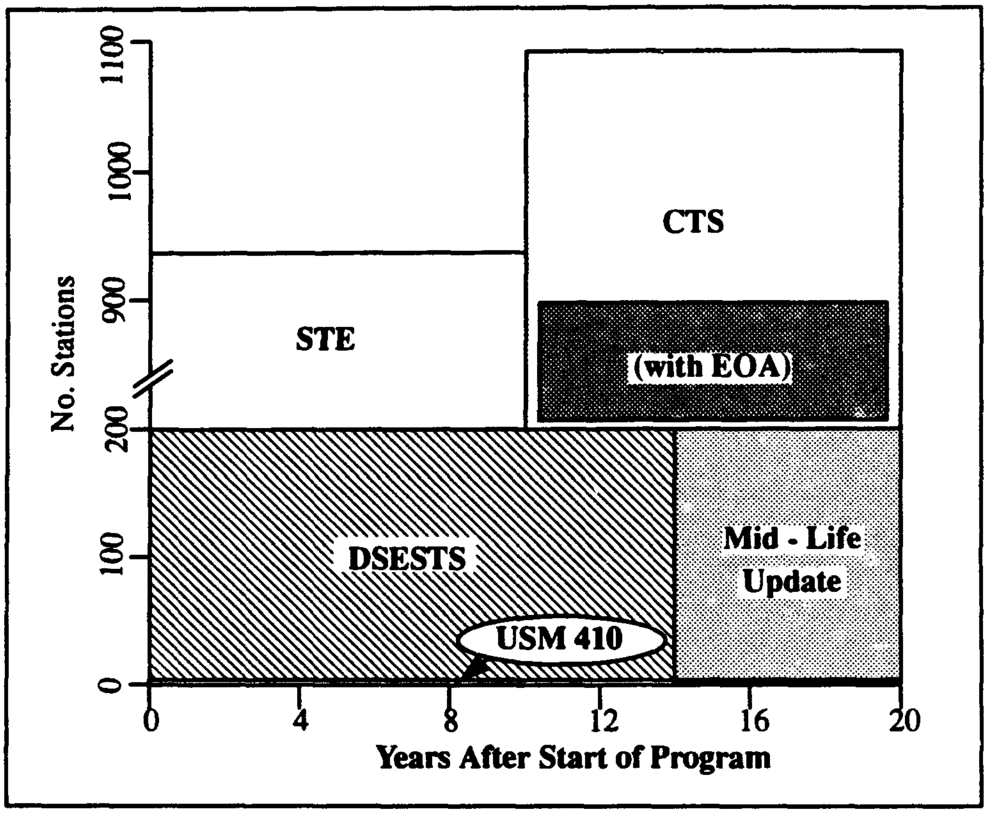


Figure 16. M-1 Weapon System ATS Evaluation Scenario for Options I, III, and IV

Since the M-1 weapon system was already using ATS families, the Option-II (Common ATS Family) scenario needed to be approached from a slightly different perspective. For this scenario, the full IFTE family of testers (Contact Test Set, Base Shop Test Facility (BSTF), and Commercial Equivalent Equipment (CEE)) were assumed to be available at the onset of the M-1 program. The Army's projected support capabilities of integrated sets of CTS, BSTF and CEE were used as the starting point:

- 2 depot USM-410 could be replaced by 2 CEE,
- 198 DSESTS could be replace with 53 BSTF,
- 737 STE could be replaced by 894 CTS augmented with 86 EOAs.

To back into the number of ATS required at the beginning of the program, the technology risk factor was applied to the BSTF quantity (e.g., same approach used on the other case studies).

The CTS presented a problem, since it is not a direct 1-for-1 replacement of the STE. The CTS is projected to reduce the work load relative to the current STE while providing increased fault isolation capabilities. At the same time technology differences ten years earlier would have posed difficulties in fielding a CTS with comparable performance. Therefore, for this scenario case study, the CTS quantity was assumed to remain constant.

Finally, 25% of the technology (or testing requirements) were assumed to change at the mid-life update, and the same approach used on the other case studies was applied. Figure 17 illustrates the M-1 ATS family scenario used to evaluate the acquisition costs.

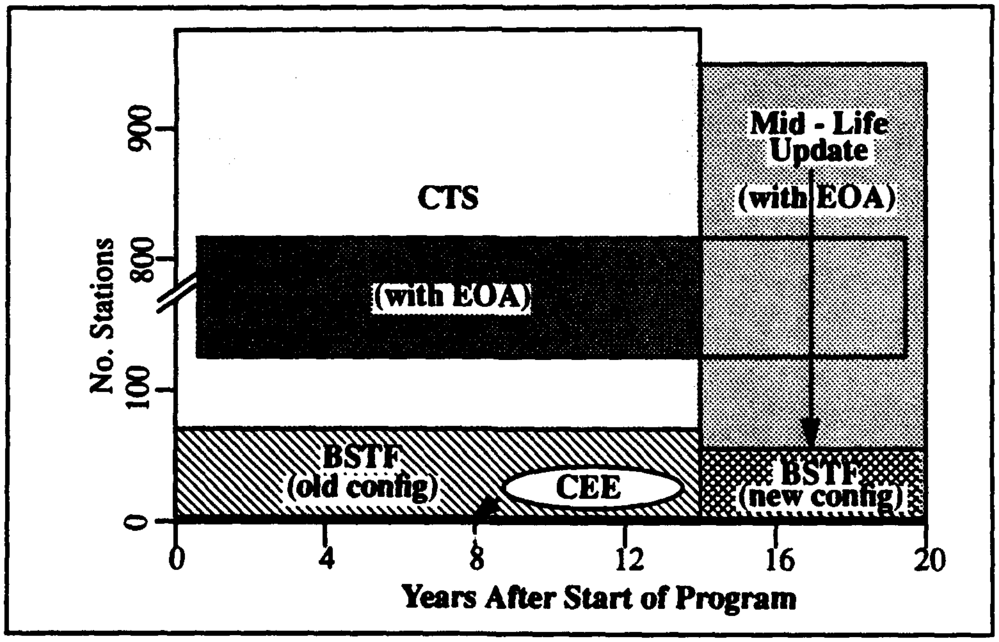


Figure 17. Option II, ATS Family Scenario for M-1 Weapon System

The baseline scenario information used to develop both figures is presented in Table 38.

Table 38. M-1 Baseline Scenario Information

ATS Name	QTY	Cards	Modules	ATE Devel ($M)	ATE Acq ($M)	TPS Devel ($M)	TPS Acq ($M)	No. ITAs/ AIS
AN/USM-410	2.	Yes	Yes	0.7	3.2	6.8	1.4	34
DSESTS	198	Yes	Yes	8.4	179.3	5.1	30.3	34
STE M1/FVS	737	No	Yes	0.4	29.3	0.4	22.5	1
CTS	896	Yes	Yes	0.0	10.1	1.0	0.1	1
EOA (CTS)	86	Yes	Yes	2.1	37.1	1.0	3.4	1
BSTF	53	Yes	Yes	14.3	116.6	5.4	5.5	21
CEE	2	Yes	Yes	0.5	3.7	3.9	0.2	15

The results of the M-1 case study scenario are presented in Table 39. Although Option II, Common ATS Families, has the lowest relative total cost, the total cost differences were not as high as computed in the other case studies. One subjective rationale for this condition is that some of the ATS being replaced by this scenario are aging ATS that had themselves been part of a family group used by the Army.

Table 39. M-1 Case Study Summary (FY93$-Million)

EXPENSE CATEGORY	OPTION-I (No Change)	OPTION-II (Common ATS Family)	OPTION-III (Common ATS Spec)	OPTION-IV (Common SW Environment) (Near Term)	(Long Term)
ATE Development	9.4	4.6	8.2	9.4	9.4
ATE Production	211.8	177.9	196.0	211.8	211.8
TPS Development	12.4	10.2	11.2	10.3	3.8
TPS Production	54.2	9.8	50.1	54.2	54.2
SUBTOTAL	**287.8**	**202.5**	**265.5**	**285.7**	**279.2**
ATE Mid Life Addition	49.2	0.0	45.4	49.2	49.2
TPS (New Dev & Prod)	5.6	0.0	5.1	5.2	4.1
SUBTOTAL	**54.8**	**0.0**	**50.5**	**54.4**	**53.3**
ATE Mid Life Update	47.9	33.7	44.2	47.9	47.9
TPS Rehost	3.9	3.7	3.9	2.4	2.4

Table 39. M-1 Case Study Summary (FY93$-Million) (Continued)

EXPENSE CATEGORY	OPTION-I (No Change)	OPTION-II (Common ATS Family)	OPTION-III (Common ATS Spec)	OPTION-IV (Common SW Environment) (Near Term)	(Long Term)
SUBTOTAL	**51.8**	**37.4**	**48.1**	**50.3**	**50.3**
Prorated Share of ATS Family	0.0	60.0	0.0	0.0	0.0
TOTAL	**394.4**	**299.9**	**364.1**	**390.4**	**382.8**

5.1.1.3.6 Sensitivity Analysis

A separate analysis was performed to assess the sensitivity of the case study results to variations of selected boundary condition assumptions. This sensitivity analysis revealed that the ATS development and production costs were relatively insensitive to large changes in (1) the option cost factors, (2) technology adjustment factor, and (3) mid-life ATS configuration changes. The major cost savings for ATS family acquisition were attributed to the reduction of duplicative engineering tasks and production economies of scale for common equipment.

A sensitivity analysis approach was adopted that computed the percent change from the nominal conditions for various parameter and option cost factor changes. Selected case parameters in the case study model were varied and the change in estimated acquisition costs computed.

Table 40 presents the results of a comparison for the F-18 Option-II (Common ATS Family) scenario. Percentage changes are presented from two perspectives: relative to the Option-II scenario (e.g., factors and parameters identical to those used in the F-18 Case Study), and relative to the baseline (No Change) Option-I scenario. These two scenario results are summarized above the bold line in this table.

Clearly, based on this data, the model was relatively insensitive to these parameter changes. The sources of greatest savings in each of the case studies were (1) the cost avoidance of duplicative non-recurring engineering development of both ATE and TPSs, (2) reduced ATE quantities attributed to general purpose ATS family candidates that meet multiple applications, and (3) production economies of scale.

An analysis was also conducted to determine how well the technology adjustment factor compensated for technology that was not available at the onset of a program. Since the F-16 A/B AIS was available at the onset of the F-18 case study scenario, the cost (or quantity) did not need to be adjusted by the 25% technology adjustment factor. Therefore, the sensitivity analysis was based on the F-18 Option-II scenario using the F-16 A/B AIS as the candidate family tester. This approach would help discount an unknown variable, specifically the technology adjustment factor.

The results revealed that the total acquisition costs varied by as much as $150 million on either side of the original computed value that had applied the 25% technology adjustment factor to the CASS quantities. This sensitivity analysis revealed that the difference in acquisition cost was less than 11% relative to the baseline for a range of assumptions (from very conservative to very extreme). The wide-range of assumptions that produced this relatively small percentage included work loading of a single RF CASS station versus a full F-16 AIS, introduction of card level testing capabilities, and the addition of F-16 AIS equivalent P^3I sustaining engineering costs.

Table 40. F-18 Option-II Scenario Sensitivity Analysis

CASE PARAMETER	Acquisition Cost (FY93$-M)	% Change Relative to Option-II Scenario	% Change Relative to Baseline Scenario
Baseline (No Change) Scenario Cost	1320.5	0	N/A
Option-II (ATS Family) Scenario Cost	576.5	N/A	0
ATE Development Option Cost Factor - Increase from 0.05 to 0.10	594.5	3.0	1.3
ATE Acquisition Option Cost Factor (Learning Curve) - Increase from 0.85 to 0.90	588.6	2.1	0.9
- Increase from 0.85 to 0.95	600.6	4.0	1.8
TPS Acquisition Option Cost Factor (Learning Curve) - Increase from 0.85 to 0.95	591.5	2.5	1.1
TPS Re-Host Option Cost Factor - Increase from 0.33 to 1.0	642.1	10.2	5.0
Mid-Life ATS Configuration Change - Increase from 25% to 50%	599.2	3.8	1.7
Technology Adjustment Factor (Compensate for Earlier Insertion) - Increase from 25% to 50%	602.8	4.4	2.0

The authors were concerned that many of its assumptions might have been too conservative, and the range of estimated savings were too low. Figure 18 illustrates the range of potential savings for the F-16 ATS under Option-II, if a more aggressive set of assumptions had been adopted. The top line of numbers reflect the results of the F-16 case study presented earlier.

	Option-I (Baseline Data)	Option-II (ATS Family)	
ATS Devel & Prod Costs	$2374M	$1716M	Conservative Total
		- $203M	Station Work Load Adjustment
		- $60M	Twice as many Systems Using
		- $110M	Reflect less Complex Depot ITAs
		$1343M	Adjusted Total

Range of Potential Savings
$658M (27%) to $1031M (43%)

Note: Additional cost savings could have been realized in this scenario if ATS families also supported other electronic testing requirements such as EW and engine controllers.

Figure 18. Additional F-16 ATS Savings Potential for an Option-II Acquisition Strategy

The $203 million reduction represents a station workload adjustment. As stated briefly in the case study, a more appropriate station workloading would be 2 or 3 CASS RF stations to 1 full-up F-16 AIS consisting of 4 station types. Although the 4 F-16 AIS station types were appropriately workloaded at the onset of the F-16 program, avionics subsystem reliability improvements, such as that for the inertial navigation system (INS), have significantly changed the station workloading of the F-16 AISs. Had the F-16 AISs been more general purpose in nature, as opposed to subsystem specific, this difference might not be as pronounced. ATS quantity reductions are reflected in this estimated additional $203 million savings.

The $60 million reduction assumes that twice as many systems will eventually use the ATS family, thereby, effectively distributing the ATS development costs across more system applications. Finally, the $110 million is based on the assumption that the depot

ATS ITAs would not be substantially more complex than those currently used in the depots. The approach used in the F-16 case study estimated the ITA costs based on I-level development and production costs. This appears to be very high, but comparable depot data was not available to develop a more representative costing model. From this perspective, the authors observed that the ATS Family acquisition strategy had the potential of producing an additional 16% savings over and above that estimated in this case study.

Alternatively, a case may be made that the F-16 ATS acquisition strategy, which was concurrent with weapon system development and ongoing support, was driven to some degree by operational support requirements and foreign military sales commitments. An estimate of savings potential of an Option II scenario based on the F-16 ATS cost, less the identified P^3I sustaining engineering costs, was still significant and computed to ranged from 15% to 34% using this same approach.

A final evaluation addressed the influences of (1) using actual data for the RF CASS or (2) applying the computer factors against the baseline (no change) Option-I scenario data. Several alternate Option-II sensitivity analyses were run in which the option cost factors were applied directly to baseline data. In the case of the F-16, directly applying the factors to the baseline data resulted in a total acquisition cost that was approximately $44 million less than the original value that was computed using the actual CASS RF data.

For the F-18 case study, the alternate approach still showed a savings of approximately $345 million, however, it was substantially higher than the original computed Option-II total acquisition cost. Upon evaluation of the specific data fields in this analysis, the approach that applies the Option-II cost factors directly to the baseline data was found to result in a very conservative estimate of total costs. The main contributing reason for its conservative nature was that it does not introduce the potential reduction of tester quantities that were observed with the actual data.

Consequently, using the CASS RF data is more representative of what would result from a new ATS acquisition strategy. However, later in Section 6, when computing estimated ATS investment savings, the more conservative approach is used for model simplification.

5.1.2 Operations and Support Costs

Operating and support (O&S) costs for each weapon system were difficult to obtain since the Services do not collect and accumulate detailed support costs for automatic test systems. The analysis presented in this section may be used to indicate trends; however it should not be considered conclusive due to the limited O&S data available. The main sources of O&S cost information included an evaluation of the IFTE support for the AH-64 Apache helicopter [APACHE 1991], the IFTE Cost and Operational Effectiveness Analysis (COEA) [IFTE 1989], data from the CASS training and manpower analysis which was used to develop the 1991 CASS Navy Training Plan (NTP), and several programmatic CASS briefings [NAJRIAN 1991] [EVANOVICH].

The study team collected available cost data for six different O&S cost categories: Operator and Maintainer Training, Support of ATS, Supply Support, Technical Data, Manpower, and Facilities. Most of the collected data in these categories may be best described as anecdotal information, yet these data also provide evidence of trends. The most consistent trend observed indicated that weapon system support is more effective with a common, as opposed to weapon system unique, ATS. A common ATS family limits the amount of support needed for a single system while simplifying other aspects of weapon system support.

The following discussions of O&S costs are broken down into five areas: Technical Publications; Support of ATS; Manpower, Personnel and Training; Supply Support; and Facilities.

5.1.2.1 Technical Publications

The primary source of information on technical publications was obtained from the Naval Aviation Technical Services Facility (NATSF) on CASS transition programs. For 5 initial ATS systems to be transitioned there are a total of 367 technical manuals. NATSF estimated that approximately $100,000 is spent annually (by NATSF and other Navy field activities) to keep these existing ATS manuals current. These resources are necessary primarily to maintain current information due to obsolescence-driven ATS spare parts changes and continuing engineering changes needed to meet evolving test requirements. NATSF representatives indicated this is a conservative estimate, and the costs could run higher depending on the number of changes needed to maintain an ATS configuration.

In contrast, CASS requires only 13 technical manuals for its four configurations. The CASS use a electronic technical manuals system on optical disks, and each CASS station has the capability to display and print its own technical documentation. Updates of technical manual information are to be accomplished by distributing an optical disk rather then by the traditional use of change pages. Although the Navy has not estimated the total savings, they indicated an overall technical publications cost reduction is anticipated. An additional benefit involves reduced facilities requirements attributed to reduced volumes of paper.

5.1.2.2 Support of ATS

Based on discussions with Navy field activity support personnel, the authors noted that between 80-200 line items of support-of-support (SOS) support equipment are required to support any particular ATE. These items include maintenance equipment such as oscilloscopes and multimeters; support software such as self-maintenance test program sets and their documentation; special tools such as card extractors, pin insertion and removal tools; and unique calibration equipment. In contrast, CASS, needs approximately 135 items of support equipment across its 4 configurations. Potential savings are expected due to reductions of SOS support equipment sets. For example, CASS requires one set whereas six unique sets are required for the 6 multiple system peculiar ATE that will be replaced by the planned off-load: EOSTS, HATS, VAST, ESTS, TMV and NEWTS. In addition, other system-unique ATS savings are anticipated due to elimination of multiple sets of ATS support equipment. Other potential support equipment (for ATS) cost saving categories include: training, maintenance personnel, technical publications, and support equipment storage space.

5.1.2.3 Manpower, Personnel, and Training

Manpower, personnel, and training savings attributed directly to standard ATS families have been identified by both the Army and Navy. The following paragraphs present the identified savings for CASS and IFTE ATS families.

The 1991 CASS Transition Plan (information provided by the Navy in the TIMs) was used as a basis for assessing personnel and training requirements for the 6 initial testers being replaced by CASS: EOSTS, HATS, VAST, ESTS, TMV and NEWTS. The Navy estimated that 871 people Navy-wide are needed to currently operate and support these 6 testers. Annual support training requirements for operators and maintainers associated with these 6 testers are budgeted at $2.514 million. In contrast, about 610 equivalent people are required to man the CASS stations. The equivalent training cost associated with the CASS is estimated to be $0.579 million This represents a personnel reduction of about 40%, and a training cost reduction of greater than 75%. The training savings are based on a reduction of training courses from 22 for the 6 testers to 3 for CASS. Tables 41 and 42 show both the current training requirements for the 6 testers and equivalent training requirements for CASS.

Table 41. Current ATE Training Requirements and Costs

SYSTEM	NEC/MOS[1]	BILLETS (TOTAL NAVY)	ANNUAL TRAINING COSTS (FY93$)
AN/AAM-60 (EOSTS)	6684/ 7959	41 67	0.231M
AN/USM-403 (HATS)	6619/ 6628	37 39	0.138M
AN/USM-247 (VAST)	6652/ 6653/ 6665/ 6659	116 132 52 71	0.987M
AN/ASM-614 (ESTS)	6608	86	0.090M
AN/USM-470 (V)2 (TMV)	6694/ 6695	45 20	0.126M
AN/USM-458 (NEWTS)	6618/ 6482/ 6622	114 51	0.942M
Summary for 6 Systems	**14 NEC/MOSs**	**871 PEOPLE**	**$2.514M**
(1) Navy Enlisted Classification/Military Occupational Speciality			

Table 42. CASS Equivalent Training Requirements and Costs

SYSTEM	NEC/MOS	BILLETS (TOTAL NAVY)	ANNUAL TRAINING COSTS (FY93$)
CASS Summary for 1 System	6704/6705 (2 NEC/MOSs)	610 PEOPLE	$0.579M

Another example of personnel and training savings is illustrated by the Army's IFTE ATS. The Army IFTE Cost and Operational Effectiveness Analysis (COEA) evaluated IFTE against 12 system-specific ATE systems [IFTE 1989]. The IFTE case was based on a Europe VI scenario (an Army operational scenario based in Europe) and included personnel from a corps and echelon above core slice. The training cost was an estimate based on total annual operator and maintainer personnel training requirements for the 12 system-specific testers versus total annual operator and maintainer personnel training requirements for the IFTE. The personnel requirements at a three-level maintenance strategy were estimated to be 641 people with an annual training cost of $4.8 million for the system-specific ATS. This was compared to 269 personnel required to operate and maintain the IFTE ATS with an annual training cost of $2.5 million performing the same functions as the 12 system-specific ATSs. This represents a personnel savings of about 42% and a training cost savings of 52%.

5.1.2.4 Supply Support

Navy projections indicated the total number of ATE related spare part line items could be reduced from 30,000 to 3,800 per aircraft carrier by replacing existing ATE with CASS. Savings, although not quantifiable in this study, are associated with line items that need to be managed, tracked, stocked, accounted for, and kept in a "ready for issue" condition. A standard ATS family will reduce the total number of SOS line items over system specific ATS by virtue of common assets for a much smaller number of ATS configurations [MERRILL].

5.1.2.5 Facilities

The Navy indicated facility space requirements could be reduced by approximately 5,000 square feet on a typical aircraft carrier by replacing the existing ATS with CASS. Their studies project total facility reductions from 15,000 square feet to 10,000 square feet floor space. This reduction in facility space requirements includes space reductions for support equipment, spare and repair parts, personnel, and technical manuals [MERRILL].

5.2 QUALITATIVE ANALYSIS RESULTS

The results of the qualitative assessment were inconclusive. Even though the qualitative results were inconclusive, the approach helped bring out several subjective observations by team members working on this portion of the analysis. Therefore, the following paragraphs are intended to provide insight into their thought process and summarize the observations upon which they gained a consensus. The observations covered three areas: (1) each of the strategy options would be able to accommodate technology and test requirements growth from within its respective framework; (2)a common ATS family strategy was the principal option that would permit operational commonality, but other resources (TPSs, ITAs, etc.) would be needed also in addition to standard ATS; and (3) depot efficiency did not appear to favor any one of the option strategies over another.

The approach attempted to use four evaluation criteria for assessing the individual strategies: operational commonality, technological feasibility, programmatic risk, and depot efficiency. These four criteria categories were then broken down into subcategories and evaluated. Figure 19 illustrates the criteria and subcategories used in the evaluation. Service representatives helped to establish the subcriteria categories. The following are the category assessment criteria used in this analysis

a. Operational Commonality: Assessment of the opportunities for and the limitations of increased inter-system and intra-Service and inter-Service application of ATS.

b. Technological Feasibility: Assessment of option evolution opportunities and limitations in terms of obsolescence, technology growth, and test requirements growth.

c. Programmatic Risks and Opportunities: Assessment of option compatibility with ATS requirements derived from mission needs, maintenance concepts, testing requirements, and weapon system and ATS acquisition strategies.

d. Depot Efficiency: Assessment of ATS-related factors influencing depot efficiency and the impact on both depot competition and Service operational maintenance requirements and capabilities.

A pair-wise evaluation concept was used to compare the strategies. A commercial software tool that runs on the standard personal computer was used to perform the evaluation. The concept implemented by this tool required that each of the subcategories be evaluated to determine its level of importance relative to each of the other categories. This was accomplished by comparing pairs of subcategories. The categories were than ranked against each of the study options to determine what effect they had on the options. Study team members (including people from OSD and each of the Services) were asked to perform the category ranking. This approach was used in an attempt to quantify this very subjective topic area. We observed that perceptions of individuals participating in the ranking process could significantly alter the analysis results. Therefore, the results of pair-wise

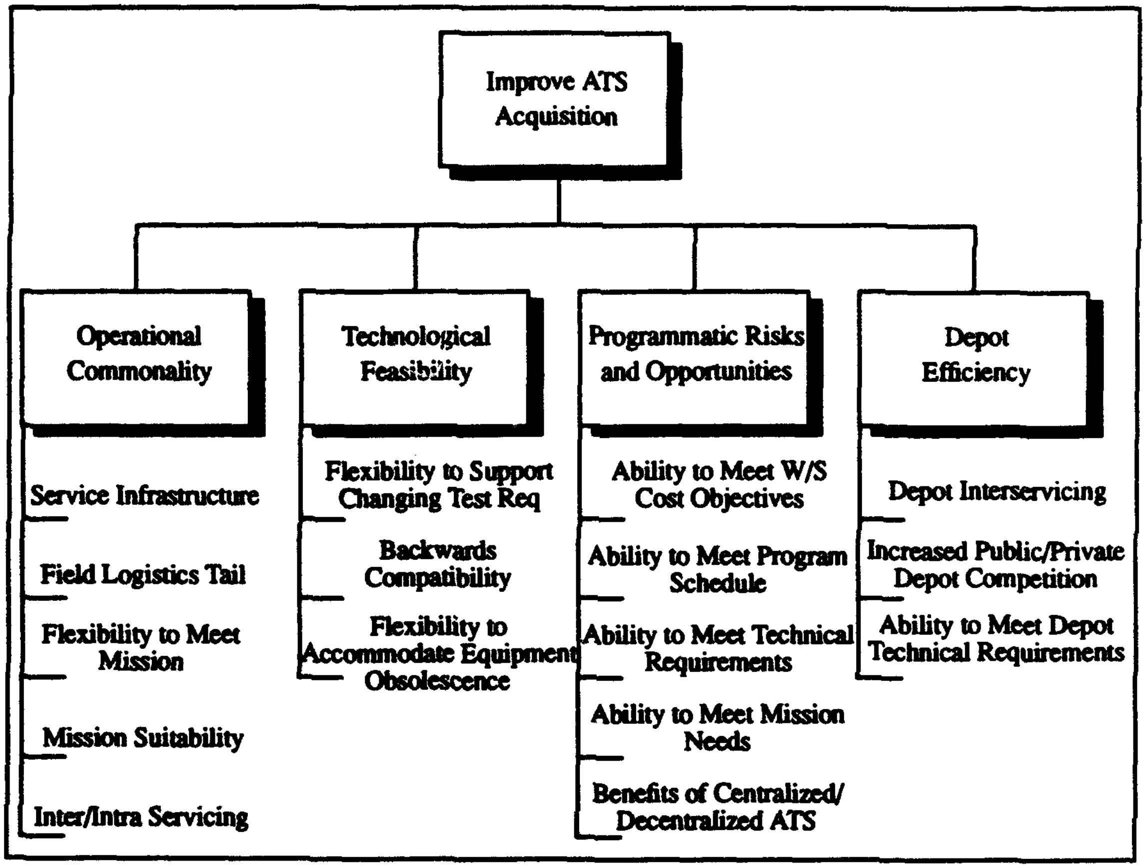


Figure 19. ATS Acquisition Strategy Qualitative Analysis Evaluation Criteria

comparison analysis were suspect. However, the participants felt that the consensus established on three areas during subjective discussions was extremely valuable. The following paragraphs highlight the consensus established.

5.2.1 Operational Commonality

Several factors were identified that influence opportunities for improving operational commonality (both cross-weapon support as well as cross-Service support). These factors are Service infrastructure, field logistics tail, flexibility to meet mission requirements, mission suitability, and the ease at which inter and intra Servicing can be achieved. Each of these factors was evaluated to determine which option would support maximum operational commonality.

During this study, the study team learned that the Air Force had requested avionics repair support from Navy aircraft carriers in the Gulf during Desert Storm. This repair support did not occur since the Air Force avionics and support requirements differed significantly from the capabilities available with the Navy forces. However, if appropriately planned, ATS compatibility could have allowed the Air Force to receive avionics repair support from Navy carriers. This example influenced most of the discussions. Compatible ATSs across weapon systems would allow the flexibility of wartime tester work-loading, help reduce unique tester deployment logistics, and permit a more flexible use of maintenance personnel. Service members felt that if there is a trend towards more joint operations, then there will also be new requirements for increased operational commonality in terms of cross-Service maintenance.

The study team observed that cross-weapon support of this nature would require extensive and detailed advanced support planning. The additional planning and resources could represent significant logistics costs depending on the specific systems involved. The participants also felt that additional analysis in this very specific cross-Service topic area was needed. However, there was agreement that increased ATS commonality would greatly enhance the feasibility of pursuing this opportunity. Cross-weapon and cross-Service support and therefore operational commonality would be enhanced by the use of identical or compatible automatic test systems. The use of common ATS families would allow flexibility of tester workloading, and possibly reduce total ATS requirements. This was the only option strategy that had the potential to increase flexibility of weapon system support, reduce deployment resource requirements, and permit more flexible use of maintenance personnel.

5.2.2 Technological Feasibility

For the purposes of this evaluation, technological feasibility was defined as the ability of ATS hardware and software to accommodate changing weapon system test requirements. In this context, technological feasibility is affected by ATS hardware and software architecture. The flexibility of the architecture determines how quickly the ATS can accommodate changes in technology and testing requirements. Several subcriteria that influence this capability were identified such as the flexibility to support changing testing requirements, backward compatibility, and the flexibility to compensate for equipment obsolescence.

The participants in this analysis agreed that each of the options appeared able to accommodate technology growth, test requirements growth, and obsolescence avoidance within its own framework. Each option was able to support changing test requirements by accommodating a capability commensurate with the needed testing requirements. Opinions of the team members did differ slightly on the rate that each option might accommodate technology change. There was general agreement that Option III (Common ATS Specifications) had the greatest potential of limiting the rate of technology growth. There was a general perception that the ATS and technologies used by them evolved faster than implemented standards.

5.2.3 Programmatic Risks and Opportunities

Several factors were identified that influence ATS programmatic risks and opportunities. These factors included

- the ability of an ATS option to meet weapon system cost objectives,
- the ability of an ATS option to meet weapon system schedule requirements,
- the ability of an ATS option to meet weapon system mission needs, and
- the benefits of centralized managed ATS.

All of the options were assessed to be compatible with the first four subcriteria constraints; however, centralized versus decentralized management of an ATS was perceived by the Services as sensitive to the success of any particular weapon system program. This was consistent with the finding that ATS were managed differently within the Services. Both ATE and TPSs were found to be a mix of centralized and decentralized management activities within the Services. Table 43 illustrates the management relationships observed.- During the period of the study, the Navy was in the process of transitioning from ATS centralized activities for NAVAIR to ATS centralized activities Navy wide.

Table 43. ATE-TPS Centralized vs. Decentralized Management

ATS Element	Air Force	Army	Navy
ATE	Decentralized	Centralized	Centralized
TPS	Decentralized	Decentralized	Centralized

The results of this portion of the analysis were inconclusive as a direct consequence of these management approach differences. Evaluations were split directly along Service lines: (1) Army and Navy representatives felt that having a mature ATS ready to support varying weapon system requirements tended to reduce weapon system risks. (2) Air Force representatives tended to feel that a predetermined ATS configuration increased weapon system risk since the ATS may not meet all specific weapon system test requirements.

5.2.4 Depot Efficiency

Analysis of the depot efficiency criteria did not appear to favor any of the options. Instead, the Service members subjectively observed that selected aspects of each of the options had the potential of improving depot efficiency. For example, Service representatives felt that improved access and delivery of product data along with standardized COTS ATE would tend to increase their efficiency, reduce cost and help foster depot competition. They also acknowledged that standard instrument interfaces, especially if widely used in the commercial sector, could improve depot efficiency.

6. DOD ATS INVESTMENT ANALYSIS

The objectives of this analysis were to characterize total DoD ATS investments and to project potential ATS acquisition savings based on a new DoD ATS investment strategy. The analysis results revealed that DoD's ATS inventory is around $45-50 billion, and projected that DoD ATS acquisition expenditures across FY93 through FY99 will total an additional $11 billion if no acquisition strategy changes are adopted. The results also projected a potential net ATS investment strategy saving of over $1.5 billion over this same period if a new DoD ATS investment strategy is adopted.

This analysis makes extensive use of ATS baseline data and investment strategy option information presented earlier. Past and projected DoD weapon systems acquisition budget information is used throughout the analysis. The approach

- uses the ATS acquisition ratios that were grouped by weapon system commodities, and
- applies these ratios to past and projected weapon system expenditures.

A model of ATS expenditures was created by combining the results of these two steps. The data used to develop the ratios in 1 and 2 above were based on current ATS acquisition practices; and therefore, the results represent a No Change, Option-I strategy cost projection.

The projected ATS acquisition savings attributable to a new investment strategy were then computed by applying the acquisition strategy option factors to the projected expenditures.

The following sections describe the DoD ATS investment strategy evaluated, characterize the investment strategy model used in this analysis, and summarize the results.

6.1 INTEGRATED ATS INVESTMENT STRATEGY

The integrated ATS investment strategy applied in this analysis adopts an approach which capitalizes upon existing and projected standards: ATS Families, ATS Specifications, and a Software Environment. The most significant influence is based on an approach that applies a DoD-wide policy to use designated standard ATS families to meet testing needs. The ATS families approach is coupled with research and development programs to converge designated ATS families towards common hardware and software standards at critical interfaces.

This investment strategy integrates elements of the individual option cost factors that were developed earlier in Section 5.1.1.2., Cost Factors for ATS Investment Strategy Options. Reviews of the case study results showed the relative influence of each option cost factor to be nearly independent; therefore, the benefits could be combined. For the purposes of this assessment, an ATS investment strategy that possessed the characteristics illustrated in Figure 20 was applied.

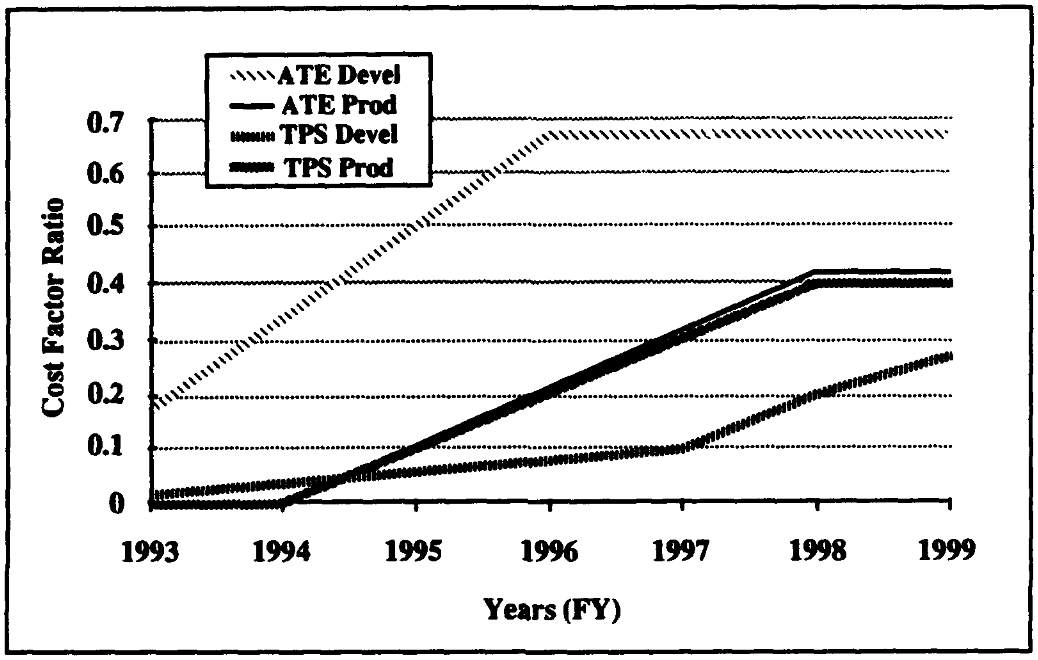


Figure 20. ATS Acquisition Investment Strategy Cost Factors

The modeling technique assumed application of a new ATS investment strategy that selects from designated DoD standard ATS families. Effectivity of benefits would be gradual over a 6 year period. That is, at the end of this period at least 70% of all ATS investments would be for DoD standard ATS families, and only 30% of the development and procurement resources would go for unique ATS. This was intended to reverse the current trend found during this study where most ATS R&D and procurement funds go directly to weapon program managers (PMs), who pursue unique ATS acquisitions. Over 70% of current development and procurement resources are for unique ATS and about 25% are for standard families (CASS and IFTE). Less than 5% are devoted to standard ATS family modernization.

The applicable percentages were applied to the identified ATS investment strategy cost factors on a linear scale beginning in FY93 at 30% and increasing to the final 70% in FY99. Therefore, the curves represented by Figure 20 illustrate the assumed implementation for the benefits postulated for Options-II, III, and IV (Common ATS Family, Common ATS Specifications, and Common SW Environment respectively). As indicated, the assumptions used to develop these strategy cost factors were based on earlier study results and their magnitude gradually ramped up to a nominal level of weapon system applicability over several years. The following provides more details of the assumptions used to develop the ratios (projected savings divided by the expense category costs of a peculiar ATS) illustrated in Figure 20.

ATE Development. Assumes 95% of common ATS family development is shared across applications. The application curve is based on an assumption that up to 70%of ATS acquisitions will be influenced by the strategy change. The implementation effectivity is phased in linearly over a four-year period.

ATE Production. Assumes both a production learning curve and a quantity reduction benefit. The application curve couples a 15% savings with a 50% quantity requirement reduction. Both of these savings benefits ramp up linearly to 70% of the systems over the same four-year period.

TPS Development. Assumes near-term development costs will be reduced by 10% due to common operating systems and station interfaces, and ramps up to 70% over 4 years. Also assumes a longer term 50% cost reduction attributed to improved TPS development and support environments. The implementation of this second benefit is delayed 4 years and ramps up to 70% over 5 years.

TPS Production. Assumptions are identical to those used in the ATE Production expense category, except that the production learning curve savings portion is applicable to only 50% of the systems. This difference reflects the fact that there is a greater potential for unique ITAs/IDs.

6.2 INVESTMENT ANALYSIS MODEL ELEMENTS

The main framework of the ATS investment analysis model is based on automatic test system to weapon system cost ratios, which when applied to total DoD budgets, will produce projections of annual ATS expenditures. The total DoD projected annual ATS costs are represented by the simple summation of estimated Service annual peculiar ATS costs combined with the planned common ATS development and acquisition. Potential savings are computed by applying the individual ATS acquisition investment strategy cost factors, discussed in the previous section, to the estimated Service annual peculiar ATS costs and comparing the results.

Because weapon system commodity areas (aircraft, missiles, etc.) exhibit different ATS ratio characteristics, this analysis was divided up into multiple weapon system groupings. The following weapon system commodity areas were selected: missiles and weapons; aircraft Army, Navy, and Air Force; weapons carrier/tactical vehicle; ships; Marine weapon systems; and other. The ratios of ATS production to weapon system costs discussed in Section 4.3.2 (and presented in Table 22) were used to compute estimated ATS total expenditures.

The study had not focused nor collected detailed data on several other weapon system commodity areas needed to form a complete model. Therefore, the ratio for Marine weapon systems was approximated by the ratio computed for Navy aircraft, and all other weapon system ratios were assigned the lowest value observed. This was considered reasonable because the 2.66% value fell close to the median of computed ratios, and Marine weapon systems would include a mix of commodity types that crossed the spectrum. The lowest ratio observed was 0.5% and it was assigned specifically to ships (represented as Ship Building and Conversions in Navy budgets) and generally to all other weapon system commodity areas. The ATS apportionment ratios described in Section 4.3.2 (and presented in Table 21) were used to estimate costs by individual ATS expense categories. Any differences in the computed apportionment ratios and actual ratios for individual weapon systems would only influence the cost distribution across the expense categories, but would not alter the computed total costs.

The investment strategy model was implemented in a spreadsheet format and its general characteristics are illustrated in Figure 21. Summaries of DoD weapon system

Weapon System (By Type)	Summary of Est. DoD WS Procurement $'s	Ratios				Projected ATS Expenditures (Without Strategy Change)	ATS Cost Adjustments	Strategy Cost Factor Ratios	Projected ATS Savings (With Investment Strategy Change)
		TPS		ATE					
Missile WCTV • • • Fighter		Production	Development	Production	Development	••• (Devel)••• ••• (Prod) •••			
									Total Savings

Figure 21. Pictorial Summary of the Spread Sheet Elements Used To Model DoD ATS Expenditures and Potential Savings

(represented by WS in this figure) procurement costs were divided by commodity area and budget year across a period from FY80 to FY99. The data is a combination of historical DoD appropriations as well as current and projected budget plans. The values used are presented in Table 44.

The projected ATS expenditures were corrected and adjusted by subtracting CASS and IFTE related ATE development and production costs (both actuals and projected) and the CASS estimated TPS off-load costs. Table 45 summarizes the ATS cost adjustments. The new ATS acquisition strategy, with its ratios presented in Figure 20, was applied against all remaining projected ATS expenditures. The total savings represent the annual sum of potential cost avoidance ATS savings across all commodity areas. The following section summarizes the results of the ATS investment analysis.

6.3 ATS INVESTMENT ANALYSIS RESULTS

This section presents the results of the ATS investment analysis and reveals that DoD could save over $1.5 billion out of an additional $11 billion ATS investment from FY93 to FY99. This section begins by characterizing the total ATS investment and comparing the results with other independent analyses, and concludes with a summary of potential annual savings.

6.3.1 Assessment of DoD ATS Investment

The projected total DoD annual ATS expenditures computed by the investment model are presented in Table 46. The data results for FY80 through FY91 are based on historical budget information, results for FY92 are based on transitional (actual and estimated) budget information, and results for FY93 through FY99 are based on budget projections. This data along with 4 data points from Frost and Sullivan, Inc. reports (three from [FROST 1983] and one from [FROST 1990]) are displayed in Figure 22.

The Frost and Sullivan totals include spare parts and some operating and sustaining engineering costs not included in the ATS investment model estimates. Upon review of the Frost and Sullivan data, it appears that their numbers reflect all potential contract line items that include ATS, even if the contract were terminated or a line item was not exercised. Finally, the dollar amounts indicated in the Frost and Sullivan data were associated with the year of award (or execution), whereas the ATS investment model reflects the estimated costs by budgeted year.

Table 44. Weapon System Procurement Costs by Commodity Areas (FY93$-Millions)

Weapon Syst Area	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89
Army A/C	1583	1863	2934	3464	4411	4959	4114	3328	3148	3255
Navy A/C	7240	9689	13005	14012	13440	13106	12597	11731	11082	10616
AF A/C	13214	15820	19918	23756	28019	31153	26501	20161	15151	17844
A Missiles	1924	2393	3093	3676	3788	3897	3426	2503	2679	2941
N Missile	3329	4259	4551	4515	4941	5368	5787	6001	6806	6945
AF Missiles	3595	5157	6539	6532	10071	8668	8978	9539	8521	8148
Ships	10673	11142	11842	19378	14724	14164	12239	13018	18830	11219
Marines	463	784	2467	2712	2312	2238	1884	1767	1509	1473
Others	11216	13977	18493	18624	21323	23969	23548	24145	20503	20070

Weapon Syst. Area	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98	FY 99
Army A/C	2260	1330	1889	1291	1318	1227	876	451	368	258
Navy A/C	9861	9160	7387	6653	7217	6459	7445	7337	7452	7596
AF A/C	13812	10048	11065	10928	10035	9778	9499	9191	8942	8685
A Missiles	3058	3169	1142	982	1267	1417	1480	1487	1608	1694
N Missile	6899	6860	4560	3718	4424	4609	3851	3670	3424	3180
AF Missile	7344	6595	5388	5378	5956	6412	6449	6733	7006	7272
Ships	9482	7863	6675	5319	3699	7912	5552	4897	6000	6300
Marines	1348	1232	1071	588	607	621	612	630	632	638
Other	18996	18001	18660	17307	16977	15690	14640	13965	13037	12306

Table 45. ATS Standard Family Cost Adjustment (FY93$-Millions)

Expense Area	FY93	FY94	FY95	FY96	FY97	FY98	FY99
IFTE R&D	2.1	3.6	2.8	2.7	2.6	2.5	2.5
CASS R&D	17.4	18.5	19.2	19.9	20.5	21.2	22.0
IFTE PROD (BSTF)	21.6	41.4	35.6	31.9	23.2	20.4	16.9
CASS PROD	196.3	169.0	165.6	164.7	161.9	159.8	157.7
CASS TPS R&D and PROD (TPS Off-load Estimated Cost)	142.0	142.0	142.0	142.0	142.0	142.0	142.0

Table 46. Estimates of DoD ATS Expenditures From FY80 To FY99

FY	80	81	82	83	84	85	86	87	88	89
Constant FY93$ in M	1,652	2,030	2,627	3,006	3,329	3,548	3,170	2,674	2,317	2,447
FY	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**
Constant FY93$ in M	2,099	1,776	1,580	1,448	1,451	1,429	1,292	1,350	1,331	1,310

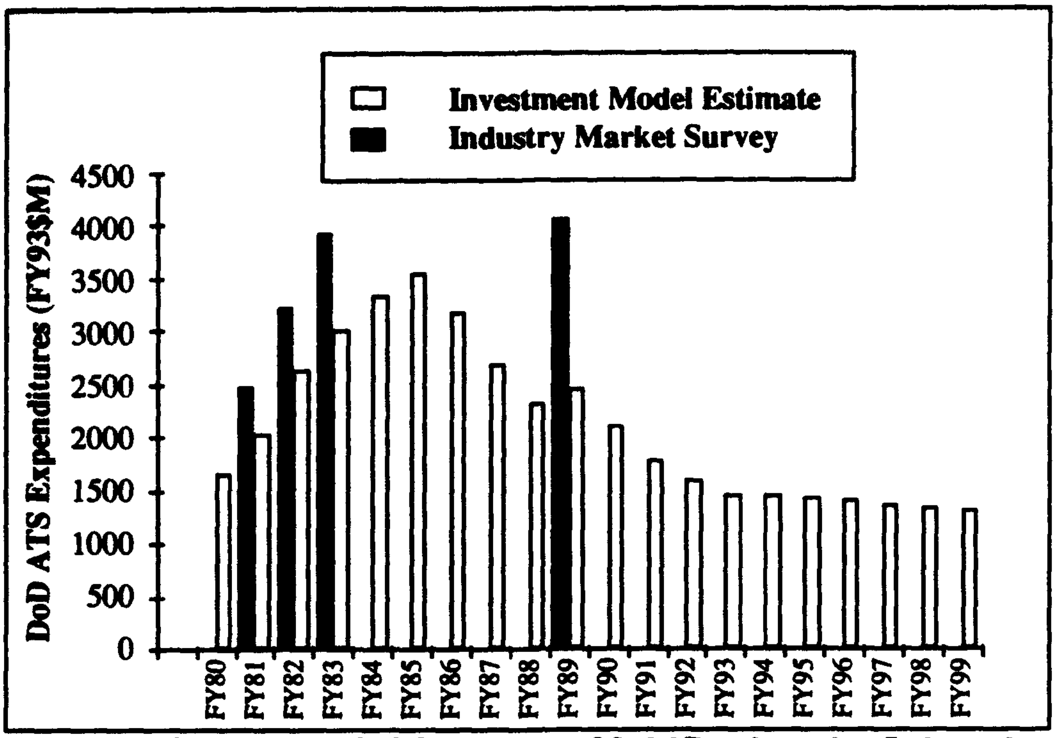


Figure 22. Comparison of ATS Investment Model Results and an Independent Market Survey of DoD ATS Expenditures

If spares and other support dollars were added to the model estimates during the build-up years of 1981 through 1983, the model would have very close correlation with the Frost and Sullivan data. The 1989 numbers from Frost and Sullivan appear to be high, and this can be attributed to several factors: spares costs not addressed by the model, and contract line items not exercised during the build-down period.

The authors also concluded that the model underestimates some of the weapon system commodity areas, and looked to the Frost and Sullivan data to identify the most likely areas. Since the ATS investment model identifies ATS development separate from production (because DoD budgets for R&D and production are separate), the assumption was made that the R&D estimates would be distributed in the same proportions as the production estimates. Based on this assumption, the relative Frost and Sullivan ATS expenditures were compared with the ATS investment model percentages of expenditures for 1989 by commodity type. The results of this comparison are presented in Table 47. We noted that the Marine commodity (3%) category was not separately identified and suspected that it is evenly distributed across the other commodity areas. The authors also noted that the ATS expenditure percentages for both ships and the other commodity areas were at least twice as much as those estimated. A potential single source of error that might have produced this difference between the Frost and Sullivan data and the model was the very conservative ATS production to weapon system cost ratio (0.5%) that was assumed due to a lack of definitive information. This would imply that the ATS study investment strategy model underestimated these two commodity areas for FY89 by as much as $300 million (constant FY93$).

Table 47. Comparison of Commodity Cost Distribution Between the Model and an Industry Market Survey

Commodity Area	ATS Investment Model - Cost Distribution	Frost & Sullivan Data - Cost Distribution
Aircraft	65%	59%
Missiles	20%	16%
WTCV	3%	4%
Ships	3%	9%
Marine	3%	(not separated)
Other	6%	12%

Given the differences noted above, the ATS investment model conservatively estimates the total DoD ATS development and production expenditures. The greatest source of ATS investment model error is believed to originate from the very conservative ratio assumption for ships and other commodity areas.

6.3.2 Assessment of Potential ATS Savings

Simply applying the ATS investment model using the cost factors for the proposed ATS investment strategy and adjusting to then-year (TY) dollars resulted in an estimated savings of approximately $1.9 billion (TY Dollars) from FY93 to FY99. However, this approach ignores additional R&D and sustaining engineering that might support the ATS family strategy approach. Therefore, a more conservative approach was considered, and the results are presented in Table 48. In this approach additional R&D and sustaining engineering funds are dedicated to efforts that support convergence of ATS families towards common hardware and software standards at critical interfaces.

Table 48. Summary of Potential Savings If a New ATS Investment Strategy Is Adopted (Then-Year Dollars in Millions)

	FY93	FY94	FY95	FY96	FY97	FY98	FY99	SUM
Pre-Strategy Investment	1,448	1,497	1523	1,531	1,532	1,559	1,584	10674
Pre-Plus Up Savings	(28)	(57)	(173)	(284)	(370)	(473)	(494)	(1,879)
Common R&D Plus Ups	21	32	44	54	56	64	78	349
IFTE Plus Up	5	5	5	6	6	6	6	39
CASS Plus Up	10	10	11	11	11	12	12	77
Man-Mobile	2	10	21	22	23	23	24	126
A Better Test Env.	2	4	4	11	11	12	12	57
Next Generation	2	2	2	4	5	12	24	51
NET SAVINGS	**(7)**	**(25)**	**(129)**	**(230)**	**(315)**	**(409)**	**(415)**	**(1,530)**

New R&D requirements were identified for five areas: IFTE advances, CASS advances, man-mobile ATS technology, a better test environment, and next generation ATS requirements. These new R&D requirements were shown as common R&D plus ups (or budget additions) in this table, and were intended to continue the conservative nature of this analysis. These R&D plus ups in five areas were intended to stimulate convergence of ATS families towards common hardware and software standards at critical interfaces. Some of the plus up values in this table do not add up to the displayed totals due to rounding error. The IFTE and CASS were both increased by $5 and $10 million annually (adjusted to estimated TY$ in the table). These additions were to address new common testing requirements and other potential P^3I needs of the future. The man-mobile plus up was intended to address portable and downsizing requirements of the future; needs of this nature have been identified by both the Air Force and the Marines. A better test environment plus up is needed to address the capabilities and benefits that were identified earlier under Option IV, Common SW Environment. Development funding will be needed to achieve these capabilities. Finally, the next generation plus up supports research and development efforts needed to plan for the next generations of common ATS families.

A graphical summary of the results is presented in Figure 23. Here again the results are shown as constant FY93$ to be consistent with the earlier figure. The dark bars illustrate the DoD annual ATS investment baseline computed using the developed model. The baseline in this figure (same curve as shown in previous figure) is defined to represent the annual investment without any ATS investment strategy change. The white bars illustrate the new annual ATS investment based on the estimated net savings from Table 48, only here they have been converted back to constant FY93$.

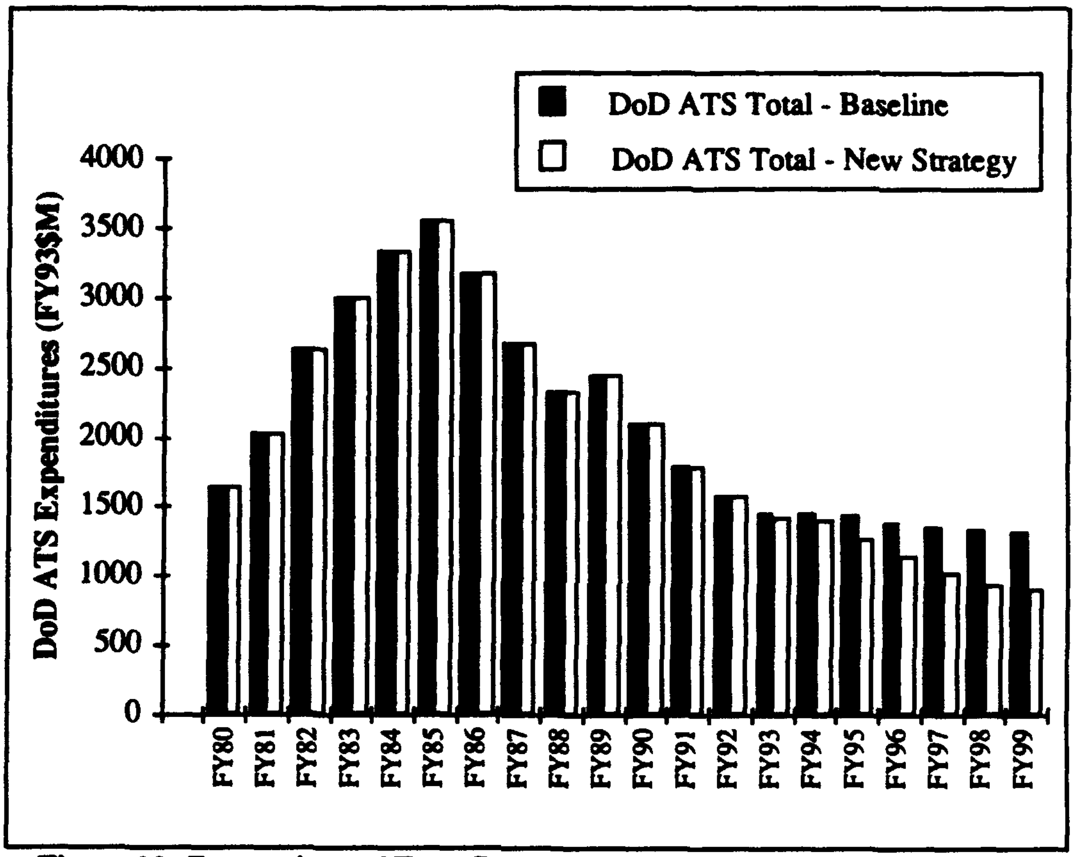


Figure 23. Comparison of Total DoD ATS Acquisition Cost Estimates Under Current (Baseline) Practices and a Proposed New Investment Strategy

7. POLICY, PROCESS, FUNDING, AND ORGANIZATIONS

Dispersed ATS investment decisions, both within as well as across Service and weapon program lines, are viewed as a major contributing factor to DoD ATS proliferation. Historically, most DoD ATS investments have been made in a decentralized fashion by individual program and depot managers. This has resulted in acquisition of many different ATS with similar capabilities. Since ATS is a key element of maintenance, defense contractors have historically gained a sole source support foothold by control of program peculiar ATS. Weapon system program logistics schedules are greatly influenced by ATS availability. Many programs, such as the F-16 and Apache, have developed and upgraded weapon unique ATS over a long life cycle; the reprocurement and support for this ATS has been essentially captured by one contractor source.

When the ATS decisions have been decentralized to the weapon manager, a weapon-unique approach was most often selected. The study data and analyses showed that, in areas where there has been clear central authority for the ATS acquisition and funding decisions, unique duplicative ATS have been minimized and standard ATS have been successfully used to achieve cost and logistics benefits.

The following sections summarize the principal ATS policies, and describe the predominant ATS management process and funding flow for DoD organizations found to be involved with ATS acquisitions. The analysis begins with discussions of current DoD policy and extends to implementation within the Services.

- DoD has no specific ATS policy and the Services' ATS policies and programs have been largely independent.
- Opportunities to leverage common investments both across and within the Services have been lost and duplicative ATS investments have been common.
- Consequently DoD is seen as having no guidance, process mechanism, or organizational approach to ensure that ATS are managed and acquired efficiently across the Services.
- The Army and Navy Service level policies and processes have evolved towards limited centralized ATS management. The Air Force's attempt to institutionalize a standard ATS management process (MATE) was unsuccessful. The Air Force is now in the process of developing a new policy and organizational structure.

7.1 DOD

There is no DoD-level policy or process limiting ATS acquisition decisions or fostering cross-Service ATS use. ATS are not specifically identified in the Department's directives or instructions and fall under the general guidelines for all systems acquisitions.

DoDD 5000.1, Defense Acquisition, February 23, 1991. Establishes a disciplined management approach for all systems acquisitions, including ATS.

DoDI 5000.2, Defense Acquisition Management Policies and Procedures, February 23, 1991. Part 6, Section D, *Computer Resources*, authorizes the ATLAS programming language for ATE; and Part 7, Section A, *Integrated Logistics Support*, requires that support structure elements be appropriately considered and acquired to ensure a supportable system.

Memorandum, Under Secretary of Defense (Research and Development), ATE Language Standardization, 1979. The DoD ATE Language Standardization Committee (DALSCOM), established by this memorandum, is chartered to mature, implement and refine the Institute of Electrical and Electronic Engineers (IEEE) ATLAS for DoD use. This is the only other DoD structured involvement in ATS policy and it addresses ATE language standardization.

Joint Services Automatic Testing Panel (JSATP), and its predecessor, the Joint Commanders Panel on Automatic Testing (originally established in 1987). Although not under the auspices of the DoD, Service members have made an attempt to coordinate development, selection, acquisition and logistics policies via these two groups. The JSATP, through its sub-panels and Executive Board, has had some success by improving communication and information exchange, but its lack of authority has limited its ability to significantly address proliferation problems identified in this study and earlier audit reports.

7.2 AIR FORCE

Historically, the Air Force has not had a Service-level ATS standardization policy and has essentially pursued unique ATS solutions for each weapon system. To cite some current examples, the Air Force is pursuing new ATS acquisitions for the F-22, the F-15 (downsized tester), the F-16 intermediate (downsized tester), and the F-16 depot; none are requiring use of the same ATS or a subset of the same ATS, although several areas of requirements overlap. The AF Systems Command/Logistics Command (AFSC/AFLC) directed approach, called MATE, imposed operating system software and a set of standards to guide weapon program ATS acquisition. The MATE policy was not effectively enforced. By the Air Force's accounting, MATE was applied in roughly 15% of the Air Force weapon programs, primarily in depot operations. The following summarize the principal Air Force ATS policies in place at the time of this study.

Air Force Regulation 800-12, Acquisition of Support Equipment, August 18, 1989. This regulation excludes ATS. Air Force activities that acquire, modify, replace, or support systems requiring ATS were to follow their respective regulations for meeting the requirements.

Memorandum, Deputy Assistant Secretary of the Air Force (SAF/AQK), Policy for Use of ADA and ATLAS for ATS, February 18, 1992. This memorandum states that:

a. New programs are encouraged to develop TPSs consistent with Ada Based Environment for Test (originally known as ABET, but due to a conflict of names is now known as ABBET or A Broad Based Environment for Test) unless the cost or risk is significant.

b. Programs intending to use ABET must submit an implementation plan for approval; this is intended so that the Air Force is able to keep ABET implementations consistent.

c. ATE that is not compliant with ABET is to be MATE compliant; and where ATE is neither, a MATE waiver is required per Air Force Systems Command/ Logistics Command (AFSC/AFLC) Regulation 800-23 [MOSEMANN 1992].

AFSC/AFLC Regulation 800-23, Policy for MATE, January 25, 1984. This regulation states that ATS for logistic support will use MATE system procedures unless a waiver is granted. Waivers are to be considered in terms of the increased life cycle costs of the prime weapon system, life cycle cost increases of the ATS with no offsetting cost benefits, incompatibility of MATE system technology with the prime weapon, and compatibility with the operational need date. The acquiring major command has the final waiver authority under this regulation.

Air Force ATS R&D and procurement funding and the acquisition responsibility have been widely dispersed in program offices and at Air Logistics Centers. As this study was concluding the Air Force published a new Service-level policy letter (July 30, 1992) stating the following: "It is the Air Force policy to use DoD inventoried ATS or common commercial ATS. Essentially, peculiar ATS should be developed and acquired on an exception basis. Funding and ultimate responsibility for ATS applicable to a weapon system must rest with the weapon system program director." The letter requires that a central ATS office be established to implement the policy; this office will cochair an ATS acquisition panel with the weapon manager ("common" and "peculiar" as used in the policy were undefined.) Under the new organization, the new ATS System Program Director (SPD) cochairs, with the applicable Weapon SPD, an ATS Acquisition Panel. The Program Executive Officer (PEO), Designated Acquisition Commander (DAC), or the Air Force Acquisition Executive (AFAE), as appropriate, resolve conflicts. Planning for the Air Force's centralized ATS organization, along with all definitions of its functions and authority, was still underway as this report was written.

A chart of the current ATS acquisition process, Figure 24, was prepared by the Air Force. The syntax used in this figure is as follows:

a. Requirements enter a process block from the left.

b. Constraints on the process enter the block from the top (e.g., funding and management).

c. Performing and participating activities that perform work enter the block from the bottom.

d. Products of the process leave the block from the right.

Simultaneous with the development of this new ATS policy, the Air Force is undergoing a substantial reorganization of the acquisition, support, and operational commands. Sweeping changes in operations could influence Air Force ATS requirements and implementation policy. For example the Air Force is investigating two-level field maintenance changes, is implementing composite wing concepts, and is discussing regional I-level maintenance concepts.

7.3 NAVY

The Navy has taken steps to acquire and manage ATS as a cross-weapon commodity. Naval aviation implemented earlier generation ATS families for a subset of its operations in the 1970s, most notably using the VAST ATS in carriers and depots. During the mid-1980s, the Navy aviation community developed their modern, comprehensive Service ATS family, CASS. The Navy aviation resolve to develop and deploy the CASS ATS family is partially attributable to the Service-wide ATS policy and a centralized ATS development and procurement organization. The Navy has a centralized organization, responsible for ATS acquisition policy and practices; however, it has not been fully

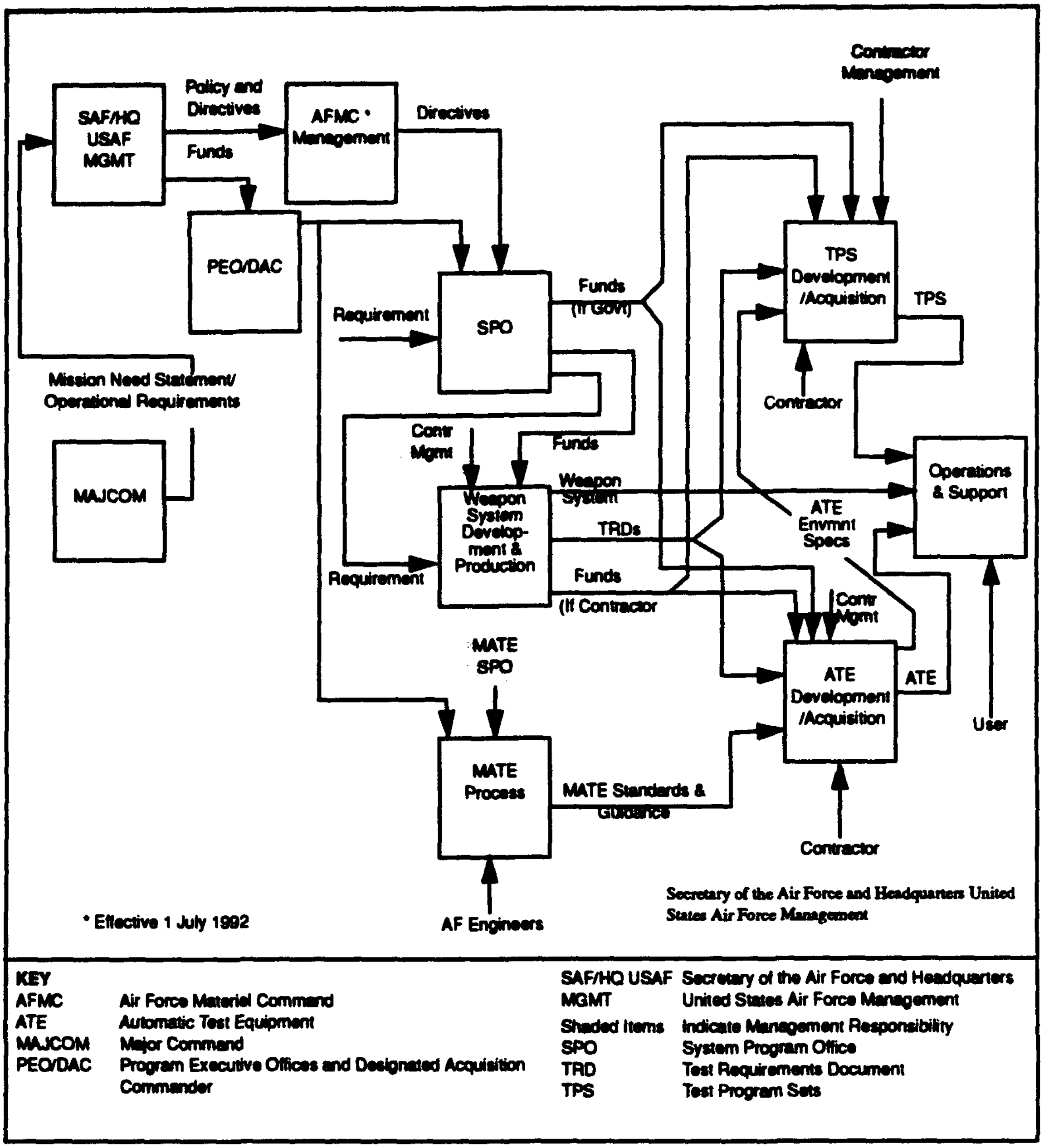


Figure 24. Air Force ATS Acquisition Process

implemented by all of the Navy's major Systems Commands. As of this study a Navy-wide implementation process was being defined. The following summarize the principal Navy ATS policies in place at the time of this study.

Secretary of the Navy Instruction 3960.6, Department of the Navy Policy and Responsibility for Test, Measurement, Monitoring, Diagnostic Equipment and

Systems, and Metrology and Calibration, October 12, 1990. Under this mandate, ATE is to be standardized as much as possible and CASS is designated as the Navy's standard ATE. Under this policy, development and acquisition of non-CASS ATE requires Assistant Secretary of the Navy for Research, Development and Acquisition (RD&A) approval.

Naval Air Systems Command (NAVAIR) Instruction 13630.2A, Introducing the CASS to Naval Aviation Maintenance, March 22, 1991. This instruction establishes the command's policy for optimizing the use of CASS and associated TPSs for all NAVAIR programs and states that all electronic weapon systems/subsystems are to be designed in consideration of the following:

a. Ease of testing and compatibility with CASS.

b. CASS or compatible equipment will be specified as the factory test equipment to be used at a development or manufacturing facility for acceptance testing.

c. The CASS is to be the target system for all intermediate and depot level ATE requirements.

d. Waiver approval is required if instances arise where CASS is determined not to be the optimum ATE support solution based on 1) life cycle cost comparison to alternatives, 2) program deployment/activation schedules, 3) Technologies not within CASS capability, or 4) facility/mobilization impacts.

Naval Sea Systems Command (NAVSEASYSCOM) Memorandum, Test, Measurement, Monitoring, Diagnostics Equipment and Systems and Metrology and Calibration, January 28, 1991. This memorandum directs the following:

a. Use of CASS when feasible for production, depot, and field testing.

b. Use of MIL-STD-2165, *Testability Program for Electronic Systems and Equipment*, to ensure effective testability is incorporated into the design of new systems.

c. The design of weapon platforms and systems diagnostics as part of system engineering.

d. Integration of system design with the Logistics Support Analysis (LSA).

Weapons & Combat Systems Directorate Guidance & Policy Paper No. 87-13 dated May 26, 1987. An earlier policy was published by the Deputy Commander for Weapons and Combat Systems to ensure implementation of CASS and the reduction of specialized ATE. This policy was intended to make CASS the preferred alternative when ATE is to be utilized.

The Naval Space and Warfare Systems Command (SPAWAR) Maintenance Policy Instruction 4600.17, (Not Signed). This instruction was awaiting final signature as this study was concluding. It mirrors the Secretary of the Navy Instruction 3960.6. The interim policy contained in the *Consolidated Automated Support System (CASS) Usage* memorandum, dated January 18, 1991, adheres to the Secretary's instruction.

The Navy ATS program is organized around PMA-260 located at Naval Air Systems Command, Arlington, VA. PMA-260 has full CASS ATS development and procurement responsibility. He is supported by AIR-552, Support Equipment Division, via a matrix organization authority structure for requirements determination and the CASS Class Desk technical systems engineering support. Assistant Program Manager for Logistics (APML) engineering support for the system is provided through the NAVAIR-04 organization. The Program Manager reports to the Secretary of the Navy via the Commander, Naval Air Systems Command, through a flag level NAVAIR-01 PEO structure. The CASS charter and matrix structure currently implement Navy-wide CASS R&D and procurement, NAVAIR-wide Common Support Equipment (CSE) R&D and procurement, and NAVAIR-wide weapon peculiar ATS and TPS management.

Currently, NAVAIR is in the process of implementing a command-wide downsizing/reorganization plan that combines the CASS Program Manager PMA-260 and the AIR-552 Support Equipment Division into a single organization. This organization will maintain the CASS (including re-host TPS programs) and CSE development and acquisition as focus areas, but transfers weapon-peculiar support equipment (PSE) and TPS management and procurement to the weapon system program managers. The new office will retain the responsibility for integrating the total aviation support equipment program policies and processes.

CASS is funded under Program Element Number PE64215N *Support Equipment (CASS)* for RDT&E and APN-7 for procurement of all production items. These funds along with the off-load TPS funds are coordinated and controlled by the CASS Program Manager through his Chief of Naval Operations (OPNAV) Program Sponsor.Emerging system TPSs are the funding responsibility of the individual weapon system program manager. However, Support Equipment Project Officers (SEPOs) within AIR-552 act as TPS requirements and acquisition managers. SEPOs determine CASS requirements and report directly to AIR-552 via a matrix organization. CASS planning is accomplished through an AIR-552 introduction planning document called the CASS Introduction Plan (CIP) which reflects those efforts required to assure timely introduction of new weapon systems support to CASS and the coordinated retirement of existing test equipment. The CIP details all programmatic information and also provides the number and type of CASS stations and ancillary equipment required for TPS development and operating fleet shore and afloat site activations. Transition efforts are being focused in the following six areas:

a. The identification and support requirements of emerging avionics systems.

b. The preparation of more cost effective TPS contracting methods and procurement management procedures that are performance driven.

c. The identification of CASS station requirements to support TPS development.

d. The identification of site-specific CASS station configurations and fleet delivery schedules.

e. The determination of ATE off-load priorities, schedules, and resources.

f. The establishment of an interim support program for specific UUTs if CASS is not the immediately available solution for emerging high priority WRAs/SRAs, as required.

The Navy uses a wide ranging suite of technical and management tools that support requirements determination and acquisition processes for CASS and weapon system TPS. These tools include the following:

a. The System Synthesis Model (SSM) mapping tool is used to define the CASS configurations best suited for UUT support.

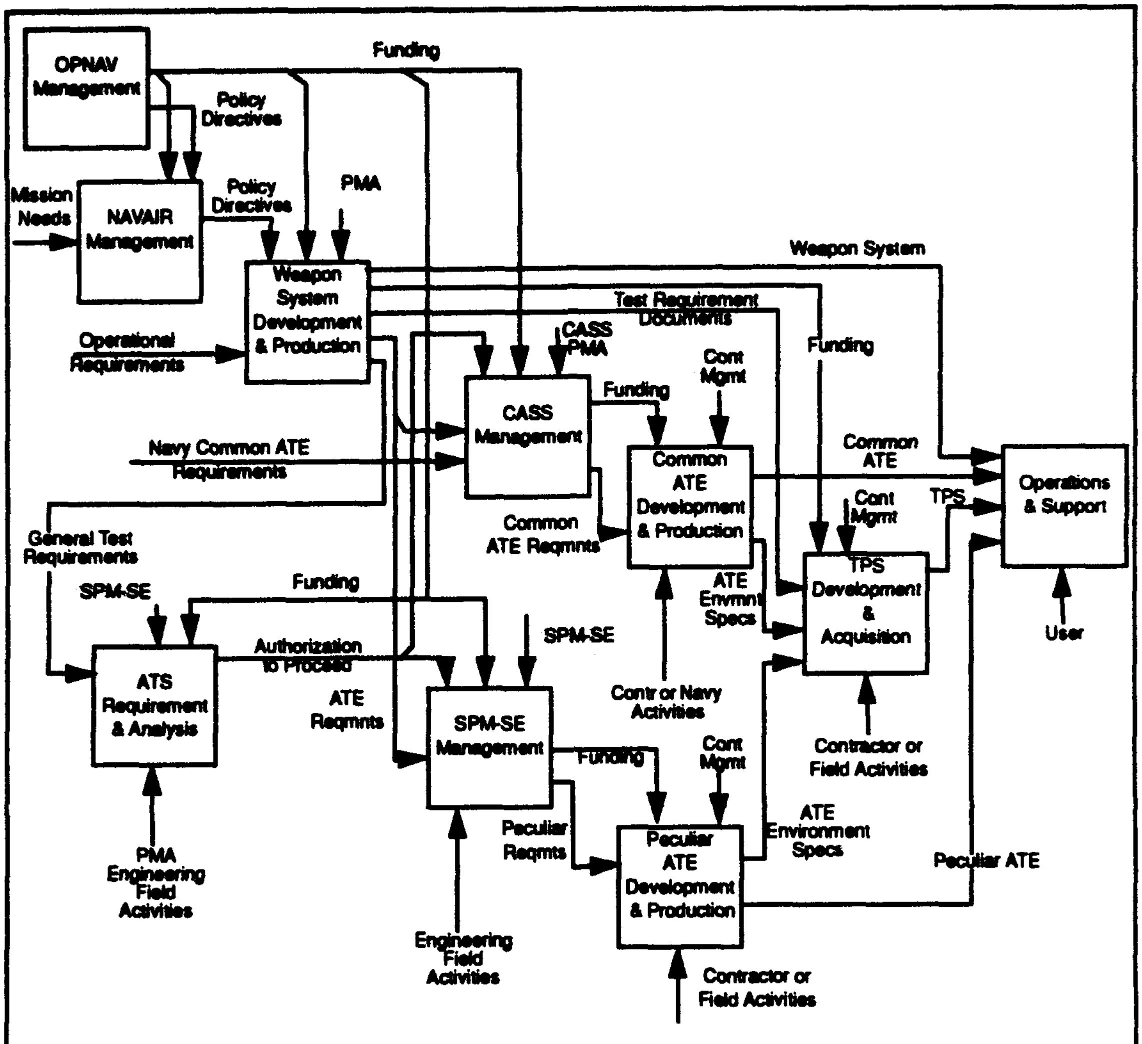
b. The SSM workload tool is used to better define the optimum configuration mix and quantity of CASS stations at a fleet site.

c. The SSM also helps identify needed interface device capabilities and potential CASS capability upgrades.

d. The Technical Risk Assessment Guide is used to determine TPS complexity factors that are used as inputs to a TPS cost model.

e. The CASS Introduction Plan data base is used to store, analyze, and distribute programmatic and financial data about all programs

A chart of the current ATS acquisition process, Figure 25, was prepared by the Navy.



KEY

ATE: Automatic Test Equipment
ATS: Automatic Test System
CASS: Consolidated Automated Support System
NAVAIR: Naval Air Systems Command
OPNAV: Naval Operations
PMA: Program Management Activity
Shaded Area: Indicates Management Responsibility
SPM-SE: System Program Manager-Support Equipment
TPS: Test Program Set

Figure 25. Navy ATS Acquisition Process

7.4 ARMY

Similar to the Navy, the Army has taken steps to acquire and manage ATS as a cross-weapon commodity. The Army's earlier (circa 1970s) ATS family example is the EQUATE, used principally in the Army depots and is now being phased out. During the mid-1980s, the Army developed their modern, and highly mobile ATS family, IFTE. The

Army's resolve to develop and deploy the IFTE ATS family is partially attributable to its Service-wide organization for all test and measurement equipment oversight.

Army Regulation 750-43, Army Test, Measurement, and Diagnostic Equipment Program, September 29, 1989. This regulation establishes Service-level policy and an Army-wide centralized organization for ATE and TPS. It is intended to ensure that development and fielding of ATE is according to the Army's maintenance structure. Under this policy, IFTE is designated as the Army standard ATE and represents an attempt to avoid ATS proliferation. The executive agent for this Test, Measurement, and Diagnostic Equipment (TMDE) is the Commanding General, U.S. Army Material Command. The Deputy Executive Director for TMDE serves as the central focal point for ATE, TPS, and software language requirements related to automated testing. In this capacity, he develops and establishes ATE, TPS and post-deployment software support policies and procedures, and reviews and approves waiver requests.

Policy implementation is controlled almost exclusively through a waiver process. Non-standard ATE will not be used in lieu of designated standard ATE without an appropriate economic analysis. System developers in coordination with the Program Manager for Test, Measurement, and Diagnostic Equipment (PM TMDE), U.S. Army TMDE Activity (USATA), and TRADOC determine ATE requirements. Once ATE requirements have been identified, the system developer determines if the designed standard ATE will fulfill requirements, and where they do not, determines the feasibility of expanding capabilities of standard ATE. If neither of the above are practical, the system developer submits a waiver request documenting the case for a non-standard ATE. Based on information provided in the TIMs, the most frequently used rationale has to do with weapon system schedule needs often associated with late ATS designation.

HQ, Army Material Command Memorandum AMC-M 750-1, Automatic Test Equipment Policy, August 6, 1991. This memorandum ensures that ATE development and fielding is according to Army Regulation 750-43. This regulation designates the IFTE, a highly mobile or fixed site tester, to be the Army standard ATE that will be used for all new systems as well as currently fielded systems undergoing P^3I. The policy requires that Army-wide cost and effectiveness considerations be made as according to Army Regulation 750-43, that PM TMDE be responsible for the logistic support of ATE and embedded software, and that the Major Subordinate Material Development Commands identify TPS requirements not later than milestone II of the prime system.

Army Pamphlet 750-43, Army Test Program Set Procedures. This pamphlet provides guidance for applying requirements, acquisition, development, and life cycle management of TPS in support of Army Material Command systems. The Program Manager TMDE manages the implementation of general purpose TMDE/ATE, promulgates technical guidance for weapon system developers, implements and controls the standard ATE language, formalizes and publishes doctrine for TPS development, and develops policy, specifications, and standards for electronic information delivery.

The Army has centrally organized its ATS program around the TMDE activity located at Redstone Arsenal, AL. The TMDE organization is under and reports to the Commanding General for the Army Material Command (CG,AMC). The TMDE charter implements Army-wide management, research and development, central procurements for common and tactical TMDE, and the ATS waiver process.

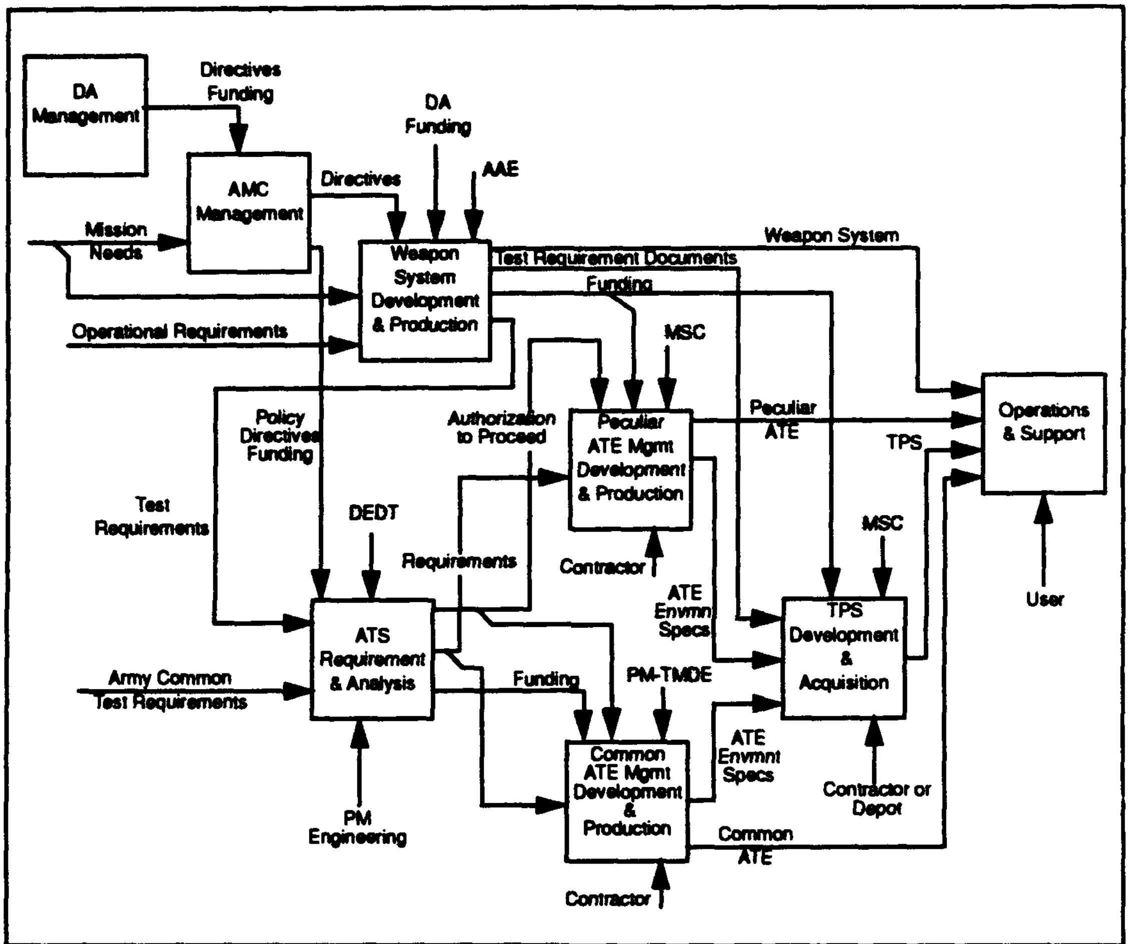
ATE requirements at all echelons of maintenance are identified and justified by a complete system Repair Level Analysis (RLA). These requirements for both hardware and software are identified and validated by the USATA, TRADOC, DESCOM, and system developer activities. After confirming ATE requirements, a determination is made if requirements can be met with the IFTE system. If not, the feasibility of enhancing IFTE capability is assessed. If neither of these alternatives is acceptable, the system developer or requiring activity will submit a waiver request. Peculiar ATE is not substituted for IFTE without an approved waiver. Consideration of a waiver requires a validated economic analysis ensuring the IFTE system as the baseline alternative.

The requirements and schedules for the system RLA and LSA are completed no later than milestone II for the prime weapon system under development while individual TPS requirements are established by the various TPS centers. The Program Manager TMDE, however, only provides policy guidance for the development, acquisition, and modernization of Army general purpose ATE. Similar to the Navy, the USATA has developed and maintains a Test Equipment Management Information System (TEMIS).

TPS acquisition is a separate action entirely. The priority assigned to the TPS development and procurement is driven by the end-item weapon system they support. Documentation for planning, development, acquisition, and maintenance of resources is contained in the TPS Master Plan (TPSMP).

IFTE R&D funding is budgeted under Program Element Number PE 64746A *Integrated Family of Test Equipment (IFTE)*. Development and procurement of all IFTE items are budgeted, planned, and coordinated by the IFTE Program Manager through his Program Sponsor. TPSs remain the funding responsibility of the individual weapon system program manager.

A chart of the current ATS acquisition process, Figure 26, was prepared by the Army.



KEY

AAE: Army Acquisition Executive
AMC: Army Material Command
ATE: Automatic Test Equipment
ATS: Automatic Test System
DA: Department of The Army

DEDT: Deputy Exec. Dir. for TMDE
MSC: Major Subordinate Command
PM: Program Manager
PM-TMDE: Program Manager for Test, Measurement, and Diagnostic Equipment
Shaded Area: Indicates Management Responsibility

Figure 26. Army ATS Acquisition Process

8. ATS CAPABILITIES AND APPLICATIONS

This section describes the capabilities of proposed DoD designated ATS standard families. Analyses of these ATS and other in-inventory ATS were performed. Several of the weapon systems LRUs were reviewed by the Services and test requirements of the most difficult to test LRUs were identified. The test requirements for these LRUs were compared with the test requirements capability envelopes of these ATS.

Several current DoD ATS test capabilities envelopes were compared to various weapon systems test requirements envelopes cutting across the Services. Results showed that many existing DoD ATS were capable of meeting 95% of the test requirements envelope without test resource extension. These ATS had not been specifically designed to a DoD-wide test performance requirements envelope as was the case for CASS and IFTE. Throughout the analysis, the data shows that for the few exceptions where testing limitations were identified, only minor additions to CASS and IFTE would be required in order to support the analyzed UUTs.

8.1 ATS FAMILY CAPABILITIES

CASS and IFTE were developed as general purpose ATS and designed to be configured into broad coverage ATS families. The Army, Navy, and Marines performed extensive mission and test requirements studies, including assessments of the capabilities of fielded ATS and future mission and test requirements across many weapon systems. These studies resulted in a new test capability requirements envelope for general purpose ATS. The ATS development programs for the CASS and IFTE met or exceeded the advanced test requirements envelope defined by these studies [NAEC 1982] [CECOM JULY 83] [CECOM DEC 83] as well as mission deployment requirements.

The ATS development requirements included projections of future test requirements, instrument, and test resource technology to assure that the CASS and IFTE ATS contractors deliver instrument and test resource technology at IOC (Initial Operational Capability) to meet or exceed the projected test envelope needed.

Test resource vendors have delivered test resources to the CASS program that represent the state of the art at IOC. Hewlett Packard has indicated that all of the instruments developed for the CASS which were put into the downsized MMS instrument packaging standard were designed and developed during the last three years to meet CASS

IOC in 1993 [STERN 1992]. The currency of this set of general purpose test resources cannot be exceeded in fielded equipment today.

A number of specific assessments of the DoD ATS families testing capability compared to specific DoD testing needs have been reported. The following sections report on these assessments. These assessments together indicate the potential test capability provided by the two designated DoD ATS standard families (CASS and IFTE).

8.1.1 CASS General Purpose Station Set

CASS is composed of four station types and five standard ancillary units. The four station types are composed of a core hybrid test capability (common low frequency analog and digital capability available in all station types) and additional specialized test resources unique to each of the four stations. The four CASS station types are the Hybrid, CNI (Communication, navigation, identification), RF (radio frequency, radar, EW, and microwave), and EO (electro-optic). The five ancillary CASS units are (1) INS (inertial navigation system), (2) ACBI (advanced communication bus interface), (3) PFG (pneumatic function generator), (4) MIL-STD 1397 (Input/output interfaces for standard digital data), and (5) the printer.

The key attributes for each of the principal ATE elements (presented in Figure 1, in Section 1.3) are listed in Table 49. The CASS capabilities for each of these attributes are summarized in Tables 50 to 53.

The common core test resources, column one of Table 54, are found in all test station configurations. The RF resources are found in both the RF and CNI configurations with the exception of spread spectrum resources, which are only found in the CNI configuration. Miscellaneous resources are used in one or more configurations and optional ancillary resources may be used in any configuration. The CASS station sets and optional ancillary units provide the most complete general purpose automatic testing capability in the DoD inventory.

CASS test stimulus and measurement capabilities at the front panel interface were specified in 1986 to take advantage of anticipated 1992 test instrument capabilities. By establishing requirements at the front panel interface, the CASS Program Office compensated for line-loses, distortion, and noise that might be introduced when integrating instruments and switches. Since all ATS architectures require interfaces (with switches, etc.) between instruments and the UUT, the achieved CASS specifications represent the leading edge of testing technology capabilities today.

Table 49. Key Attributes of ATE Elements

Interface	Stimulus	Measurement	Control and Switch	Test Equipment Operating System
General Purpose Electrical Interface Type	Digital Stored Pattern	Digital Response Pattern	Power	Test Language
Programmable Power Supplies	Analog Waveforms	Waveform Analysis	Signal Matrix Switch	Digital Test Formats
Microwave Signal Interface	Communication Waveforms	Modulators, Demodulation	Stimulus Synchronization	Complex Waveform
Cooling Source Interface	Microwave Signals, Modulation, Broadband Noise	Spectrum Analysis, Volts, Power, Phase Demodulation, Phase Noise	Measurement Synchronization	Real Time Software Control
Heating Source Interface	Electro-Optic Waveforms, Sources	Optical Detector Power/Frequency Modulation	Standard Buses/ Protocols For Mode Control	Simultaneous Thread Management
Optical Bench and Collimator Interface	Target Collimator	Optical Detector Image Analysis	Interface Characteristics Control	Maintenance Data/Services Interface
Motion Source Interface	Multiple Target Generators	Current, Voltage Power, Noise	UUT Synchronization	Technical Manual Services
Pneumatic Interface	Pneumatic Functions	Pressure/Rate	ID Mode Control UUT Mode Control	Self-Test Services
Uut Structural Support Interface			Calibration Sources	Self-Calibration Services

Table 50. Interface Characteristics of CASS

Interface	Characteristics
General Purpose Electrical Interface Type	Virginia Panel, 1486 Total Quantity, 1500 Volts/Pin, 76 Power Paths, 512 Signal Paths, 210 Low Frequency Pins @ 3 amps DC to 10 MHZ 64 Coax @ 500 ma, DC to 2 GHZ 448 Digital Pins, DC to 40 MBIT/Sec 40 Power Pins @ 25 amps, 36 Power Pins @ 10 amps
Programmable Power Supplies and Loads	Low Voltage 11 @ 900 W/450V/25A AC Power 3 @ 55 --> 1200 HZ, 1 --> 135 V, 5A, 675 W, 115/200V 3PH 400 HZ MIL-STD-1399 Feedthrough 1 Load 500W, 500V 20 amps, 1 TO 5 K ohms +/- 5% 1 load 5W, 200V, 0.5A, 1 --> 100 K ohms +/- 0.25%
Microwave Signal Interface	Various Coax Connectors
Cooling Source Interface	Unique Per Operational TPS
Heating Source Interface	Unique to Operational TPS
Optical Bench and Collimator Interface	0.5 --> 10 Inches Air Shutter, Broad Bandwidths
Motion Source Interface	Standard INS Table and Unique Interface Per OTPS
Pneumatic Interface	Use: -4 and -6 "O" Ring Seal Bulkhead Unions for P_t and P_s Respectively
UUT Structural Support Interface	Small Shelf For UUT or Unique Per Operational TPS

Table 51. Stimulus Characteristics of CASS

Stimulus	Characteristics
Digital Stored Pattern	Logic Familes - TTL, CMOS, ECL, DCL, DTL, RTL, HTL, MOS, CML 336 I/O Pins, 0 to 20/40 MBITS/Sec, -5 --> 15 V Diagnostic Probe to 20 MBITS/Sec
Analog Waveforms	Signal Gen. @ 0.01 --> 25 MHZ, -5 --> +5 Volts Arbitrary Wave 48 HZ --> 200 MHZ, TACAN, ILS, and VOR Modes, Pulse Generator 4 NS --> 99.9 Sec, Synchro Generators
Communication Waveforms Modulators	High Accuracy AM (ILS & VOR), TACAN, Linear Pulse, FSK, MSK, BPSK, QPSK, OQPSK(GPS), Spread Spectrum 10 MHZ -->1.3 GHZ,
Microwave Signals, Modulation, Broadband Noise	Synthesizer 10 MHZ --> 40 GHZ, 19 --> -110 DBM, Fast Switching 3 MHZ --> 18.4 GHZ, Noise Source 10 MHZ --> 26.5 GHZ
Electro-Optic Waveforms, Sources	1.064 uM LASER Aperture 0.5 --> 5.0", 5E-10 --> 5E-6 W/SQCM, Range Gate 0.5 --> 10 KM, FOV 20 --> 500 mrad, 1.064 +- 0.01um
Target Collimator	Selectable Targets on Wheel, 0.5 to 8 urad, 10 Inch Aperture, 7 --> 12 um Visual Targets, 0.5 to 8 urad, 1.1 um
Pneumatic Functions	0.6 --> 100 Inches Hg Absolute Pressure, 0 --> 50,000 ft/min

Table 52. Measurement Characteristics of CASS

Measurement	Characteristics
Digital Response Pattern	Logic Familes - TTL, CMOS, ECL, DCL, DTL, RTL, HTL, MOS, CML 336 I/O Pins, 0 TO 20/40 MBITS/Sec, -5 --> 15 V Diagnostic Probe to 20 MBITS/Sec
Waveform Analysis	Synchro Resolver, Multimeter 0 --> 1000 Volts (Probe only capability from 200 to 1000V), Freq. 0.001 HZ --> 200 MHZ, Time 4 NSEC --> 15E3 Sec., Waveform Digitizers @ DC --> 500 MHZ, 8 BITS, 25uSEC --> 50 Sec.
Demodulators	High Accuracy AM (ILS & VOR), TACAN, Linear Pulse, FSK, MSK, BPSK, QPSK, OQPSK(GPS), Spread Spectrum 10 MHZ --> 2 GHZ,
Spectrum Analysis, Volts, Power, Phase Demodulation, Phase Noise	Power -60 --> + 2DBM @ 100 KHZ --> 50 GHZ, Peak Power 30 KHZ --> 26.5 GHZ, Network Analysis DC --> 26.5 GHZ; Spectrum Analysis - 100 hz --> 22 GHZ, MOD AM, FM, Pulse, MSK, BPSK, QPSK, Demodulated AM and FM.
Electro- Optical Laser Receiver Power/Frequency Modulation	1.064um LASER, Aperture 0.5 --> 5.0 Inch, 30 to 300M Joules, Range Gate 0.5 --> 10 km, FOV 20 --> 500 MRAD, 1.064 +- 0.01 um
Optical Detector Image Analysis	Tracker 30 to 300 M Joules @ 1.064 um, Aperture 0.5 --> 5.0 Inch, FOV 30 DEG., PRF 8-20HZ, RS343, RS170, Raw Video to 40 MHZ
Current, Voltage Power, Noise	Multimeter 0 --> 1000 Volts (Probe only capability from 200 to 1000V), Freq. 0.001 HZ --> 200 MHZ, Time 4 NSec --> 15E3 Sec., Waveform Digitizers @ DC --> 500 MHZ, 8 BITS, 25USec --> 50 Sec.
Pressure/Rate	0.6 --> 100 Inch Hg / 0 --> 50,000 ft/min

Table 53. Other Characteristics of CASS

Control and Switch	Characteristic	Test Equipment Operating System	Characteristic
Power	Programmable Except Feedthrough of AC Power 115/200 V 3 PH 400 HZ	Test Language	716-1985 C/ATLAS With Extensions (e.g. EO), Non ATLAS Modules Ada, C or FORTRAN (All supported VMS languages)
Signal Matrix Switch	420 Pins, Relay Matrix 21@ 1X4, 35 @ 1X2, DC --> 1 MHZ 192 Coax, Relay Matrix 27@ 1X4, 9@ 1X2, DC --> 16 GHZ 76 Power, 5 @ 1X4, 2 @ 1X2, 6 @ 1X2	Digital Test Formats	LASAR V6 Source & Binary File Format for L200 Series
Stimulus Synchronization	10 MHZ Precision Ref., and TPS & OTPS ID, Triggers, Delays	Complex Waveform	716 C/ATLAS Proposal With Spread Spectrum Extensions.
Measurement Synchronization	10 MHZ Precision Ref., and TPS & OTPS Triggers, Delays	Real Time Software Control	Not for TPS Developer
Standard Protocols & Buses	MIL-STD-1553 A/B, 1773, 1397A, EIA RS232-C, RS422-A, ARINC AR-57A, ARINC-429, IEEE 488, 802.3, RS485 Manchester, (HSDB, FODB Not Populated for LRIP)	Simultaneous Read Management	Single Thread ATLAS (With Specific Exceptions, e.g. AWG Channels)
Interface Characteristics Control	ATLAS Programmable Control	Maintenance Data/Services Interface	Diagnostic Results for CASS Logged, UUT Results Logged
UUT Synchronization	Digital Pattern Sync, TPS & OTPS ID Triggers	Technical Manual Services	IETM Format Based On Commercial Tools & Formats
UUT Mode Control ID Mode Control	All Buses And All Signal Sources	Self-Test Services	Extensive Power Test And Continuous Monitoring
Calibration Sources	DC 0 --> 200 Volts 0.1 UV --> 10 UV AC 0.022 --> 220 VRMR 8 UV --> 220 UV DC 0 --> 2.2 A, AC 0 --> 2.2 A, Resistance 1 ohm --> 19 Mohm @ 10ma Max	Self-Calibration Services	Automatic Calibration, One Year Field Use Between External Calibrations, Based on Built-In Calibration Standards

Table 54. CASS Test Resources

Common Core Resources (Low Frequency, Digital, Bus)	RF Resources	Misc. Resources	Optional Ancillary Resources
Digital Multimeter Module	Spectrum Analyzer Assembly	Synchro/Resolver	Inertial Navigation System - AR-57A Bus Interface
Frequency/Time Interval Counter	Power Meter	Electro-Optical System	Advanced Communication Bus Interface - RS-485 Manchester/Harpoon, HSDB(A12), FODB(A12)
Waveform Digitizer	Microwave Transition Analyzer	UUT D.C. Power Supplies - Low Voltage 0-32V, 0-100V, 0-450V	Military Communications Bus Interface
Pulse Generator Module	40 GHZ Synthesizer	UUT AC Power Supplies 0-135V Synchronized	Pneumatic Function Generator
Arbitrary Waveform Generator	20 GHZ High Power Synthesizer	400 HZ UUT Power Feedthrough and Monitor	
Low Wattage Power Load	Fast Switching Synthesizer (Low Frequency)		
High Wattage Power Load	Fast Switching Synthesizer (Microwave Extension)		
Switch assemblies	Modulation Control Instrument		
Digital test unit	RF Interface/Coax Switch		
Commercial Bus Interface: RS-232C; RS-422A, IEEE- 488, 1978; IEEE802.3-1985; ARINC429-10	Spread Spectrum Generator		
Military Bus Interface: MIL-STD-1553; MIL-STD-1773; MCAIR A3818	Spread Spectrum Modulators And Demodulators		

8.1.2 CASS Introduction Planning

The NAVAIR PMA 260 (CASS) Program Office maintains a current schedule of weapon systems and subsystems to be allocated CASS stations. Table 55 provides a list of station allocations current to March 1992. This allocation has been made on the basis of System Synthesis Model (SSM) analysis. These tables illustrate the breadth of weapon system requirements attained by the CASS.

Table 55. Programs With Planned CASS Station Allocations

AIWS	AN/APG-73 Radar (F/A-18)	HARM
AMRAAM Missile	AN/APN-217(V)5 Doppler	HARPOON/SLAM Missile
AN/AAS-33A	AN/ARN-138 MMR	JSOW Missile
AN/ALE-47 Chaff Dispenser	5400 COMP F-14	AN/ASN-139 CAINS II
AN/ALQ-126B EW (RF SRAs)	EA-6B ADVCAP (RPG & AIP)	MIDS LVT
AN/ALQ-165 (ASPJ)	EA-6B/ALQ-149	PHOENIX
AN/ALR-67 ASR	AN/ARC-210 Radio	AN/USN-2V SAHRS
GPWS/HELO	F-14D WRA/SRA	SCS (Standard Compass Sys.)
GPWS/TRANS (Transport)	SH-60F/ALFS	SH-60B Upgrade II
F-14D IRSTS	URC-107 JTIDS	AN/ZSD-1 ATARS
AN/ALQ-156 IDAP	MAGR	DAFCS F-14
AN/ALE-50 Decoy	LPI Altimeter	Common Recorder

Table 56 shows which existing NAVAIR ATS will be off-loaded to the CASS stations. Longer term planning for Navy CASS allocation is underway for (1) Sparrow, Phoenix, Sidewinder Missiles, (2) F/A-18 E/F, and (3) AFX.

Table 56. CASS Station Off-Load Programs

AAM-60 EOSTS	AN/USM-247 VAST S-3, F-14	AN/USM-470 (V) 2 TMV F-14B
AN/APM-446 RSTS F-18	ASM-614 SH-60F	AN/USM-470 (V) 1 ATS F-18
ASM-614 EA-6B	AN/USM-403 HATS S-3	AN/APS-137 S-3C Radar
EETS (V) 1 AV-8B	HTS AV-8B	

8.1.3 IFTE General Purpose Station Set

IFTE has been developed and manufactured as the Army's standard automatic test equipment for commonality across field, depot, and factory. The IFTE has demonstrated broad based, general purpose test capability as the following analyses indicate. Yet, an IFTE Base Shop Test Facility (BSTF) is the most mobile, general purpose, automatic test equipment ever built. It is designed to be transported in its chemical, biological, and nuclear protective shelter. The IFTE can be set up and in full operational mode within 30 minutes.

The IFTE Base Shop Test Facility is composed of one station set and a number of standard ancillary units. The station is composed of low frequency analog, digital, communication, and RF capability. The EO capability is provided by the CASS EO ancillary unit integrated into the IFTE with an IEEE 488 hardware/protocol link and CASS EO ATLAS extensions to IFTE ATLAS.

In addition, the commercial equivalent equipment (CEE) is available from Grumman Corporation for ATS development, depot, and factory applications not requiring the protective shelter capability that comes standard with the base shop test facility. The IFTE BSTF, the CEE, and the ATSE (Army Test Support Environment) work stations provide the full spectrum of off-equipment test development, maintenance, and operational use capability within the IFTE.

The key attributes for each of the principal ATE elements (presented in Figure 1, in Section 1.3) were listed in Table 49. The IFTE capabilities for each of these attributes are summarized in Tables 57 to 60.

Table 61 summarizes the test instruments and resources by resource category type used to provide the key stimulus and measurement characteristics of the IFTE stations. The test resources listed as optional ancillary resources in Table 45 do not affect delivery schedule. The digital and analog test resources are listed in column one. Miscellaneous resources are used in one or more configurations and optional ancillary resources may be used in any configuration. The IFTE station set and optional ancillary units provides the most mobile, state of the art, general purpose automatic testing capability in DoD inventory.

Table 57. Interface Characteristics of IFTE

Interface	Characteristics
General Purpose Electrical Interface Type	Gold Dot 3200, Total Quantity, 200 Volts/dot, 200 Power Paths,1400 Signal Paths, Allocated as Follows: 130 (2 Dot) Universal @ 1 amps DC to 40 MHZ -3db 144 (2 Dot) Ext. Perf. @ 1 amp DC TO 100MHZ -3db 224 (2 Dot) Digital IO Pins, DC -> 50 MBIT/Sec 32 (3 Dot) Form C Relays 145 (2 Dot) Derated Signal Path 1418 Signal Dots Unallocated 11 Auxilliary Interface Panel Connectors
Programmable Power Supplies and Programmable Loads	Low Voltage 12 @ 1750W/200V/72.8A Low Voltage Fixed 1 @ 630W/28V/22.5A Reference Voltage 8 @ +10/-10V / 100MA High Voltage -- 0-600V @ 0.75A Current Source --12 @ Ranging 0.75A --> 20.5A AC Power 1 @ 45 --> 5000 HZ, 4000W/270V/ 10A/3PH 8 Loads @ 750W, Ranging 50V@30A TO 250V 10 Fixed Resistance 50 TO 1000 ohm
Microwave Signal Interface	9 RF Outputs -- Type N Precision SS 4 RF Inputs -- Type N Precision SS
Cooling Source Interface	Unique To Operational TPS
Heating Source Interface	Unique To Operational TPS
Optical Bench And Collimator Interface	0.5" --> 5" Air Shutter, Broad Bandwidths
Motion Source Interface	INS Static Load 100 LBS, Rate 0-1000 DEG/Sec, Acceleration 3000 DEG/Sec/Sec, Torque 0.8 Foot LBS, Option, Other by Unique Interface Per OTPS
Pneumatic Interface	Static 0.3 - 36 Inch Hg, Total 0.3 - 100 Inch Hg, Differential 0 to 100 Inch Hg, Rate 120 Inch Hg / Min, Option
UUT Structural Support Interface	Small Shelf For UUT or Unique Per Operational TPS

Table 58. Stimulus Characteristics of IFTE

Stimulus	Characteristics
Digital Stored Pattern	Logic Familes - TTL, CMOS, ECL, DCL, DTL, RTL, HTL, MOS, CML 192 I/O Pins, 0 to 20 MBIT/Sec 48 I/O Pins @ 50 MBITS/SEc, -10 --> 10 V, Expansion to 256 by Channel Cards/Max. Channels 1024, 32 IO Pins @ 10 MBITS/SEc -30 --> 30 V Current Injection Probe (Bus Source/Sink)
Analog Waveforms	Signal Gen. @ DC to 25 MHZ, 0 -->10 V P-P Arbitrary Wave 20 NS, TACAN, ILS, and VOR Capable, Pulse Generator 40 NS --> 50 Sec, Synchro/Resolver
Communication Waveforms Modulators	High Accuracy AM (ILS & VOR), TACAN, Linear Pulse, FSK, MSK, BPSK, QPSK, OQPSK(GPS), Spread Spectrum 1 MHZ --> 2.3 GHZ,
Microwave Signals, Modulation, Broadband Noise	Synthesizer 10 KHZ -->22 GHZ, 38 --> -120 DBM, Fast Switching 1.0 MHZ TO 2.3 GHZ, Broadband Noise Source -- 10MHZ - 26.5 GHZ - Option
Electro-Optic Waveforms, Sources	RS343, RS170, Raw Video, 12 Target Simulator (IF, RF, Video) Barker, PN, Doppler - Option 1.064 um LASER Aperture 0.5 --> 5.0 Inch, 0.5E-10 --> 0.5E-6 W/SQCM, Range Gate 0.25 --> 10 km, FOV 20 --> 500 MRAD, 1.064 +- 0.01 um
Target Collimator	Selectable Targets on Wheel, 7 to 67 DEG C, 10' Aperture, 7 --> 12 um Visual Targets 1' by 1" Max 0.6 --> 1.1 um
Pneumatic Functions	Static 0.3 - 36 Inch Hg, Total 0.3 - 100 Inch Hg, Differential 0 to 100 Inch Hg, Rate 120 Inch Hg / Min, Option

Table 59. Measurement Characteristics of IFTE

Measurement	Characteristics
Digital Response Pattern	Logic Familes - TTL, CMOS, ECL, DCL, DTL, RTL, HTL, MOS, CML 192 I/O Pins, 0 to 20 MBIT/Sec 48 I/O Pins @ 50 MBITS/SEc, -10 --> 10 V, Expansion to 256 by Channel Cards/max. Channels 1024 32 IO Pins @ 10 MBITS/Sec -30 --> 30 V Diagnostic Probe to 50 MBITS/Sec
Waveform Analysis	Angle Position Indicator, Multimeter 0 --> 200 V, Freq. 0.0001 HZ --> 100 MHZ, Time 100 NSec --> 10E3 Sec., Waveform Digitizers @ DC --> 50 MHZ,12 BITS, 10 NSec -->42.9 Sec.
Demodulators	High Accuracy AM (ILS & VOR), TACAN, Linear Pulse, FSK, MSK, BPSK, QPSK, OQPSK(GPS), Spread Spectrum 1 MHZ --> 2.3 GHZ,
Spectrum Analysis, Volts, Power, Phase Demodulation, Phase Noise	Spectrum Analyzer 100 HZ --> 22 GHZ +40 DBM --> -100 DBM, Power -70 --> + 40 DBM @ 8 MHZ -->22 GHZ, Power Via Millivolt Meter to 1.2 GHZ, Prog. Attentuator 0 --> 100 DB to +40 DBM, Network Analysis 45 KHZ --> 26.5 GHZ, Phase Noise 10MHZ --> 18 GHZ - Option
Electro- Optical Laser Receiver Power/Frequency Modulation	1.064um LASER, Aperture 0.5 --> 5.0", 5E-10 --> 5E-6 W/ SQCM, Range Gate 0.25 --> 10 km, FOV 20 --> 500 MRAD, 1.064 +- 0.01 um
Optical Detector Image Analysis	Tracker 5E-10 --> 5E-6 W/SQCM @ 1.064 um, LASER Transmitter Aperture 0.5" to 5.0", FOV 30 DEG., PRF 8-20HZ, Divergence, RS343, RS170, Raw Video to 40 MHZ
Current, Voltage Power, Noise	Multimeter 0 --> 200 Volts, Freq. DC --> 100 MHZ, Time 100 NSec --> 10E3 Sec., Waveform Digitizers @ DC --> 50 MHZ, 12 BITS, 10NSec -->42.9 Sec.
Pressure/Rate	Ancillary Equipment

Table 60. Other Characteristics of IFTE

Control and Switch	Characteristic	Test Equipment Operating System	Characteristic
Power	Programmable Except As Noted Under Interface	Test Language	ATLAS, Non ATLAS Modules
Signal Matrix Switch	10 Signal Buses, 130 Universal IO (40MHZ -3 DB), 48 Instrument Ports - Internal Switching, 144 Extended Performance Direct Connect to 48 Instruments (100 MHZ - 3 DB), 32 Form-c Utility Relays	Digital Test Formats	LASAR V6 Capable MATE-STD-SDF All Digital Tests Developed Using ATLAS Statments
Stimulus Synchronization	10 MHZ Precision Ref., System Triggers/ Delays, and UUT	Complex Waveform	None Direct, Must Use Existing 1985 C/ATLAS and AFG
Measurement Synchronization	10 MHZ Precision Ref., Systems Triggers/Delays, and UUT	Real Time Software Control	In "Ada" and "C" Modules
Standard Protocols and Buses	MIL-STD- 1553 A/B, MIL-STD-1773, 1397A, EIA RS232-C, RS422-A, AR-57A, IEEE 488, 802.3, RS485	Simultaneous Thread Management	Single Threaded ATLAS
Interface Characteristics Control	ATLAS Programmable Control	Maintenance Data/Services Interface	Logging UUT Test Results Logging Maintenance Test Results
UUT Synchronization	Digital Pattern Sync, TPS & OTPS ID Triggers	Technical Manual Services	Cals Compatable IETM
UUT Mode Control ID Mode Control	All Buses And All Signal Sources	Self-Test Services	Extensive Power On Self-Test and Continuous BIT Monitoring, Self Test ID, ATLAS Initiated Self Test
Calibration Sources	DC 0.09, 0.9, 9.0, 18.0 V +- 0.008%/YR AC 1, 10 VRMS +- 0.06%/YR Resistance 100 ohm --> 1 Mohm +- 0.0055% Prog Load Current Sense Res. STDS 0.01 TO 0.06 ohm +- .55% Thermal Transfer Standard	Self Calibration Services	Automatic Calibration With Self-Alignment ID

Table 61. IFTE Test Resources

Low Frequency Analog and Digital,	RF Resources	MISC. RESOURCES	OPTIONAL ANCILLARY RESOURCES
Digital Multimeter Module	Spectrum Analyzer to 22GHZ	Synchro/Resolver/ Indicator & Simulator	Electro-Optical System
Frequency/Time Interval Counter	Power Meter to 22 GHZ	UUT D.C. Power Supplies - Low Voltage to 36v, High Voltage to 600V,	Broadband noise source
Waveform Digitizer	Millivolt Meter 1.2 GHZ	UUT AC Power Supplies 0-270V 3 ph,	Sampling Signal Analyzer to 26 GHZ
Pulse Generator Module as a Function of AWG	Synthesizer to 22 GHZ	High Power Load (3000W)	Noise Figure Measurement
Arbitrary Function Generator	RF Interface/Coax Switch	Precision Reference Source (+/-10V)	VXI Chassis
Low wattage power load	Fast Switching Synthesizer to 1.3 GHZ		Low Phase Noise RF Generator
Digital Test Unit With Voltage and Current Probe	Pseudorandom Sequencer		Carrier Noise Test Set
Video Analyzer and Simulator	Spread Spectrum Modulators and Demodulators		Spectrum Analyzer to 22 GHZ, FFT Under 1 KHZ Measurements
Switch Assemblies			
Commercial Bus Interface: RS-232C; RS-422A; RS-423; RS-485, IEEE 488,1978; IEEE802.3,1985; VME			
Military Bus Interface: MIL-STD-1553A/B, MIL-STD-1773, MIL-STD-1397A, AR-57A			

8.1.4 IFTE Laydown Planning

The introduction of the IFTE is referred to as the IFTE laydown by the Army. The funded and near term projected (FY93 to FY95) laydown of IFTE BSTS are summarized in Table 62. Two principal Army ATS types, the EQUATE and Hawk High Frequency

Console, will be replaced by IFTE. The data in this table was provided by the Army during the TIMs, and is subject to changes resulting from DoD budget revisions. Information from the IFTE Program Office in of March 1993 implied that current budget trends indicate that revised quantities may be closer to 200 total.

Table 62. Planned Laydown of 239 IFTE ATS (FY93-FY95)

7 each Avenger	53 each Hawk	50 each Hawk Phase II
5 each ASAS	12 each Singars	31 each MLRS
22 each Paladin	1 each Javelin	41 each EQUATE
17 ea (Other Support)	Possible upgrades UAV, Apache, M1, and Bradley	

8.2 WEAPON SYSTEM TEST REQUIREMENTS ANALYSES

Cross-weapon and cross-Service ATS requirements analyses were conducted in conjunction with this study. These analyses demonstrated that CASS and IFTE exceed most technical test requirements. More importantly, since CASS and IFTE use flexible industry standard architectures that promote modularity and partitioning (e.g., MMS, VME, Ethernet), they may be updated relatively easily. As significant performance enhancing technologies become available, the CASS and IFTE families can incorporate the improvements without disturbing basic architectures.

The cross-weapon/Service review compared difficult to test weapon system items against the capability of selected automatic test equipment to meet related technical testing requirements. F/A-18 subsystems were compared with IFTE, F-22 subsystems (projected) were compared with CASS, and Apache subsystems were compared with the F-16 IAIS ATS. The Army and Navy were asked to select assemblies that represent a challenge for other ATS. Since actual test requirements for an F-22 system have not been determined yet, the F-22 Common Automatic Test System (CATS) preferred equipment list was used as a comparison baseline. Three F/A-18 weapon replaceable assemblies (WRAs) were evaluated against the IFTE Base Shop Test Facility. Finally, in order to gain insight into the capability of existing ATS to support cross-Service testing requirements, three Apache line replaceable units (LRUs) were evaluated against the F-16 Improved Avionics Intermediate Station (IAIS).

Comparisons results are presented in Table 63. Other comparisons of the F-16 IAIS, and CASS and IFTE showed these ATS family candidates have more extensive capabilities. For example, CASS and IFTE possess both LRU and SRU testing capabilities, while the IAIS focuses principally on LRU testing. This table also addresses the exceptions and what the impact of these exceptions might be. The "Exceptions" in Table 63 are grouped as none, minor, modest, and major.

Table 63. Cross-Service ATS Review Results

SYSTEMS	ITEMS COMPARED	EXCEPTIONS
F-18 WRAs to IFTE	Radar Set Receiver-Extension	**None** -Full capability exists
	Radar Target Data Processor	
	FLIR Receiver & Optics Stabilizer	**Minor** -Stimulus and measurement requirements within capabilities - IR/EO testing needs HW fixturing augmentation - Optics stabilizer needs HW augmentation for vibration test stand and motor-powered mechanical interface
F-22 CATS Preferred Equipment List to CASS	VXI Instruments	**None** - Comparable capabilities
	RF Equipment	**None** - Technical capabilities comparable, CATS large rack & stack equipment, CASS downsized MMS based
	EO Equipment	**None** - Capabilities: CATS limited, CASS broad based
Apache LRUs to F-16 IAIS	PNVS Electronic Unit Assembly	**None** - Full capability exists
	PVNS Night Sensor Assembly	**None** - Stimulus and measurement requirements exist, holding fixture augmentation needed
	Day Sensor Assembly	**None** - TPS augmentation of a transformer (on qualified parts list-QPL) needed
	TADS Night Sensor Assembly	**None** - Temperature probe, voltage divider and variable temperature target source required for TPS interface adapter

- A minor exception is defined as a change or extension of test operation software and the addition of a few test resources not necessarily affecting the overall ATE footprint.

- A modest exception is defined as the addition of a new chassis resource which may lead to an extension of the ATE footprint after a few are implemented.

- A major exception is defined as a new configuration with an enlarged footprint by 20% or more.

Few minor and no modest nor major exceptions were identified.

Additional comparisons of DoD tester capabilities are presented in Appendix D. Based on the analyses from these comparisons, only minor tester capability technical improvements to ATS families will be required over the next decade.

8.2.1 A-12 Test Requirements

The development of the A-12 test performance envelope for a CASS IOC 1993 was progressing effectively up until the time the program was cancelled. In one study [CASS 1992] done for NAVAIR 552, it was determined that the Navy's replacement for the A6 aircraft, the A-12 (now the AFX) to be fielded perhaps before the year 2005 would be fully tested by the CASS test suite with the addition of three new cards. With respect to the summary of CASS capabilities presented earlier, these resources fall under the Control and Switch characteristics listed in Table 53 under Standard Protocols & Buses.

Because these cards represent a small set of the interfaces required to test, these cards represent a less than 5% change in the number of unique test resources available within the CASS. Test resources represent approximately 60% of the total value of a complete CASS station set. Therefore, only minor changes (less than 3% impact) are required to accommodate the most advanced avionics technology known.

8.2.2 AFX Test Requirements

During the ATS study questions arose concerning CASS compatibility with JIAWG modules and components anticipated as elements of F-22 LRMs, LRUs, and SRUs (therefore, comments apply equally to F-22). The Navy performed [JIAWG 1992]

> ... an analysis of approximately forty specifications which establish the Common Avionics Baseline [CAB III Revision 3, 2 Dec 1991] for the AX. The areas investigated included JIAWG architecture, module and processor standards, system and module bus specifications, input/output and BIT specifications, test software specifications, Software Engineering Environments, Reliability and Maintainability and Integrated Logistic NAVAIR's current ASTEC, Testing 2000 and ABET efforts.

Table 64 defines the major components of interest to this analysis. Additional specifications under development and of interest to this analysis include:

a. High Bandwidth Interface Module
b. Signal Interface Module
c. Video Data Interface Module
d. Signal Data Distribution Network
e. Video Data Distribution Network

Table 64. JIAWG Specifications For CASS Analysis

JIAWG SPEC	PACKAGING	DESCRIPTION
J87-01	SUBSYSTEM	Advanced Avionics Architecture (A3) Standard
J90-CNI-01	SUBSYSTEM	Integrated CNI System Standard
J89-SP-01	SUBSYSTEM	Signal Processor, Common Avionics Processor
J88-M1D	LRM	Data Processor, Common Avionics Processor (CAP-16)
J88-M2D	LRM	Data Processor, Common Avionics Processor (CAP-32)
J88-M5D	LRM	High Speed Data Bus (HSDB) Interface Module)
J88-M6D	LRM	1553 Multiplex Data Bus Interface Module Specification
J89-N1A	SUBSYSTEM BUS	JIAWG Parallel Inter-module Bus (JPI-Bus)
J89-N1B	SUBSYSTEM BUS	JIAWG Test and Maintenance Bus (JPI-Bus)
J89-N1C	SUBSYSTEM BUS	Utilities Signals Specification
J89-N1F	SUBSYSTEM BUS	User Console Interface Specification
J89-S10	SUBSYSTEM MISCELLANEOUS	Module Initialization, Test and Software Interface Specifications
J88-G6	SUBSYSTEM MISCELLANEOUS	Integrated Logistic Support Standard
J88-G3	SUBSYSTEM MISCELLANEOUS	Reliability and Maintainability Standard

Preliminary information indicates that these are point to point buses operating in excess of 200Mhz.

> The general conclusion to be drawn from the specifications reviewed is that CASS will still be required for all of the non-JIAWG components in the weapon system (RF transmitters and receivers, electro-optics, displays, etc.)
>
> With regard to the JIAWG elements, the Navy reports:
>
> The voltage, logic levels, impedance, speed of the module interfaces, pin count and other parametric of the JPI, and JTM buses are well within CASS capability.
>
> The Navy report concludes:
>
> 1. CASS has the inherent capability to test JIAWG modules as currently defined by CAB III revision 3 of December 1991, but some effort will be required to address the protocol of the JPI and JTM high speed data buses.

In fact, the CASS Digital Test Unit (DTU) with proper programming can test JPI and JTM (nomenclature for two high-speed data buses). However, for efficiency, when functional stimulation is desired, it would be useful to have a new stimulus and measurement standard bus module as an ancillary unit (e.g., the ACBI). The Navy report goes on to state:

> 2. Additional JIAWG components will be developed and will have to be addressed. These include signal data and video data interfaces, image processing, graphics processing and EW processing.

JIAWG requires that module BIT software interfaces be written in Ada. This Ada code may be used to support test vector application generation either through software tools used to generate a LASAR stored stimulus/response database or through direct execution of a non-ATLAS module. A specialized interactive Ada BIT interface test module as an extension to the CASS stimulus and measurement modules may also be required.

The examination of the AX ATS requirements compatibility with CASS indicated that there are no known exceptions that would prevent the use of CASS. In fact, CASS had more capability than the other testers reviewed and appeared to be the best ATS match to meet the anticipated AX test requirements. Further, testing areas yet to be determined represent a small fraction of the ATS requirements, and most fall in the area of standard bus protocols that will ultimately need to be addressed for multiple systems applications.

8.2.3 F-22 Test Requirements

The F-22 CATS ATS will permit easy configuration of separate instrument on a card to meet dedicated factory (and possible depot) testing requirements for digital and low frequency analog. CATS is not well suited for microwave or RF since it currently does not include the MMS architecture. This is a probable future addition to CATS, without which some testing capabilities may not be attainable.

The integration of general purpose robust testing capabilities (equivalent to CASS or IFTE) will require additional ATS design. This design is currently unfunded and unplanned. Furthermore, reuse of test programs from full sized GPIB instruments suites like the CATS to downsized I-level test equipment like the CASS will be difficult. In general, instrument performance will be different in downsized MMS or future VXI RF instruments.

The I-level or depot level test requirements for the F-22 were not available for study. However, the Air Force did provide a preferred equipment list for factory test equipment [CATS 1992]. Interesting properties of this equipment list are depicted in Table 65. Most notable is the lack of MMS RF and microwave downsized packaging. During the ATS study, the instrument vendors indicated that commercial enterprises would not pay the extra cost for downsized test equipment. The contractors have chosen modified VXI for relatively inexpensive, simple general purpose test functions and full sized GPIB packaging for microwave and RF

From a different perspective, the AX WRAs and SRAs are expected to be based on the same technology as the F-22 aircraft. Therefore, based on analysis summarized earlier in this section of the report, CASS will provide excellent test coverage for the known F-22 requirements.

Table 65. F-22 CATS Preferred Equipment

Architecture	Number of Instruments	Comments
Modified VXI	37	Provided by 15 instrument manufactures
Modified VXI	9	All instruments in this class are power or switch modules
GPIB	26	IEEE-488 based microwave and RF instruments
IEEE 488 RACK & STACK	30	OEM components that are accessories to GPIB instruments
TBD	1	High voltage power supply
Totals	103	Test resource items

8.2.4 F-15 Test Requirements

Recent studies by the Air Force, Army, and Navy have concluded that CASS and IFTE meet the technical testing requirements of the Air Force's new requirement for a downsized tester with only minor enhancements. Due to differing user mobility requirements, the IFTE BSTF appears most compatible with stated requirements. The Air Force stated its principal concern rested with IFTE schedule risks that had the potential of impacting overall need. However, subsequent analysis by the Army observed that IFTE would actually lower overall program risk and could be available far earlier than a new F-15 Downsized Test Set (DSTS) acquisition.

Test requirements that were not met with the current Army configuration of the BSTF were phase noise measurement for ground tracking radar, possible higher accuracy RF frequency measurement, and added procedure libraries invoked via the "perform" statements for avionics waveforms. Analyses showed that these additional capabilities could be added with minor impact to schedule and cost.

8.2.5 F/A-18 Test Requirements

NAVAIR-552 selected a number of F/A-18 WRA test requirements documents (TRD) which would challenge the BSTF ATS test capabilities envelope. The Army IFTE BSTF TPS analysis team evaluated these TRDs compared to IFTE BSTF capabilities [F/A-18 1992] and returned the following result:

> A review of the TRDs for the *F/A-18 Radar Set Receiver-Exciter and the Radar Target Data Processor* was made to determine if they are testable on the BSTF or the CEE. Each TRD was analyzed to determine power, stimulus, and measurement requirements. Table A [see Appendix... ATS Study Analyses] is a summary of this analysis. The test envelope of both the Receiver-Exciter and the Radar Target Data Processor are within the capabilities of the CEE and BSTF...
>
> A review of the Test Requirements Documents (TRD) for the *F/A-18 FLIR Infrared Receiver and Optics Stabilizer* was conducted to determine if they were testable using the IFTE. While the TRDs accurately defined AC and DC Power Requirements in a tabular form, stimulus and measurement requirements were not clearly defined. A review of the documentation revealed no stimulus or measurement requirement that is not within the IFTE. The BSTF Electro-Optic B (EOB) would be the basis for all IR/EO testing augmented by special (TPS) fixturing as required...
>
> The *Infrared Receiver* does not require the elaborate mechanical fixturing but it does have optical test requirements that has the capability of generating an infrared target from 0 to 99 degrees Celsius with a resolution of 0.01 degree Celsius. The capability of the Navy provided Electro-optical work bench (verify referring to the CASS EO) is +30 to -10 (degrees Celsius) from ambient temperature. Additional target generation would be provided using a (TPS) fixture...

In summary, the weapon system capability and requirements comparisons indicate that the BSTF ATE is capable by virtue of its test capabilities envelope to test the F/A-18 WRAs.

8.2.6 APACHE (AH-64) Test Requirements

An analysis of the F16 AIS and IAIS was performed for capability to test Army aviation electronics. The Army again selected the most difficult LRUs for analysis. The IAIS turned out to be a very capable ATS, with almost all requirements covered with the exception of multiple targets for FLIR testing.

Five major LRUs were compared. One Apache TADS/PNVS Targeting and Night-Vision subsystem and four LRUs from the Apache Targeting and Night-Vision System were selected by the Army for the review to determine if the Improved F-16 AIS (IAIS) could meet their testing requirements. General Dynamics Electronics Division reported the results [TADS/PNVS 1992] [APACHE/F-16AIS 1992].

> The test parameter matrix was constructed utilizing appendix D of the TRDs. Tolerance assessments for both depot and AVIM were compared to IAIS measurement capabilities. Each test was reviewed for required stimu-

lus and results compared to IAIS stimulus capabilities. Comparison to AIS capabilities assumed that the IAIS Optical Test Bench (OTB) would replace the AIS OTB.

The stimulus and measurement capability for all tests of the *PNVS Electronics Unit Assembly* presently exists within the IAIS.

The stimulus and measurement capability for all tests of the *PVNS Night Sensor Assembly* presently exists except for the measurement of a mechanical angle of 22 +-2 degrees. This capability would be integrated into the TPS holding fixture.

The stimulus and measurement capability for all tests of the *Day Sensor Assembly* presently exists except for the stimulus of 6.6 VRFMS, 5 AMP, 400 Hz. This capability would be integrated into the TPS electronics hardware as a transformer, QPL M27/335-02.

The stimulus and measurement capability for all of the tests of the *TADS Night Sensor Assembly* presently exists except for: (1) the measurement of temperature in degrees Celsius, (2) the stimulus of a ninth DC power supply which would be added to the TPS interface test adaptor, and (3) a variable temperature target source for infrared sensor testing producing absolute or differential temperature control for one or more targets.

In summary, the IAIS provided excellent test capability coverage with the exception of electro-optic target stimulus attribute for FLIR testing targets which are not part of the IAIS current mission requirements.

8.3 DOD ATS COMMON R&D REQUIREMENTS

Three specific investment areas have been identified for common R&D necessary to maintain a DoD family of capable ATS. These areas include (1) ATS family convergence, (2) next generation test software environment, and (3) ATS family modernization. This common R&D discussion assumes that each specific ATS family member will have its own R&D as well as P^3I maturation or modernization budgets.

The common R&D cuts across Service and weapon system requirements to identify and develop the following:

a. Methods, tools, military and commercial standards to improve specific ATS concept and design development that will support interoperability of existing and future family members.

b. Improved next generation test software environment.

c. New test functions that address fundamental, new test requirements

Table 66 identifies several important aspects of each of the three principal investment areas. These important aspects are presented as three separate and distinct lists under each of the investment areas.

Table 66. Common ATS R&D

ATS FAMILY CONVERGENCE	NEXT GENERATION TEST ENVIRONMENT	ATS FAMILY MODERNIZATION
Interface Commonality	CAE Design Interface Specification (WRA, SRA, mixed signal type technologies, model representations)	Evolving Test Requirements
		Test Methods Specifications
Common Language Interfaces	Test Strategy/Reqt. Specification (AI Tool Integration, Dependency Models, Computed Diagnostic Flow, Tech. Data Integration, Test Requirements Languages)	Test Resource Development and Demonstration
Interoperability Support Tools	Test Practices and Libraries	Tools for Analysis of ATSs and UUTs

8.4 DOD ATS FAMILY P^3I IMPLEMENTATION

Designated DoD ATS should continue to be matured as they are fielded to obtain the full system performance. It is anticipated that these systems will require test requirements extensions throughout their 10-to-20 year life cycle. Designated DoD ATS architectures were designed to be flexible and to accommodate technology improvements. These improvements must require upward compatibility so that TPSs developed for the previously fielded configurations will run on new improved configurations with the same test resources.

Limited test requirements capa[illegible] technical improvements to ATS family members will be required over the nex[illegible]ade. New test requirements identified in Technical Interchange Meetings (TIMs) and subsequent meetings with the Navy Program Office and the Army Program Office have identified that these potential test requirements for common use across multiple systems and Services may be integrated into the designated DoD ATS platforms.

The test performance requirements envelope analyses are performed with the aid of an automated tool developed during the CASS program. This tool, the System Synthesis Model (SSM), is critical to defining broad complex test performance envelopes to be compared with new weapons test requirements. As new test requirements are identified, these requirements must be evaluated with SSM models to determine if test requirements lay outside of the performance envelope of existing family members. If so, then enhancements of capabilities of existing family members must be identified and implemented. Areas of possible extended test requirements were identified and presented in the tables of Part II, Summary, of this paper, Section 2.3.1, CASS and IFTE Technical Capabilities.

Testability reviews have been conducted by the Navy at NAWCAD, Lakehurst, NJ using the SSM on over 2500 weapon subsystems. The SSM analysis indicated that CASS will provide approximately 90% test coverage of these subsystems based on the input specifications given to the model. The Navy went on to indicate that this model does not have an ability to consider revised test strategies nor the addition of test resources in TPSs. These results tend to substantiate the conclusion of the test equipment technical experts at the TIMs that modern general purpose ATS will accommodate 95% of weapon systems electronic maintenance technical testing requirements.

8.5 ATS FAMILY SYSTEM ARCHITECTURE

CASS and IFTE use flexible industry standard architectures that promote modularity and partitioning. CASS and IFTE incorporate open architectures with MMS, VME, and Ethernet interfaces. These architectures provide the most robust interface capability available and all new testing requirements that have been identified to date may be accommodated with these interfaces. As significant performance enhancing technologies become available, the families can incorporate the improvements without disturbing the basic architectures. Upgrades to incorporate new technologies should be limited to those technologies required to meet specific DoD test needs. For example, the insertion of a VXI chassis or the additional use of Ada at this time provides no specific new test capability.

In contrast to an ATS family architecture, the Air Force is using a series of evolving testers that grew out of the F-16 AIS automatic test system. While the F-16 ATE (A/B, C/D, Advanced Computer AISs and the IAIS), the B-1 ATE, and C-17 ATE do possess high degrees of commonality, they do not exhibit the same general purpose application flexibility that was a design feature of IFTE and CASS. If they had a more general purpose interface with robust control and switching capabilities as opposed to targeted system specific testing interfaces, they might well have been viewed as an early ATS family approach. But the architectures of these ATE, as designed, make them dedicated system specific ATE; and as such, they are not designed for general purpose, multi-system testing applications nor suitable for a wide range of UUTs from the system level down to removable cards and components.

An ATS family architecture must be flexible and promote modularity and partitioning of the principal ATE elements: test equipment operating system, stimulus, measurement, control and switch, and interface. Equally important, the architecture must be structured such that the interface will accommodate multiple general purpose applications.

9. ATS TECHNOLOGY DEVELOPMENT AND EVOLUTION

This section of the report provides an analysis of ATS technology development and technology evolution influences that have a direct affect on ATS used by the Services. The development and evolution will be addressed from six different perspectives: ATS industry, standardization, TPS development and support environment, vertical testability, Built-In-Testing (BIT) applications, and DoD unique ATS needs.

The analyses presented in this section touched on each of these areas and produced the following general findings. Aside from the consequences of anticipated DoD budget reductions, ATS industry will not be adversely affected by a common ATS family investment strategy. Standardization efforts, originating from both the military and commercial sectors, have provided benefits to the DoD designated ATS families by introducing architectures and common instruments that permit design and use flexibility. Advances to TPS development and support environments will reduce future TPS costs, and combined with standard ATS families, will improve TPS vertical testability by increasing the transportability of TPS elements across applications. While BIT improvements will enhance system diagnostics, increasing weapon system design integration and complexities will preclude substantial reductions of the total DoD need for off-equipment automatic test systems. DoD will continue to possess many ATS needs that are unique when compared with those of the commercial sector.

9.1 ATS INDUSTRY

The DoD ATS vendor market may be partitioned into three aspects: (1) ATS system integrators, (2) ATE developers, and (3) test resource (e.g., instruments, power supplies, digital test units). The test resource suppliers are mostly second or third tier sub-contractors to DoD prime equipment or prime support contractors.

DoD ATS R&D and production expenditures are evenly spread across a large number of contractors, with a small fraction of the DoD ATS market in any one firm. Table 67 provides an example of the range and depth of ATS, ATE, and instrument providers; however, it is not an exhaustive listing. Like with any set of products and manufacturers, it is difficult to assign specific ATS industrial capability categories that fit all providers uniquely. Therefore, prominent trends are indicated based on the observations of the authors.

Table 67. Early 1990s ATS Industrial Capabilities

ATE SYSTEMS INTEGRATORS		COMMERCIAL ATE SYSTEMS & INSTRUMENTS/ MODULES
PRIMES	ELECTRONIC FIRMS/ ATS HOUSES	
BOEING	AAI**	FLUKE
GM HUGHES	ALLIED BENDIX**	GENRAD
GRUMMAN**	CHRYSLER PENTASTAR**	* HEWLETT-PACKARD
LOCKHEED	EATON	* RACAL-DANA
MARTIN MARIETTA	EMERSON (ESCO)	* SCHLUMBERGER
MCDONNELL DOUGLAS	GDE SYSTEMS, INC	TEKTRONIX
NORTHROP	GE**	TELEDYNE
RAYTHEON	HARRIS**	* TERADYNE
ROCKWELL INTERNATIONAL	HONEYWELL	WAVETEK
	IBM	
	LORAL	
	UNISYS	
	WESTINGHOUSE	

* Mfgr Special Test Equipment (STE) Providers. Note: All develop own in-house STE.
** DoD ATE is a Major Product Line

There was general consensus with all equipment manufacturers interviewed that the critical test equipment technical capability resides with the commercial tester and instrument manufacturers who make the test resources which are integrated into ATS. The commercial tester, instrument manufactures, and test resource providers develop products to meet market needs for commercial customers. Although the actual ATS market shares are proprietary, and therefore not presented here, the vendors observed that DoD constitutes only a small percentage of their market. For example, worldwide test instrument sales are over $6 billion annually [VXI 1992]. It is estimated that 50% of the manufactured cost for a DoD ATS is derived from COTS test resources. The cost savings economic model presented in Section 5 of this paper predicted a savings that averaged out to $300 million annually through FY99. Test instruments and other test resources represent about 50% of the anticipated savings identified by this macro model. These savings would come from quantity reductions and economy of scale factors. The net result is a potential savings of $50 million per year which is less than 0.5% of the test resource COTS market.

On the other hand, most electronics firms and defense primes have in-house organizations which develop ATS as adjuncts to their primary products. Only a few major defense corporate divisions and other firms have ATS as a principal business. The key technical capability common to these businesses is complex electromechanical or electro-optical system integration and packaging to DoD requirements.

DoD test program software houses are even more numerous and include many smaller businesses. No indications were found that emerging ATS technologies will reverse this trend. There are two primary ATS software categories involved: (1) test program set (TPS) development support software, and (2) test executive software. TPS development support software is provided by many sources and typically integrated into a loose knit development environment. Much TPS development support software is produced by computer-aided engineering vendors for both commercial and defense markets.

The dominant test program software standard (ATLAS) was jointly developed with the Institute of Electronic and Electrical Engineers (IEEE) in cooperation with DoD, and Defense Ministries of NATO countries, airlines and U.S. defense contractors. The airlines through Aeronautical Radio Incorporated, ARINC, developed their own standard which is coordinated with the IEEE standard. The TPS software using specific applications of this standard is supplied by a broad set of defense contractors in highly competitive procurements.

DoD's use of a few designated ATS families should improve TPS quality by providing a smaller set of target ATE systems to focus TPS development process and third-party software development support tools. TPS quality has the potential of being further enhanced by the introduction of an improved standard for ATS software language and improved user-friendly support environments.

The authors observed that ATS expenditure reductions of the magnitude outlined above might be attributable solely to DoD budget reductions. An ATS family investment strategy was found to provide the means to compensate for potential budget resource reductions and to meet weapon system ATS needs, both without adversely affecting operational ATS capabilities nor adversely affecting ATS industry.

There is no expectation that the application of DoD designated ATS families or the adoption of new, improved test software development environments will adversely affect industry. There is an expectation that productivity increases should be expected from the TPS industry.

9.2 STANDARDIZATION

This section presents a short discussion on the evolution of ATS standardization approaches and concludes with analysis of two ATS instrument buses, VXI and MMS.

9.2.1 ATS Standardization Evolution

A number of standardization efforts and approaches have been applied to ATS. The Services have initiated various standardization approaches to reduce duplication, obsolescence upgrade, and operating and support costs generated from unique ATE. In the 1970s the Navy introduced the Versatile Avionics Shop Test (VAST) system as its standard ATE. In the early 1980s, the Air Force introduced its Modular Automated Test Equipment (MATE), sometimes referred to as a *system of standards*. In the 1980s, the Army began the IFTE program. Now in the 1990s, the Navy is about to begin operational fielding of CASS.

In addition, there are a number of other ATS-related standardization efforts that are on-going in areas below the ATS system level. Many of these efforts have yet lower levels of standardization opportunities. Figure 27 illustrates several standardization opportunities that are below the system level. These include major functional elements (usually represented by hardware components), architectures, test languages. Table 68 provides a list of many standards currently in use, and indicates if the standard is controlled by the military or the commercial sector, and the Service using the standard. This list represents many of today's major ATS-related standards; however, it is not all inclusive.

The newest standard ATS, CASS and IFTE, were designed to take advantage of modularity and flexible architectures. Both of these ATS take advantage of COTS standard components. Therefore, CASS and IFTE can be characterized as standard ATS, that are in themselves broad collections of proven standards.

Both the CASS and IFTE program office personnel indicated that the flexibility and upgradability attributes of these ATS are due, in part, to the use of COTS and de facto standard components. The high percentage of commercial items (approximately 65% for both CASS and IFTE) permitted the design teams to focus on ATS system requirements and integration. This approach left the design and production of very accurate and precise stimulus and measurement equipment to instrument manufacturers who possessed the needed advanced technical expertise. Additional acquisition side benefits include improved quality, higher reliability, no development costs, and lower production costs (attributable to competition and economies of scale).

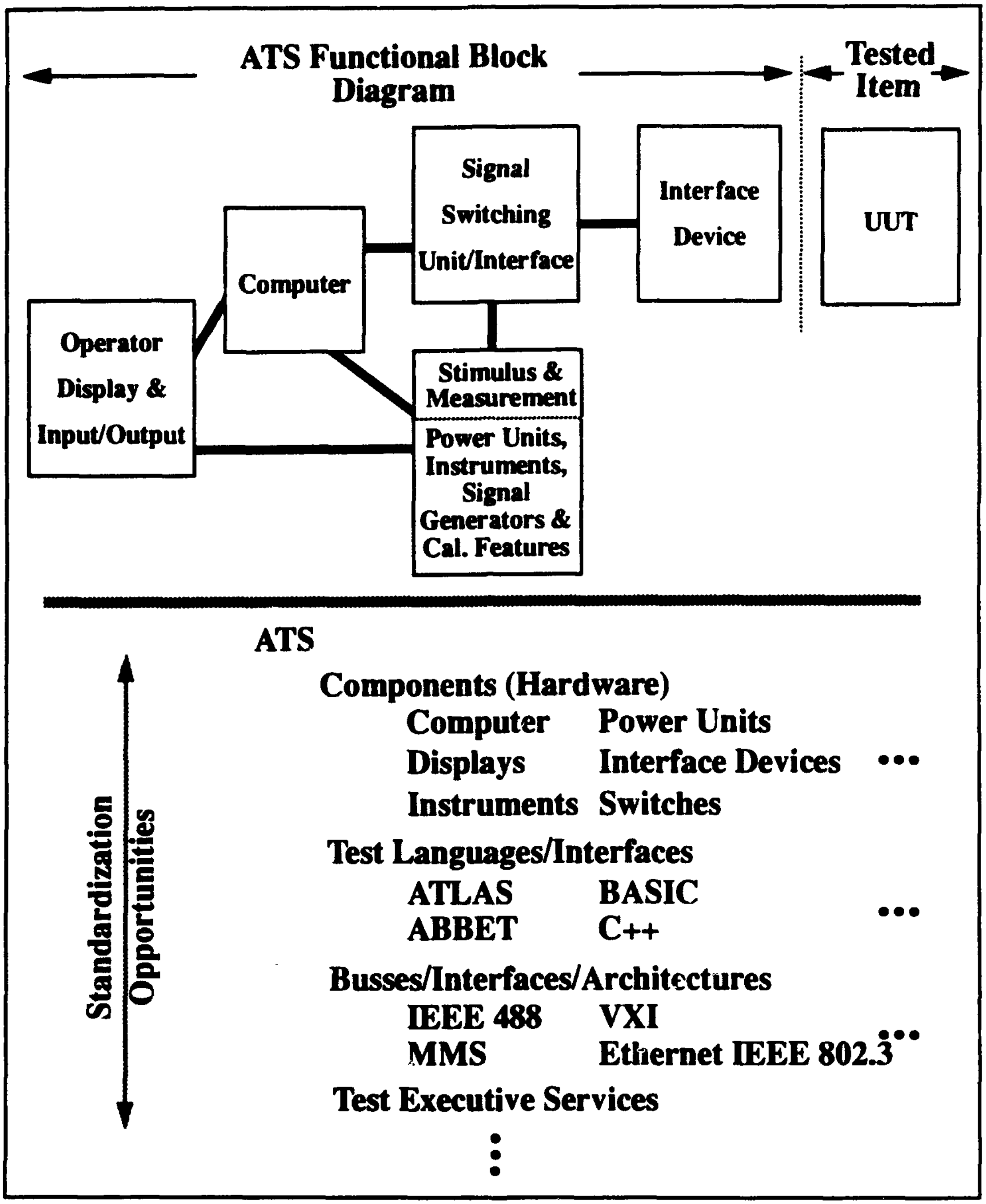


Figure 27. ATS Standardization Opportunities

The authors observed that CASS and IFTE, by design, addressed weaknesses found in other ATS standardization efforts. They use flexible industry standard architectures that promote modularity and partitioning (e.g., MMS, VME, and Ethernet). As performance enhancing technologies become available, these families of testers can incorporate the

Table 68. Summary of Selected ATS Related Standards

Standard	Use	Mil.	Comm.	AF	Army	Navy
ABBET (IEEE P-1226)	Test Environment		X	X		
Ada (Mil STD-1815A)	Programming Language	X		X	X	X
JOVIAL (Mil Std-1589)		X		X		
ATLAS 416	Test Programming Language		X	X	X	X
ATLAS 716-1985			X	X	X	X
ATLAS 716-1989			X	X		
SCPI (Std Commands for Prog. Instruments.)	Instrument Programming		X	X	X	X
IEEE-488.1 &.2	Instrument Bus		X	X	X	X
MMS	Instrument Hardware Interface Bus		X	X	X	X
VME			X	X	X	X
VXI (IEEE-1155)			X	X	X	
MATE-STD-CIL	Instrument Programming	X		X		
MATE-STD-CSS	Computer Subsystem	X		X		
MATE-STD-IAC	Instrument Hardware	X		X		
MATE-STD-ICA	Electrical Interface	X		X		
MATE-STD-I/O	Input/Output	X		X		
MATE-STD-ITA	Interface Test Adapter	X		X		
MATE-STD-SDF	Digital Simulator Test Format	X		X		
LASAR V6			X	X	X	X
Ethernet (IEEE-802.3)	Interface Bus		X	X	X	X
SCSI (Small Computer System Interface)	Computer Interface		X	X	X	X
RS-232	Communications Interface & Weapon System Buses		X	X	X	X
RS-422			X		X	X
RS-423			X		X	
RS-485			X		X	X
Mil-STD-1553		X		X	X	X
Mil-STD-1397		X			X	X
Mil-STD-1773		X		X	X	X
MCAIR-A3818		X				X
IEEE P1149.1	Boundary Scan Microcircuit	X	X			
IEEE P1149.5	Module Test Bus	X	X			

improvements without disturbing basic architectures. The authors observed that upgrades to incorporate new technologies should be limited to only DoD test needs. For example, the insertion of VXI or Ada at this time provides no specific new test or cost benefits to either the CASS or IFTE. Equally important, if VXI or Ada should be required in the future, current architectures are flexible enough to accommodate without drastic design revisions.

The authors concluded that the use of a DoD-defined set of specifications and interfaces to guide the evolution and transition to new capabilities will help in economically accommodating technological change. In this light, DoD should not only establish standard ATS families, DoD should define key family elements and interface standards to be used when implementing ATS families to help manage their technology evolution.

Applying a standard family, along with the related subset architectural and instrument standards, is fully consistent with integrated diagnostic approaches. For example, when a contractor determines that ATS are needed as part of the most effective weapon diagnostic mix, the proper ATS family may be matched to this need. This approach supports concurrent engineering in that selecting the target ATS family at Milestone II allows an earlier focus on the test and manufacturing aspects of the weapon system design. The standards also reduce the risks of developing test software programs on new, design-unstable testers.

9.2.2 Instrument Busses: VXI & MMS

VXI and MMS are two test instrument bus standards used by the DoD. VXI stands for VMEbus (a computer backplane bus standard) Extensions for Instrumentation. VXI was developed by a consortium of companies and has become an IEEE standard. Potential VXI standard changes are controlled by IEEE under its balloting processes. MMS stands for Modular Measurement System, and was developed by Hewlett Packard. Hewlett Packard has subsequently turned over rights and controlling ownership of this standard to a consortium of companies. Each participating company is entitled to only one vote regarding potential MMS standard revisions. Although, Hewlett Packard originally developed MMS, they possess only one vote over potential standard changes, equal to other participating consortium companies.

Both of the standards include open architectures that permit the interconnection of modular instruments. The specifications for these standards define the chassis, mechanical and electrical interfaces, cooling, communications protocols, etc. The open architecture of both standards permits compliant products from different manufacturers to interconnect and operate within the same package or chassis.

The worldwide market shares for both VXI and MMS have been nearly equal. In 1991 both had sales of approximately $55 to $60 million dollars. An early 1992 assessment projected these sales to increase to approximately $80 to $100 million by the end of 1992. More recent Prime Data information indicates that the VXI 1992 totals may be higher, or around $146 million. An assessment of the VXIbus systems market in 1990 by Prime Data revealed that the military was the principal user (64% on a systems basis and 44% on a module basis). The same 1992 VXI data indicates that the commercial market share is growing and is now approximately 64%. Assessments of MMS markets from 1989 through the end of 1992 from Hewlett Packard estimated that 54% of the users fall in the Aerospace/ Defense and DoD/MoD Programs. [Source data are compilations of information provided by VXI Consortium and Hewlett-Packard, both referencing data provided to them by Prime Data.]

The standards were developed primarily to meet defense needs for modular ATE. The operational needs that lead to the VXI and MMS designs are found mostly within DoD military operational environments. Industry representatives (that sell VXI- and MMS-based products) indicated that in contrast with DoD, the majority of the commercial sector users do not have specific requirements for downsized, portable, or militarized ATE. Product selections are based more on cost and performance criteria. Product flexibility attributes to meet specific testing applications are sometimes used as criteria. In meetings with instrument manufacturers, they indicated that the vast majority of test instrument users in the commercial sector rarely select products based on VXI or MMS interfaces.

Although military applications have (prior to 1992) accounted for the greatest percentage of VXI sales, the market sales for other commercial electronics sectors are growing faster. While portability, ruggedness and downsizing are not the driving factor, other benefits of performance, open standards, flexibility, and time to market are influencing the commercial application growth. However, many VXI-based products are yet to be developed, such as a comprehensive set of RF and microwave instrumentation.

The total worldwide test instrument market sales are over $6 billion [VXI 1992] annually. This includes many product categories not applicable to either VXI or MMS (i.e., oscilloscopes, power supplies, X-Y recorders, etc.). The combined sales of VXI and MMS for 1992 will represent less than 2% of total instrument market sales, and that DoD related sales constitute over half of this market share. However, when sales are compared to the applicable sub-segment of the markets each potentially support, the combined VXI and MMS sales percentage increases to approximately 16%. Even at projected growth rates, sales to DoD of these two product lines will constitute the largest single customer for the next few years.

In subsequent meetings with Army, Navy, and Air Force personnel, there was general agreement that future ATS developments or modifications should not limit to a single open architecture standard, but rather specify system test performance requirements for identified application environments. There was general consensus among the three Services personnel that other system-level requirements better determines bus structures and packaging scheme requirements. Examples include requirements for an open systems architecture, the specific stimulus and measurement domain, downsizing, accuracy and precision, modularity, interoperability, and upgradability. The following summarize the general consensus of the participants:

a. It does not appear the VXI or MMS standards are mutually exclusive, there are valid application reasons for several architectures, and each specification is expected to have future growth.

b. VXI and MMS architectures were originally developed in response to DoD needs and had migrated to the commercial sector.

c. DoD should specify in terms of requirements as opposed to solutions (e.g., VXI or MMS) and that different requirements may in fact drive different results.

d. DoD should not exclude either VXI or MMS solutions, but rather DoD should let cost and performance determine applications.

e. Open hardware standards, like MMS and VXI, provide the widest commercial base to address DoD general purpose ATS needs and offer opportunities to reduce life cycle costs.

The following sections are intended to summarize major attributes and support the conclusion that different requirements often stimulate different engineering trade-offs. VXI and MMS have technical merit depending on their intended use. Open architecture standards like VXI or MMS are highly desirable when interoperability of modules from multiple venders is likely.

9.2.2.1 VXI

The initial VXI standard was jointly developed by five companies in 1987. Since that time it has become an IEEE Standard (1155-1992). There are currently over 60 VXI manufacturers with over 500 identified products. The VXI standard, as its name implies, is an extension of the VME microcomputer backplane bus standard (specifies mechanical and functional structure). The following details are quoted from the VXIbus system specification:

> The VMEbus is an open system architecture primary focused at computer systems... VMEbus modules are approximately six inches deep and come in two heights, about four inches and nine inches. The VXIbus specification refers to these as the A and B sizes respectively. . . The A size board has a single 96 pin connector known a P1, while the B size may include a P1 and P2 connector. Each of these DIN connectors consists of three rows of 32 pins on 0.1 inch centers. . .
>
> VXI retains P1 and the center row of P2 exactly as defined by VMEbus... However, VXI has made substantial additions to the VMEbus specification oriented towards instrumentation that can best be described as an electromechanical super-set and a logical subset. . . VXI has added two Eurocard module sizes of about 13 inch depth referred to as the C and D sizes. These modules are 9 and 14 inches high respectively, and are placed on 1.2 inch centers. The C Eurocard is the same height as the VXIbus B size board, and may sport both P1 and P2. The D size module is a triple high Eurocard that may include a P3 connector in addition to P1 and P2...The VXIbus adds a 10MHz ECL clock, ECL and analog supply voltages, ECL and TTL trigger lines, an analog summing bus, a module identification line, and a daisy chain structure known as the local bus... The VXIbus P3 connector adds many of the same resource types as described for P2, but is aimed at higher performance instrumentation. Included on P3 is a 100 MHz clock and sync signal, additional power pins of the same supply voltages, more ECL trigger lines, and 24 additional lines (48 pins) of daisy chain local bus.

9.2.2.2 MMS

The open architectural concepts of the MMS standard were developed in the early 1980s. They were intended to provide an environment for microwave measurement using modular instruments. The following details are quoted from the MMS bus system specification.

> Modularity in large Automatic Test Equipment (ATE) systems was recognized as an important attribute in the 1980's because of potential size reduction, serviceability improvements, and the ability to reconfigure. The United States Air Force, Navy, and Army reflected this in their requirements for ATE systems. Modular instrument solutions for digital and low frequency analog applications became possible using card-based architectures. Modular test equipment solutions for microwave applications were being built using MMS equipment... MMS addresses the needs of microwave test systems

and other applications where modularity and sensitive measurement capability are needed

The Modular Measurement System architecture is based on standard sized modules, in increments of a minimum module width, with external support functions provided by the mainframe. The mainframe provides modules with power, cooling, physical structure, and digital communication capability.

Two methods of digital communication are provided by the Modular Measurement System architecture. A common IEEE-488.1 interface is provided to each module interface connector, providing standardized computer-to-instrument interface. The Modular System Interface Bus (MSIB) provides general purpose high speed digital communication between logical modules and also provides a standardized computer interface. The MSIB system also defines an extension between mainframes, allowing module placement to be dependent only upon instrument and measurement system requirements.

9.2.2.3 Instrument Bus Comparison (VXI and MMS)

VXI and MMS specification standards cover modular instruments with partially overlapping stimulus and measurement domains. Because it evolved from a computer backplane bus, VXI is generally well suited for digital communications and testing. Principal VXI applications are digital, mixed-signal, and analog up to 1 GHZ. MMS, on the other hand, was specifically targeted towards RF and microwave instruments. Several VXI and MMS attributes are compared in Table 69.

Instrument manufacturers observed that both standards approaches can be made to work and work well in the primary domain of the other. However, making them perform well in the principal domain of the other often requires unique designs and super-sets of the basic standards. When these special design characteristics are needed, the products are rarely COTS.

9.3 TPS DEVELOPMENT AND SUPPORT ENVIRONMENT

9.3.1 Magnitude of TPS Development, Support, and Rehost Costs

TPS development costs were found to vary from between 5% and 26% of the total ATS acquisition for field (I-level) maintenance applications. In contrast, for depot applications where fewer quantities of testers are purchased, the TPS development costs were found to have a wider and generally increasing range from 8% to 50% of the total ATS acquisition (previously discussed in Section 4.3.2). Although specific TPS support costs could not be determined from the collected data, evidence collected indicated that TPS support costs are

Table 69. Comparison of Selected VXI and MMS Attributes

ATTRIBUTES	VXI	MMS
Size	Based on C-Size: a) Module to Rack Height:) $\frac{(12.25 in Tall Mainframe)}{(12 + 1 Slot 0 Controller)} = \frac{1.02 in}{Slot}$ b) Available Volume Per Slot: $H9.187 in \times W1.188 in \times D13.386 in = \frac{146 in^3}{Slot}$ (Multiple sizes available: "B" used ~10%, "C" used ~80%, "D" used ~ 10% of time.)	a) Module to Rack Height: $\frac{(7 in Tall mainframe)}{(8 Module Slots)} = \frac{0.875 in}{Slot}$ b) Available Volume Per Slot: $H4.457 in \times W1.827 in \times D18.386 in = \frac{150 in^3}{Slot}$
Cost	Chassis costs are comparable: MMS mainframe costs a little more; however, VXI requires a 0-Slot controller (MMS ~ $900/Slot & VXI ~ $800/Slot). The module costs are generally the same relative cost per function.	
Market Share	~ 8% of related test instrumentation market. DoD/aerospace acquires ~1/2.	~ 8% of related test instrumentation market. DoD/aerospace acquires ~1/2.
Digital Reference	10 MHz clock (B-D size cards) and 100 MHz clock (D size card)	10 MHz clock
EMC: Radiated Module to Module	MMS and VXI applications require near field magnetic radiated and susceptibility compliance and specified limits similar. VXI has reduced susceptibility area and may require adapters or module to module placement constraints depending on module size and application.	
EMC: Radiated Mainframe to Module	Does not have mainframe requirements, & has reduced area available for susceptible circuits.	Mainframes comply with near-field specifications
Cooling	Air flow specified; however, integrator of modules may need to consider differences between mainframes and modules. (Rev 1.4 defines cooling on a slot/module basis.)	Air flow path and minimum air flow per module specified (high degree of repeatability between modules and mainframes)
EMI	Implementation of most RF noise constraints beyond VXI standard & left to module integrator to implement or incorporate necessary physical features.	Physical specifications and required electrical shielding developed to minimize in the RF environment.
Vibration Noise (Microphonic)	Not specified	0.010 g limit
Status	IEEE Standard. Over 240 mfgr's IDs assigned. Approximately 5-years old. Is not optimized for RF; therefore, number of RF products very limited.	Standard controlled by consortium of 9 companies, consortium considering submitting to IEEE for standard consideration. Approximately 8-years old. Large product base.

also substantial. One final TPS cost category, also difficult to quantify, includes the costs of update and rehost to new or substantially modified ATS. Information provided at the TIMs suggests that these updating and rehosting costs are of the same relative magnitude as the original TPS development. Applying estimates of these TPS development, support, and rehost cost distributions to total projected ATS acquisitions (estimated earlier in Section 6) indicates that these costs will range between $3 and $4 billion over a 6-year budget cycle.

9.3.2 Opportunities to Reduce TPS Costs

The option cost factors (developed in Section 5.1.1.2) hypothesized near- and long-term improvements to current approaches used to develop and support TPSs. The near term improvements were estimated to reduce the development type costs by approximately 17% and they increase to 70% over the long term.

Although these cost avoidance benefits do not exist at this time, there is evidence that improvements of this magnitude are feasible. Results from an Air Force laboratory study titled "Tester Independent Support Software System" (TISSS) provided an example of potential test development cost reductions. TISSS applies an automated approach based on new digital design descriptions and tools coded in the VHSIC Hardware Description Language (VHDL). The TISSS approach permitted more efficient design capture and analysis, facilitated the reuse of test specifications and test coding details, and accelerated the test program integration and acceptance phases of the development cycle. The TISSS approach specifically touches on seven of the eight TPS development cycle elements (all but the interface device design as previously summarized in Table 27). The TPS development process elements influenced by TISSS compose 87% of the identified total process.

The data from the following two charts come from TISSS program analyses. Figure 28 illustrates representative test development complexity growth arising out of increasingly more complex digital designs. The arrow in this figure indicates the increasing test vector count resulting from increasing device complexity. Figure 29 illustrates the potential development time reductions that may be achieved if new test program development and support environments become a reality. Metrics of microelectronic device complexity illustrated by this figure include the gate count of the device and the number of input/output pins on each device.

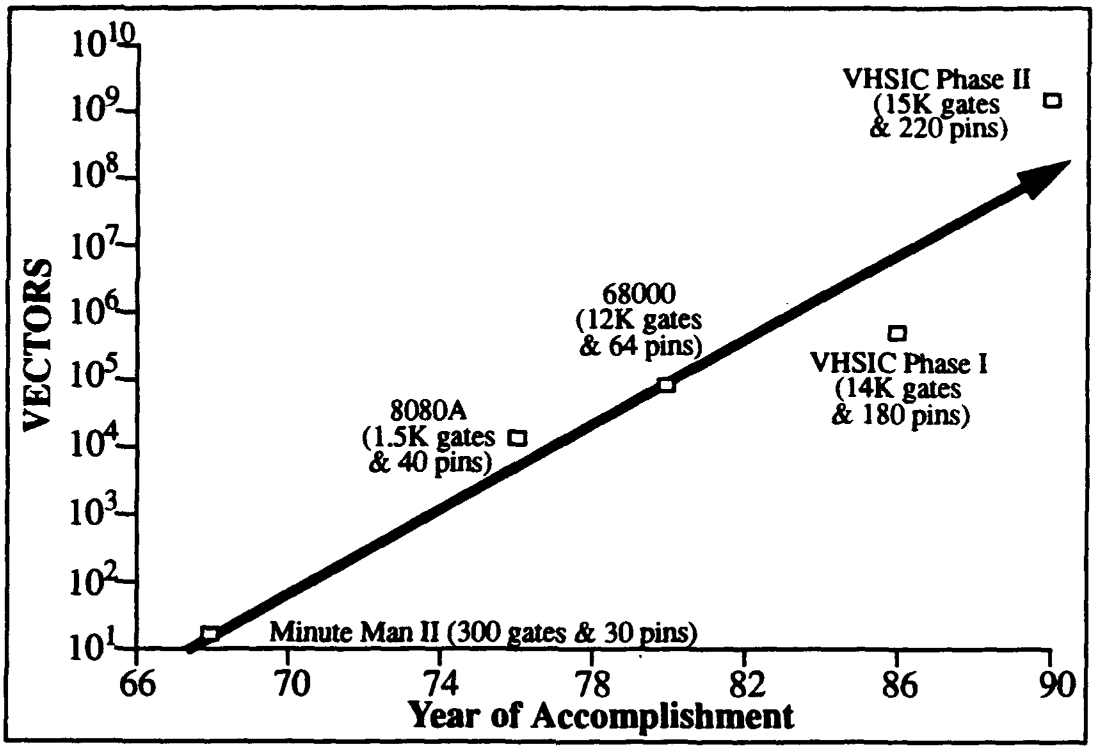


Figure 28. Growing Systems Complexity and Test Vector Growth

Figure 29 presents the results of comparing the test program development times for the conventional development process and for the TISSS method. The man-years required for the first four data points are estimates based on the TISSS method, and the final data point represents actual results from the TISSS program.

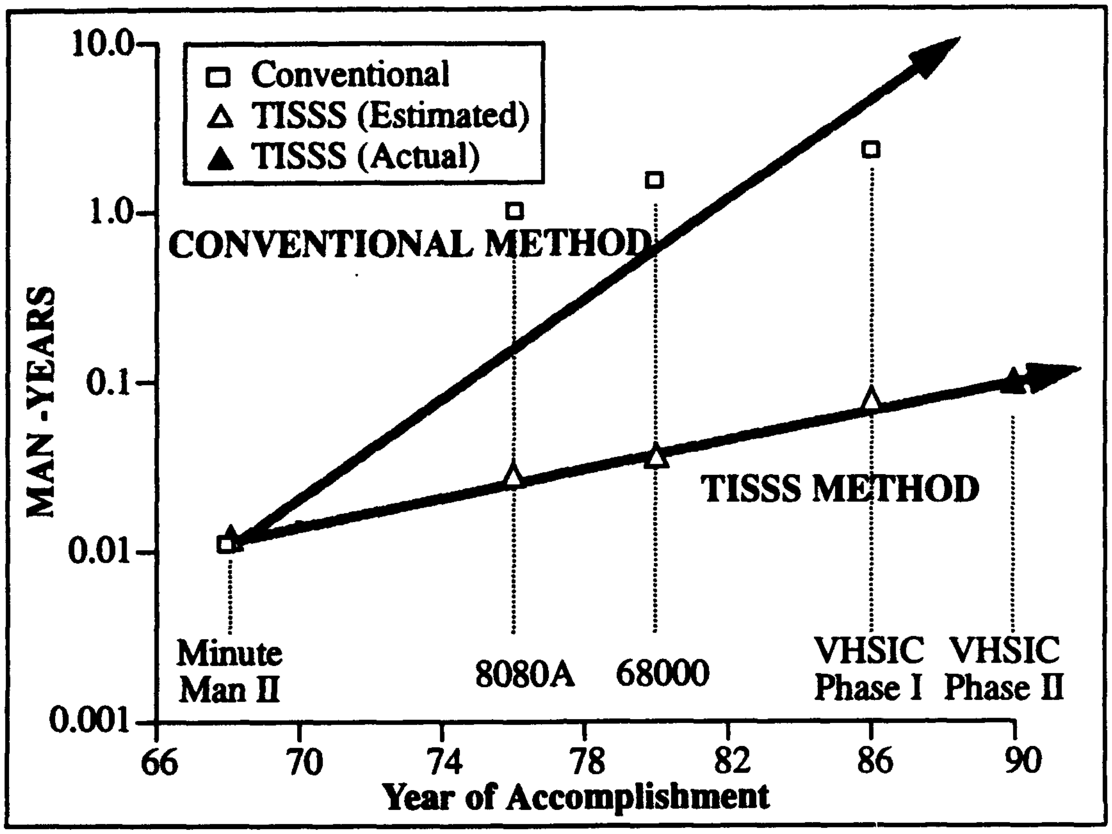


Figure 29. Comparisons of Test Program Development Times

9.3.3 TPS Development Environment Concept

Ongoing efforts by (1) the Air Force to reduce the proliferation of computer programming languages, (2) the Joint DoD/Service DALSCOM (DoD ATLAS Standardization Committee), and (3) the IEEE have all culminated in draft specifications for A Broad Based Environment for Test (ABBET). ABBET is intended to be an environment for developing, maintaining, executing, and improving test programs used on automatic test systems. An objective of the ABBET standardization effort is to improve test software quality, and reduce test software initial acquisition and subsequent rehost costs. Much of the ABBET benefits will be achieved through standardization that will support reuse of test program data and common test software across the product (UUT) life cycle from design, factory testing, and operational maintenance testing.

The ABBET concept is illustrated in Figure 30 which depicts a layered drawing of engineering process domains. Key relationships between domains are indicated at the bottom of each layer. These layers represent engineering processes which (1) start with a description and information source of a product to be tested, and (2) resolve the detailed behavior of instruments and test resources that will be used to test and diagnose the product.

The ABBET environment is not one specific implementation of the functions described in this figure. Instead, one of the principle goals of ABBET is establishing standards for the Services, data formats, information exchanges, and interfaces that constitute an ABBET environment for ATS. With those standards in place for the elements of ABBET, any number of separate, competitive, yet compatible implementations will be possible. The standards which define the pieces of an ATS ABBET environment will be concerned with identifying what is standardized already instead of how to implement standards.

Major elements of an ABBET implementations will focus on the development of test program information that is independent of any one particular suite of ATS. Using an ABBET compliant environment to develop tester independent TPS information is the key to reducing the cost of rehosting. The top-down model presented in Figure 30 shows existing and potential test-related standards on the left-hand side, and possible practices and libraries using these standards on the right-hand side. The majority of the standards activities have taken place in the IEEE. However, other standards bodies, such as the Electronic Industry Association (EIA), have worked many areas of computer-aided design and manufacturing. A third standards body, the International Standards Organization (ISO), is developing Product Description Exchange standards for mechanical, electronics, shipsbuilding, etc.

However, ABBET is at an initial conception and formulation stage. More R&D across multiple standards areas is needed in order to gain the benefits advertised. However, benefits to both industry and DoD are feasible, and interested parties are seriously pursuing this development. A draft specification has been balloted by the IEEE members and will be undergoing subsequent standardization development and review this next year. The authors working on this report recognized a need for continuing development of an improved test environment, and identified R&D "plus-up" resources in Section 6 towards this goal.

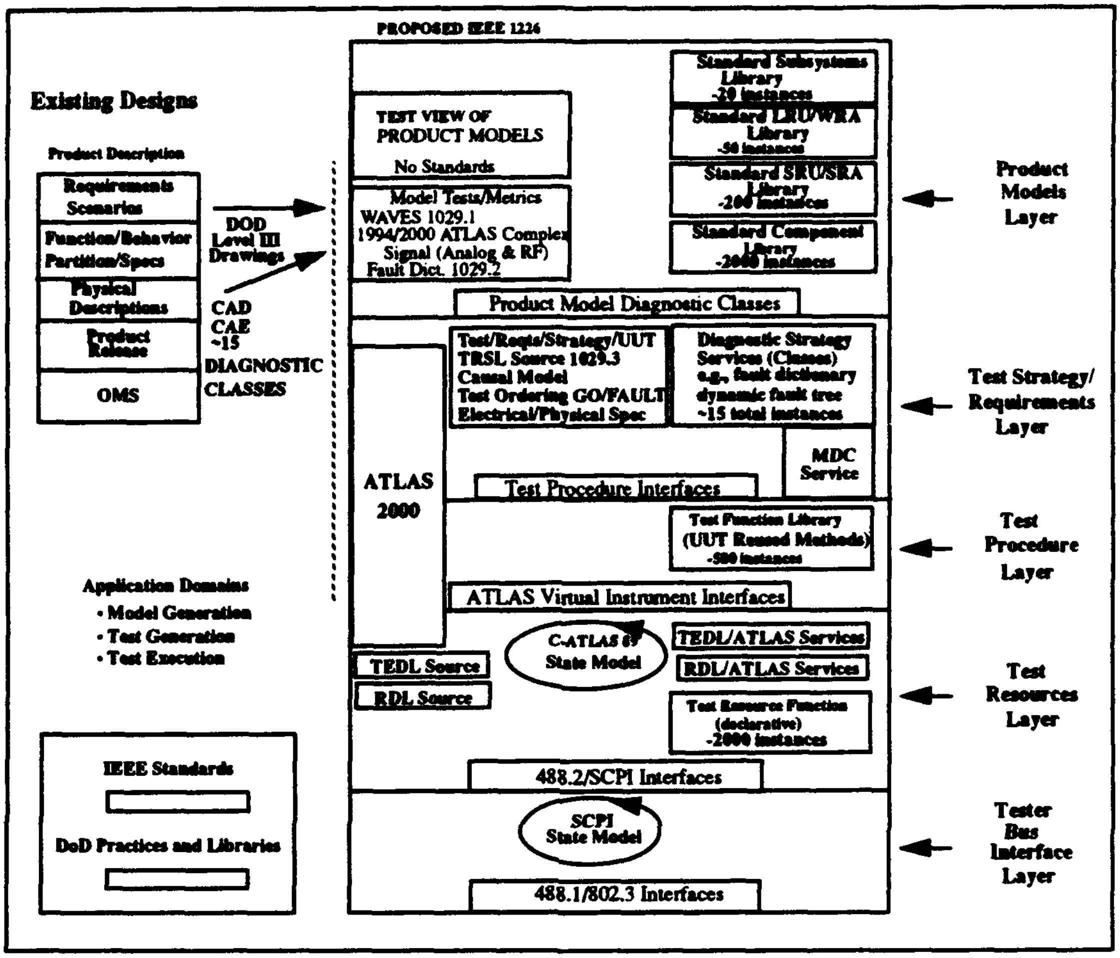


Figure 30. A Broad Based Environment for Test (ABBET)

9.4 VERTICAL TESTABILITY

Three very different concepts or views of vertical testability are present within the ATS technical communities: measurement accuracy cones of tolerance, TPS transportability across application levels, and testing correlation across application levels. The first is well understood and involves a cone of calibration accuracy tolerances (Tolerance Accuracy Ratios or TARs) between test equipment and calibration standards. With the proper control of the TARs, the absolute accuracy requirements between measurements (such as various maintenance levels) may be controlled. The second area is the least well defined or understood, and involves the ability to move TPSs both among and across functional testing levels: from factory to lower maintenance levels [VERTICAL 1992]. The third area is the relative testing and diagnostic accuracy between applications, usually maintenance levels [MC COMB 1992].

Because of the impact to an ATS investment strategy, this analysis focuses primarily on the TPS transportability aspects of vertical testability. Finally, this section concludes with a discussion of the third area, the relative diagnostic accuracy improvements that may be associated with the adoption of common ATS families. The first view involving calibration accuracy and TARs involves basic measurement sciences. This area was not separately analyzed as part of this study; however, aspects of calibration accuracy are discussed within the Relative Diagnostic Accuracy Test Result Correlation Section 7.4.2.

9.4.1 TPS Transportability

Vertical testability, as principally addressed in this study, represents a notional measure of how well some or all of a product's test program set (TPS) elements may be reused at different testing levels. The primary TPS elements are the test program software, testing documentation and instructions, and interface/test adapter hardware. The reusability of these elements is directly tied to three critical ATS design factors: Test Strategy, ATS Flexibility, and Data Transportability.

a. **Test Strategies** directly influence design characteristics of the TPS elements. These strategies are based on the intended purpose of desired tests, and very frequently the specific testing purpose is linked with the application level (e.g., factory, depot, or operational). In general, it is easier to transport TPS elements from one ATS to another if similar test strategies are employed.

   Test strategies generally fall into three categories: Process Verification, Product Verification, and Diagnostic (or Fault Detection/Isolation). Depending on the intended application level, one or more of the strategies may be used. For complex systems, the number of tests may range upwards to the hundreds or even thousands. Also, the order in which the individual tests are conducted may vary, depending on the test strategy used. Due to the unique objectives of different strategies, specific design characteristics of individual ATS elements may have substantive differences that impede vertical testability.

   The following summarizes principal differences between test strategies. Process Verification test strategies are intended to keep a manufacturing or assembly process in statistical control. Product Verification Test Strategies are intended to indicate the status of, or verify that, a product (or subcomponent during a manufacturing process) meets specified characteristics. Diagnostic test strategies are intended to detect and isolate faults, and link identified faults to corrective actions. In addition, each of these basic strategies may be further implemented with a parametric or functional testing approach. The parametric methodology involves the sequential application of prescribed stimulus and quantitative measurements to prescribed limits, whereas the functional methodology involves verifying an ability to perform intended functions when subjected to emulated operational signals.

b. **ATS Flexibility** describes an ability of the testing system to adapt to changing test requirements or to incorporate additional capabilities. In general, it is easier to transport TPS elements from one ATS to another of equal or greater flexibility provided they both have, or may incorporate, capabilities to cover the same testing requirements spectrum.

   The effect of ATS flexibility on the ease of transporting TPS elements may be addressed from several flexibility perspectives: the ability of the ATS to accommodate new requirements at flexible physical interfaces, the ability to accommodate the same range of stimulus and measurement performance properties across ATE versions, and the degree to which a TPS specification language will accommodate common syntax and common testing methods. Vertical transportability of TPS elements is severely impeded when the target ATS are neither identical (or nearly so) nor incorporate features that foster ATS flexibility.

c. **Data Transportability** is an ability to obtain and reuse information in a digital format that describes the design of the product being tested, the capabilities and characteristics of the source and target ATS, and the testing strategies. In general, it is easier to transport TPS elements from one ATS to another if there is an automated mapping of data fields, ATS capabilities and characteristics, physical connections, and alternative testing strategies.

   Full one-to-one compatibility of TPS elements from one tester (or application level) to another is rare, and even in the best of cases, some mapping of data fields, physical connections, or alternate strategies are required. The ease of this mapping is dependent on how well this information has been captured, recorded, and verified. In some cases this information mapping may even lend itself to automation. If this data is in neither a retrievable or transferable form, some degree of reverse engineering will be required to rehost TPS elements on different ATS.

In general, vertical testability will improve when the impediments directly related to the critical ATS design factors are reduced. The authors concluded that the following three essential actions are needed to reduce impediments and improve vertical testability.

(1) Test strategies should take into account the intended purpose of needed testing at all levels where the TPS elements may be used.

(2) ATS flexibility may be addressed from two perspectives: standardized ATS (i.e., a common ATS family) or flexible architecture, general purpose ATS. The standard ATS approach avoids the need to account for differences, because the equipment is identical at all levels. Since it is unlikely that full standardization could (or should) be achieved, highly flexible architectures that accommodate a wide range of general purpose testing needs are most desirable. This is presently achievable with the CASS and IFTE general purpose ATS families of testers.

(3) Given that full one-to-one compatibility of either ATS hardware or test strategies will not be achievable for a wide range of applications, the greatest overall improvements to vertical testability will come from the creation of a software development and support environment that minimizes reverse engineering tasks for rehosting TPS elements across ATS and testing levels.

9.4.2 Relative Diagnostic Accuracy Test Result Correlation

The relative diagnostic accuracy between maintenance levels (i.e., organizational, intermediate, and depot) is measured in terms of RTOK, CND, and NEOF. These stand for ReTest OK, Can Not Duplicate, and No Evidence of Failure respectively. They are generally applied when an item is checked out at the next level of maintenance in a repair chain and the alleged problem can not be found nor duplicated. Adverse consequences of diagnostic inaccuracies include increased maintenance work load, increased spares logistics pipeline, increased support costs, and reduced systems availability. Although not the only source of these problems, ATS must be considered one of the primary contributors. In this context, vertical testability is a metric of how well testing results correlate at different maintenance levels.

This form of vertical testability is directly influenced by five testing process conditions that may vary across maintenance levels: test strategy, test equipment, weapon subsystem configuration level, pass/fail thresholds, and calibration approaches. (There are yet other non-ATS driven testing process condition differences that can affect diagnostic accuracy, and these will be discussed briefly in a subsequent paragraph.) These testing process differences can result in measured variables that indicate a good item at one maintenance level and yet indicate a failed item at another maintenance level (or visa versa). In order to assess how this might occur, a simple model of a subsystem soft failure mode is used as an illustrative example.

Many failure modes do not fall into the category of a "hard failure" (i.e., a burnt-out resister or an open diode). Instead, an item may exhibit a "soft failure," where there are only slight changes in critical output performance levels such as time, current, or voltage. In most cases, a gradual degradation of performance levels within some tolerance is acceptable, and will not significantly affect desired performance of the full-up system. However, once the performance of an item varies beyond certain limits and some aspect of the full up system performance falls below a required capability, both the system and the item are said to be experiencing a soft failure. In a soft failure mode, some aspect of the system still may be partially capable of meeting mission requirements.

As noted, the five ATS related testing process conditions may influence the relative diagnostic accuracy (or vertical testability) across maintenance levels. The following examples illustrate some effects of these differences:

a. A system may be tested as a complete entity, or assemblies that make up the system may be tested as separate units. The configuration level, in this context, addresses the complete hierarchy of elements that compose the system (e.g., from system, to a subsystem, to a component). When tests are conducted at different configuration levels (e.g., LRU, SRU, or component) at different maintenance sites, measured parameters are often influenced by other circuits present in an electrical path. The electrical circuits undergoing test and measurement are determined by the configuration level of the unit being tested. In some instances, the desired parameter may not even be accessible while combined with its next level of system assembly; therefore, a totally different testing approach must be used at each location.

b. The test strategies for assessing performance at various maintenance levels are frequently different, resulting in different reported values for the same unit under test. For example, one strategy may determine a level of performance by measuring power around a specified tolerance range, while another test strategy measures current over a related, yet different, tolerance range. To eliminate diagnostic accuracy error sources, these differences must be correlated to a high level of precision. Given there may be hundreds or even thousands of parameters to be measured, reference correlation between measurements is not always given the rigorous attentions required to prevent error sources.

c. Different ATS at different maintenance levels may have the same consequences as item b. above.

d. Even if all of the above conditions are minimized by using identical ATS and identical test strategies, the applied tolerance around the pass/fail threshold of a specified parameter can influence diagnostic accuracy. The pass/fail performance threshold may vary enough at different maintenance levels to result in either falsely accepting or falsely rejecting an item. This condition frequently results when the ability to measure a specified parameter to a level of precision is less than the accuracy permitted by the ATS, the test strategy, or the calibration. Due to the sheer number of potential parameters that may be measured in complex electronics, coupled with many test approaches available to a test engineer, it is questionable that all specified test tolerances have been rigorously analyzed to ensure overlapping tolerances at different testing levels do not result.

The testing process condition, which involves overlapping thresholds of pass/fail parameter tolerances at different maintenance levels, may be the most difficult to manage. To manage this diagnostic error source problem, an in-depth knowledge of nearly every parameter measured on a specific unit under test is required. Specific details must include an understanding of tolerance guardbands needed for each parameter and at each maintenance level where the parameter might be measured. In general, the tolerances should be adjusted such that the least accurate (or widest tolerance) exists closest to the user. The goal in this case is to eliminate the possibility of a specific measured parameter value being outside the pass/fail tolerance guardband (or a failure) at the maintenance test level closest to the operator, while being inside the pass/fail tolerance guardband (or a pass) at the next level of maintenance.

Management of this error source is further hampered by weapon systems that require higher levels of accuracy and precision. As needed accuracy and precision approach current technology limits to calibrate test instruments, the available tolerance guardband at different maintenance levels shrinks.

Based on discussions with both designers and users of ATS during this study, the authors were left with the impression that this specific problem is generally overlooked and only addressed when identified as a specific problem through a variety of maintenance data collection and information feedback tools found in the Services. Standard ATS families will not eliminate this error source problem; however, it may be easier to identify and isolate these problems if other potential error sources are eliminated from contention by using the same equipment at multiple levels.

Finally, the error sources from the other four testing process conditions may be reduced or even eliminated by using the same ATS at multiple maintenance levels. Test strategy, test equipment, calibration approaches, and even the subsystem configuration level may be identical (or at least managed) if the same ATS is used at the various testing sites. Furthermore, other testing process conditions such as the quality and thoroughness of ATS training, consistency of calibration procedures, operator errors, communication between maintenance levels, etc., may be better managed if the same ATS is used at multiple maintenance levels.

Therefore, the authors concluded that common ATS families, when used at multiple maintenance levels, will tend to improve the relative diagnostic accuracy across different maintenance levels.

9.5 BUILT-IN-TEST (BIT) APPLICATIONS

BIT will not reduce ATS requirements for off-equipment repair over the next decade. BIT does not have the same accuracy and range of testing capabilities as modern general purpose ATS. BIT technology development is not keeping pace with built-in-testing needs of new systems employing emerging technologies due to missing integration of necessary control and observation pathways and sensors.

BIT is a key element of current and evolving on-equipment maintenance strategies for fault detection and fault isolation of advanced ground electronic and avionic systems. Some future maintenance concepts are being developed on the premise that organizational and intermediate level test equipment will be eliminated by improvements in reliability and BIT. Also, BIT may be used to support factory acceptance and depot level ATS-based test. But designing a BIT system for so many test roles is quite difficult. The absence of BIT standards in each of these test roles requires custom hardware and software engineering which is difficult to achieve across a multiple contractor base.

This section provides a short discussion on the types of BIT, and provides an analysis of why current DoD systems are not achieving the full potential of BIT capabilities in present designs. This is followed by discussions of current BIT technology limitations, and how BIT and ATS might collectively be used to improve integrated diagnostic capabilities.

9.5.1 Types of BIT

There are two basic types of weapon system BIT. Logic level based BIT, also identified as digital BIT, takes advantage of digital pathways to concurrently or off-line verify system performance and fault isolate to a removable item. The second type of BIT is sensor and microcomputer based and can be applied across all electronic, electro-optical, and electro-mechanical applications.

The first type of BIT may support certain ATS applications. The second type of BIT is typically not effective in supporting ATS applications. BIT integrates with modest effort into subsystems that are computer controlled and makes use of many sensors integrated for system control. Systems may provide stimulus, and most definitely provide observation paths necessary for effective BIT. But when examining subsystem components encompassed by BIT at a system level, the BIT functions and/or information often are incomplete and disjointed. The BIT requires computation and sensors in place acting in unison. In general, line removable units and lower levels of indenture components cannot utilize this kind of on-equipment BIT to supplement or replace ATS applications for removable item testing.

Both types of BIT will increase off-equipment testing needs because of the added circuitry and untestable elements within the BIT design.

9.5.2 BIT Applications

BIT is not being integrated to the fullest extent possible in most current DoD systems. The reasons are several: (1) it is not an effective add-on feature for existing systems, (2) many commercial devices do not support BIT capabilities, (3) BIT does not come free, and (4) there are some technology areas where BIT has not matured enough to meet current needs. This section will discuss the first three reasons, and the last will be covered in the next section.

BIT is not an effective add-on to existing complex electronic systems. Granted, some minor BIT features might be added; however, full robust fault detection capabilities need to be designed and integrated into the system circuitry. If a system is undergoing major modifications, the portion of the system being redesigned may incorporate BIT. However, the BIT that is being added must be consciously designed into the system. Also, it is not practical to use BIT to test each parameter or condition subject to failure, since each BIT feature has its own overhead burden (space, heat, interconnections, software/firmware, etc.). Implementation of an on-board testing capability that provides full fault detection over the system operating range would require the incorporation of some major subset of a full sized general purpose ATS on each circuit card. This also is valid at all design levels down to and including individual components. BIT only checks for a unique problem or set of problems that might be detectable within a subsystem. There is a wide range of problems within each BIT implementation that are non-detectable.

Some of the electronic components planned for the advanced avionics of the F-22 aircraft were reviewed. Many of these proposed digital microelectronic devices are commercial or militarized versions of commercial products, and they do not include architectures and features compatible with BIT (such as boundary scan and diagnostic bus interfaces). Consequently major portions of critical line replaceable module (LRM) circuitry (often controlling portions) either must be void of BIT or must be redesigned to incorporate BIT capabilities. Due to cost and programmatic risk concerns, major developments other than the F-22 which also involve complex electronics will use high relative percentages of commercial-based microelectronic devices. Therefore, until the commercial sector demands more BIT features, full digital BIT will rarely be as extensive as proposed.

There are both direct and indirect costs associated with BIT. BIT adds complexity to the circuits. It introduces additional testing requirements. Total device reliability is reduced since there are more microcircuit elements. BIT is also another source of diagnostic accuracy errors. Once implemented in a design, BIT diagnostic accuracy problems are difficult and often costly to eliminate since they require system configuration changes. Finally, redesigns of commercial devices to incorporate BIT must be funded; and once incorporated, the benefits of adopting a commercial based device are reduced (i.e., economies of scale, quality, yield). Additional problems with BIT in other domains are discussed in the next section.

9.5.3 BIT Technology Limitations

The performance requirements for BIT are often set at very high levels in terms of technical parameters like fault coverage. Perhaps, even a more user-oriented criterion like mean-time-to-repair may be applied to measure the performance of BIT based designs. Yet BIT suffers from the designers' inability to truly assess the effectiveness of BIT designs until after fielding a system. Other BIT technology limitations include the following:

a. The criteria for successful BIT design is difficult to relate to measurable user-oriented performance criteria in each test role before design completion.

b. The user oriented performance criteria are not related to the physical fault mechanisms. Physical fault consideration allows the designer to take into account the probability of failure in assessing overall BIT effectiveness. BIT models that consider fault mechanism probabilities and user-oriented performance criteria are not well explored except for very critical subsystems analyses that might be performed as part of a Failure Mode, Effects, and Criticality Analysis (FMECA).

c. BIT is most effective in digital electronic subsystems where every circuit path can serve as a sensor and stimulus for built-in test. But digital BIT typically cannot measure large classes of faults that are common to electronic circuits such as non-detectable, timing, and some open circuit faults. Further, even considering what are called stuck-at-logic-level faults, BIT performance analysis ignores circuit nodes which are untestable by design and reports metrics against those faults that BIT could have detect. This leaves a large gap between a narrowly defined technical metric and a user-oriented performance metric.

d. BIT design for fault isolation requires the addition of electrical and physical isolation elements added to the subsystem. These additions may decrease system reliability. BIT designers focus on on-equipment test requirements, recognizing that off-equipment BIT requirements cannot be met without affecting weight, reliability, or engineering cost.

For example, in 1988 during the preliminary design of the F-22 Environmental Control System, it was found that the addition of sensors beyond those required for mission performance actually decreased system reliability. Even though the BIT and sensor redundancy might have afforded increased availability, they were deleted from the design to achieve reliability goals. A careful analysis concluded that BIT based on mission sensor and microcomputer resources would be more reliable, yet less effective. [KOTO 1989]

The ability, permitted by current BIT technology, to detect faults rapidly degrades as the required testing spectrum broadens to mixed signal or analog. For example, requirements for high RF, microwave, and many analog domains exceed current BIT technical capabilities. Yet future weapons will have a majority of subsystems that fall in the domains where BIT is either limited or impossible at this time. The following are projected percentages for the F-22 and A-12 aircraft avionics systems:

(1) F-22: 24% digital, 43% analog/mixed, 33% RF/EO

(2) A-12: 42% digital, 33% analog, 15% RF/EO

9.5.4 Integrated Diagnostic Applications

Decisions regarding fault detection, fault isolation, and repair verification should not be limited to BIT and ATS, but rather should embrace a systems design and trade-off decision process that addresses the advantages and disadvantages of BIT and ATS, along with projected reliability, mission criticality, and safety considerations of each device, unit or subsystem. For example, microelectronic subsystem reliability growth has been a major factor in enhancing BIT attractiveness for operational applications. Due to the complexity and expansive interconnection between subsystems, BIT may provide a good indicator for a technician to begin trouble-shooting a problem. But as indicated earlier, BIT is poor at fault isolation, even in the domains where the technology is mature.

The ATS family concept is fully compatible with BIT and where appropriate should continue to exercise internal BIT of the UUT under off-equipment testing. In fact if designed appropriately, BIT may reduce repair times by helping assist the diagnostic process. For example, BIT may be used to steer the TPS during execution on an ATE. The diagnostic process is essentially a divide-and-conquer approach that isolates and narrows down, through the design hierarchy, to a specific replaceable item. Any tool that supports the process and can do this job economically (in terms of acquisition as well as support costs) should be considered. For example, as systems become more complex, and as the percentage of input/output (I/O) access points available for external testing relative to the number of items on a UUT are reduced, new dedicated diagnostic I/O features will be needed. BIT, in combination with diagnostic buses and on device matrix switches, may further enhance system diagnostic performance.

Designers should not think in terms of BIT versus off-equipment ATS, but rather how to best design systems with integrated diagnostics capabilities that use the best attributes of both to sustain high system availability with the lowest maintenance resource burden (costs, people, spares, space, training, manuals, etc.). There is no indication from the information obtained in this study that either BIT or off-equipment ATS will have a tendency to replace the other; instead, a trend towards a growing interdependence of one technology on the other to meet mission requirements is evident. Further, the need exists for both of these technologies at all maintenance levels, with possible remote processing and/or communication interface capabilities that may link off-equipment ATS elements with on-equipment subsystem I/O.

9.6 DOD-UNIQUE ATS NEEDS

When examining the utilization of ATS throughout commercial industry, it is difficult to find another user of ATS with the same field mission requirements of DoD. The closest comparison for the fielded ATS came from the airline industry. But the airline industry, while having systems of similar electronic and system complexity, has products that are optimized for reliability and durability. Mission performance parameters tend to dominate DoD systems and must be considered often ahead of reliability and durability in order to fulfill mission objectives. The resulting military products are not able to operate like airliners which use transported spares only for forward maintenance and depot maintenance for repairables. While the trends in this area may improve, a significant change in DoD field maintenance requirements is not anticipated in this decade.

Field-level maintenance deals with weapon replaceable assemblies (WRA) for the first level of off-equipment maintenance activities. In the process of repairing weapon replaceable assemblies, forward maintenance activities generate shop repairable units (SRU). Forward ATS may or may not be capable of testing SRUs. This level of field testing capability varies by system application and is usually a function of several operational factors: mobility requirements, spares availability and cost, level of economical repair, training, facilities and space, and the weapon system/subsystem reliability.

DoD depots appeared to have the greatest flexibility in choosing specific ATS. The choices for depot ATS noted during this study were generally cost based relative to immediate needs. There were examples where factory equipment was transferred to depots. In some instances, these factory tester solutions were not the preferred choice, but were temporary solutions due to schedule or cost justifications. Other ATS selection examples ranged from COTS products to sets of I-level fielded ATS.