

AERONAUTICAL TEST FACILITIES  
CAPABILITIES AND USE

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### I. ABSTRACT

This paper reviews the technical capabilities of the National Aeronautical Facility Program (NAFP) and other new aeronautical test facilities. It explores the subject of better data collection and diagnostics, increased national and international cooperative efforts that can result in better use of and better results from Aeronautical Test Facilities.

### II. INTRODUCTION

The advent of gas turbine propulsion in World War II involved a quantum jump in speed, altitude, power of propulsion systems and for propulsion test facilities. This led to Congress approving the unitary Wind Tunnel Plan. In other countries other major facilities developed and NATO AGARD played a role as catalyst in cooperative efforts. (1) Over the years two trends developed. Aeronautical Test facilities were considered as institutional capabilities for the benefit of one agency, firm or nation. Economic realities are limiting this institutional concept. The other trend was we were unable to further modify existing test facilities for necessary R&D testing. Typical factors for high by pass ratio turbofans were increased air flow requirements, speed, altitude ranges, fuel consumption, noise and transients.

The deficiencies between aeronautical system test requirements and test facility capabilities is undesirable because of the impact it has on the life cycle costs. Also, advances in propulsion R&D facilities frequently lead advances in aerospace performance capabilities because propulsion technology is a prime mover for aerospace developments. The lack of advanced test facilities did have an economic impact on aerospace systems. In the United States we recognized and identified the requirements for additional test facilities as part of the National Aeronautical Facilities Program (NAFP) and a similar program is being considered in NATO (AGARD) for a European Wind Tunnel. While doing the NAFP Study it was apparent that adequate development test facilities are expensive to construct, update, operate; (2) that the facilities should be better utilized; that we needed cooperation between different agencies and programs to justify and utilize these facilities. A cooperative attitude within government and with

industry has developed and this is but a start that can lead to better national and international use of test facilities.

### III. NAFP STATUS

The NAFP consists of the following three facilities: The Aeropropulsion System Test Facility (ASTF) was approved by the Congress in the FY 1977 Military Construction Program (MCP) at \$437 million. Construction started at the Arnold Engineering Development Center (AEDC), Tenn. in August 1977 and is scheduled for completion in mid 1982. All indications are that the ASTF will be completed within the budget and on schedule. The National Transonic Facility (NTF) at NASA Langley, Virginia, is estimated to cost \$85 million. Congress approved construction increments totalling \$48 million. Construction started in mid 1977 and is scheduled for completion in mid 1982. The modifications of the AMES 40' x 80' tunnel at NASA, AMES, California is programmed at \$85 million. Congress approved increments totalling \$19 million. Contracts were awarded in 1977 and construction is scheduled for completion in mid 1981.

### IV. NAFP CAPABILITIES

The NAFP capabilities are as follows: Aeropropulsion System Test Facility. The ASTF is designed to develop complete jet aircraft engine systems on the ground at conditions simulating actual flight environments. The complete systems, including portions of the aircraft that affect engine performance - inlets, exhaust nozzles, control systems - will be tested over a wide range of speeds and altitudes and over the rapidly changing transient conditions encountered in maneuvers. A comparison of ASTF with existing test capabilities at AEDC are shown in Figures 1A, 1B, and 1C.

Materials and equipment required for construction - electric motors, compressors, refrigeration units, heater, ducting, pumps, controls, electronics, computers-- are currently being purchased from commercial sources. Although the facility is large, it is similar in concept to existing facilities; it involves standard fabrication techniques, and we believe there is little risk of construction difficulties. ASTF's increased capabilities are evident in the following.

PRESENT CAPACITY FOR TESTING TURBOFAN ENGINES

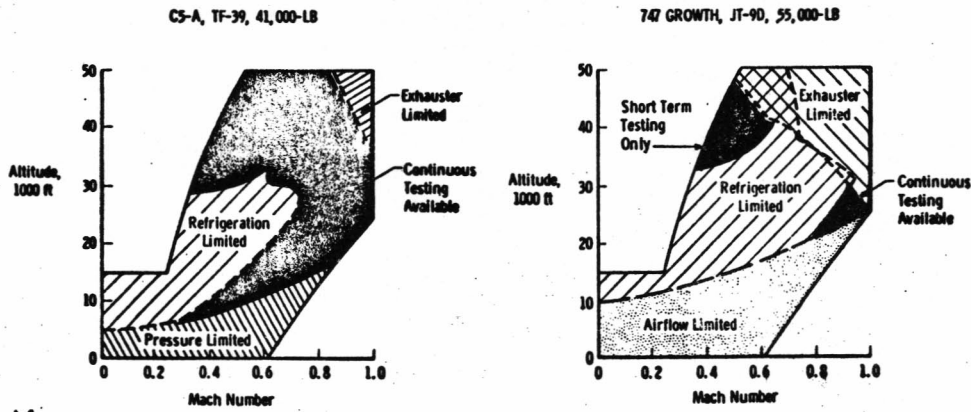


Fig. 1A

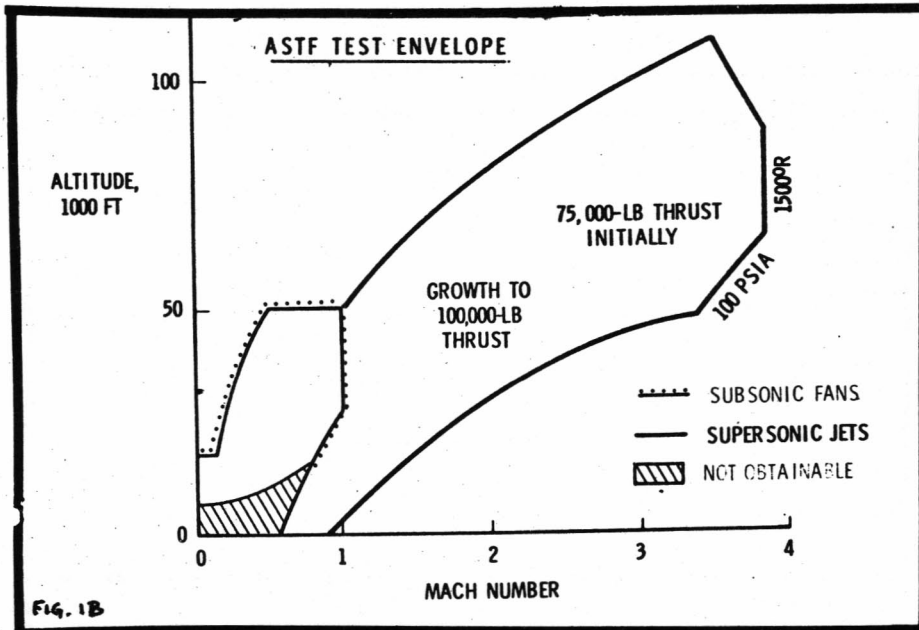


Fig. 1B

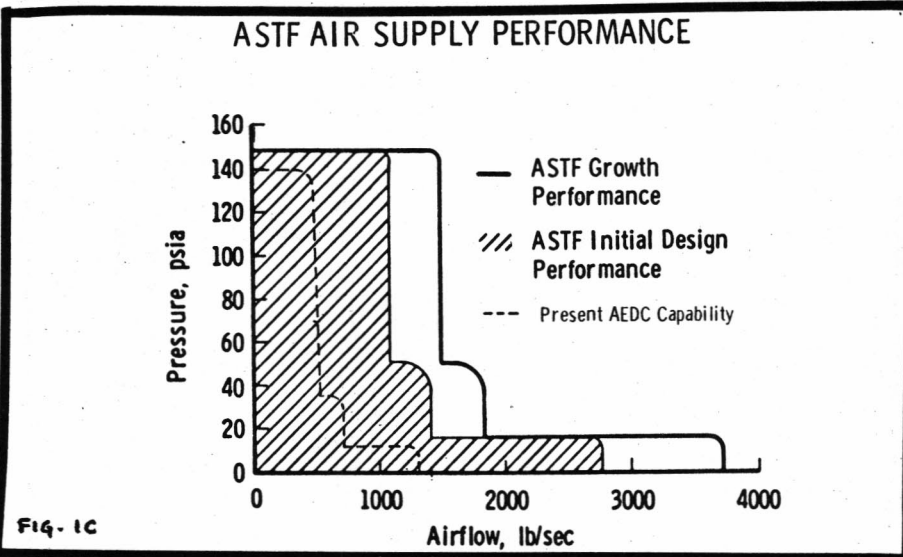
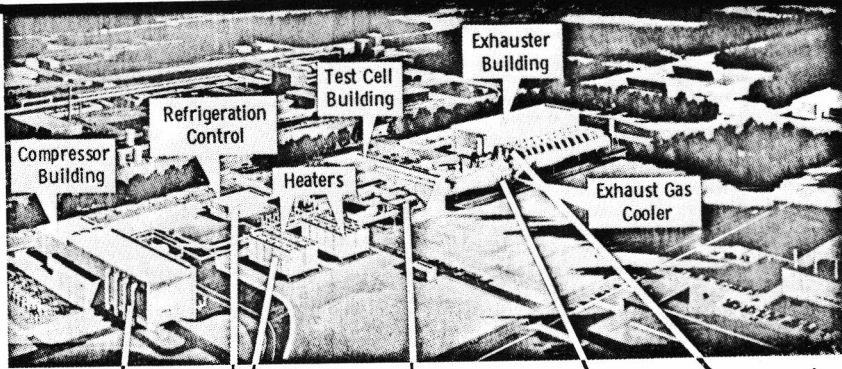


Fig. 1C



# A S T F DESIGN CONCEPT AND SCHEMATIC

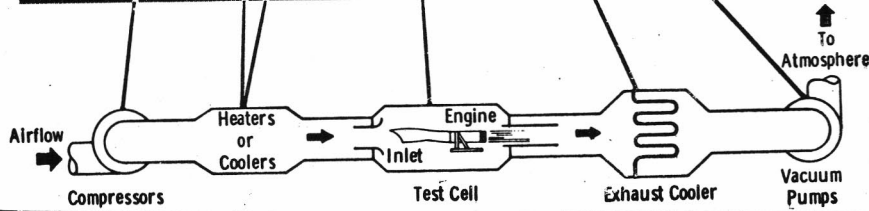


FIGURE 2

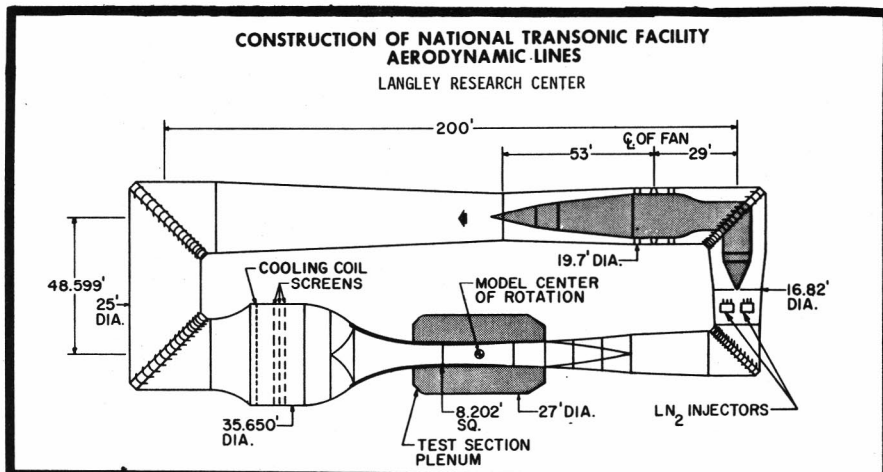


FIGURE 3A

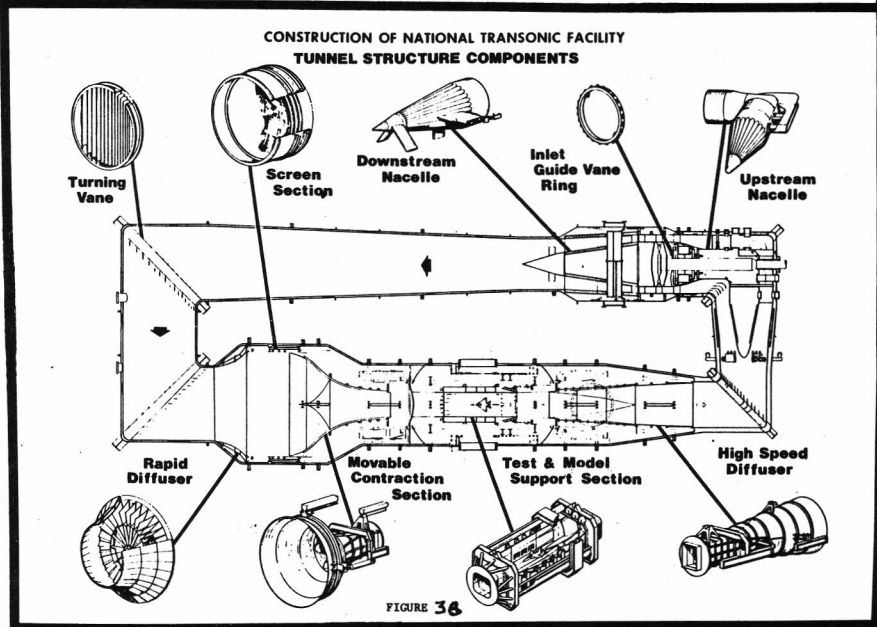


FIGURE 3B

ASTF Specifications - Air Flow (lbs per second), 1,450; Air Temperature Range (°F), -100 to + 1,020; Cooling System (tons/refrigeration cap), 23,000; Motor Drive Systems (installed h.p.), 611,000; Test Cell Dimensions (diam. X length), 28' x 85'; Instrumentation Channels 2,170; Cooling Water (gallons per minute), 387,000. (3)

National Transonic Facility - The National Transonic Facility (NTF) (Fig 3A and 3B) at the Langley Research Center is a transonic wind tunnel which will serve aerospace research and development testing needs and will provide a totally new and vital capability to test a broad spectrum of aeronautical vehicles at full-scale Reynolds numbers. It will employ a cryogenic test medium for achieving high Reynolds numbers without excessive model loads or power requirements. This will involve injection and subsequent evaporation of liquid nitrogen to develop the extremely low temperature test medium in an otherwise conventional fan-driven closed circuit wind tunnel. With temperature, pressure and speed independently controlled, the facility will permit clear separation of aeroelastic, Mach number and Reynolds number effects on the aerodynamic performance of test configurations. (4)

The operating parameters shown in Fig 3b. are: Mach No Range of 0.1 to 1.2; Pressure 1 to 9 bars; temperature 78 to 340 Kelvin; Sound pressure level 150 db; flight Reynolds number at Transonic Speeds ( $R = 120$  million based on wing mean chord length at  $Mn=1.0$ ); a workable size test section 8 ft x 8 ft (2.44m x 2.44m); and a testing time interval sufficient to obtain accurate data for the complete spectrum of aerodynamic research.

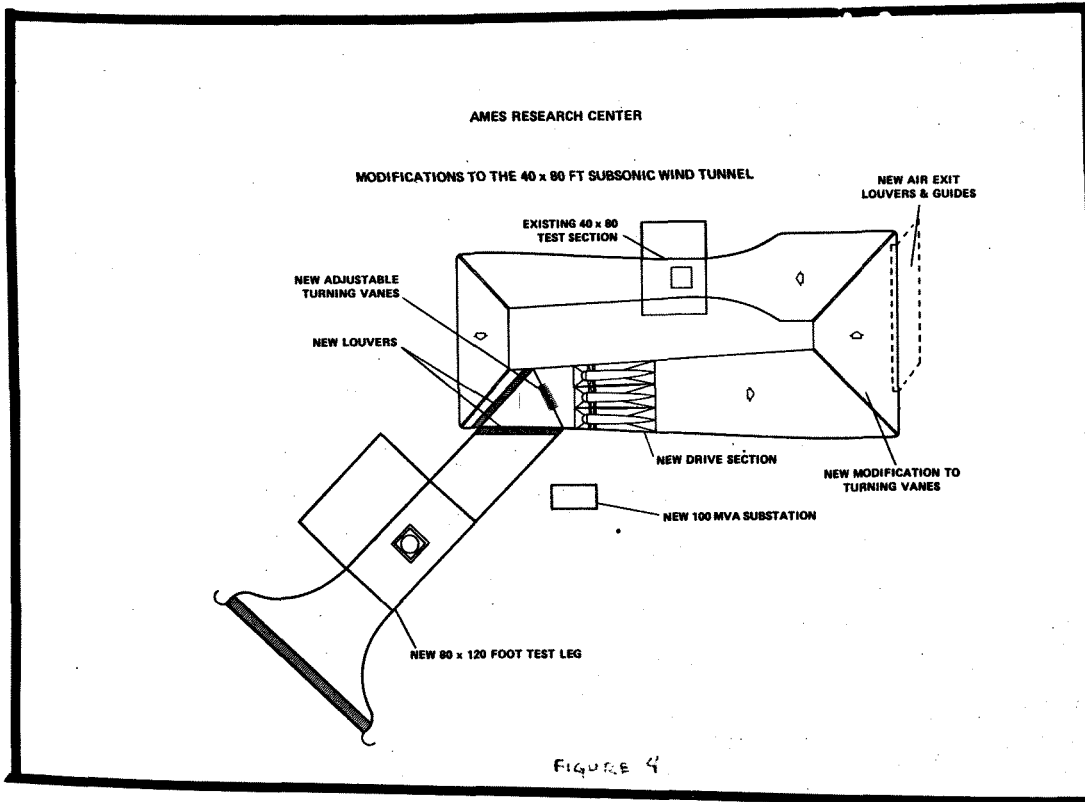
AMES TUNNEL - The present 40 x 80 feet (12.2m x 24.4m) subsonic wind tunnel at the AMES Research Center in California is limited to testing rotorcraft at a maximum test speed of 200 knots (103m/s) and to a test section size of 40 x 80 feet. An increase in wind velocity to 300 knots will be achieved by replacing the present drive motors and fans. The total drive system will be increased from 36,000 HP (27,000 KW) to 135,000 HP (101,000 KW) and the present 6-bladed, fixed-pitch fans will be replaced with 15-bladed, variable-pitch fans. The resultant decrease in the maximum tip speed of the fan blades from 600 fps (180 m/s) to 377 fps (115 m/s) reduces the noise levels significantly. This drive replacement, together with the structural modifications will provide for the increased test speeds. The combination of variable pitch fans and frequency control will provide precisely controlled and range of 5 to 300 knots (2.6 to 154 meters per second) within the 40 x 80 foot (12.2m x 24.4m) test section. This broad phase of work is termed the "repowering phase." Full-scale testing of verticle and short take-off and landing (V/STOL) aircraft

requires the addition of a new 80 x 120 foot (24.4m x 36.6m) test section which has been designed as an extension or "leg" off the 40 x 80 foot wind tunnel (Fig 4A and 4B). This new leg will be located just upstream of the drive motor section. This section will allow for testing of full-scale V/STOL aircraft in the speed range of 5 knots (2.6m/s) to 100 knots (51 m/s). Air will enter the tunnel through a 360 x 130 foot (110m x 40m) opening, pass through the test section, through the main drive section, and then exhaust to the atmosphere through louvers to be installed in the south walls of the 40 x 80 foot wind tunnel. Flow diversion vanes and louvers, together with adjustable turning vanes, will be installed to permit operation in either the 40 x 80 or the 80 x 120 foot mode. (5)

#### V. OTHER R&D FACILITIES

After the initial studies of large national requirements, the NAEP did not include other Air Force and NASA technical facility requirements. These requirements are in the Air Force Technical Facility Program which stresses test/facility deficiencies and the economic impact of proposed facilities. The following are other aeronautical facilities.

The Turbine Engine and Load Simulator (TELS). The advanced turbine engine technology which improved aircraft performance also precipitated engine life cycle problems. Larger and faster rotors, closer operating clearances, lighter and more flexible engine cases and components, higher operating temperatures and pressures, and more maneuverable aircraft all contribute to rapid deterioration in engine performance compared to its performance when new. Since turbine engine development relies heavily on a "trial and error" experimental process, a test facility which simulates this flight environment is necessary. (6) A \$13M TELS facility is proposed for AEDC. The TELS facility (Fig 5A) is basically a centrifuge which will support and subject an operating turbine engine to combinations of gyroscopic and inertial forces imposed by a maneuvering aircraft. It will provide the necessary diagnostic tools, including real time x-ray, to inspect engine case, rotor movement and distortion during such tests. TELS will subject an engine to forces up to 15 g's. By means of a 6 degree of freedom hinge-gimbaling mechanism and real time x-ray of the engine while in operation, actual simulation of forces seen by an aircraft engine can be accomplished and the affects observed. (7) This will assist the engine designer to evaluate the affects of flight maneuver loads and identify the conditions under which they occur. TELS should help discover, early in an engine's development cycle, problems which would affect life cycle costs by



**TEST REQUIREMENTS AND FACILITY TEST CAPABILITY**

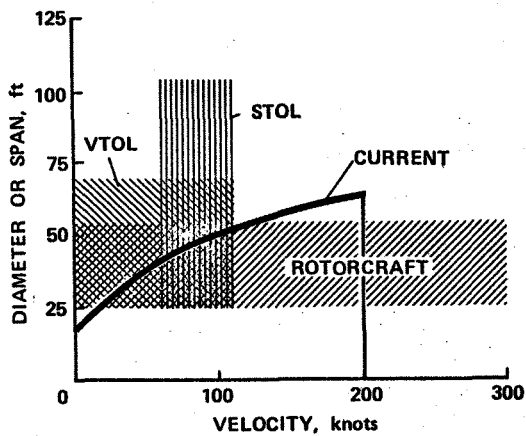


FIGURE 4A

**TEST REQUIREMENTS AND FACILITY TEST CAPABILITY**

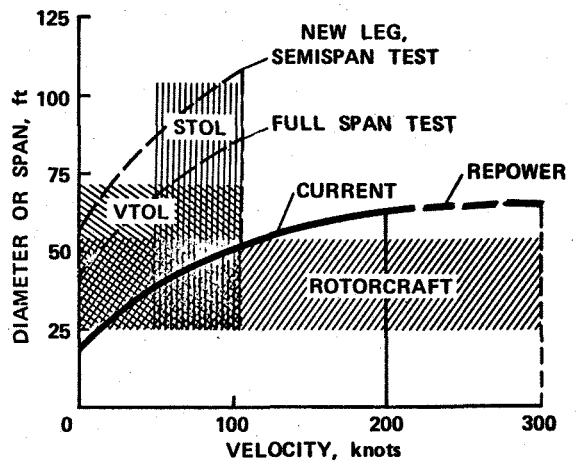
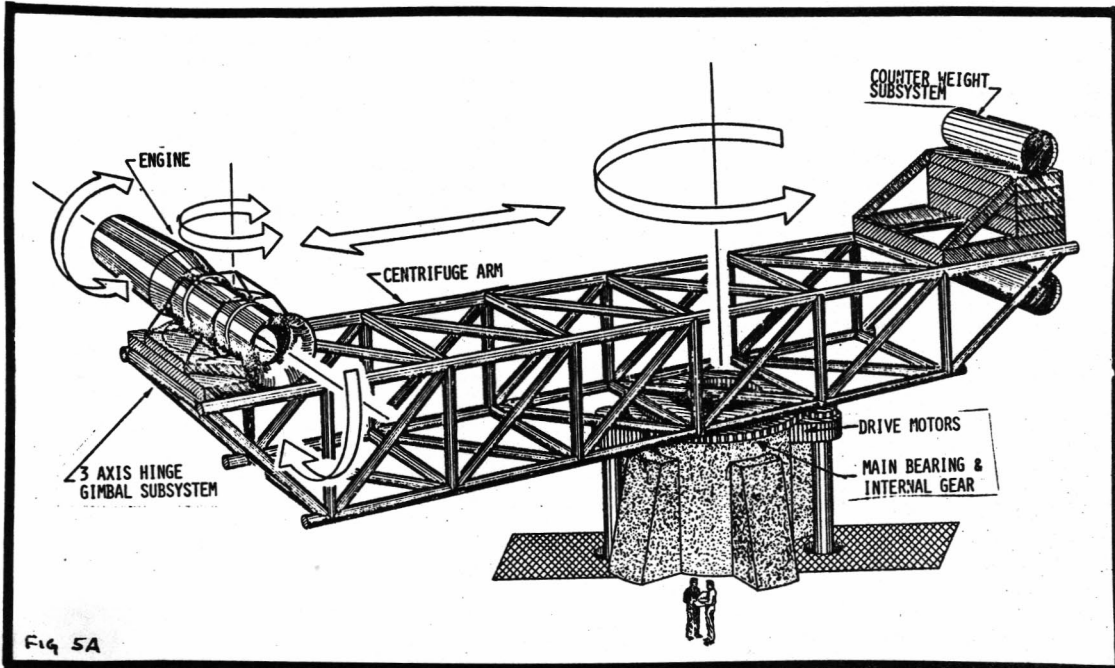
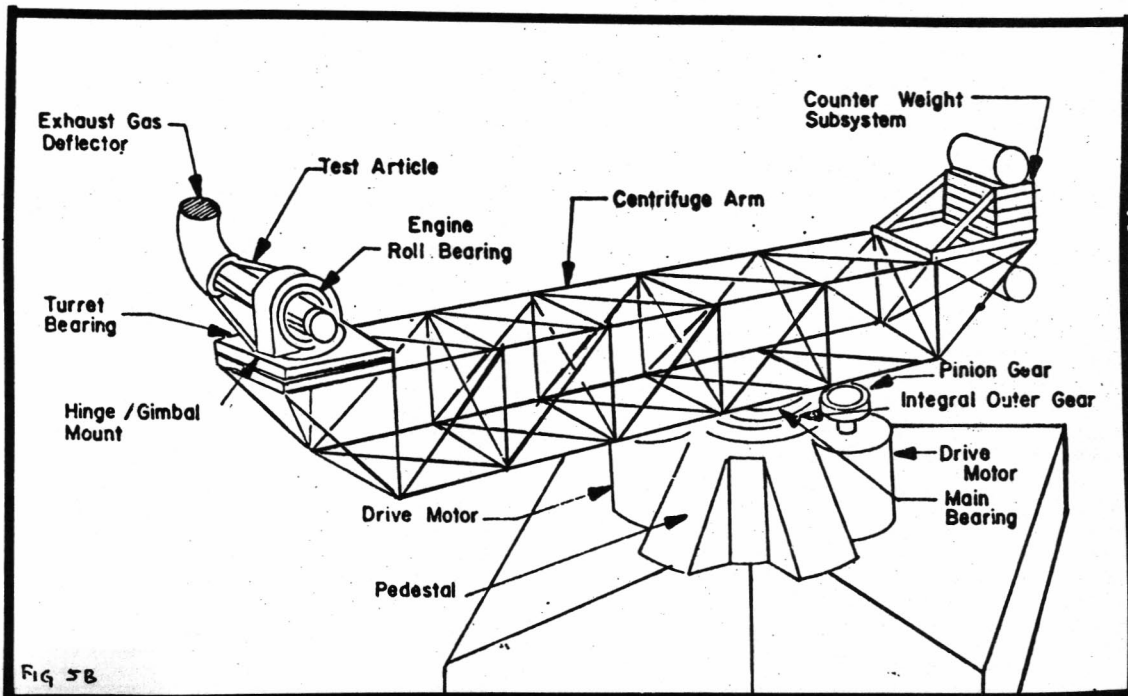


FIGURE 4B



## TURBINE ENGINE LOADS SIMULATOR



millions of dollars. TELS is programmed in FY 1980 with an operational date of 1982. The following are major components of the facility (Fig 5B). The Pedestal. This is a large concrete foundation supported by pilings driven to bedrock. It supports the centrifuge arm on a large bearing that can absorb up to 4000,000 foot pounds of cyroscopic moment thru the arm. The bearing is geared and driven at speeds up to 3.5 radians per second (33.4 rpm) by two 2500 horsepower electric motors also mounted on the pedestal.

The Arm - The centrifuge arm is fixed-length, lightweight, open-tubular frame structure with a 40 foot test radius and a 20 foot counterweight radius. The counterweight arm balances the engine on the test arm using removable solid weights for gross adjustment and a system of tanks for transferring liquid for vernier adjustment. (8)

Compressor Research - A 30,000 H.P. electric drive steady-state and transient aircraft turbine engine compressor test facility is currently under construction at Wright-Patterson Air Force Base, Ohio and scheduled for completion/operation in 1979. It will be capable of steady-state and transient testing of fans and compressors. Known as the AFAPL Compressor Research Facility (CRF), it will provide the means for obtaining the data required to gain a basic understanding of steady-state and dynamic behavior characteristics of full scale turbine engine fans and compressors. Knowledge gained from the CRF will enable maximum compression systems performance and stability capabilities, both steady-state and transient, to be approached while reducing the cost and time currently required for this type of investigation.

Initially, the facility will provide the following capabilities: A drive system that can deliver 30,000 horsepower (11, 250 KW) from 16,000 to 30,000 RPM; Air flow rate of 15-750 lbs/sec; Inlet pressure range-2 psia to ambient; discharge temp. range - up to 1480 F; Discharge pressure range-up to 588 psia; Data acquisition 100,000 samples/sec; Test chamber-25' diameter x 65' long (7.62M 19.82M) Test article - 10' (3.05M) diameter. The facility will have a 500 channel data system with a sampling rate of at least 24,000 samples per second. (9)

#### Fuels and Lubricants Laboratory

Although this is not a test facility the work performed in this laboratory has such an economic and performance impact on engines that it is listed here (Fig 6). The facility is programmed in the FY 1979 Military Construction Program with an operational date 1981. It will provide in one location at Wright Patterson AFB a safe place for combustor research and necessary supporting laboratory areas to develop

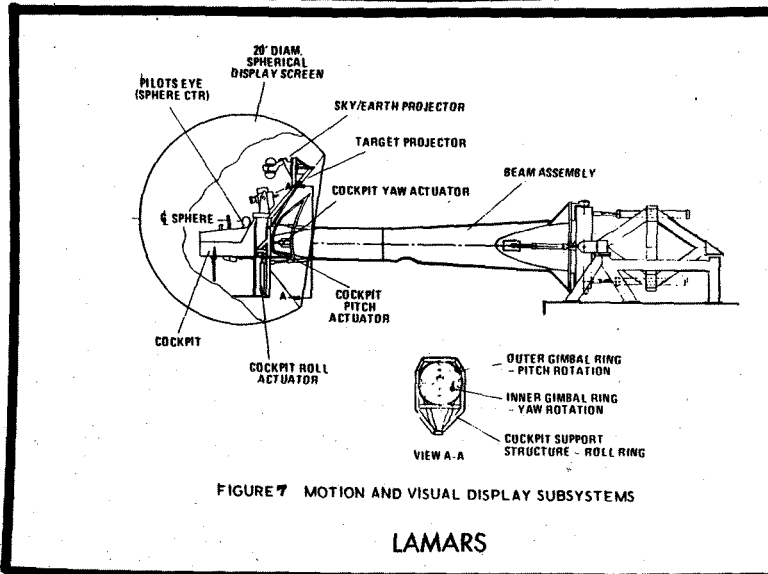
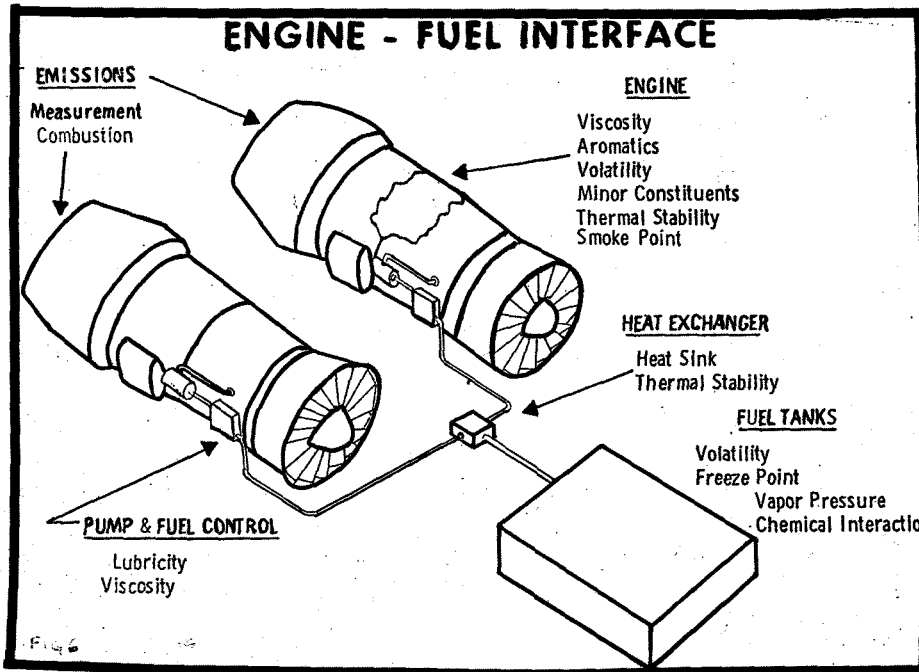
the important matrix of data on variations of existing and future fuels. The impact and need for this facility can be reflected in the fact that if fuels R&D work can save only 1 cent per gallon it will avoid expenditures of \$40 million per year for just the Air Force. (10)

The combustion test facility capabilities will include an Air Flow Rate of 7 (PPBS), Pressure (atm) 18, Temp 900° F. The combustor area will be used primarily for studying the impact of alternate fuels (coal, oil shale, or tar sands derived from liquid hydrocarbons) on turbine combustion systems. The facility will provide for realistic temperature, pressure and airflow rate simulation in these investigations. In addition to assessing the impact of fuel variations on current designs, new combustor concepts intended to overcome difficulties with current hardware will be investigated. Other combustion technology programs to be undertaken include combustion diagnostics, catalytic combustion, and exhaust emissions. Available spectroscopic techniques (laser Raman scattering and coherent anti-Stokes Raman scattering) will be used in both fundamental and applied combustion studies. This laser-based instrumentation allows measurement of important combustion parameters (e.g. temperature, fuel-air ratio, molecular concentrations) without the use of physical sampling probes. Catalytic combustion is a new concept involving reaction of premixed fuel and air with the assistance of a ceramic honeycomb, catalytically coated bed. Studying exhaust pollutant emissions will continue in the new facility.

Further testing can be expected to concentrate on resolving pollutant measurement difficulties, reducing exhaust emissions at altitude and ground level, and assessing the impact of future fuel variations on the environment.

Illustrations of the work on Lubricants include a Jet Engine Simulation Area. In this room we will study a full scale engine simulation of bearing and seal compartments and sumps of current and advanced Air Force propulsion systems to evaluate lubricant performance. Synthetic experimental and candidate lubricant performance will be investigated by studying the interaction of oil thickening, acid increase, additive depletion and deposits in the seals, pumps, bearings, and gears of the simulator.

Another area is for Deposit Investigations. This effort will investigate the deposit forming characteristics of jet engine lubricants. Excessive deposits often cause malfunction of engine components and must be kept to a minimum. Ways to reduce the deposits and their effect on engine components will be studied. Full scale bearings, seals, pumps and



LAMARS		MOTION			VISION		
		Operating Envelope			Projection Optical Lens	Air-to-Air	Air-to-Ground
	Displacement (usable travel)	No-load Velocity	Stall Acceleration <sup>(3)</sup>	Magnification (Approx)			
Beam Vertical	±10 ft	13 ft/sec	±3 g	Lens Angle	±7.6 Deg	±30 Deg	
Beam Lateral		10 ft/sec	±1.65 g	Object Field Diameter	5 inch	5 inch	
Sphere Pitch	±25 deg	60 deg/sec	±400 deg/sec <sup>2</sup>	Lens-to-Screen distance	110 inches (Nom)	110 inches (Nom)	
Sphere Yaw		50 deg/sec	±200 deg/sec <sup>2</sup>	Focal Length	18 inch	4.4 inch	
Sphere Roll		60 deg/sec	±460 deg/sec <sup>2</sup>	f/no. at infinity	f/3.5	f/1.2	
				Numerical Aperture	0.127	0.42	
				Distortion	0.25%	1.0% at 0.5 Field on axis	
				Resolution (Ave MTF)	15 LP/mm at 60% on axis	15 LP/mm at 55% on axis	
				Relative Illumination	50% at 0.8 Field	75% at 0.5 Field	
				Transmission	70% on axis	75% on axis	
				Projected Display Screen Brightness	2.5 Ft lamberts at 120 inches (measured on unity gain screen)		
				Screen resolution	700 TV lines on axis		
				*Total zoom range	119:1 (with 7.1 master range)		
				*Simulated Target range	400 ft to 47,600 ft		
				*Range of correct perspective	1000 feet		
				*Air-to-air configuration			



sump surfaces will be used in this research area to evaluate the effects synthetic lubricant deposits have on engine components. (11)

Flight Control Development Lab - At Wright Patterson AFB the Air Force Flight Dynamics Laboratory is planning the acquisition of the second section of the Flight Control Development Laboratory complex. The west wing of the complex was completed in 1975 and has flight simulators and supporting laboratory facilities. The most significant item is the Large Amplitude Multimode Aerospace Research Simulator (LAMARS). This consists of a five-degree of freedom beam type motion system which carries a single place cockpit and a display screen on the end of a 30 foot beam (Figure 7). The motion base produces motion at the pilots station in precise phase and amplitude corresponding to the electrical signals provided by a computer. The on board Visual Display System utilizes a wide angle ten foot radius, spherical projection screen on which a sky earth projector and a target projector provide the pilot with a visual representation of the outside environment. The spherical contour of the display screen provides a 266° field of view in the horizontal plane of 108° in the vertical plane. The motion and vision capabilities are shown in Figure 8. The east wing of this complex is proposed in the FY 1980 Military Construction Program for \$9 million. It will provide space for: (a) Stability and Control Section decoupled controls (direct left, direct side force, drag modulation); (b) Flight Deck Development Section for crew station integration involving pilot, cockpit, aircraft, instruments and lighting; (c) Aerospace Vehicle Analysis Section involving all aspects of flight control (fire, propulsion, trajectory and sensor integration); (d) Control System Section for design of digital fly by wire controls. This facility will provide the Air Force with means of providing: Design guides for new control systems; predictive techniques for development of control systems; criteria for performance specifications; specifications for hardware acquisition. In effect it will provide a totally integrated flight control development capability.

Integrated Facility for Avionics Systems Testing (IFAST) - This facility is proposed for Edwards AFB, California with acquisition in the early 1980 time period. It consists of four 6,000 square feet test bays and other support areas. It will provide a capability to conduct ground test and evaluation of integrated avionics systems in support of flight test programs. It will provide a capability:

a. To resolve system anomalies via "hot bench" mock up (hardware and software).

b. Evaluate built in test and self tests.

c. Evaluate system hardware and software modifications.

d. Verify new technology concepts.

e. Provide for training support for operational transition.

The IFAST facility will provide the Air Force with a means of providing a better qualified system in the field earlier and at less cost. The importance of this type capability can be appreciated in view of Gen Alton Slay's comment that avionics is 30% of fly away cost, 75% of support cost and the limiting factor of overall reliability.

Materials Laboratory - The second phase of the materials Laboratory Complex at Wright Patterson AFB is also scheduled for early 1980. It is estimated to cost \$14 million and will be used for R&D of metallic materials and processes. The facility design of the first phase has provided desirable features and capabilities which will be included in the second phase. These include room size, utility distribution system, environmental controls and safety features. Other aeronautical laboratories and facilities are being planned for acquisition in the mid 1980 time period but are not reviewed in this paper. We believe all of those facilities are important because progress in the aeronautical sciences will continue through the use of existing, modified, or new R&D facilities.

## VI. LESSONS LEARNED

Lessons learned from the facility acquisition cycle were very basic. It was imperative to identify existing and anticipated test requirements to review existing test capabilities and deficiencies, to identify in qualitative and quantitative terms the impact of test capability deficiencies. We established a plan for acceptance of the needed facilities by the "approving corporate structure." This included the Aeronautics and Astronautics Coordinating Board (AACB), a joint NASA/DOD group which deserves much credit for the thoroughness of its review and its recommendations to proceed. Other groups such as the Air Force Scientific Advisory Board and the National Science Foundation provided assistance and important recommendations. In effect, the NAFF was first approved at very high levels. This approach was very time consuming, but it (1) avoided competing for funds with operational requirements and (2) it gained the endorsements of military and civilian recognized authorities. For ASTF the 14' x 15' scale model built to assist in the design process was a very effective tool in briefings during the budget review process. For the Space Shuttle facilities at Vandenberg AFB a model was also

used. Thus, for lessons learned we believe no new techniques were developed. Rather, known techniques were used well.

#### VII. BETTER USE OF AERONAUTICAL CAPABILITIES

The availability of new expensive aeronautical test facilities possess a challenge to R&D managers. How do we obtain maximum utilization of Test Facilities and Resources, prioritize requirements and scheduling, and reduce test cell costs. Are we planning to improve our data collection and diagnostic capabilities? Methods of obtaining increased use of existing or proposed propulsion test facilities must be developed. When you consider the high cost of facility acquisition, update and operation and reflect the actual hours of test time for any one program it becomes apparent that usually no individual program can afford the facility acquisition price. This was an important factor in establishing the National Aeronautical Facilities Program (NAFP). If this is a logical approach for a national program, the extension of this to an international program should be considered.

##### Test Facilities in Other Nations

The National Gas Turbine Establishment (NGTE) at Pyestock is the UK Government center for research on gas turbine engines. There are currently five test cells in operation. Cells 1 and 2 are small cells (12 ft diameter) originally designed to test ramjet engines; Cell 3 is a larger cell (20 ft diameter). Cell 4 is a large 25 sq ft free jet supersonic test cell. Cell 3 West is the largest cell of the facility (25 ft diameter) and was built for testing with bypass turbofans in the 50-60,000 lbs thrust class (12). The Noise Test facility at the NGTE provides the means of conducting detailed measurements of noise generation and propagation in aero-engine components under ideal conditions. This facility complements the existing Noise and Compressor Test Facility at Rolls-Royce, Ansty. It consists of two units; the Absorber Facility with a working area 40 feet long, by 20 feet wide and 16 feet high (14.6M x 6.1M x 4.9M) for testing acoustically absorbing treatment for engine ducts. The second unit is the Anechoic Facility for testing hot and cold engine exhaust systems, including turbines, jets, etc. The dimensions of the anechoic room is 120 feet long x 100 feet wide x 80 feet high (37M x 30M x 24M). (13) The Noise Test Facility at NGTE in conjunction with the Ansty Noise and Compressor Test Facility, provides the British Aerospace industry outstanding static facilities for research and development of noise testing in an

effort to produce quieter engines and aircraft (14). Other fine aeronautical test facilities in Europe are the Center for Propulsion Studies at SACLAY, France; the Onera Test Center at Modane Arrieux, France; the NRL in Amsterdam, Holland; the FKFS at Daimler Benz, Stuttgart, FRG; and the DFVLR at Gottingen, FRG. (15) There are just some of the test capabilities in Europe which like the British NGTE capabilities, illustrate the point that many propulsion and aerospace test capabilities exist. In most cases, and with little modification, these facilities can be made available for other than institutional work.

#### VIII. INTERNATIONAL COOPERATION

For an international program some of the problems that surface are governmental approval, knowledge of requirements and matching them with capabilities, security and proprietary interests, logistical support, etc. Except for government approval and the requirements/capability match most of these problems can readily be resolved with adequate resources. With the proper interest and effort the first two problems can be resolved.

Examples of government interest are illustrated by the 1978 Memorandum of Understanding between the United States Department of the Air Force and the French Ministère De La Defense Concerning a Joint Study of Icing Cloud Formation, and the September 1975 Memorandum of Understanding Between the Government of the United States and the Government of the United Kingdom of Great Britain and Northern Ireland Relating to the Principles Governing Cooperation in R&D, Production, and Procurement of Defense Equipment (Cooperation Agreement). The agreement states the governments "---- are seeking to achieve greater cooperation in research, development, production, and procurement in these areas in order to make the most rational use of their respective industrial, economic, and technological resources,---." Another illustration of international cooperation agreed to at high levels in government are the test programs between the UK and France for the SST. The problem of knowledge about and matching requirements with capabilities was referred to as a marketing problem. It involves the "selling" of a facility capability to potential customers. It is frequently possible to obtain information on development programs and then educating potential customers about existing test capabilities. An example of this is the participation of personnel from Government, Industry, and the National Gas Turbine Establishment (NGTE) at the University of Tennessee Space Institute, (Tullahoma, Tennessee) Short

Course on Aerospace Ground Test Facilities. These suggestions may not have immediate results because of the time phasing of test requirements, but in the long run they can create the proper environment that will result in international use of aerospace test facilities.

#### IX. CONCLUSIONS

The paper briefly reviewed the status of technical capabilities of the NAEP and several facilities that will support future aeronautical RDT&E. We believe there is a need for government and industry to support the facility investment necessary to make progress in aerospace technology and then to make the best possible use of these facilities. Aeronautical technology will be constantly resolving uncertainties evolving with new designs, materials, synthetic fuel systems. Dr. Naka, Chief Scientist USAF, recently stated, "Without adequate test facilities, these uncertainties will continue to plague the engine designer. (16) Whatever the circumstances, investment in and use of aeronautical test facilities will be mandatory in the future if our aerospace systems are to maintain an economic and military competitive advantage. To accomplish this at the lowest cost we should learn to use and share our own technology capabilities and use these of other nations when their capabilities are better suited to our needs. National and International cooperative efforts can result in obtaining better results from and making better use of aeronautical Test Facilities.

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