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**Transitioning Navy Aero Engine  
Test Capability**

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## Abstract

The reduction in military force levels requires a corresponding decrease in the shore based infrastructure. Many bases and laboratories were selected for closure or realignment as part of the BRAC process. The Navy's aeropropulsion test facility at Trenton, NJ, would transfer its large and medium propulsion engine test capability to the Air Force's propulsion facility at Arnold Engineering Development Center, Arnold Air Force Base, TN. Two small altitude test cells will be disconnected and physically moved; the test capability of two large engine environmental test cells will be transferred by utilizing standard Air Force A/F32T-9 test cells as building blocks. The two T-9 cells will be modified to duplicate the ram air test capability of current Navy cells. The transition process is described from both technical and management viewpoints. Test facility requirements, funding, organizational responsibilities, partnering, and design and construction are discussed. Test cell scale model tests with engine simulators formed the basis for equipment modifications. Activation/validation efforts with appropriate engines will document the required test capability. Current program status and final test cell capabilities are presented. Criteria for engine performance measurement, engine/cell operability, and acoustical requirements are discussed. Operational capability for the altitude chambers is late 1997, and the large environmental sea level cells in late 1998.

## Introduction

The Naval Air Warfare Center (NAWC), located in suburban Trenton, NJ, is one of the world's facilities for the research, development, test and evaluation of airbreathing propulsion systems. Within

the bounds of its 65 acres lie test facilities that possess the ability to simulate any atmospheric condition an aircraft powerplant may encounter in flight. To take advantage of NAWC's capabilities, the Center employs people who, in many cases, are world-recognized authorities in their fields of research. This team is dedicated to providing Navy aircraft with the world's best powerplants.

The physical plant at NAWC is one of the most unique test facilities in the world. Temperatures from  $-65^{\circ}$  to over  $200^{\circ}\text{F}$  can be generated; altitude pressures from sea level to 100,000 ft are possible. In addition, environmental conditions such as salt, sand, and exhaust gas ingestion can be duplicated, and a fully instrumented chemistry lab is available for the analysis of aviation fuels and lubricants. Also, the Center's efforts in the areas of propulsion research and related fields have advanced the current state of the art, resulting in lighter, more efficient, and more reliable propulsion systems.

Located midway between Nashville and Chattanooga in middle Tennessee is the U.S. Air Force's best well-kept secret – Arnold Engineering Development Center (AEDC), Arnold Air Force Base, TN. AEDC covers an area of approximately 3,000 acres.

AEDC is divided into three functional areas: the Engine Test Facility (ETF), the Propulsion Wind Tunnel (PWT) Facility, and the Von Karman Gas Dynamics Facility (VKF). The Center was constructed in the early 1950s and the initial testing activities got underway in 1953. Within the following two years, the Trenton facility became operational. AEDC has, since its beginning, conducted a wide range of tests and simulations in aerodynamics, propulsion, and aerospace systems.

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This paper addresses the transition of some of the Navy's propulsion test capability to the Air Force's test facility at AEDC.

## **Background**

### **Objectives**

As a result of the 1993 Base Realignment and Closure Act (BRAC), the U. S. Navy's test facility, Naval Air Warfare Center Aircraft Division (NAWCADTRN), Trenton, NJ, will be closed. The Navy's mission contains wide ranging requirements that demands testing at a highly sophisticated test facility complex. The Trenton test complex contained the means to satisfy these requirements. However, as mandated by Congress, Trenton will close by the end of 1998. A program objective is to transfer the existing, required turbine engine environmental and altitude test capability to AEDC. After the transition has been completed, the Navy mission must not have been reduced nor hindered as a result of the BRAC actions.

The primary objective of all agencies associated with this project is to provide quality facilities which meet the NAWCADTRN/AEDC mission requirements on time and within available funds. To achieve this end, all agencies have agreed to minimize design and construction changes and related cost growth.

### **Base Realignment and Closure Act (BRAC)**

Trenton and BRAC are not new. In 1991, Trenton was first affected by BRAC. The BRAC'91 action transferred Trenton propulsion engineers to NAWCAD, Patuxent River, MD, and the large gas turbine engine testing from Trenton to AEDC. Since October 1993, AEDC has successfully conducted this large gas turbine engine testing for the Navy in existing AEDC test cells. Ultimately, the requirement to close NAWCAD Trenton and transfer small engine and large engine environmental test capability was mandated by the BRAC '93 decision.

### **Test Capabilities at Trenton**

#### **Large Sea Level/Environmental Cells**

The 1W and 2W sea-level test cells at Trenton are used to conduct environmental engine testing

to measure and collect data for engine design risk assessments for medium-size turbine engines (on the order of those used in fighter aircraft). Test capability is needed to generate data that support aircraft engine development, service life assessment, and fleet service problem investigation programs. The 1W and 2W test cells were constructed as sea-level exhaust test stands with ram air inlets. Tests conducted include accelerated, simulated mission endurance tests (ASMET), icing tests, corrosion tests, sand and water ingestion tests, and high- and low-temperature start tests. Control and data acquisition/processing rooms for directing and controlling the tests and for collecting, processing, and analyzing the data are an integral part of the test cell configurations.

1W and 2W test equipment presently scheduled to be transferred to AEDC includes:

- Thrust stand and engine supports
- Salt air corrosion housing
- Icing spray booth
- Inlet ducting/bellmouths
- Load extraction systems
- Two 50 lb/sec low-pressure air blowers
- Inlet air "mixer" system
- F402 engine exhaust collector ducts
- Instrumentation equipment

### **Small Engine Altitude Cells**

Test Cells 4W and 5W are utilized in the testing of small turboprop and turboshaft engines used in helicopters, and engines used in cruise missiles and unmanned air vehicles. The test cells generate data for risk assessment of engine development and design changes by performing sea-level and altitude testing, steady-state and transient testing, and, in 4W, salt air corrosion testing. Control rooms are also integral parts of the 4W and 5W test facilities, for direction and control of the tests, and for collection and analysis of the test data.

Both the 4W and 5W facilities are capable of complete flight envelope evaluation of small turbofan, turbojet, and turboshaft engine designs under starting, steady-state, and transient conditions.

Mission environment is duplicated within the test cell for evaluating:

- Salt air corrosion susceptibility
- Ice ingestion
- Water ingestion
- High- and low-temperature starting
- Engine performance

4W and 5W test hardware presently scheduled for transfer to AEDC includes:

- Test cell chambers
- Thrust stand and engine supports
- Corrosion spray system
- High-/low-temperature soaking system
- Inlet ducting/bellmouths
- Water brakes for power absorption

Other test equipment/material, such as valves and piping system components, instrumentation items and components, and display and control systems, may be used.

### **Transition to AEDC**

#### **Requirements**

Test Cells 1W/2W: The Navy requires that its turbine engine developments undergo evaluation at various operating environments simulated by salt air corrosion testing as well as icing testing, and maintains this capability at NAWCAD. The approach is to relocate two BRAC-excessed test cells (A/F 32T-9 Noise Suppressor System equipment); install the test cells, ducting, thrust stands, salt spray generators, mixing equipment, process air blowers with electric motors and control centers, ducting valves, and fuel conditioning systems; and then to verify construction and installation.

The in-cell ducting, salt spray mixers and generators, two of the three required air compressors with electric motors and control centers, ducting valves, fuel conditioning systems, and test stands are existing items at NAWCADTRN, and will be transferred to AEDC. The third air compressor with electric motor will be a new acquisition. Salt air cor-

rosion testing will be a new test capability for AEDC. This project also includes the ducting for the required ram air capability.

Test Cells 4W/5W: This project transfers existing altitude test capability for two small turbine engine ground test cells at NAWCADTRN to AEDC. It integrates the Navy's existing 4W and 5W test cells into existing infrastructure at AEDC's Engine Test Facility (ETF) Building No. 878. Project RELIANCE and BRAC '91 designated NAWCADTRN as the DOD lead facility for small engine testing, while all medium and large engine testing was to be done at AEDC. BRAC '93 required NAWCADTRN to transfer its small engine altitude test capability to AEDC. The method of transfer is to dismantle, package, and ship Test Cells 4W and 5W, as well as necessary support equipment such as engine test stands and associated ducting and valves to AEDC.

Building No. 878 at AEDC will be modified and altered by removing existing USAF test cells to accommodate NAWCADTRN Test Cells 4W and 5W, and will provide plant and utility resources for cell and test requirements. Both of the facilities at either NAWCADTRN or AEDC have the existing plant and infrastructure to support turbine engine testing. The Navy has both plant and test cell capability for small engine testing. Small engines have been tested at AEDC in the past on an irregular basis; however, additional cell capacity at AEDC is needed to support increased test requirements and schedule demands due to the projected Navy workload. The project will include an initial shakedown effort to verify integration of each test cell with the AEDC facility, including alterations and modifications made during installation.

#### **Management Philosophy**

The overall management responsibilities for the Air Force, the Navy, and the Army Corps of Engineers (COE) organizations participating in the NAWCADTRN/AEDC design, construction, activation, and validation program are included in this section. The organizational relationships are shown in Fig. 1.

The magnitude and diversity of agency involvement in the Trenton Transition program require

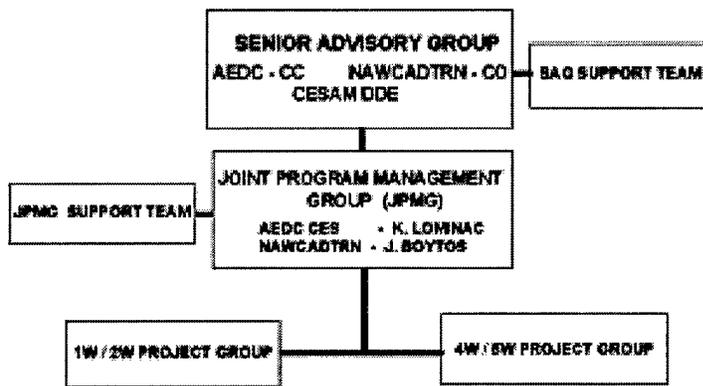


Fig. 1. Organizational relationships.

coordination of all aspects of design, construction, activation, and validation. Also, it is important to keep all participants informed of the status, existing or potential problems, and change requirements, in order to manage the program and to meet Navy/Air Force needs. The information exchange for facility acquisition management is formalized through a system of established working groups. These groups operate at three distinct levels within the system, with the mutual objective of meeting the functional needs of the user while completing construction on time and within available funds.

An architect/engineering (A/E) firm was retained by the COE Mobile District to design the 1W/2W project. The AEDC test contractor designed and contracted for the instrumentation and control systems for both projects.

### Organizational Relationships

The Senior Advisory Group (SAG) will review progress being made in executing the design and construction program, identify potential problem areas, determine actions to be taken to resolve these problems, and assign responsibility for implementing SAG decisions. The SAG will review the results of day-to-day management and coordination efforts of the Joint Program Management Group (JPMG).

The JPMG is a joint management review organization with primary responsibilities for integration of the activities of all organizations and agencies involved with the design, construction, activation,

and validation of the Navy transition to AEDC. These responsibilities include ensuring that project designers are provided adequate design guidance for the respective design of each test cell project, coordination of design and construction with operations schedules, change order control, and review of changes for configuration control or interface impacts. The JPMG reviews and resolves mutual design/construction management problems.

The 1W/2W Project Group (PG) and the 4W/5W Project Group are primarily responsible for integration of the activities of all organizations and agencies involved with the design, construction, activation and validation of test cells 1W and 2W, and 4W and 5W, respectively.

The JPMG Support Team is responsible for providing assistance, consultation, and direction to both Project Groups, and to the JPMG.

### Partnering

Partnering is a term that is becoming more and more prevalent in the government, especially in construction. The word "partner" means "one who shares." But partnering is more than sharing with someone. Partnering as we now use it was developed and implemented by Corps of Engineers as a better way of doing business. Specifically, it has been utilized in construction to overcome the adversarial relationships with construction contractors.

But partnering should not be limited only to government construction contractors. There are many Government agencies that should conduct partnering sessions. The idea is for the individuals who are involved to work together on a project to share a common understanding of the goals and each other's objectives, as well as the group's common goals. Partnering is a dynamic, living philosophy that is necessary for a successful project/program. Both projects have established partnering agreements, and Fig. 2 is an example of the 4W/5W agreement.



Fig. 2. Example partnering agreement.

**Funding**

The transition program funding is a Navy responsibility. Overall, the total cost projected for the transition is approximately \$90 million, which can be broken down into the following projects: the Corps of Engineers, through the 1W/2W project, has the largest percentage of the transition cost, approximately 69 percent, followed by the 4W/5W project managed by AEDC at an approximate percentage of 27 percent. The Government Furnished Equipment (GFE) is approximately 4 percent of the total cost, and primarily the cost of the A/F 32T-9 NSS test cells. Figure 3 is the graphical representation of the program funding.

**Limitations by BRAC**

Since the BRAC laws allow only the replication/duplication of an existing requirement at the gaining installation, the requirements were a very vital part of the transition. The transition requirements as previously stated were mandated by Congress through the BRAC. In order to successfully transition the test capabilities to AEDC, these requirements had to be fully defined.

It is significant to address the issue of duplication or replication. This requires a very close understanding of the test methods and strategies

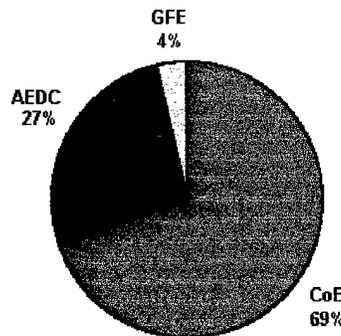


Fig. 3. Total program funding.

that the both the Navy and Air Force use and implement. To only be allowed to match existing capabilities and not plan for the future became very frustrating. In some instances, the situation led to a very clean solution; however, other instances led to a close examination of the requirements, producing only complicated solutions, or, situations that had no apparent solution. One major problem that had to be overcome was one of doing the “smart thing” as opposed to doing only what the BRAC allowed. This required a management philosophy that fully explained the BRAC’s rationale, limits, and penalties. There were opportunities to utilize better technology in the BRAC transition, but if, and only if, there were significant savings in using the “smarter technology” or doing the “smart thing” during the design.

**Responsibilities**

Each agency’s responsibilities were agreed upon at the initial set-up meetings. Since the Navy was identified by the BRAC to close their base, they are the agency responsible for all transition funding. AEDC, on the other hand, has the major requirement to develop the system concept definitions based on the NAWCAD system requirements definitions. Both Naval Facilities Engineering Command (NAVFAC) and the CoE deal primarily with construction; however, since the transition is to an Air Force base, NAVFAC agreed that the CoE would be the design and construction agent (DACA) for the 1W/2W project, and AEDC the DACA for the 4W/5W project. Shown below in Fig. 4 are the respective agency responsibilities.

As the requiring organization, NAWCADTRN exercises oversight management for Navy activi-

ties during the design, construction, activation, and validation efforts.

AEDC is responsible for the overall program management for the Air Force. AEDC provides a team of program management and technical personnel during all phases of the program. These individuals perform design reviews, review of construction contractor changes or clarification requests, monitor general progress, and participate in the activation and validation for both projects. AEDC will coordinate activation and validation activities through final certification of mission operational capability. This also includes technical review of the design and construction activities.

**New Facilities - Design Concept Test Cells 1W/2W**

Figure 5 shows the design concept of the 1W/2W test cell facility as prepared by the architect - engineer (A/E) firm. The layout includes the two A/F32T-9 NSS test cells side by side, separated by the control room building. In the foreground are the ram air inlet ducts, the refrigeration turbine system, and the hydraulic control building. At the end of the test cells are the exhauster stacks.

Figure 6 is a cutaway view of an A/F32T-9 NSS that is used as the building block of the new facility. Figure 6 also identifies the primary air intake, engine test section, exhaust gas augmentor, and exhaust stack.

**Environmental Facility Model Tests** — The baseline Air Force T-9 Test Cells were designed as demountable/movable facilities, and could be transferred to AEDC. Therefore, most of the aerodynamic and acoustical design effort concentrated on the modifications required to make the T-9 facilities suitable for Navy testing purposes. Since the T-9 was designed as an atmospheric test cell, major modifications were needed to accommodate ram air and environmental test capabilities.

Two-scale model tests were conducted to identify and evaluate the modifications required to accommodate ram air testing in the T-9, and to determine the airflow treatment required to bring the T-9 front cell velocity distortion down to the

Fig. 4. Program responsibilities.

	AEDC	Trenton	NAVFAC	COE
Program Funding		X		
System Requirements Definition		X		
System Concept Definition	X			
RAMP Preparation	X			
DD1391 Submission		X	X	
EQUIPMENT Funding		X		
MILCON Funding			X	
Design	4W/5W			1W/2W
Construction	4W/5W			1W/2W
Equipment Installation	X			
Instrumentation & Controls	X			
Activation/Validation	X			

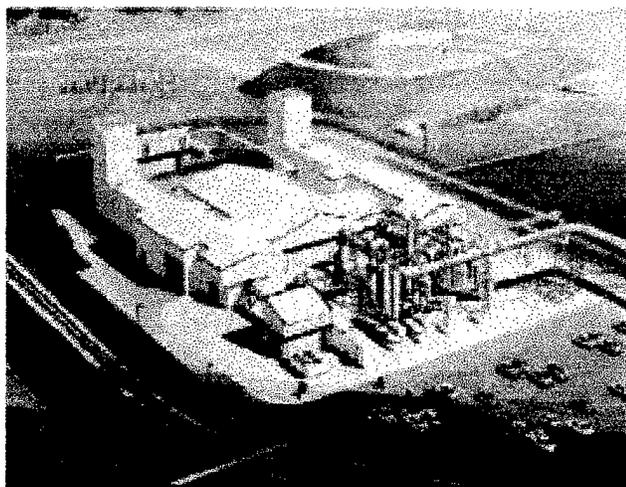


Fig. 5. A/E design.

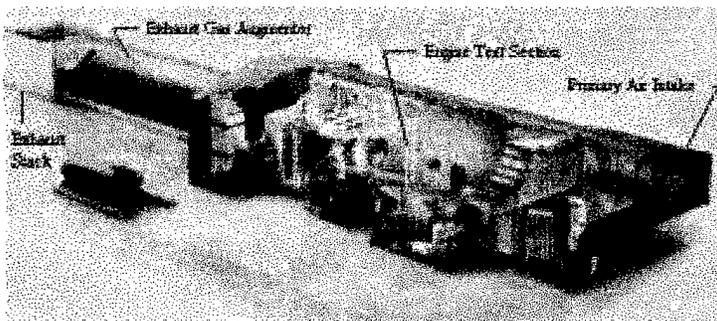


Fig. 6. Cut away view of A/F32T-9NSS.

level of the Trenton test cells. A 1/12th-scale model study of the T-9 test cell with F110 engine simulators was conducted at Ohio State University Aero/Acoustic Laboratory in Columbus, OH. Test techniques were consistent with the guidelines of Ref. 1. An illustration of the model setup is shown in Fig. 7. The purpose of the Phase I test was to develop and evaluate ways of adding ram air hardware to the baseline T-9 while concurrently improving airflow quality to a comparable level with Trenton. Various alternative configurations were selected and constructed.

The objectives of Phase II were to evaluate changes proposed to the atmospheric testing configuration based on the Phase I tests; measure internal ram air duct airflow quality for engine operating conditions up to the full-scale corrected flow of 550 lb/sec; and determine ram air duct/plenum geometry from the flow mixing header downstream to the engine.

Analysis of the results of the model tests led to the following recommended improvements:

- **Ram Air Modifications** - To meet the ram air testing requirements, the T-9 will be modified to accommodate an 8-ft ram air delivery plenum through the front cell wall. The 8-ft plenum will reduce down to a 5-ft direct-connect pipe just upstream of the primary intake acoustic baffles, and penetrate the acoustic baffles at the engine centerline. The 5-ft ram air pipe will terminate with a blank-off plate 10-ft downstream of the primary intake baffles. The cell can perform atmospheric testing

with the blank-off plate installed, or ram air testing with the blank-off plate removed and the direct-connect hardware installed. Additionally, the exhaust collector intake lip will be modified to accept direct-connect exhaust for environmental/corrosion testing.

- **Air Flow Modifications** - The baseline T-9 has substantially greater front cell velocity distortion [ $FC_d = (V_{max} - V_{min})/V_{avg}$ ] than measured in 1W/2W at NAWCADTRN (115 percent versus 50 percent). In order to reduce the front cell velocity distortion in the T-9 to 1W/2W levels, and to minimize the distortion caused by the ram air plenum and duct, two flow-smoothing screens will be installed in the modified T-9, one each upstream and downstream of the primary intake acoustic baffles. These flow-smoothing screens will reduce the front cell velocity distortion from 115 percent in the baseline T-9 to 45 percent in the modified T-9. The modified T-9 will duplicate the atmospheric testing front cell velocity quality of the 1W/2W facility.

**Cell Operation and Maintenance Issues** —

The baseline T-9 test cells have two exhaust system problems that needed correction in order to duplicate the NAWCADTRN test capability. The T-9 test cell has high levels of low-frequency vibration (> 110 dB). Past experience has shown that low-frequency levels over 100 dB can cause physical damage to adjacent structures and equipment; in this case, the control room/ancillary buildings and equipment as shown in Fig. 5. Existing maintenance problems with the exhaust system of the

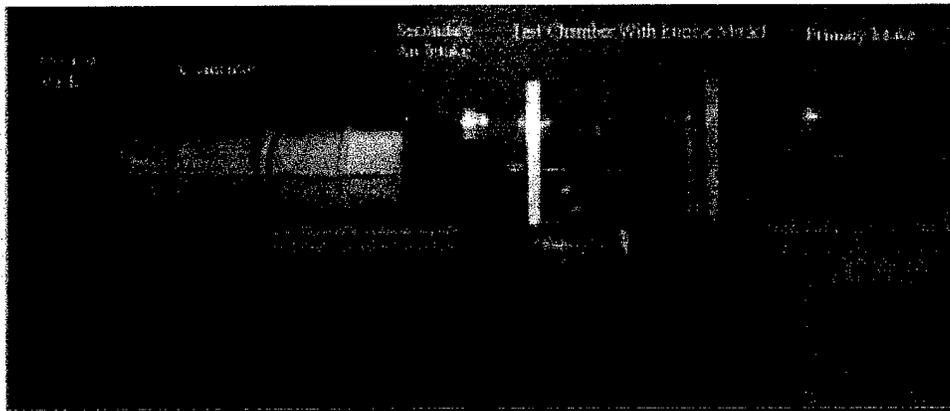


Fig. 7. Scale model test.

baseline T-9 will be accentuated by environmental testing in the modified T-9. The perforated liner and liner acoustic fill deteriorate during afterburner operation, and are expected to suffer additional deterioration due to high heat loads during ram air afterburning testing and corrosion/cold soak testing. The following solutions were developed to address these problems:

- Replace the existing perforated acoustic augmentor tube with a non-perforated, hard augmentor tube of identical interior geometry.
- Enclose the new augmentor tube with a concrete enclosure.
- Replace the acoustic baffle exhaust silencer with a tubular silencer package.
- Replace the existing concrete stack with a larger and higher concrete stack that encloses the new tubular exhaust silencer package.

These modifications will also reduce the overall exterior acoustic levels of the modified T-9 test cell.

The test techniques, methods of measurement, analysis parameters, and suggested modifications are consistent with the guidelines of SAE Aerospace Information Report 4869 - "Design Considerations for Enclosed Turbofan/Turbojet Engine Test Cells."<sup>2</sup> The important factors of engine operational stability, aerodynamic performance, and acoustical control have been properly addressed.

#### Existing Facilities - Test Cells 4W / 5W

As mentioned earlier, some of the equipment to be relocated from NAWCADTRN to AEDC included the Test Cells 4W and 5W. The plan was for the NAWCADTRN to remove the test cells and ship them to AEDC one at a time, based on the Trenton test schedule. In February 1995, Test Cell 5W was removed and shipped to AEDC. It underwent clean up and modifications prior to its installation at AEDC. Figure 8 shows the test cell upon its arrival at AEDC; Fig. 9 shows the test cell cleaned, modified, and installed. Figure 10 shows Test Cell 4W in place at NAWCADTRN prior to its removal.

#### Activation/Initial Operating Capability

The Trenton Transition acquisition process includes Requirements Development, Demolition, Design, Installation, Activation, Validation, and Initial Operation Phases. The definition, design, demolition, and construction of the acquisition is being accomplished under BRAC '93 funding. This process will bring the new facilities to Initial Operational Capability (IOC) following the Validation Phase.

The objective of the Activation and Validation Management Plan (AVMP) is to define the management approach to be used to bring the Naval capability to IOC following construction. Lessons learned from activation and validation of past complex AEDC projects show the need for a comprehensive management plan to guide these activities for the transitioned facilities. The overall facility



Fig. 8. Test Cell 5W arrival from Trenton.

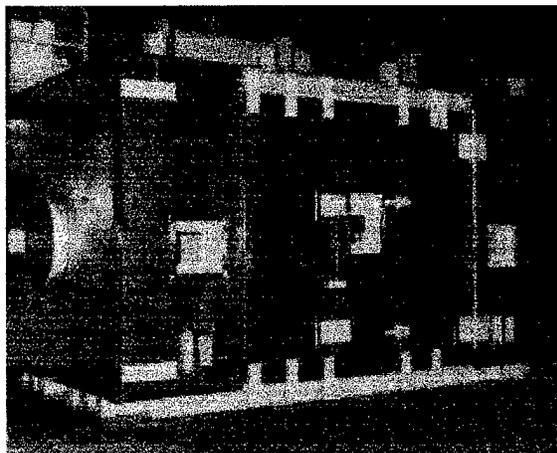


Fig. 9. Test Cell 5W Installed At AEDC.



Fig. 10. Test Cell 4W At NAWCADTRN.

requirements and acquisition management approach for design and construction of the facility are addressed in the project Requirements Analysis and Management Plan (RAMP). This AVMP plan supplements the RAMP document to extend the process through Activation and Validation.

The scope of work covered by the management plan begins with the preparation of systems activation plans and will be accomplished in two phases defined as Activation and Validation. In the case of 4W/5W for example, activation will (1) demonstrate the independent operation of the facility subsystems and systems, and (2) demonstrate the integrated operation of facility systems with an engine simulator (cold pipe) at altitude conditions selected to demonstrate the required facility operational envelope. Validation will confirm the operation of the facility with the successful testing of an operational turbine engine at simulated altitude. The scope of work will end with the completion of the Validation phase, which is defined as IOC.

Engines to be used for validation testing as well as the target IOC date are:

Engine	Test Cell	IOC Date
F112	T11 (5W)	May 1997
T406	T12 (4W)	December 1997
F404	SL2/SL3 (1W/2W)	September 1998

## Status

As this paper is prepared, the 1W/2W replacement (to be designated SL2/SL3) is designed and construction has begun. The 4W/5W project (T12/T11) is also under construction. Both control rooms are complete, and Test Cell 5W has been installed at AEDC. The various ducting, instrumentation cables, data acquisition units, and electrical conduits have also been installed.

## Final Systems Capabilities

Once the transition and transfer is successfully completed, the test cells will have the following system capabilities:

- SL2/SL3
  - Sea level cells; 50 ft long
  - 550 PPS airflow
  - $-65^{\circ}$  to  $+260^{\circ}$ F (inlet air)
  - 30 psia max. inlet (Mach 1.1)
  - Corrosion, icing, water and transient capable
- T11/T12
  - Small engine altitude cells (cruise missile and shaft engines)
  - 75 lb/sec airflow
  - $-65^{\circ}$  to  $+220^{\circ}$  F (inlet air)
  - 45K ft altitude

## Summary

Both the Navy and the Air Force have world-class airbreathing propulsion test facilities. With the closure of the Navy's Trenton facilities, some of the physical facilities will be transferred to the Air Force at AEDC, and some to the Naval Air Station at Patuxent River, MD. Although Trenton will close in 1998, the Navy's aircraft propulsion test capability will remain intact, but operation will be at sepa-

rate physical locations. The AEDC facilities will be utilized by the Air Force, Navy, and Army, and are also available to engine manufacturers and other commercial customers.

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2. "Design Considerations for Enclosed Turbofan/Turbojet Engine Test Cells," SAE Aerospace Information Report AIR4869, Society of Automotive Engineers, Warrendale, PA, issued October 1995.

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