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AIRCRAFT AND ENGINE DEVELOPMENT TESTING

Committee on Aircraft and Engine Development Testing
Air Force Studies Board
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STATEMENT OF TASK

The Committee on Aircraft and Engine Development Testing will study the use, timing, and costs of development testing in the new aeronautical test facilities. Effective use of the new capabilities can mean reduced risk in the flight testing program and decreased engineering changes, modifications, and retrofits.

The committee should recommend in its final report concepts, methods, and schedules that will take maximum advantage of increased ground testing capabilities to shorten development times and reduce life cycle costs.

EXECUTIVE SUMMARY

BACKGROUND

The importance of aerospace technology to the United States for both military preparedness and defense, and to the economy in the commercial aircraft sector is well known. To maintain and strengthen the scientific, development, and manufacturing capabilities for aircraft and missiles requires continual improvement and periodic enhancement of ground test facilities for the testing of aircraft and engines. When major changes in capability for ground testing occur or when revolutionary steps in engine aircraft technology are imminent it is prudent to reexamine the program testing philosophy to see if it is responsive to emerging changes and new challenges.

The dedication of three new Air Force ground testing facilities that significantly enhance aircraft and engine development capabilities suggests that it is appropriate to examine current Air Force testing procedures. Dr. James Mitchell, Chief Scientist at the Arnold Engineering Development Center (AEDC), asked the Air Force Studies Board to form a committee to study this question. In the spring of 1984 the Air Force Studies Board approved the study and the committee on Aircraft and Engine Development Testing was formed.

The committee met five times between June 1984 and July 1985. The meetings included visits to two of the new aerospace testing facilities: the National Transonic Facility (NTF) at NASA-Langley Research Center, Hampton, Virginia, and the Aeropropulsion Systems Test Facility (ASTF) at Arnold Engineering Development Center, Tullahoma, Tennessee. Presentations and discussions with representatives of the military, government, aerospace industry, NASA, DARPA, and private citizens were held at four of the five meetings. The fifth meeting concentrated on preparation of this report.

FINDINGS

The committee found that the ground test community is confident that the available test procedures can handle most problems presented by new aircraft and engine designs. However, when new and radically different design concepts appear there is uncertainty in appropriate test methods and difficulty in obtaining necessary levels of funding early enough in the program cycle. The emergence of new designs emphasizing integration of the airframe, engine, and flight control systems will provide a synergistic effect producing revolutionary changes in the flight envelope. Simultaneously, this integration introduces testing problems for which there is no previous experience and which requires the combined testing of components that were previously tested separately. Thus there is increased risk of development problems and the potential for expensive and time consuming corrective measures. Consequently, the potential capabilities of the ASTF should be developed and brought to operational status as quickly as possible.

Successful implementation of such highly integrated designs will require significant changes in the method for funding aircraft and engine development. The current system for funding engine and airframe ground testing requires that Air Force test facilities be industrially funded, which transfers the costs of testing to the development program. The same requirement does not apply when

NASA test facilities are used. This dichotomy in funding systems may inhibit the use of the best facility for a given program and often prevents the early testing in ground based facilities which is essential with integrated designs to avoid the late identification of problems and their associated penalties.

RECOMMENDATIONS

The complete set of conclusions and recommendations of the committee emphasizes three main points. These are in priority order:

1. A policy incorporating advanced planning and early funding commitments for testing and test facility preparation should be implemented. At the same time the manner in which aerodynamic testing costs are determined and charged to development programs for government owned and operated facilities should be closely examined to insure that the best facility for a given investigation is used regardless of funding and accounting procedures.

2. The ASTF should be brought to operational status as quickly as possible and should include the immediate design, development, and funding of free jet test capability. The free jet nozzles should be capable of providing variable Mach number, transient, and asymmetric flows.

3. Rapidly developing technologies such as integrated designs and new programs such as the transatmospheric vehicle (TAV) will continue to place emphasis on the capabilities of ground test facilities. Current and projected weaknesses should be reviewed annually and funding for new and improved facilities should be sought to insure that the necessary capabilities are available when needed.

1.0 INTRODUCTION

Unprecedented changes in aeronautical research and technology are anticipated during the next 10 to 15 years.[1,2] Indeed, the aeronautical policy review committee has suggested that "all currently operational aircraft could be technologically superseded by the year 2000."[1] The basis for such a rapid evolution are commercial and military demands coupled with the available and emerging advances in engine-airframe-control system integration; lightweight, high strength composite aircraft structures; stealth technology with the engine and airframe as merged components; advanced aerodynamics and propulsion; relaxed aerodynamic stability; and coupling of computational fluid dynamics (CFD) with design and ground testing procedures. Taken together, these will present an increased challenge for the entire aerospace community with particular emphasis on ground test facilities.[2,3]

The joint demands of improved and guaranteed performance coupled with the costs of development and production have led to dramatic increases in wind tunnel time for each new aircraft.[2] Consequently, the need to improve the available facilities was recognized in the late 1960s[4] and an investment of approximately $800 million was approved in the mid-1970s to develop the NTF at NASA-Langley, the ASTF at Arnold Engineering Development Center; and the low speed 80' x 120' tunnel at NASA-Ames Research Center, California. Recent studies have reiterated the need to continually examine and upgrade U.S. national aerospace testing capabilities.[3]

As the new facilities approach operational status,[5,6] the Air Force Studies Board was requested[7] to examine the impact of ASTF, NTF, the 80' x 120' low speed tunnel, and complementary facilities on Air Force wind tunnel test procedures and programs. This request is timely because it comes at a time when the importance of U.S. aerospace leadership is being challenged[1] and new aerodynamic and control concepts[2,3] are forcing changes in the traditional approaches to design, testing, and flight confirmation.

NASA has also recognized the need to examine long lead time facility requirements and requested the NRC to convene a workshop on Facility and Aerodynamic Possibilities for the Year 2000.[3] This study confirmed and reemphasized the conclusions reached in other reports[1,2] and found that new technologies will cause synergism in design particularly from component integration.

These studies[1-3] have concluded that <u>ground test facilities will continue to provide the foundation on which the projected advances will occur</u>. They also recognize that current and planned facilities must include CFD and must use CFD and conventional wind tunnel concepts to increase their capabilities and effectiveness. The tremendous cost of facilities such as ASTF (see Section 5) will require improved and expanded cooperative programs, both among government agencies and with industry. <u>Duplication and overlap of ground test facilities of this size is unfeasible</u>. An additional danger is that new facilities may be delayed or not constructed at all, leading to a declining aerospace capability in future years.

The use of experimental aircraft and technology demonstrators is also suggested by some studies[1,3] and was discussed during briefings to the committee (see Appendix B for a complete list). The tremendous cost of actual flight testing (as discussed in Section 3.5), approximately 10 to 1 compared to ground testing, and the need for extensive ground testing (regardless) prior to flight, particularly for new technologies such as those of the X-29, further supports the need for continued improvements in U.S. aerospace technology testing capability.

During presentations to the committee (see Appendix B) a common and recurring message was apparent. The ground test community, including the military, airframe contractors, and engine manufacturers, are comfortable with their methods, even for past cases where problems arose during flight tests, such as occurred with the F-111 inlet, where by experience, good or bad, it has learned and developed the necessary instrumentation and techniques. However, in new areas such as the emerging integrated designs of the ATF and stealth configurations, they are uncertain that current methods will provide enough information to avoid costly changes or performance penalties during the flight testing phase. A second thread in virtually every presentation was the need to provide for earlier funding of complementary and integrated components such as the airframe inlet and engines.

This committee was charged specifically with "studying the use, timing, and cost of development testing in the new aeronautical test facilities."[7] Two of the new facilities will provide improved information (NTF by using cryogenic techniques and the 80' x 120' by size increase) that more closely approaches full-scale conditions. These are essential input to the system design problem but do not represent the significant concept change of high speed integrated testing, including flight transients, which ASTF pioneers. Early in its deliberations[8] the committee had to more closely define the objectives of the task. Consequently, this report will concentrate on the effects on the Air Force aircraft programs of wind tunnel testing from the configuration-specific development level through early flight testing emphasizing the impact of ASTF on this process. The objectives include the impact of the capabilities for full-scale integrated engine-airframe testing on the use of government and contractor facilities and the design and planning of test programs. Also examined are testing support, funding, and timing of ASTF use and interaction with other facilities, in addition to the new capabilities it provides and its future development.

2.0 TECHNOLOGY TRENDS

2.1 INTRODUCTION

Technology develops along complementary but somewhat different paths. The most common progression is one of evolutionary change that builds on existing capabilities and leads to a series of incremental improvements in performance. This is typical of aircraft re-engineing as more powerful engine types or derivatives become available, of new wing profiles, and of improved avionics. This process depends heavily on experiences and facilities, and this relationship is well documented and understood.

Periodically, however, the development of new capabilities and technologies leads to a synergism in which step changes in design, testing, and performance can occur. In these cases there is little previous experience on which the engineering community can depend. The emergence of the turbojet engine in the early 1940s, with its increased altitude and speed capabilities is an excellent example. As flight technology pushed into transonic and low supersonic speeds, fundamental difficulties in aircraft development, such as control problems, were encountered. These difficulties required aerodynamic concepts and facilities unimagined only a few years before. NASA's Unitary Tunnel program was one result.

Figure 2.1 shows the roles that both evolutionary and step changes in technology have played in aircraft development. In many cases, there were development problems with associated costs when the aircraft moved into the flight prototype or technology demonstration phase and when the changes were beyond the experience of the ground test community.

Current and future high performance aircraft must be highly integrated and consequently the airframe, engine, controls, and avionics cannot be developed separately, but must be designed and developed as related components. Such a procedure leads to major performance improvements but at the cost of increased test difficulties. Figure 2.2 shows how the integration of the flight control system with various aircraft components has been systematically evolving with each new design. We believe that the total integration of all components, as indicated in Figure 2.3, and the resulting synergism represent one of the biggest steps in aircraft development since the introduction of the jet propulsion engine. Simultaneously, a new approach to ground testing will be required.

Future aircraft will incorporate several new technologies that differ significantly from those of current operational aircraft. These new technologies are evolving rapidly and will greatly affect all aspects of the performance of advanced aircraft. The emphasis in this study is on those aspects that traditionally have been labeled aerodynamics and propulsion. It is clear, however, that the line between these two areas is no longer sharp and that the marriage of these components coupled with computer control will require new approaches to the design process. The integration of the propulsion system and airframe leads to, and is pushed by, several new technologies and requirements that will have important effects on the design of military aircraft. The following subsections briefly discuss the more important factors that will influence aerodynamic ground testing procedures in the immediate future and will lead to new steps in the development process.

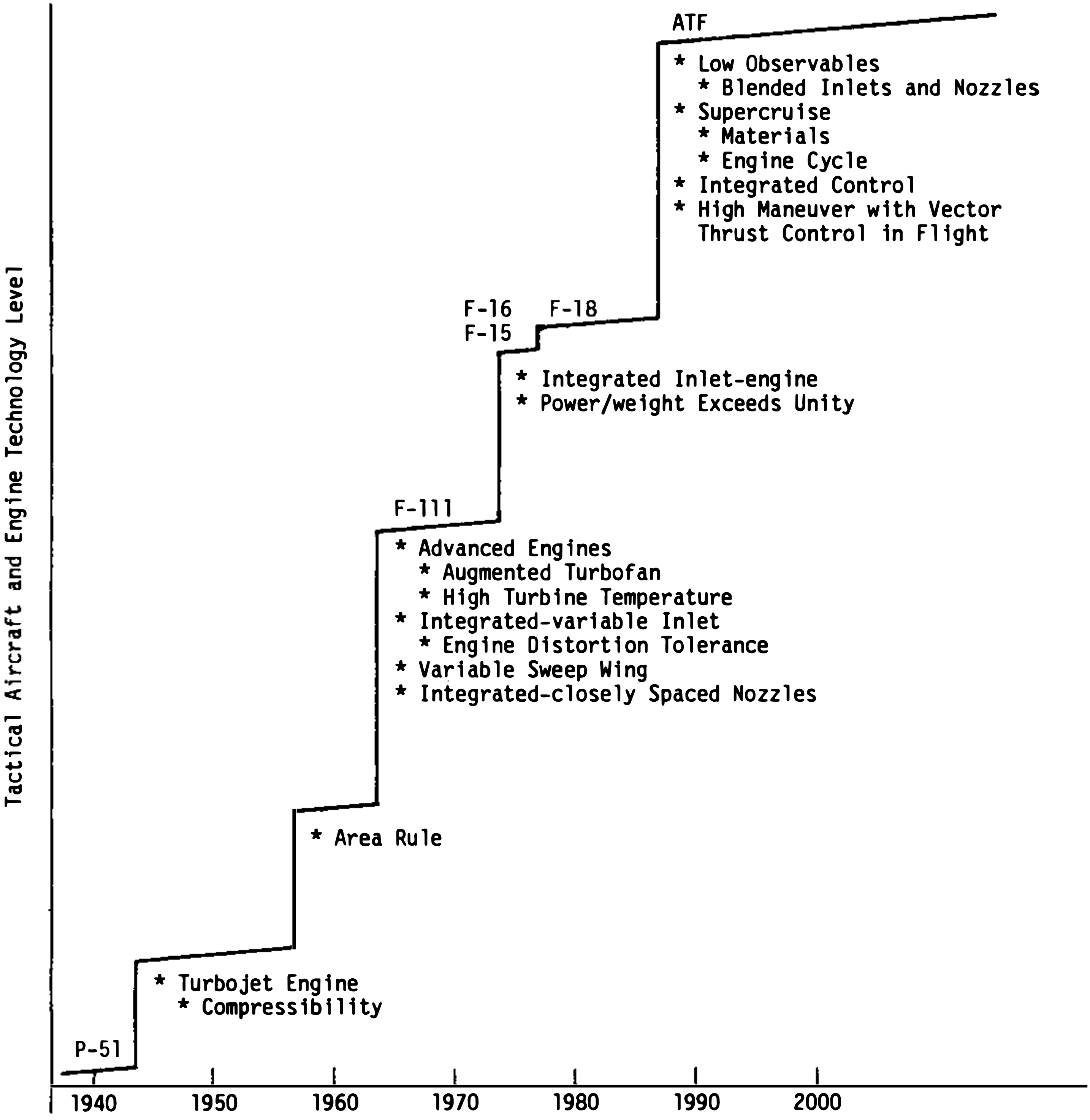

Figure 2.1 Relation of Aircraft Component and Technology Development to the Evolutionary and Step Change Design Process

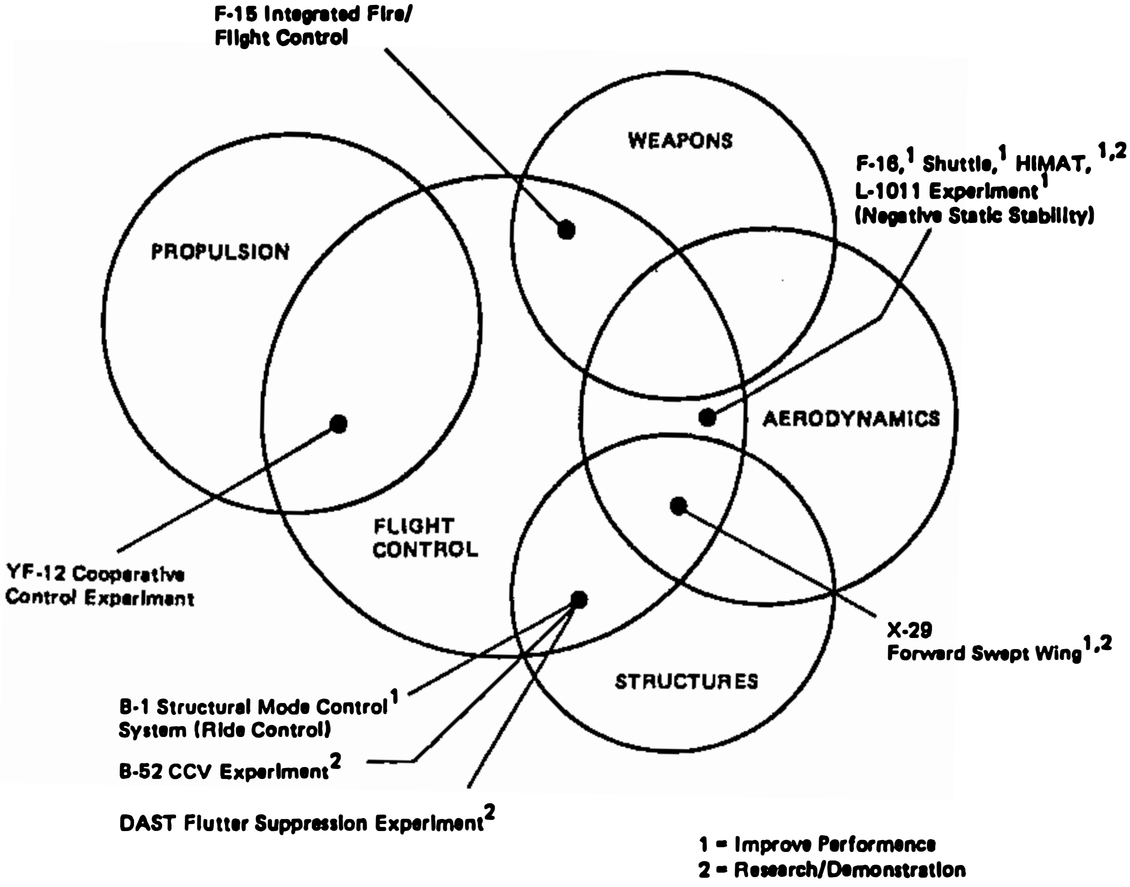

Figure 2.2 Control System Integration State-of-the-Art from *Aeronautics Technology Possibilities for 2000*

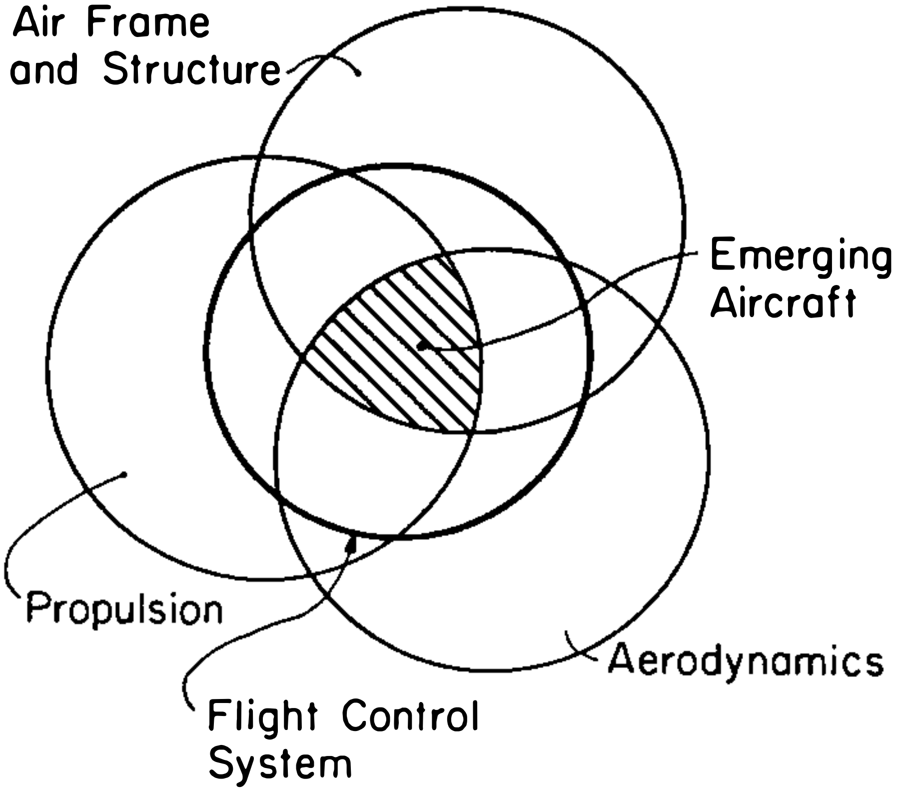

Figure 2.3 Future Control System and Aircraft Component Integration (some components such as weapons systems delivery are not shown for clarity but are considered part of the overall integration concept)

2.2 EMERGING TECHNOLOGIES AND REQUIREMENTS

2.2.1 Stealth Technology

One key part of evolving stealth technology is a clear need for inlets and exit nozzles that minimize the visibility of future aircraft. This will affect the location, shape, and possible internal/external treatment of both inlets and nozzle exits and thus will have major effects on the environment in which the engine operates, including the flow quality delivered to the engine face and on exhaust-airframe-external slipstream interaction.

2.2.2 Flight Operational Envelope

Many future combat aircraft will operate at extreme angles of attack and high angles of yaw. This requirements will have several effects on the propulsion system, including the ability to cope with highly distorted inlet and exhaust flows. Also, it will be desirable for the propulsion system to be able to provide major inputs to the control and stability of the aircraft. Non-ballistic military vehicles are under consideration which in the not too distant future will travel at hypersonic speed, first missiles and then manned aircraft.

2.2.3 Propulsion System Control Capability

Operation at wider angles of attack and yaw plus other operational requirements will emphasize the desirability of in-flight thrust vectoring and reversal. The use of the propulsion systems in this manner can significantly increase aircraft combat effectiveness, including the ability to deliver air-to-air weapon systems.

2.2.4 Intake and Nozzle Geometries

Thrust vectoring and reversal accentuate the desirability of non-circular nozzles which are better able to produce variable geometry. Variable geometry also provides advantages when propulsive lift is required for STOL operations.

2.2.5 Transient Operations

Military aircraft operations often require rapid changes in power, angle of attack, roll, etc. Furthermore, most aircraft excursions to extreme altitudes will not be steady state but will be of relatively short duration. The propulsion system will thus be exposed to transient or dynamic environments that can have major effects on engine performance and stability.

2.2.6 Control System Integration

Recent research shows that measurably improved performance can be obtained by using advanced digital engine and flight control systems. These systems reduce pilot workload, permit the optimization of maneuvers, improve weapons system delivery, allow flight with reduced aerodynamic stability and operation at the extreme limit of the flight envelope.

2.2.7 High Speed Flight

Future aircraft and missiles (some highly maneuverable) might operate at the Mach 3-6 range. Some may use methane fuel and dual-cycle propulsion systems such as turbojets and ramjets. Other advanced aircraft such as TAVs may use air-breathing propulsion at much higher speeds. At the very high speeds, hydrogen will be the fuel of primary interest.

2.3 SUMMARY

Propulsion systems for some advanced aircraft will be required to have low observables, operate in a dynamic environment and at extreme altitudes, contribute to aircraft control, stability, and maneuverability; incorporate noncircular nozzles; fly at hypersonic speeds; and have their control systems integrated with flight control systems. These changes will also help reduce crew workload, improve flight efficiency and fuel consumption, increase passenger comfort, reduce flying times, and improve navigational and landing procedures. The foregoing are some of the major changes from current technologies and design requirements associated with propulsion systems and their integration with available engineering information is limited. This imposes new and difficult responsibilities and requirements on ground test facilities to assure the validity of the total integrated design prior to commitment to flight hardware and flight testing.

3.0 ABILITY OF GROUND TEST FACILITIES TO SUPPORT DEVELOPMENT OF NEW MILITARY FLIGHT SYSTEMS

3.1 INTRODUCTION

This section examines the requirements for and facilities to support development of the overall flight system, including the entire propulsion subsystem, the airframe subsystem, all of their respective integrated control subsystems, and the interactions of all of these subsystems. The other electronics and weapons subsystems are not specifically considered. Only turbojet, turbofan, or ramjet/scramjet propulsion systems will be discussed; propeller, rocket, and other systems have been arbitrarily omitted, since they are only weakly related to the committee's charge. The topics covered sequentially in this section are given in the paragraph below.

The capability of existing facilities for engine and aerodynamic ground testing are first summarized and then compared to the key parameter requirements for such testing. Because ground testing of completely integrated airframe and propulsion systems is always very difficult and often impossible, the approaches employed in testing general subsystem components are first described and then followed by a description of dedicated facilities for the integrated testing of a single special aircraft. Facilities to test specific operational aspects (such as angles of attack and yaw, nozzle thrust vectoring and reversing, transients, rain and ice, etc.) are then discussed briefly. The section concludes with the capabilities of major new (or proposed) facilities that can contribute greatly to ground testing of engines and air frames, and their integration.

3.2 SUMMARY OF EXISTING FACILITIES

Tables 3.1 and 3.2[9] list most of the free world's significant air-breathing engine test facilities with certain pertinent operational features for both sea level and altitude testing. Table 3.3[10] is a summary of 250 U.S. wind tunnels categorized by speed range, owner/operator, and size. The criteria used for "large" or "small" size are relative and depend on the speed range of the tunnel. Since the basic data of these tables are a few years old, some facilities have been dismantled and others added to "standby" while only a few new ones have come on line. However, the overall capabilities outlined in these tables should still be available.

3.3 ABILITY TO DUPLICATE OR SIMULATE KEY AERODYNAMIC AND PROPULSION PARAMETERS AND OPERATIONAL CHARACTERISTICS

3.3.1 Overall Key Parameters for Testing

The most important key parameters for ground test capability are air velocity, sound speed (temperature), inlet ambient density, vehicle attitude, air flow rate, fuel flow rate, fuel injection pattern, heat of combustion, component dimensions, configuration shapes, and controls. To further complicate the problem, the rates of change of these parameters (transients) externally imposed or internally generated are also primary forces.

Table 3.1

List of Sea Level Test Facilities

ENGINE TJ	RJ	TS	MASS FLOW KG/S	THRUST/ SHAFT P. kN/kW	SPECIAL CAPABILITY SECTION	TEST FACILITY DESIGNATION	ORGANIZATION NAME (*=FOREIGN)	FREE JET & STATIC	CONNECTED PIPE	TRANSIENTS
x			Unlimited	310 kN	3/5	TB No 9	RR-HU*	x		
x			Unlimited	222 kN	1/3/7	METS A+B	RR-BR*	x		
x		x	Unlimited	222 kN	4/7/9	Var. Attitude Stand	NAPC	x		x
x		x	Unlimited	222 kN	3	Turntable Engine Stand	NAPC	x		
x		x	Unlimited	180 kN	2	TX	CEPr*			
x		x	Unlimited	2x90kN	2/5/9	TB No 5	RR-HU*	x		
x		x	Unlimited	90(45)[1]kN	3/5	TB No 7	RR-HU*			
x			Unlimited			ISite No 3	SNECMA*			
x			Unlimited			ISite No 5	SNECMA*			
x				445 kN	6	A-8	P&W-FL			
x				334 kN	7	C-10	P&W-FL			
x		x	1300	20 kN Lift 10 kN Drag		Propulsion Tunnel	NRC*			
x			1200	250 kN		T 1	CEPr*			
x			1045	267 kN		SLETF	AFAPL			
x			1000	310 kN	7	TB No 48	RR-DE*			
x			1000	310 kN	7	TB No 49	RR-DE*			
x			907	310 kN	2/5	TB No 10	RR-HU*	x		
x				267 kN		A-2	P&W-FL			
x				180 kN		No 3 TB	RR-CA*			
x			536	178 kN	7	TP 105	RR-BR*	x		
x			536	178 kN	7	TP 137	RR-BR*	x		
x			500			W 1 C 7	SNECMA*			
x			500			W 1 H 8	SNECMA*			
x			454	98 kN	10	TP 107	RR-BR*			
x			400			W 2 C 7	SNECMA*			

Table 3.1

List of Sea Level Test Facilities

ENGINE			MASS FLOW KG/S	THRUST/ SHAFT P. KN/KW	SPECIAL CAPABILITY SECTION	TEST FACILITY DESIGNATION	ORGANIZATION NAME (*=FOREIGN)	FREE JET & STATIC	CONNECTED PIPE	TRANSIENTS
TJ	RJ	TS								
x			400	100 kN		Cell No 6	FIAT*			
x			304	98 kN	10	TP 103	RR-BR*			
x			304	98 kN	10	TP 104	RR-BR*			
x			272	222 kN	6	TP 140	RR-BR*			
x			272	222 kN	6	TP 141	RR-BR*			
x				222 kN		5-11	P&W-AC			
x			250[2]	80 kN		ETB No 1	MTU*			
x			250[2]	80 kN		ETB No 2	MTU*			
x			227	22 kN		1-16/1-17	P&W-AC			
x		x	204	133 kN		TB No 8	RR-HU*	x		
x		x	200	190 kN		Glen Test House	NGTE*			
x			200			W 11 H 7	SNECMA*			
x			180	130 kN	10	TB No 41	RR-DE*			
x			180	130 kN	10	TB No 42	RR-DE*			
x			180	130 kN	10	TB No 43	RR-DE*			
x			180	130 kN	10	TB No 44	RR-DE*			
x			180	90 kN	7	TB No 2	RR-HU*			
x			170	222 kN	10	TP 108	RR-BR*			
x		x	159	133 kN	1/8	SLC 1 W	NAPC	x		
x		x	159	133 kN	1/8	SLC 2 W	NAPC	x		
x			136	135 kN		No 5 TC	NRC*			
x				111 kN			AIRes.			
x				111 kN			AIRes.			
x			100	80 kN	2/4	Field	MTU*	x		
x			100			W 9 H 7	SNECMA*			
x			100			W 10 H 7	SNECMA*			

Table 3.1

List of Sea Level Test Facilities

ENGINE TJ	RJ	TS	MASS FLOW KG/S	THRUST/ SHAFT P. KN/KW	SPECIAL CAPABILITY SECTION	TEST FACILITY DESIGNATION	ORGANIZATION NAME (*=FOREIGN)	FREE JET & STATIC	CONNECTED PIPE	TRANSIENTS
x			100			W 12 H 7	SNECMA*			
x			100			W 7 H 5	SNECMA*			
x			100			W 8 H 5	SNECMA*			
	x		90	10 kN	4	VMK	DFVLR*	x		x
x				67 kN		No 2 TB	RR-CA*			
x				67 kN		Honiley	LUCAS*			
x			77	36 kN		TP 131 E	RR-BR*			
x			77			TP 125	RR-BR*			
x		x		2 kN 2000 kW	4	H 9	CEPr*	x		x

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[1] Reverse thrust

[2] Exhaust 700

Key for Special Capability Section Column, Table 3.1

1	Icing
2	Foreign object damage
3	Noise
4	Attitude (pitch and yaw)
5	Intake compatibility/cross wind
6	Preheated air/heated inlet
7	Vectored and reversed thrust/jet deflection
8	Cold Start
9	Twin Engine
10	Reheat

Table 3.2

List of Altitude Test Cells

ENGINE TJ	ENGINE RJ	ENGINE TS	ALTITUDE KM	MACH RANGE	MAX. MASS FLOW RATE KG/S	TEST FACILITY DESIGNATION	ORGANIZATION NAME (*=Foreign)	FREE JET/WIND TUNNEL	DIRECT CONNECT	TRANSIENTS
x	x		52	0.8-8.2	363	TC-8	MAR			
x	x		13.7-47.2	1.5-4.75		PWT 16 S	AEDC	x		
	x		45.7	1-10	68	TC-1	JHU-APL			
	x		45.7	1-10	68	TC-2	JHU-APL			
	x		45.7	1-10	68	TC-3	JHU-APL			
	x		45.7	1-10	68	TC-4	JHU-APL			
x	x		30.5	0-3.8	1,250	ASTF C 2	AEDC	x	x	x
	x		30.5	0-5.6	863	APTU	AEDC	x	x	
x	x		30.5	0-3.8	660	ASTF C 1	AEDC	x	x	x
x	x		30.0	0-3.5	270	ATF Cell 4	NGTE*	x		x
x	x		30.0	0-3.5	180	ATF Cell 1	NGTE*	x		x
x	x		27.5	0.2-1.5		PWT 16 T	AEDC	x		
x			27.4	0-3.0	263	X-207	P&W-AW			
x			27.4	0-3.0	263	X-208	P&W-AW			
x			27.4	0-3.0	227	X-210	P&W-AW			
x	x		27.4	0-4.2	182	TP 131 A	RR-BR*	x	x	x
x			27.4	0-3.0	147.6	X-209	P&W-AW			
x	x		24.4	0-3.3	636	J-1	AEDC	x	x	x
x	x		24.4	0-3.3	636	J-2	AEDC	x	x	x
x			24.4	0-3.0	454	TC-43	GE			
x	x		24.4	0-3.0	363	T-1	AEDC	x	x	
x	x	x	24.4	0-3.0	363	T-2	AEDC	x	x	
x	x		24.4	0-3.0	363	T-4	AEDC	x	x	

Table 3.2

List of Altitude Test Cells

ENGINE			ALTITUDE KM	MACH RANGE	MAX. MASS FLOW RATE KG/S	TEST FACILITY DESIGNATION	ORGANIZATION NAME (*=Foreign)	FREE JET/WIND TUNNEL	DIRECT CONNECT	TRANSIENTS
TJ	RJ	TS								
x	x		24.4	0-3.0	318	3 E	NAPC		x	
x			24.4	0-2.4	195	2 E	NAPC		x	
x			24.4	0-2.4	195	1 E	NAPC			
x	x		24.4	0.8-5.0	182	TC-2	MAR			
x			24.4	0-3.0	182	TC-44	GE			
x			24.4	0-3.0	170	T-6	AEDC	x	x	
	x		24.4		81.6	IRR-GTF	UT-CSD	x		x
x			21.3	0-4.0	340	PSL-4	NASA-LE		x	
x			21.3	0-3.0	340	PSL-3	NASA-LE		x	
x		x	21.3	0-2.5	272	ATF Cell 1	RR-DE*	x	x	x
x			21.3	0-2.5	272	ATF Cell 2	RR-DE*	x	x	x
x	x		21.3	0-3.0	204	PSL-1	NASA-LE		x	
x	x		21.3	0-3.0	204	PSL-2	NASA-LE		x	
x			20.0	0-4.0	375	R 5	CEPr*	x	x	
x			20.0	0-2.4	200	R 3	CEPr*	x	x	
x			20.0	0-2.4	200	R 4	CEPr*	x	x	
x	x	x	20.0	0-2.2	70	HPT	US-ILA	x	x	x
		x	20.0	0-1.0	54.5	871-2	DDAD			
		x	20.0		54.5	3 W	NAPC			
		x	20.0		54.5	4 W	NAPC			
		x	20.0		54.5	5 W	NAPC			
		x	20.0		54.5	6 W	NAPC			
x	x		19.0	0-3.5	270	ATF Cell 3	NGTE*	x	x	x
x			18.0	subsonic	630	ATF Cell 3 W	NGTE*	x	x	x
x	x		17.0	0-2.5	180	ATF Cell 2	NGTE*		x	x

Table 3.2

List of Altitude Test Cells

ENGINE			ALTITUDE KM	MACH RANGE	MAX. MASS FLOW RATE KG/S	TEST FACILITY DESIGNATION	ORGANIZATION NAME (*=Foreign)	FREE JET/WIND TUNNEL	DIRECT CONNECT	TRANSIENTS
TJ	RJ	TS								
x	x		16.8		109	Ramjet	AFAPL			
x			15.2	0-1.0	190	881	DDAD			
x			15.2	0-1.5	109	TC 21	AFAPL			
x			15.2	0-1.5	109	TC 24	AFAPL			
x	x	x	15.0	0-2.0	100	S 1	CEPr*	x	x	
x			13.7	0-1.0	545	X-217	P&W-AW		x	
x		x	13.7	0-1.0	45.4	873	DDAD			
x		(x)	11.0 (5.6)	0-1.0	55	C 1	CEPr*	x	x	
x		x	10.0	.1-1.0		R 2	CEPr*			
x		x	10.0	.1-1.0		R 6	CEPr*			
	x					TC-7	MAR			
x						A-1	P&W-FL			
x						C-4	P&W-FL			
x						C-5	P&W-FL			
	x		35.0	7.0	2.3	M7-SJTF	NASA-LA	x		

Abbreviations[1] for Tables 3.1 and 3.2

AIRes.	AIResearch Manufacturing Company
AEDC	Arnold Engineering Development Center
AFAPL	Air Force Aero-Propulsion Laboratory
AR*	Alfa Romeo
BR*	Bristol
CA	California
CC-AMPD*	Confederation College of Applied Arts & Technology Aviation & Motive Power Department
CEPr*	Centre d'Essais des Propulseurs
CT	Connecticut
CU-GTL*	Carleton University Gas Turbine Laboratory
DCU	Data Collection Unit
DDAD	General Motors Corporation Detroit Diesel Allison Division
DE*	Derby
DFVLR*	Deutsche Forschungs- und Versuchsanstalt fur Luft- und Raumfahrt e.V.
EM*	Costruzioni Aeronautiche G. Agusta Elicotteri Meridionali
FIAT*	Fiat Aviazione S.p.A.
FL	Florida
FOD	Foreign Object Damage
GE	General Electric Company

---

[1] Test Cell Designations, Engine Designations, and SI-Units excluded.

* = Foreign Facility

Abbreviations for Tables 3.1 and 3.2

H	Height
HA*	Hatfield
HU*	Hucknall
IRR	Integrated Rocket Ramjet
JHU-APL	The Johns Hopkins University Applied Physics Laboratory
L	Length
LUCAS*	Lucas Aerospace Limited
MAR	Marquardt Company
MTU*	Motoren- und Turbinen-Union Munchen GmbH
NAPC	Naval Air Propulsion Center
NASA-LA	National Aeronautics and Space Administration Langley Research Center
NASA-LE	National Aeronautics and Space Administration Lewis Research Center
NGTE*	National Gas Turbine Establishment
NPT*	Noel Penny Turbines Limited
NRC*	National Research Council Canada
PL*	Plessey Company Limited
P&W-AC*	Pratt & Whitney Aircraft of Canada Ltd.
P&W-AW	United Technologies Corporation Pratt & Whitney Aircraft Division Commercial Products Division Andrew Willgoos Turbine Laboratory
P&W-FL	United Technologies Corporation Pratt & Whitney Aircraft Division Government Products Division Florida Research & Development Center
RJ	Ram-Jet

Abbreviations for Tables 3.1 and 3.2

RR-BR*	Rolls Royce Limited Aero Division, Bristol
RR-CA*	Rolls Royce (Canada) Limited
RR-DE*	Rolls Royce Limited Aero Division, Derby
RR-HA*	Rolls Royce Limited, Hatfield
RR-HU*	Rolls Royce Limited, Hucknall
SNECMA*	Societe Nationale d'Etude et de Construction de Moteurs d'Aviation
TE-CAE	Teledyne CAE
TJ	Turbo-Jet (including turbo-fan)
TS	Turbo-Shaft
US-ILA*	Universitat Stuttgart Institut fur Luftfahrt-Antriebe
UT-CSD	United Technologies Corporation Chemical Systems Division
W	Width
WE-CA*	Westinghouse Canada Limited

Table 3.3 Inventory Summary of U.S. Wind Tunnels

	Large ≥ 6 x 9 ft		Large ≥ 4 ft		Large ≥ 4 ft		Large ≥ 3 ft		Large ≥ 2 ft		
	Subsonic		Transonic		Transonic/ Supersonic		Supersonic		Hypersonic		Totals
	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	
DOD	4	8(2)	2	3	1	2	2	10(3)	10(2)	13(6)	55(13)
NASA	11	0	5	5(1)	1	3	6	7(3)	8(1)	8	54(5)
Industry	14	5	4	3(1)	7	5(1)	2	7(3)	11(8)	10(6)	68(19)
Other Govt & Schools	14	30(2)	0	5(1)	0	2	0	13(3)	2	7(4)	73(10)
Totals	43	43(4)	11	16(3)	9	12(1)	10	37(12)	31(11)	38(16)	250(47)
	86(4)		27(3)		21(1)		47(12)		69(27)		250(47)

( ) Standby

July 1978 Survey

3.3.2 Key Parameters and Facility Capability for Aerodynamic Testing

For purely aerodynamic consideration at non-hypersonic speeds, and which are not concerned with the mechanism of combustion, several of the important parameters can be combined into two non-dimensional numbers: Mach number and Reynolds number. Transient behavior also can be expressed in normalized form.[11]

The new NTF has the ability to match most of the Reynolds number/Mach number flight envelope for subsonic (< Mach 1) and transonic flows (Mach 0.8-1.3). This new capability reases an order of magnitude Reynolds number deficiency of prior U.S. tunnels for many configurations, but a Reynolds number deficiency factor of 2 to 3 still remains for the largest advanced transport aircraft (Fig. 3.1).

The curves plotted in Figure 3.2 illustrate a similar deficiency factor of 2 to 3 for supersonic and hypersonic testing. None of the facilities can match the requirements for a large (300-ft. long) high dynamic pressure (2000 psf) hypersonic air-breathing vehicle. Such a vehicle, however, is believed to be in the relatively distant future.

3.3.3 Key Parameters and Facility Capability for Propulsion Testing

For combustion processes the reduction in variables by non-dimensionalization is much more complex than for the purely aerodynamic phenomena and requires consideration not only of the above Mach number, Reynolds number, geometry, normalized transients, attitudes, controls, etc., but also consideration of the Lewis number, Prandtl number, modified Eckert number, Stanton number, and several Damkohler numbers. The interactions of these various parameters are very complex, especially the effects of several other parameters upon the Damkohler numbers (chemical process time divided by flow or residence times). Also, fabrication of a small scale "hot" engine with rotating components such as compressors and turbines with cooled blades, is often impossible (beyond the state of the art) or has a prohibitively high cost. Consequently, most development testing is conducted with the basic key parameters of the same order as those anticipated for flight. Thus these parameters require testing facilities that can supply air at approximately engine face considerations (velocity, density, pressure, and their distribution) for "connected pipe" type testing (see Figures 3.3a and 3.3b) with flow rates equal to that of the full-sized engine. For free jet (Figure 3.4) or wind tunnel testing (i.e. non-connected pipe) of only the propulsion system, the air must be supplied at approximately atmospheric ambient or inlet-face conditions with flow rates increased to approximately 1-1/2 to 2 times that of full-size engines to minimize the effects of the air flowing past the engine inlet not extending out to infinity. The air flow required will increase even more as additional parts, such as the forebody or forebody simulators, of the flight system are included with the propulsion system (Figure 3.4).

All the facilities in Tables 3.1 and 3.2 have air flow capability of at least 45 kg/sec (100 lb/sec) except for one facility discussed in the next paragraph. High thrust military engine testing will require air flow rates over an order of magnitude greater than this lower limit. The air supply capability of three major DoD engine testing facilities is plotted in Figure 3.5. The added capability of the new ASTF is evident, and this capability could be used to fill the Mach number altitude envelope shown on Figure 3.6 if the correct flow generating nozzle(s) becomes available.

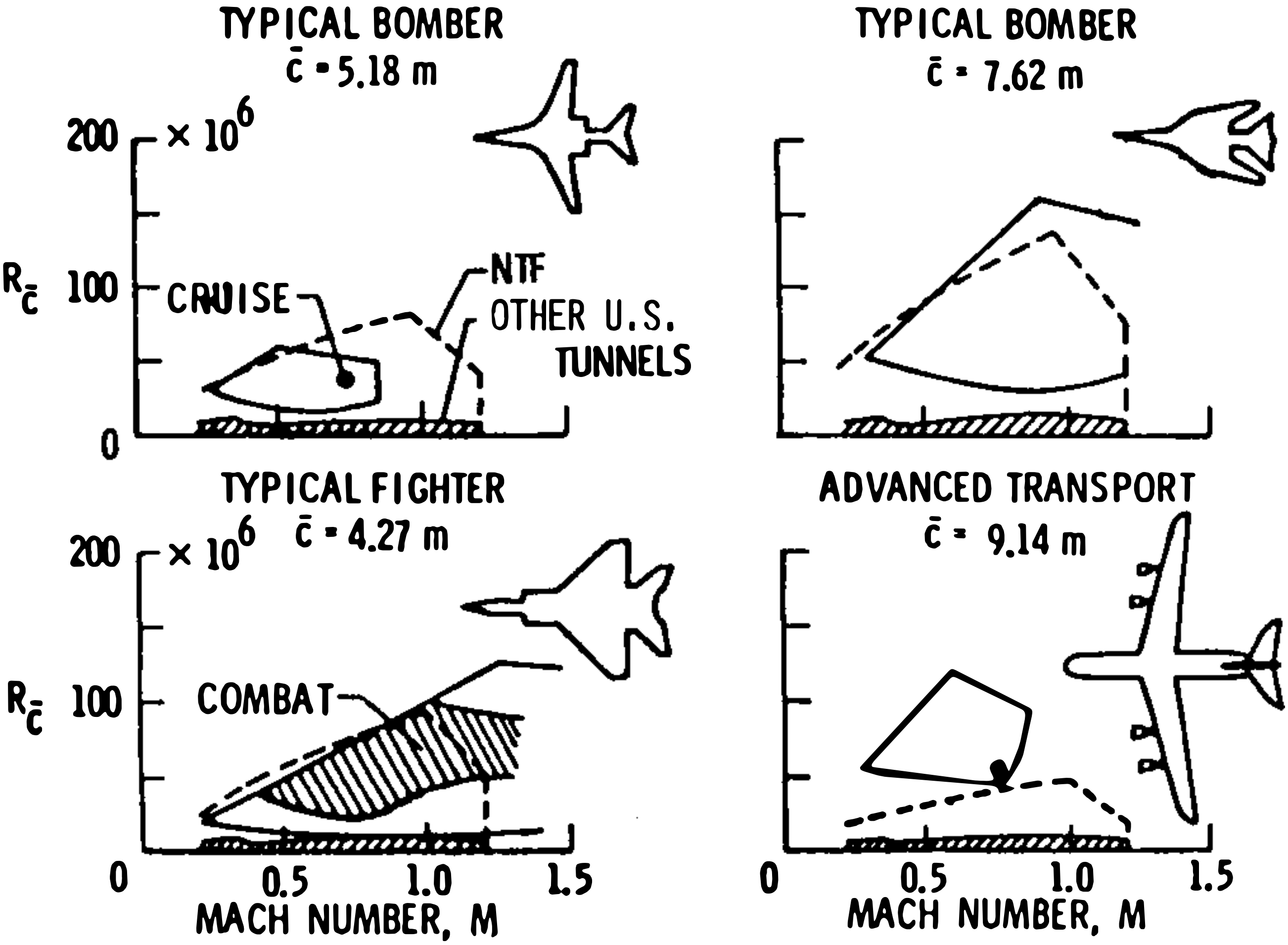

Figure 3.1 U.S. Subsonic/Transonic Wind Tunnel Capability

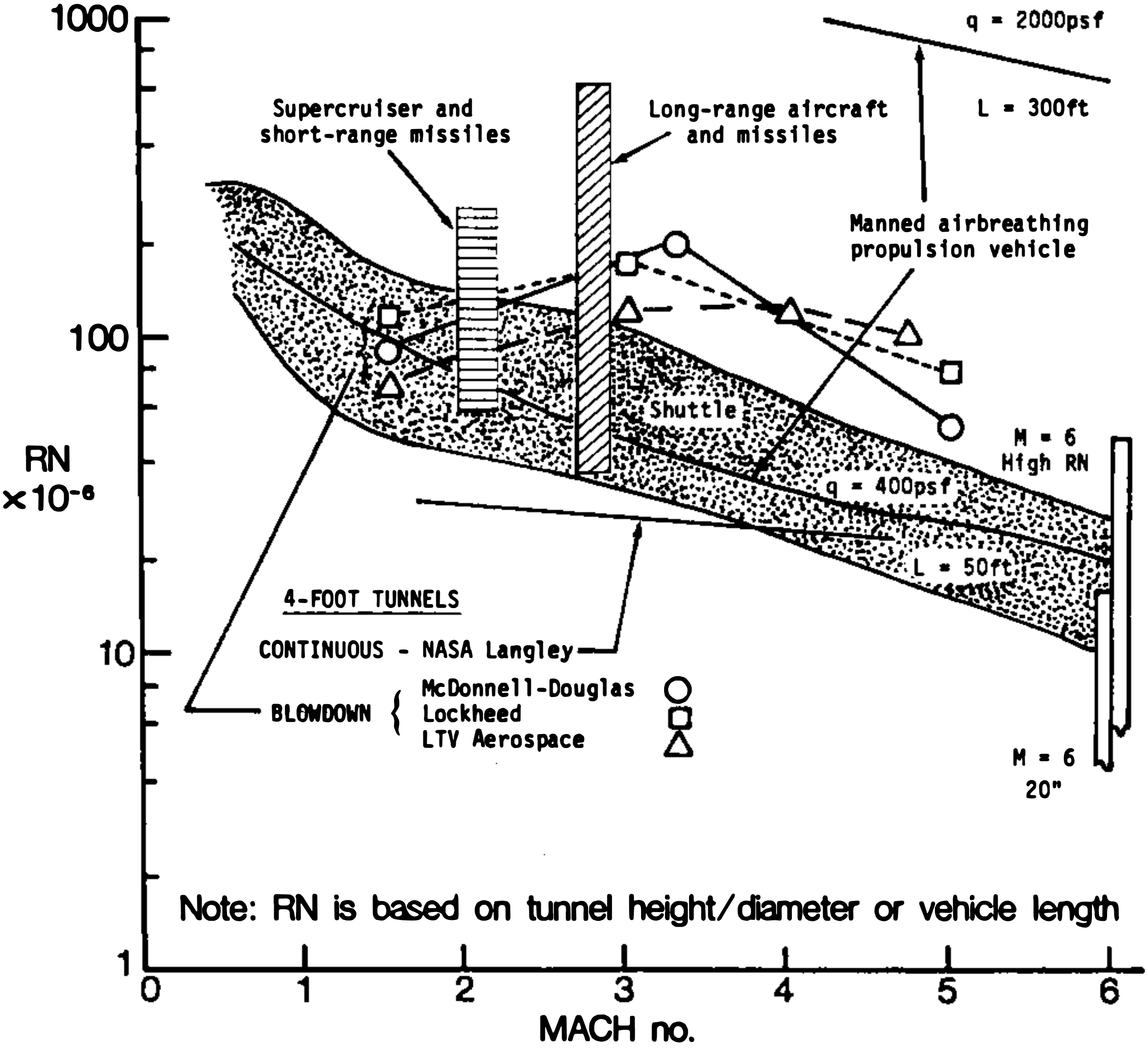

Figure 3.2 U.S. Supersonic and Low Hypersonic Wind Tunnel Capability (Air)

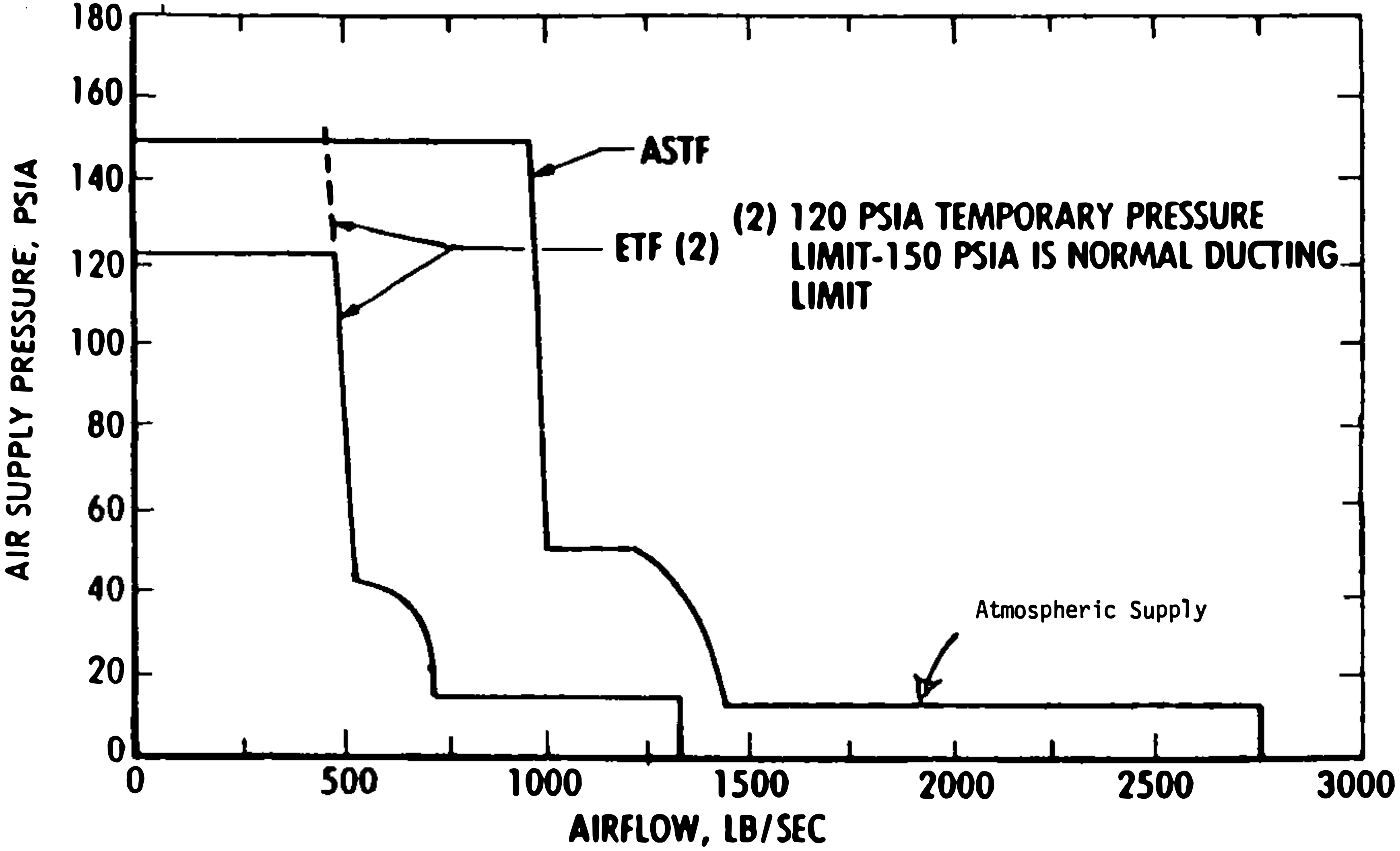

Figure 3.3a Connected Pipe Air supply Capability of Major AEDC DoD Propulsion Test Facilities

DIRECT CONNECT INSTALLATION

(VECTORING AND REVERSING EXHAUST)

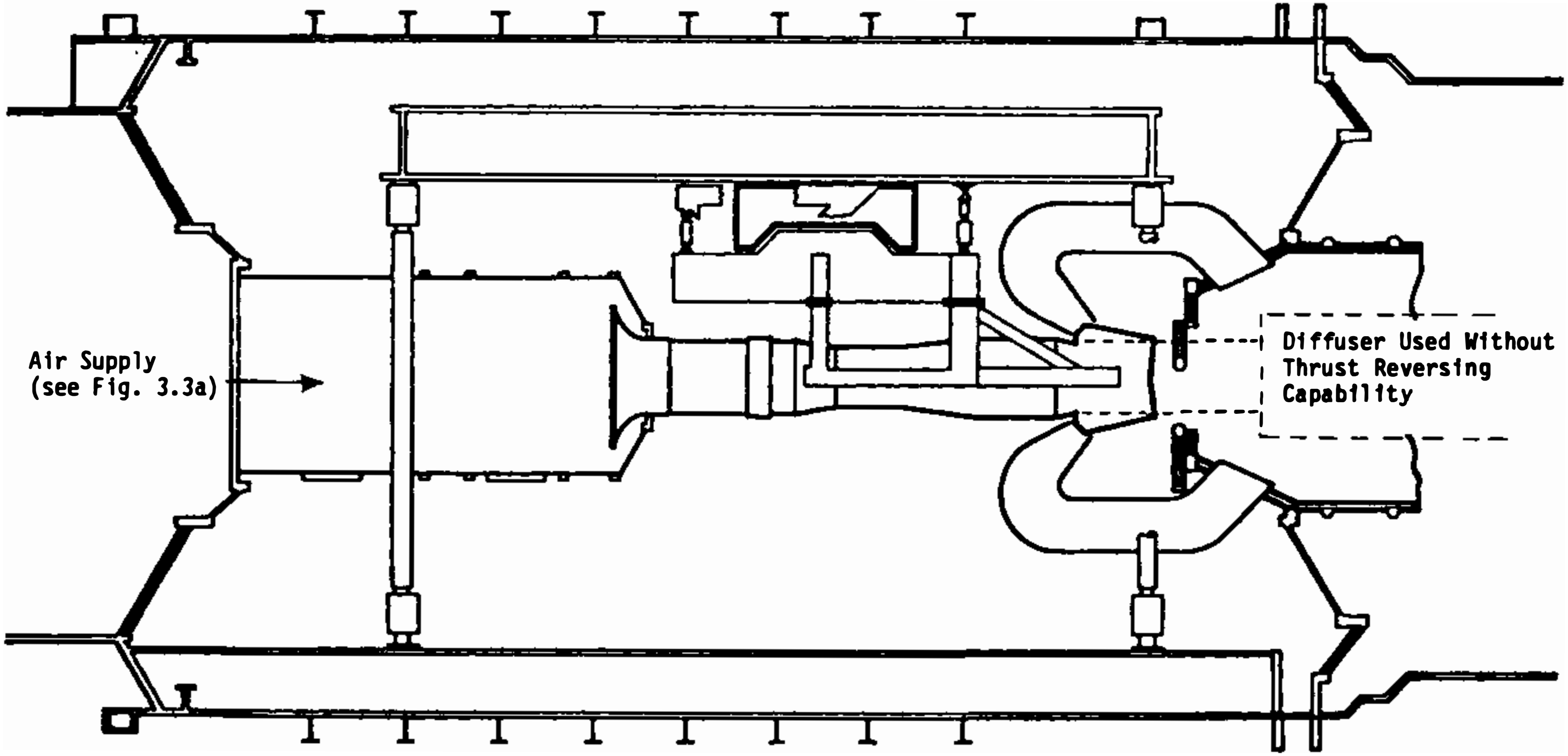

Figure 3.3b Connected Pipe Testing as Used in Engine Test Facilities

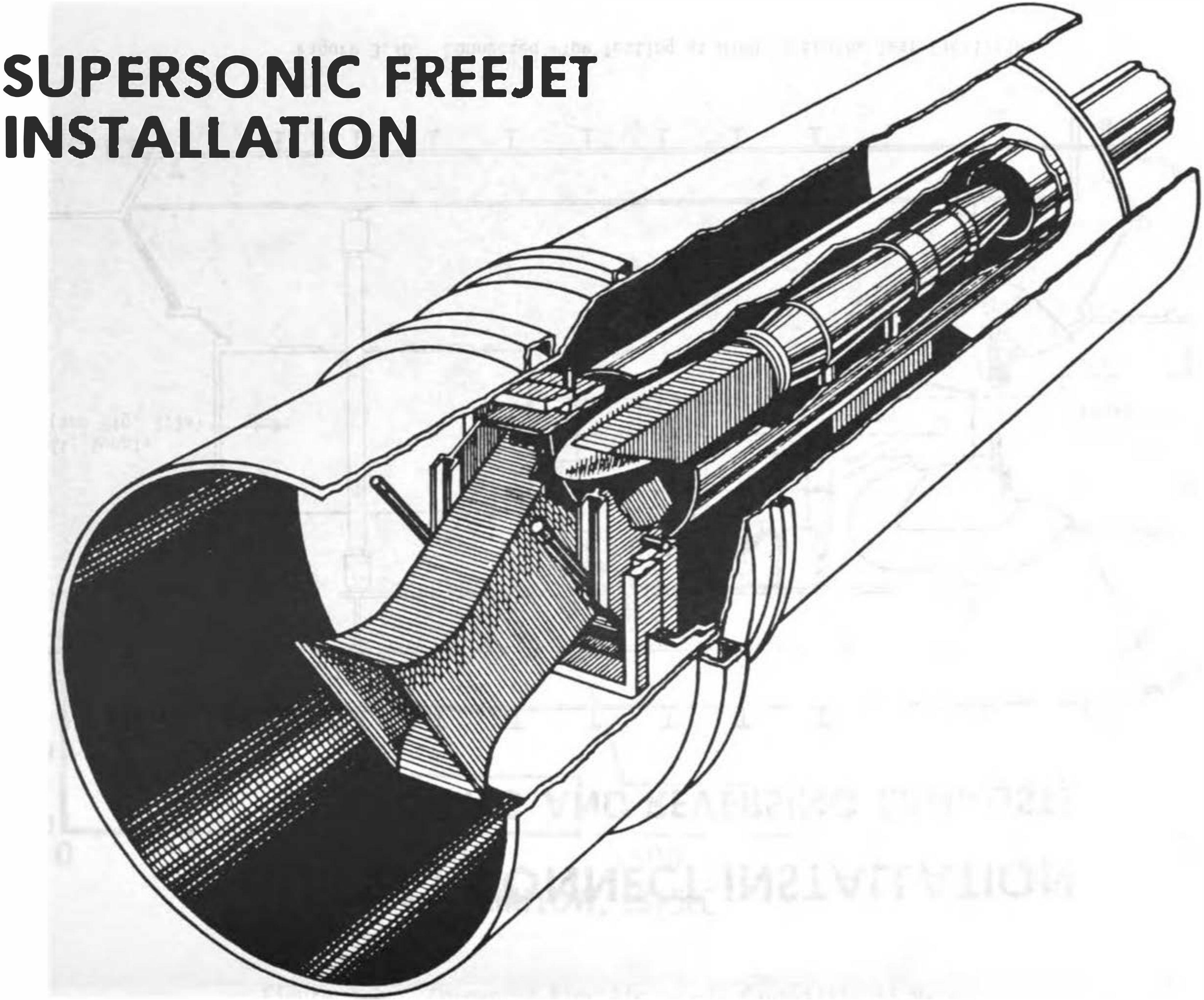

Figure 3.4 Supersonic Freejet Testing Concept for ASTF

ASTF AIR SUPPLY PERFORMANCE

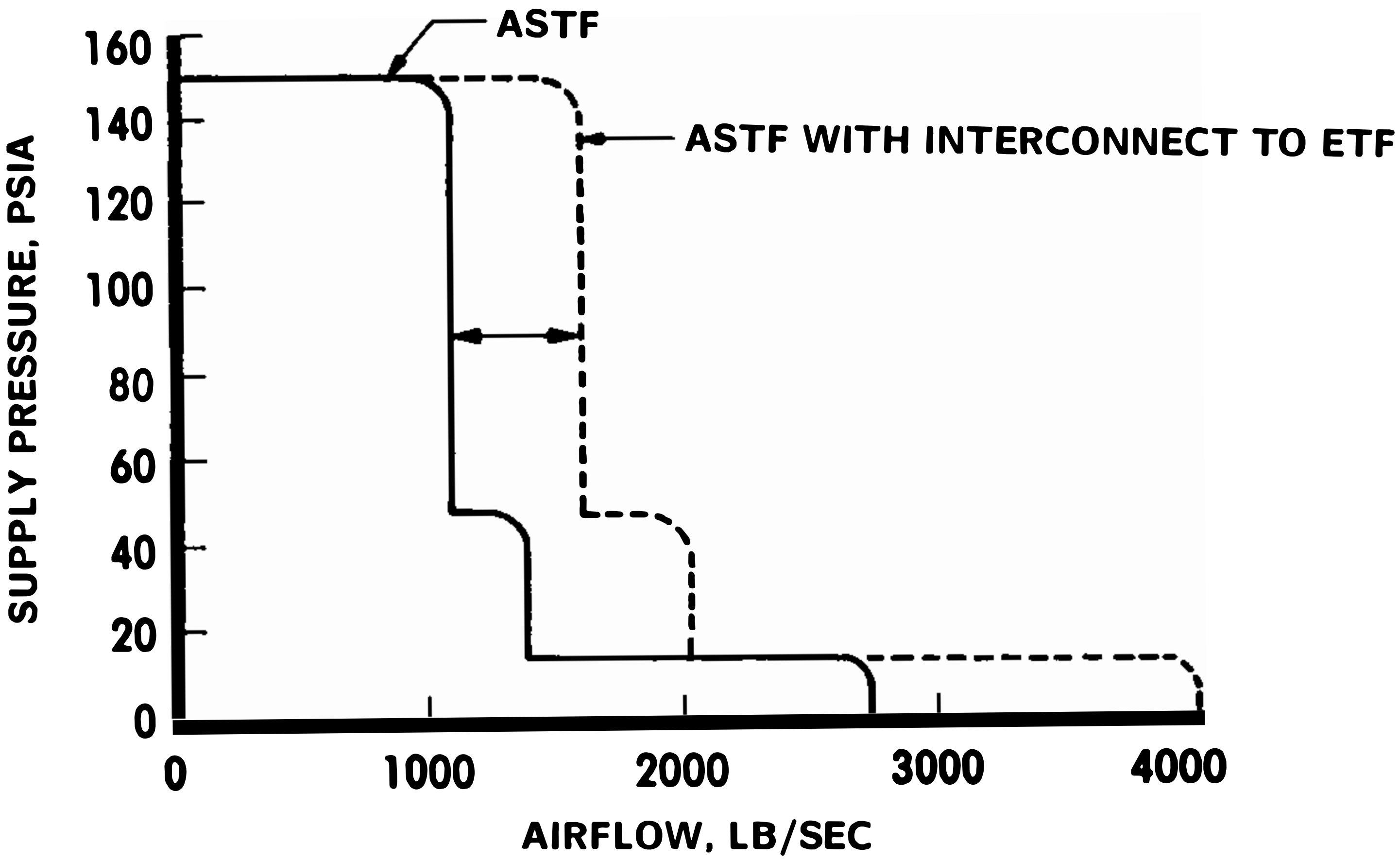

Figure 3.5 Free Jet Air Supply Capability of Major
AEDC DoD Propulsion Facilities

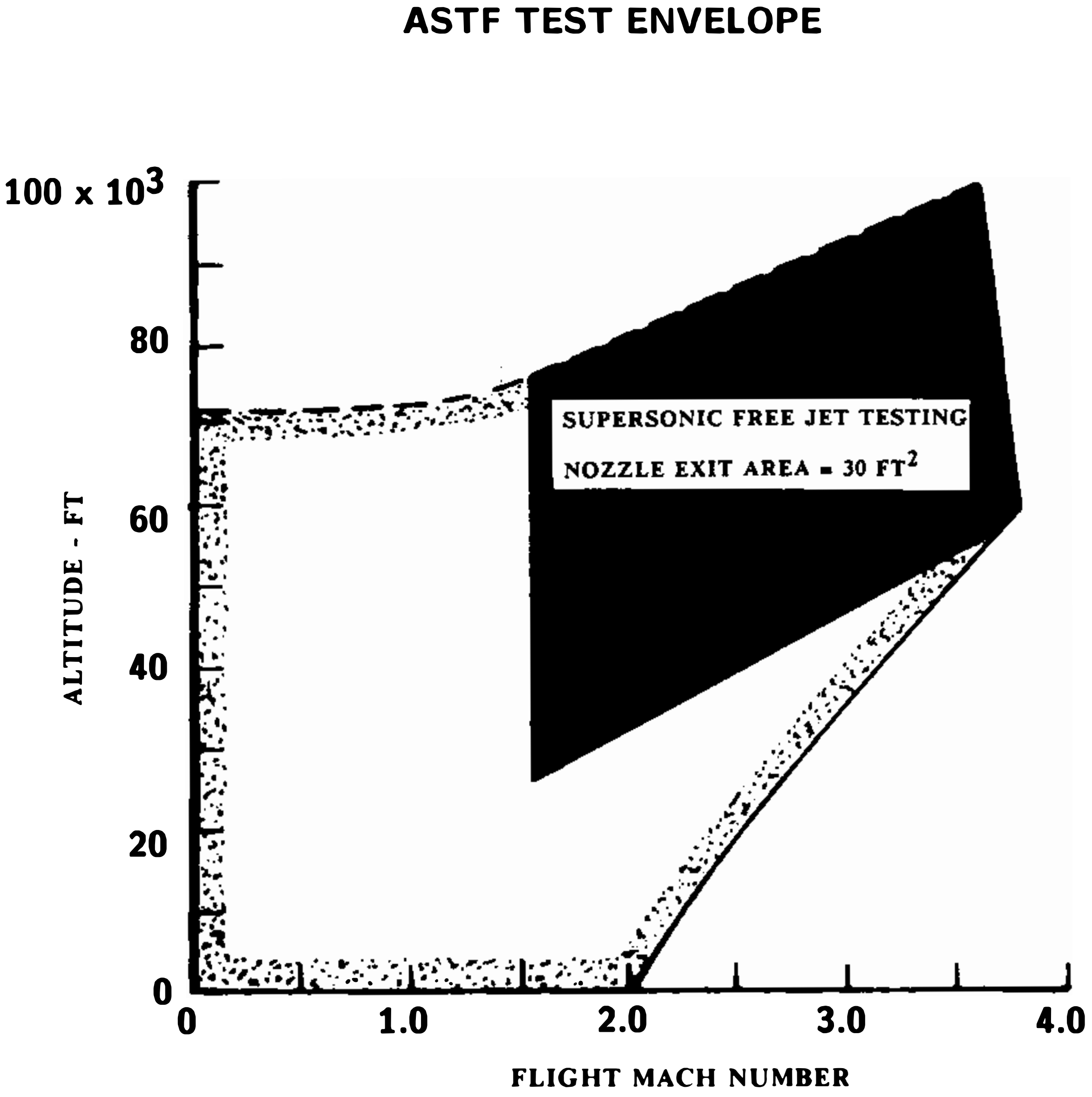

Figure 3.6 ASTF Supersonic Free Jet Test Envelope

The above exception to the air-flow requirement in Table 3.2 is the Langley Research Center Mach 7 Scramjet Test Facility (M7-SJTF). This facility is included because the major portion of the U.S. scramjet developmental work, which is so critical to the performance of the proposed TAV (also known as the National Aerospace Plane or X30A), has been done here.

The unvitiated test airflow is obtained by mixing arc-heated air with cold air in the settling chamber upstream of the nozzle. Total energy (temperature), pressure, and velocity at the scramjet model inlet can be duplicated for Mach 7 flight at an altitude of 35 km.

3.4 FACILITIES FOR GENERAL SUBSYSTEM COMPONENTS TESTING

The building block approach must be used to step-wise integrate the various components of the complete system before the eventual testing of the "all-up" weapons system. Since the task outlined by the committee considers test programs from the aircraft specific level, only a brief and definitely non-all-inclusive discussion of component integration facilities will be given in this section.

3.4.1 Basic Engine Components

The compressor-combustor-turbine components of the basic engine can be evaluated for compatibility and performance in connected pipe, altitude, and sea level facilities. Performance and surge limits usually are determined first for no air flow profile distortion at the compressor face and then for nominal (radially and circumferentially averaged) distortion. Also, for high performance military systems, localized distortions more closely approaching those anticipated at the extremes of the flight envelope are generated by screens or airjets placed upstream of the compressor. These latter distortion distributions can be determined by measurements made at the exit plane of models tested in high Reynolds number wind tunnels such as those of Figure 3.2. While such distortion generators may be valuable for steady flow performance and for the determination of the onset of instabilities, their value for determining transient behavior is very questionable. The basic engine component controls are also tested to insure satisfactory steady and transient performance at this level of integration.

3.4.2 Basic Aerodynamic Components

Grouped together here for convenience are not only the lifting components (wings, control surfaces, fuselage) but also the interconnecting elements (inlet and exhaust nozzle) to the basic engine. All of these non-engine components can be studied in cold flow wind tunnels without combustion but with various engine simulators (small turbines, airjets, etc.) installed in the engine nacelles. Such tests demonstrate the major portion of the influence of the engine on the lifting parts. These tests require Reynolds numbers approaching full-scale to ensure that viscous phenomena (such as boundary layers, separations, vortices, cross-flow, and inlet distortion) correctly reflect the phenomena found in flight. The need to accurately deflect control surfaces, to vary inlet and exhaust nozzle geometry, and to make detailed flow measurements usually require large models and the larger high Reynolds number wind tunnels (at least 4 ft.) of Table 3.3 and Figures 3.1 and 3.2.

In such cold flow wind tunnel tests the aerodynamic performance (lift, drag, moments, etc.) and control surface effectiveness throughout both the steady and transient flight envelope are determined, first for the basic airframe alone, and then with the inlet, simulated engine, and nozzle added. The flow is surveyed both at the inlet entrance and exit for use as input to much larger scale inlet and engine tests. Surveys are also conducted near the nozzle exit plane to determine the external flow boundary conditions for other tests with large scale nozzles and also to evaluate the interference effects of the simulated propulsion systems.

Inlet and nozzle pressure measurements are also used to determine the aerodynamic loads that these components must withstand. High performance systems usually require variable inlet and nozzle geometry together with variable engine bleed and bypass. Transient simulation in the cold flow wind tunnel tests is introduced to the degree permitted by model construction limits (complexity/size) and cost.

The control surface deflections for the basic aerodynamic components are found from the cold flow wind tunnel tests. The control system to generate these required deflections is determined analytically, and the resulting control inputs are subsequently verified on a non-flyable prototype using full-scale networks, actuators, and loading for both steady and transient conditions.

3.5 SPECIAL FACILITIES FOR TESTING INTEGRATED AERODYNAMIC, ENGINE, AND CONTROL COMPONENTS

Complete integration verification requires that all the key parameters of the previous sections be duplicated, including their ability to interact under both steady and transient conditions. In addition, such verification requires tests for the effects of several other phenomena including icing and rain, after-burner light-off, air restart after flameout, etc. Furthermore, all the foregoing would have to be explored throughout the entire flight envelope. Obviously, the only way to satisfy all these criteria is a flight test of the actual vehicle. Flight testing, however, is expensive (see Table 3.4) and requires construction of at least one prototype aircraft. While the increased use of prototypes has considerable support and technical merit,[1-3] prototype testing also must be based on sound simulation results that support the concepts to be used. Specialized facilities that realistically simulate or duplicate the component interactions under the correct environmental conditions can contribute significantly to overall system integration. Some of these special capability facilities are discussed below.

3.5.1 Inlet/Engine/Nozzle Duplication (NGTE Cell #4)

The National Gas Turbine Establishment Test Cell #4 (Farnborough, England) was modified and stretched to test the Olympus 593 engine for the Concorde supersonic transport. Figure 3.7 is a layout of a Concorde engine in Cell #4. The 5 ft. x 5 ft. free jet nozzle has a continuously variable speed capability from Mach 1.7 to 2.4, which in flight is the equivalent of Mach 1.8 to 2.5. The nozzle can also be programmed to produce transient pitching and yawing flows. Size restraints excluded the simultaneous testing of both engines in the Concorde pod so individual tests were run for the inboard and outboard engines with the inlet

Table 3.4 RELATIVE COST OF AERODYNAMIC TESTING

A. UNIT COSTS

Engine Test Facilities	
Current Facilities[c]	$10,000 per AOH[a]
ASTF	$20,000 per AOH
Wind Tunnels (AEDC)	
16T	$6,200 per UOH[b]
4T	$3,700
A,B,C	$8,300
Arc Tunnels	$10,000 per run
Ranges	$7,500 per shot
Flight Test	
F-15 Type Aircraft	$50,000 per hour
Large Aircraft such as B-1	$125,000 per hour

B. OVERALL TESTING COST

	(per Insertion or Test Segment)	Total Program
Typical Engine Test Program	\$3 x 10^6	(50 x 10^6)[e]
Typical Large Wind Tunnel Program	\$1 x 10^6	(20 x 10^6)[f]
Typical Flight Test Program[d]	\$10 x 10^6	(~100-300 x 10^6)[g]

C. COST IMPACT ON AIRCRAFT DEVELOPMENT PROGRAMS

Cost of Vehicle Changes Identified in Preflight Wind Tunnel Tests	Small in relation to total program cost
Cost of Vehicle Changes Identified in Flight Testing	Can be a significant fraction of total program cost

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[a] AOH denotes air on hours.

[b] UOH denotes user occupancy hours.

[c] FY89 testing costs.

[d] Typical flight test program estimate based on noted rates obtained from Edwards Air Force Base.

[e] This only represents engine test facility costs such as those of AEDC and does not include static ground tests, component testing, etc.

[f] Based on 10,000 wind tunnel hours. Not all hours are run in large facilities, such as the AEDC tunnels, so unit costs were taken at $2000 per hour.

[g] This is difficult to determine since flight tests cover many aspects of aircraft development and continue after production aircraft are in service, see Aviation Week, 11 June 1984 article on F-20 flight test program.

SUPERSONIC FREE-JET TEST OF CONCORDE POWERPLANT

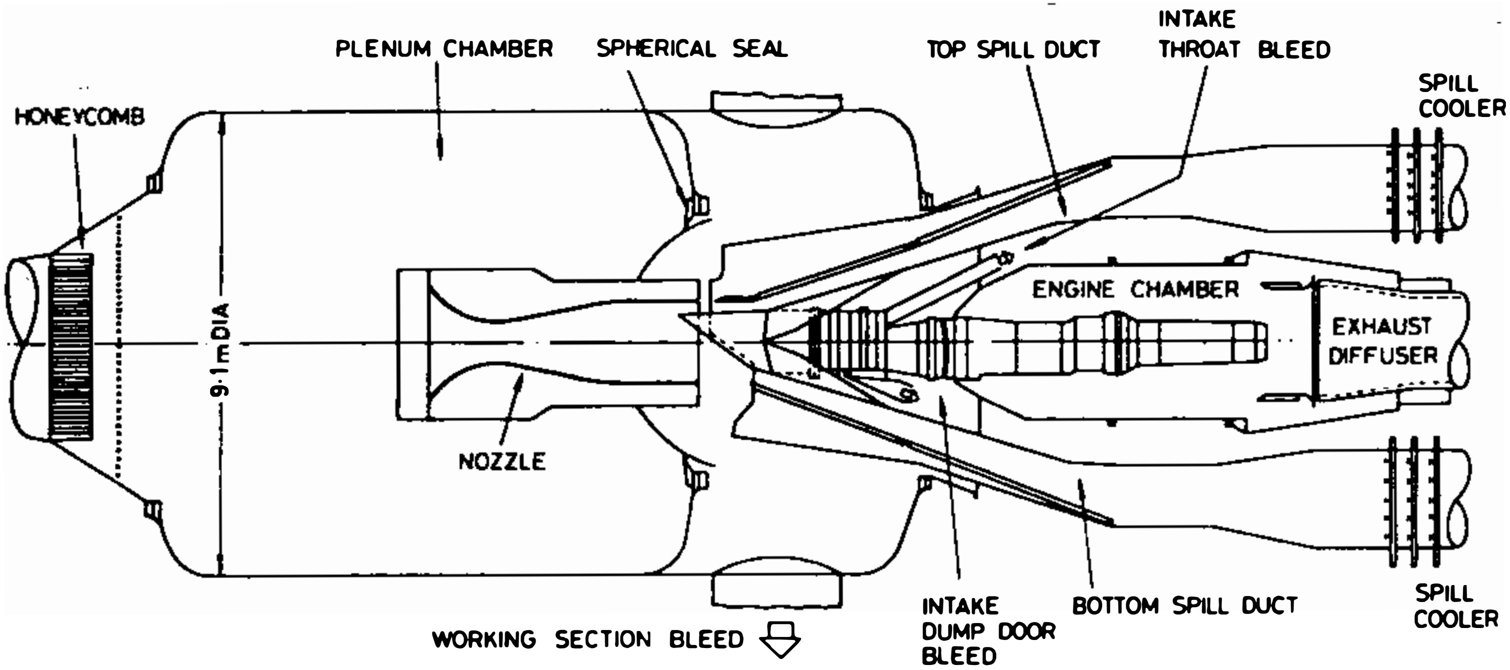


Figure 3.7 Supersonic Free-Jet Test of Concorde Powerplant

splitter plate, which normally separates the engines, in place. The pitch capability was not exercised for the Olympus 593 tests because the engine location on the underside of the wing aft of the leading edge reduced aircraft attitude effects on the airflow pitching magnitude at the inlet face. Yaw tests were run up to yaw angles of ± 4 degrees at transient rates up to 4 degrees/sec. Cell #4 has been on "standby" for several years.

3.5.2 Inlet/Engine/Nozzle Simulation (F-15 Inlet Simulation)

This simulator was specifically built to produce realistic engine face conditions.[12] The inlet simulator has the same aerodynamic shape (not necessarily geometric) as the F-15 inlet from the second ramp back to the engine face, and by using an upstream variable two-dimensional nozzle together with various trips, bleeds, and bypasses, the simulator can duplicate the important flow conditions ahead of (and aft of) the last oblique shock wave (Figure 3.8). The F-15 inlet simulator was installed with an engine and exhaust nozzle in the J-1 altitude test cell of the AEDC Engine Test Facility (Figure 3.9). This approach proved to be especially useful in determining the transient response of the inlet/engine/-nozzle system to the combined destabilizing effects of power lever transients, Reynolds number, time-variant distortions, and planar pulsations.

3.6 FACILITIES FOR SPECIFIC OPERATIONAL ASPECTS

3.6.1 Angle of Attack and Yaw

The extreme maneuverability required for many new military systems, plus the sensitivity of the propulsion system to distorted inlet flows, highlight the necessity for accurate determination of the effects of not only the absolute level of angles of attack and yaw but also of their angular rates of change. Prior sections of this report have discussed the approach of first measuring inlet or engine face flow profiles on fairly large cold flow wind tunnel models, then attempting to impose such profiles (either parametrically on average or with detailed spatial distributions) on the full-scale engine by using screens or airjets. Such an approach has some value for steady performance and in certain cases for the determination of stability limits. However, it has little value for predicting complete system performance and for certain other cases in the determination of stability limits. It also has little value for predicting system performance under transient vehicle attitude and power conditions, and it contributes practically nothing to the assessment of inlet and nozzle internal loads during engine surging or inlet buzzing. Consequently, the simulation or duplication of the inlet flow resulting from angles of attack or yaw without using screens, etc., is an important goal for system test facilities.

One approach for subsonic flow is to vary the attitude of a wing and an engine attached thereto. The NAPC Variable Attitude Test Stand (sea level) has such a capability for large angles of attack with pitch rates up to 12 degrees per second.

In supersonic tests a pitching and yawing nozzle with flexible walls for varying test Mach number would be the best general approach if cost constraints were eliminated. The presence of costing limits can force testing geared to support a

TESTING CONCEPT

INLET SIMULATOR TURBULENCE GENERATOR

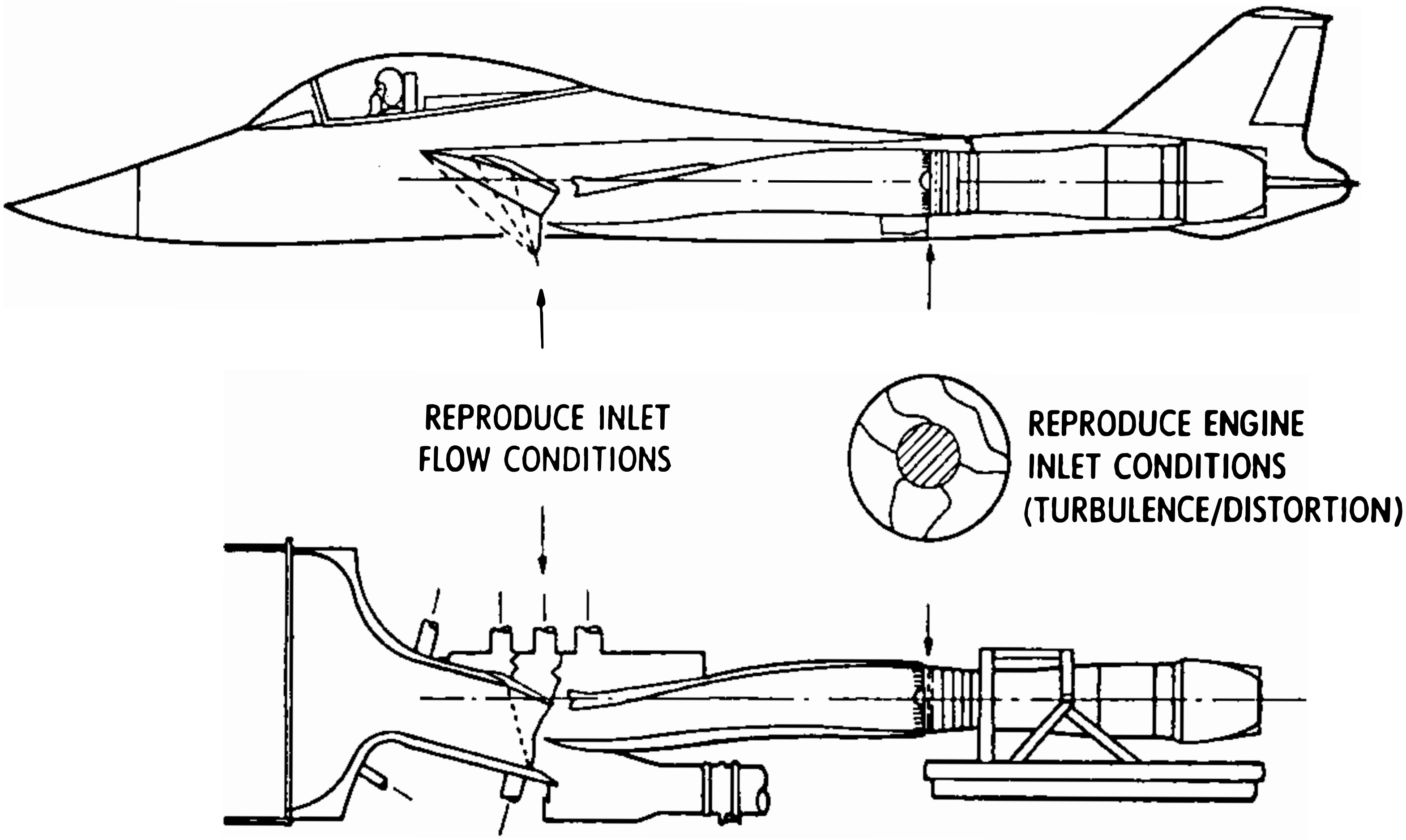


Figure 3.8 F-15 Inlet Simulator Concept

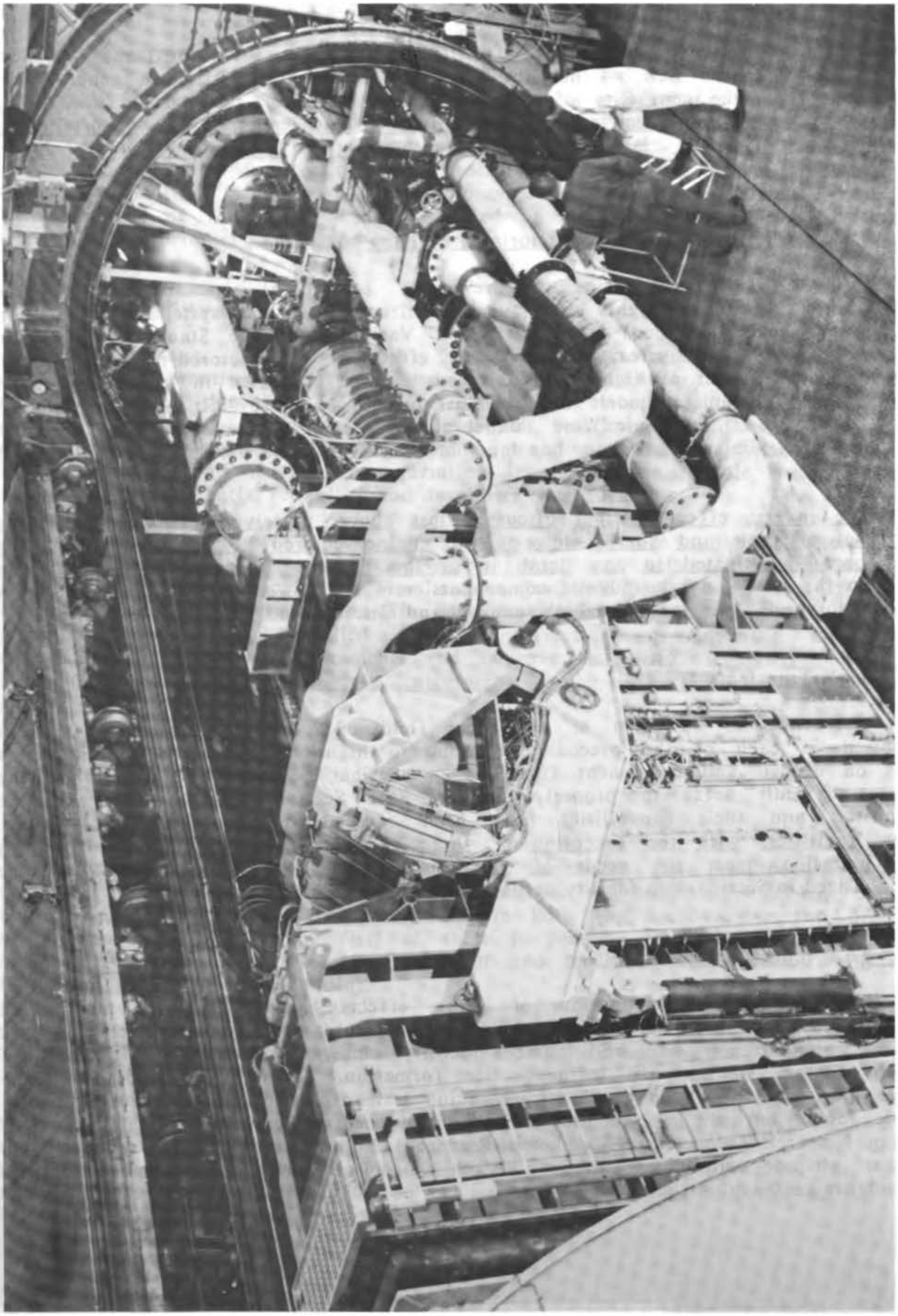


Figure 3.9 Full Scale Inlet Simulator Installed in Test Car S-1

particular program to a specialized facility such as the F-15 apparatus (see Section 3.5.2). NGTE Cell #4 has the above desired characteristics in general, but does not have the capability of varying the symmetry of the nozzle flow. The ability to generate a specified asymmetric nozzle flow can be very important for systems operating at large incidences without the "guide-vane" effect of a closely adjacent large wing.

3.6.2 Exhaust Nozzle Thrust Vectoring/Reversing

In-flight thrust vectoring or reversing (or both) is another probable contributor to future highly maneuverable airborne weapon systems (See Section 2.0). Sea level test beds like the NAPC Variable Attitude Stand are available for very low speed system testing. The effect of the vectored/reversing nozzle on the aerodynamics at high subsonic speeds can be evaluated in "cold flow" wind tunnels using complete models with exhaust nozzles blown by air or other selected gases. The 16-ft. Transonic Wind Tunnel at NASA-Langley has often been used for such tests. Similar tests can be done in several of the larger supersonic wind tunnels.

The inverse effect to that discussed just above, namely the influence of the external airframe and nozzle flow on the engine/vectored nozzle combination, has not been investigated to any depth in ground facilities. Static tests have been run on the ADEN nozzle (50% of components were flight weight) in combination with the prototype F-18 engine under both sea level and altitude conditions.

3.6.3 Transients

The timewise variation of the flow field and engine operation has been stressed in each of the preceding sections to highlight the strong influence it has on overall and component functions. Transient behavior also is one of the more difficult areas to properly simulate (see Section 3.5.1). The available facilities and their capabilities have been covered in the preceding sections. Few facilities, with the exception of those specifically constructed for a given configuration, meet the needs of emerging flight technologies. This will be emphasized in Section 4 on facility needs and emerging capabilities.

3.6.4 Icing and Rain Ingestion

The accurate determination of icing effects usually requires testing at nearly full-scale with true ambient air temperature, density, and velocity, and with water droplet size and number density closely approximated since all of these factors significantly influence ice formation.[13] The J-1 and J-2 facilities of AEDC have the capability for icing tests over a wide air speed and altitude range, but are mainly used at zero incidence angles. A dedicated 6' x 9' Icing Research Tunnel at NASA-Lewis Research Center has been used frequently for lower altitude subsonic testing (< Mach .4) of inlet/airframe combinations at incidence angles other than zero.

3.6.5 Controls

Highly integrated propulsion and flight control systems are essential if the full potential of these synergistic technologies are to be exploited. Facilities exist for testing the digital flight control systems and, separately, the engine control systems, and for testing inlet control systems. However, there are currently no facilities where the fully integrated system on the airplane can be tested. Some of this need can be satisfied by a test facility able to integrate system testing during engine ground runs.

3.6.6 Durability and Reliability

The importance of both durability and reliability to the success of any aircraft program, whether military or commercial is well known. Normal testing of this kind is not done in the type of aerodynamic simulation facilities discussed in this section but typically in sea level test stands. Regardless, it is necessary to examine the response of the engine and airframe to dynamic transient loads, pressures, and temperatures variation to determine probable problem areas that may lead to potential reliability and durability consequences.

Inlet buzz, compressor stalls, and nozzle vibration are typical problems, the discovery of which during early integrated testing can help avoid later reliability and durability difficulties. Simultaneous installed performance data are useful in determining possible trade-offs between performance and durability. Thus, meeting or surpassing installed thrust specifications or lowering anticipated drag can reduce power requirements and improve reliability. <u>This type of testing, however, requires full-scale integrated testing of the inlet/engine/nozzle and airframe</u>.

3.7 PROPOSED AND NEW FACILITIES

3.7.1 NASA Facilities

Three major additions to NASA's testing capability have surfaced since the compilation of Tables 3.1-3.3. These facilities (described in 3.7.1.1, 3.7.1.2, and 3.7.1.3, respectively) can greatly improve both the aerodynamic and propulsion testing envelopes. The first of these is nearing completion of the checkout/shakedown phase, the second is funded and in the design phase, while the third is proposed for future funding.

3.7.1.1 80' x 120' and 40' x 80' Subsonic Wind Tunnel (Ames Research Center)

Repowering of the original 40' x 80' facility and the addition of the new 80' x 120' test section have greatly enhanced NASA's capability for large scale subsonic testing. Both units operate at atmospheric stagnation pressure. The 40' x 80' test section, with speeds up to 500 ft/sec ($M = 0.45$), is scheduled for operational status during FY86. The 80' x 120' test section, with speeds up to 170 ft/sec ($M = 0.15$), will follow a year later.

3.7.1.2 8' High Temperature Tunnel (Langley Research Center)

A large increase to the existing capability of the 8' HTT was funded for approximately $14 million in the NASA FY85 appropriation. The principal foci of this improved facility will be the structural and combustion testing of scramjet engine components and complete engine modules. Operation is targeted for 1987.

The test gas will duplicate the oxygen content and total enthalpy of air for Mach 4, 5, and 7 atmospheric flight. This test gas is obtained by mixing the combustion products of oxygen-enriched air and methane with varying amounts of additional cold air. The design limits for the facility range from a gas flow of 2900 lb/sec at 1640° R to 860 lb/sec at 4000° R. The usable test core of the 8' diameter test section is predicted to have a diameter of approximately 4 ft. Facility test run times are 3 to 4 minutes. The facility will initially have only a cooled hydrogen fuel supply to test hydrogen-burning scramjets.

3.7.1.3 Altitude Wind Tunnel (Lewis Research Center)

A major upgrading of the AWT is being proposed by Lewis Research Center but to date no project approval has been obtained. The proposed facility would provide the ability to (a) test large high speed propellers and their auxiliary equipment, and (b) test fairly large aircraft/propulsion sections under icing and heavy rain conditions.

The test section would be slotted with an octagonal cross-section of 20-ft. span. This subsonic wind tunnel would cover the altitude range from nearly sea level up to 55,000 ft. Preliminary estimates indicate that this facility could be brought on line approximately six years after project approval.

4.0 FACILITY REQUIREMENTS FOR FUTURE AIRCRAFT AND PROPULSION SYSTEM DEVELOPMENT

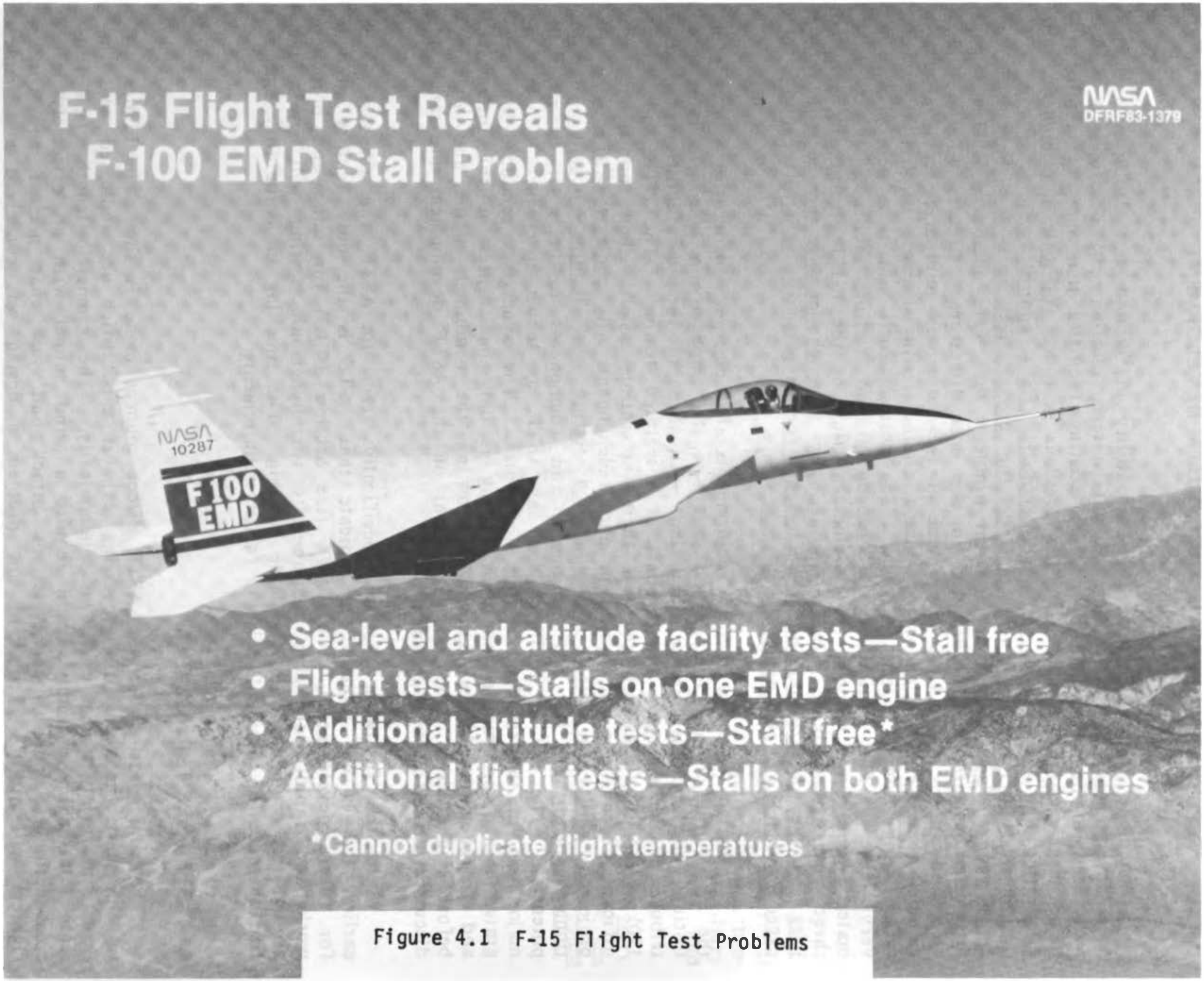
Technology trends (Section 2.0) and ability of ground test facilities to support development of new military flight systems (Section 3.0) describe the tasks that need to be accomplished and the existing facilities that may be applied to those tasks. As pointed out in the previous sections, full-scale development and integration of the new propulsion/inlet/nozzle/flight control systems is one of the most significant challenges to face the ground test facilities community in many years. Past aircraft development problems that were uncovered during flight test programs are well documented in the open literature. Figures 4.1, 4.2a and 4.2b, and Tables 4.1 and 4.2 show some of the more well publicized technical deficiencies that were not uncovered during ground testing because of limitations of the existing ground testing facilities. The ensuing costs and time delays can be very large. The availability of proper ground testing facilities, it is estimated, would have reduced the development time of the F-111 aircraft by one to three years (see Figure 4.2a). Another key area challenging the current facilities is the Aero/Propulsion development for hypersonic vehicles capable of exceeding Mach 3 to near orbital Mach range.

The major thrust in facility requirements that emerged during this study from the standpoint of use, timing, and cost was the emphasis on full-scale integrated testing and Reynolds number simulation. All three of the new facilities can contribute to the emerging requirements of integrated testing. The NTF and 80' x 120' NASA facilities can perform their integration tasks without additional significant expenditures for equipment and development. By contrast, ASTF with its projected ability to allow for integrated testing will require substantial additional expenditures for test equipment and components to bring it to its full potential. The use of facilities such as ASTF, as shown in Figure 4.3, fills a major gap in the standard testing procedures. The synergism produced by integrated design procedures and their testing is only one aspect of the interactive and feedback possiblities achieved by testing the combined engine and airframe before flight tests. The most important of the ASTF development programs are discussed in the following sections.

While the following sections specifically refer to ASTF for reasons given earlier, this is not intended to indicate that ASTF is the only facility needed for future developments. The AWT (see Section 3.7.1.3) for icing and propeller work and rapidly emerging requirements for hypersonic testing will strain the ground test community and available funding. The time lag in availability emphasizes the need for continual review of facility requirements.

4.1 ASTF FREE JET NOZZLES

The configuration for the ASTF direct connect mode is shown in Figure 4.4. In this case, vectoring and reversing exhaust capabilities are indicated and the thrust measuring system is shown schematically. The geometric length of a full-scale inlet/engine assembly would require a wind tunnel with an extremely large cross-section to obtain the angles of attack and yaw that present and future fighters will attain. To avoid this problem a design was conceived and implemented in the original ASTF configuration in which the angles would be obtained by means of a free jet concept. This allows a flow facility with a smaller cross



F-15 Flight Test Reveals F-100 EMD Stall Problem

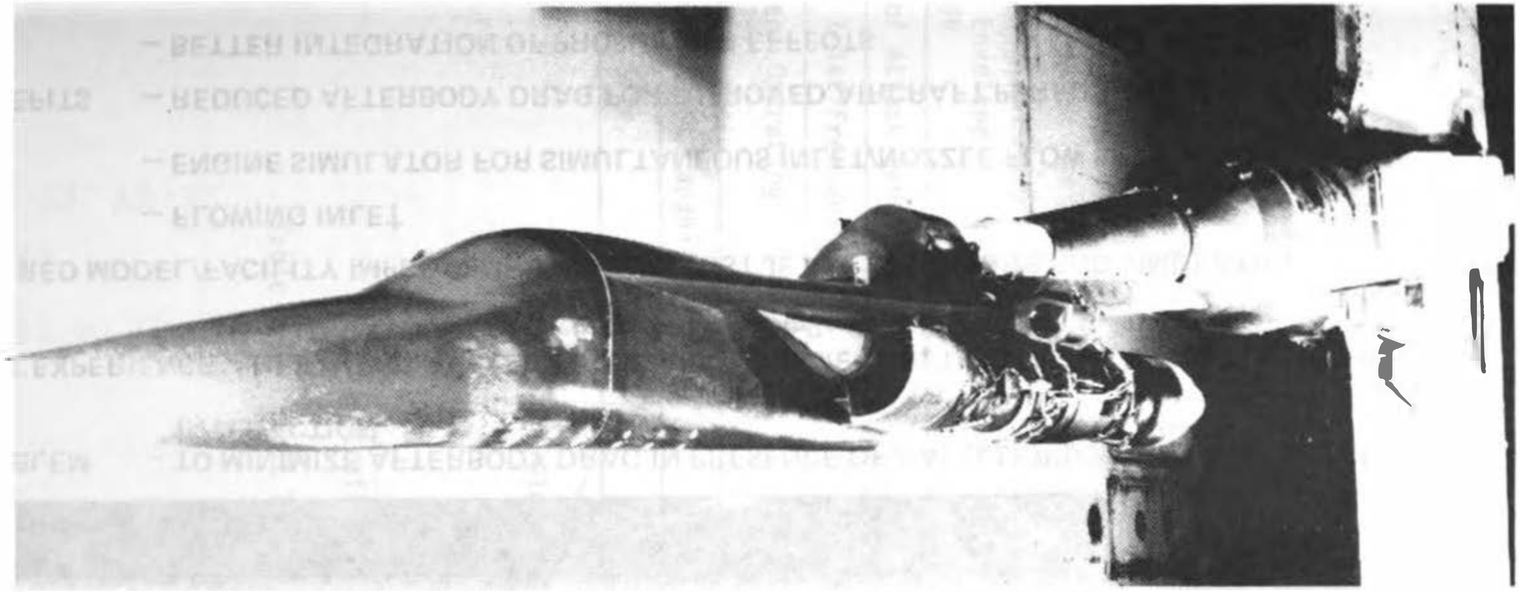
NASA
DFRF83-1379

- Sea-level and altitude facility tests—Stall free
- Flight tests—Stalls on one EMD engine
- Additional altitude tests—Stall free*
- Additional flight tests—Stalls on both EMD engines

*Cannot duplicate flight temperatures

Figure 4.1 F-15 Flight Test Problems

F-111 EXPERIENCE



PROBLEM – AUGMENTED TURBO FAN/INLET COMPATIBILITY

INITIAL AIRCRAFT OPERATION REVEALED DISTORTION & AFTERBURNER LIGHT-OFF PRESSURE SPIKES CAUSED ENGINE FAN & COMPRESSOR STALLS

- ✓ Engine Stability Characteristics Not Defined for Transitory Effects
- ✓ Inlet Dynamic Characteristics Not Defined in Early Tests

TEST EXPERIENCE – HIGH-RESPONSE INLET MULTI-PURPOSE PRESSURE INSTRUMENTATION DEVELOPED TO EVALUATE & SOLVE INTERFACE PROBLEM FOR ENGINE & INLET

DESIRED TEST FACILITY IMPROVEMENTS – TRANSIENT ALTITUDE, MACH NUMBER, ENGINE AIRFLOW CAPABILITY WITH HIGH-RESPONSE PRESSURE DATA SYSTEM FOR INSTANTANEOUS DISTORTION LEVEL DETERMINATION

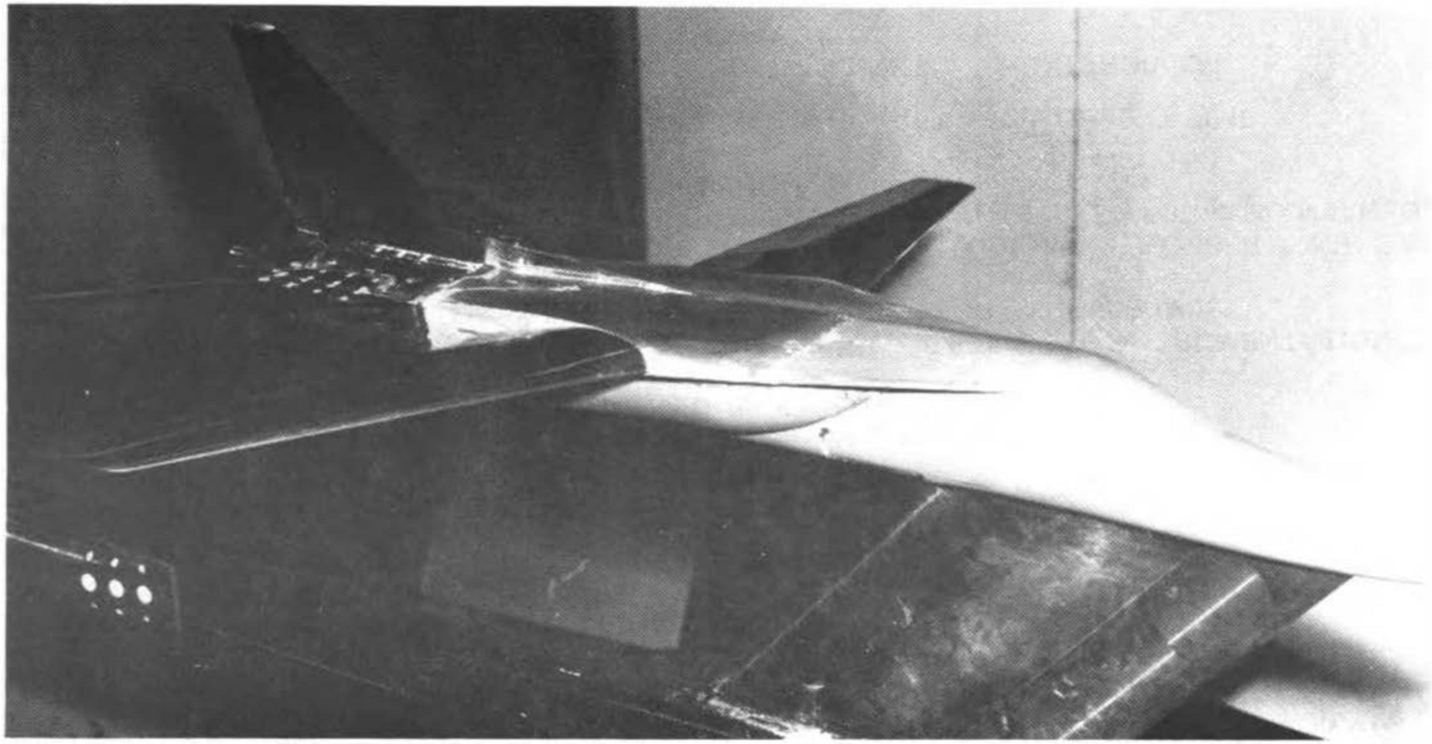
BENEFITS – ONE TO THREE YEAR REDUCTION IN AIRCRAFT DEVELOPMENT TIME

– REDUCTION/ELIMINATION OF INLET/ENGINE MATCHING PROBLEM

B78982A

Figure 4.2a F-111 Development Problems and Solution Methodologies

F-111 EXPERIENCE



PROBLEM – TO MINIMIZE AFTERBODY DRAG IN PRESENCE OF NACELLE/FUSELAGE/BASE (NFB) INTERACTION

TEST EXPERIENCE – NFB MODEL TESTED TO OBTAIN INCREMENT BETWEEN FORCE MODEL AND AIRPLANE WITH FLOWING NOZZLE (Decomposition of H_2O_2 to Simulate Exhaust Jet)

DESIRED MODEL/FACILITY IMPROVEMENTS – EXHAUST JET TEMPERATURE AND SIMULATION

– FLOWING INLET†

– ENGINE SIMULATOR FOR SIMULTANEOUS INLET/NOZZLE FLOW SIMULATION

BENEFITS – REDUCED AFTERBODY DRAG FOR IMPROVED AIRCRAFT PERFORMANCE

– BETTER INTEGRATION OF PROPULSION EFFECTS

B78983

Figure 4.2b F-111 Development Problems and Solution Methodologies

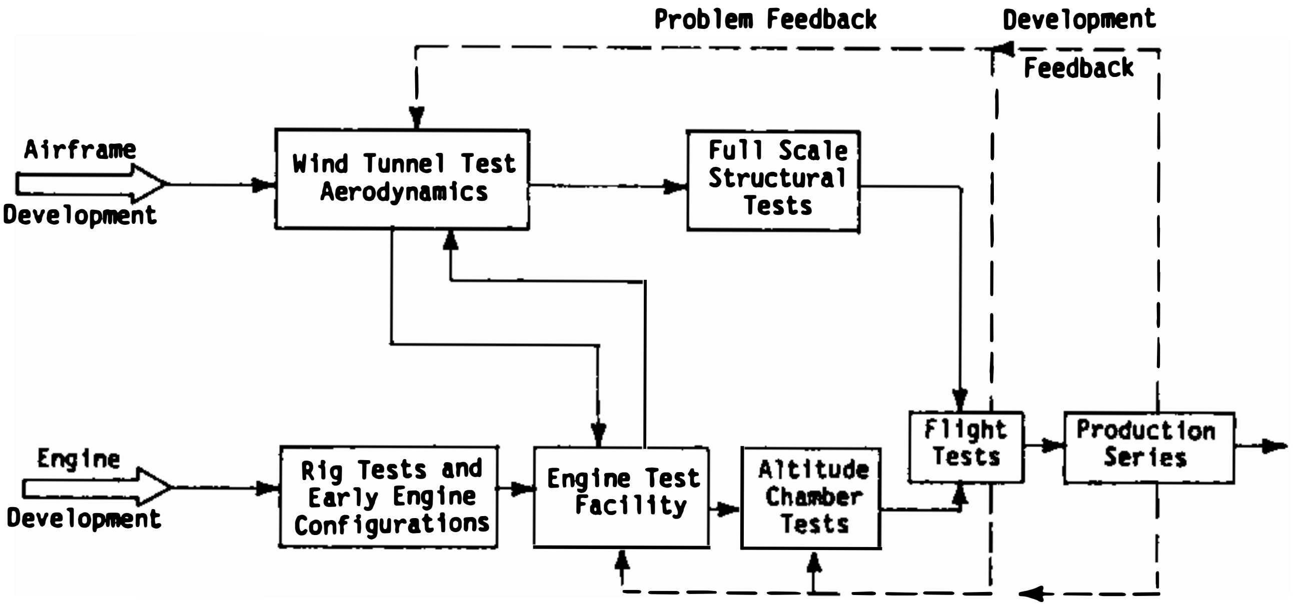
Existing Ground Test Facility Deficiencies	Low Power Compressor Stall	Engine Trim Altitude Effect	Augmentor Mis-light	Separation/Cracking of Nozzle Segment	Short Engine Life	High Power Compressor Stall	Nozzle Transonic Performance	Low Cycle Turbine Life	Inlet Icing	High Specific Fuel Consumption	Low Net Thrust
Flight Envelope Coverage	X	X	X			X		X		X	
Angle of Attack Range	X	X				X				X	
Engine Inlet/Free Jet	X	X	X			X			X	X	
Transient Operating Capability	X	X			X	X				X	
Airflow/Exhaust Capability				X			X				
Test Cell Size											X
	F-15/F100				F111/TF30 A7/TF41				F16/F100	B1/F101	C5/TF39

Aircraft/Engine Experiencing Flight Test Problems

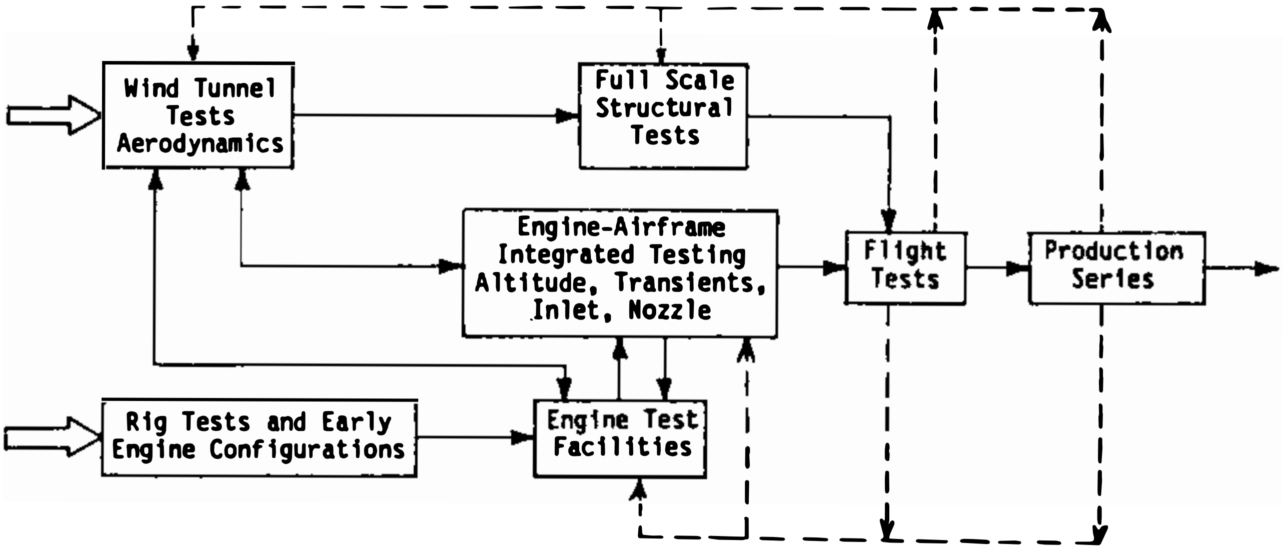
Table 4.1 Flight Test Problems of Various Engine Combinations

- **TEMPERATURE SENSOR HYSTERESIS**
  - F110 Powered F-16
  - F110 Powered F-14
  - F-18
- **INLET BUZZ ONSET**
  - F110 Powered F-16
  - F-18
- **INLET "PURR" (SUBSONIC)**
  - F110 Powered F-14
- **INLET RAMP BLEED**
  - F-18
  - SR-71, YF-12
- **AFTERBURNER**
  - Screech }
  - Lightoff at Limits } F-16
- **EXTERNAL NOZZLE FLAP FAILURES**
  - B-1
  - F-18
- **ENGINE STALLS**
  - F-111
  - F-15

Table 4.2 Some Flight Test Incidents



(a) Standard Test Proceedings



(b) Integrated Test Procedures

Figure 4.3 Procedures Required for Integrated Ground Testing

DIRECT CONNECT INSTALLATION

(VECTORING AND REVERSING EXHAUST)

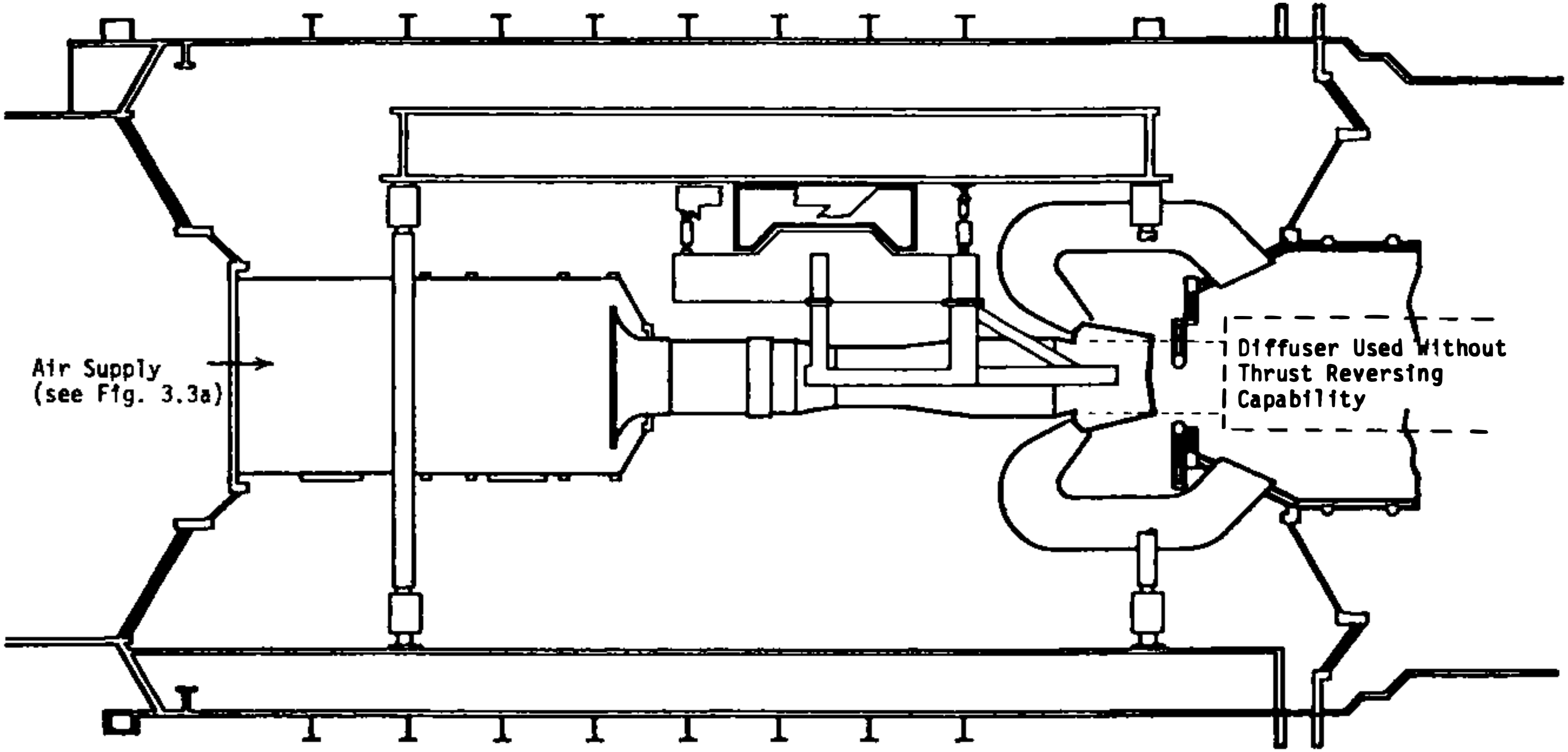


Figure 4.4 Connected Pipe Testing as Used in Engine Test Facilities

section. ASTF is the only facility that provides both airflow and size potential for testing with angle of attack, yaw, and transients. Figure 4.5 illustrates the concept of using an articulating free jet nozzle to vary the angle of attack and yaw. A 1/10 scale pilot model of the ASTF with a free jet nozzle and small-scale aircraft models has been tested with reasonable success, including the simulation of inlet conditions at angle of attack and yaw.[14] Figures 4.6a and 4.6b show the concept of using a forebody simulator for the free jet testing in ASTF. The simulated forebody is based on empirical wind tunnel data and CFD studies and designed to produce the correct aerodynamic flow field at the inlet that is experienced in full-scale flight conditions.

The current design goals for the free jet are presented in Table 4.3 and the operating envelope shown by Figures 4.7 and 4.8. While the transient rate goals may not cover all current and anticipated values, they are a major step forward in test capability. Realization of these goals should provide the ability to simulate full-scale inlet flow characteristics for steady state, transient, and high angle of attack conditions.

Test requirements for operation in the steady state flight corridor, and extended capabilities for ramjet propulsion systems and advanced tactical missiles are shown in Figure 4.9. The performance of ASTF compared with the 8' HTT facility and the Aeronautics and Propulsion Test Unit (APTU) facilities is also shown. The free jet operation of the facility is of prime importance if adequate simulation of installed engine performance is to be obtained. While relatively small inlet forebody models can be tested to create the proper flow entering the inlet, the flight Reynolds number simulation is not achieved. On the other hand, large scale isolated inlets can be tested, but non-uniform flow fields found in flight will not be duplicated.[15] The current deficiencies in propulsion test facilities can be met largely with a free jet installation in the ASTF.

4.2 ASTF ABILITY FOR TESTING THRUST VECTORING AND REVERSING

The ability of future fighters to vector their thrust and reverse it in flight for super control and maneuverability has been covered in Section 2.0 and by Reference 3. While the general aerodynamic effects on the aircraft may be evaluated in current facilities, it is believed to be essential that the full-scale hardware nozzle system and local afterbody effects be evaluated to minimize flight development time and costs. The ASTF can provide this testing capability with the exhaust system illustrated by Figure 4.10. This configuration will provide near full-scale flow conditions on the aft end of the nacelles/nozzles/-empennage for supersonic flight conditions.

4.3 ASTF COUPLING TO EXISTING AEDC AIR SUPPLY SYSTEMS

Inspection of the operating performance curve, Figure 4.11, indicates that a significant increase in test capability especially in the transonic test regime can be made available by connecting the ASTF system into the existing AEDC air supply system. This would provide maximum use of the test complex air system at AEDC and should be undertaken. While current studies do not indicate a strong need for connection of ASTF to the overall AEDC vacuum system, future needs for this connection are expected and should be planned for future implementation.

SUPERSONIC FREEJET INSTALLATION

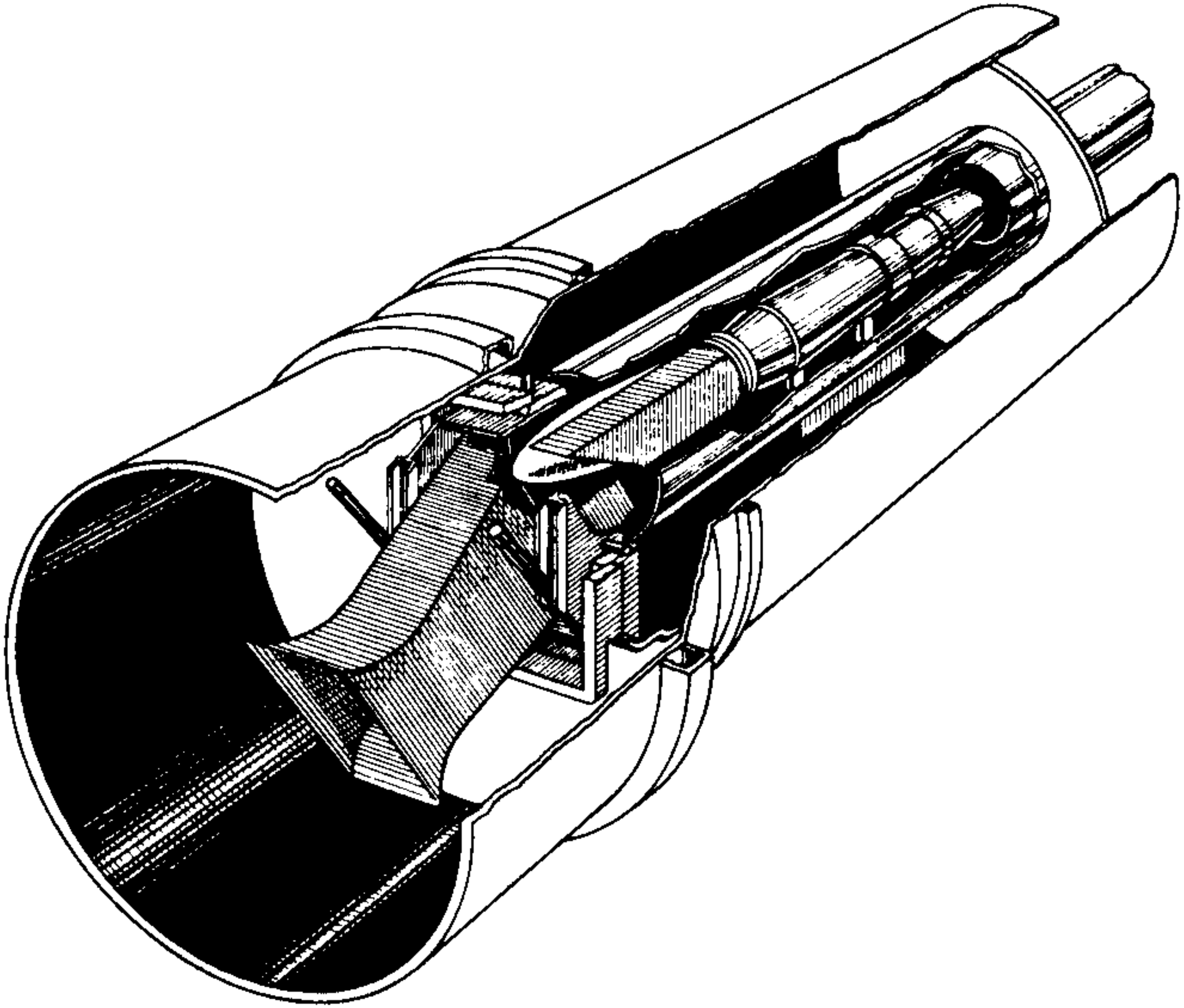
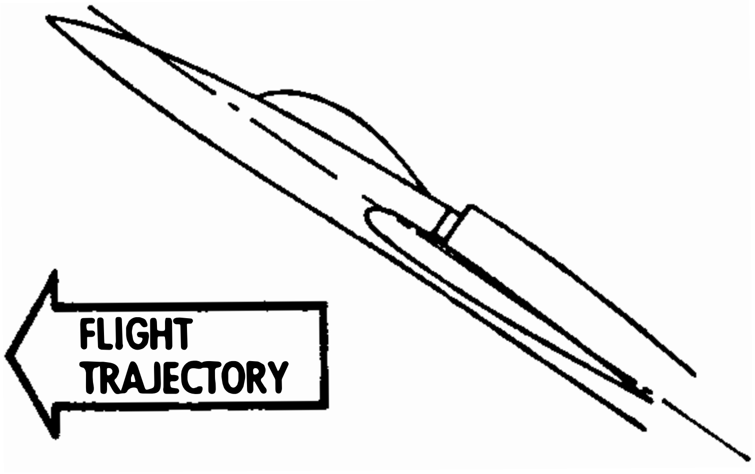


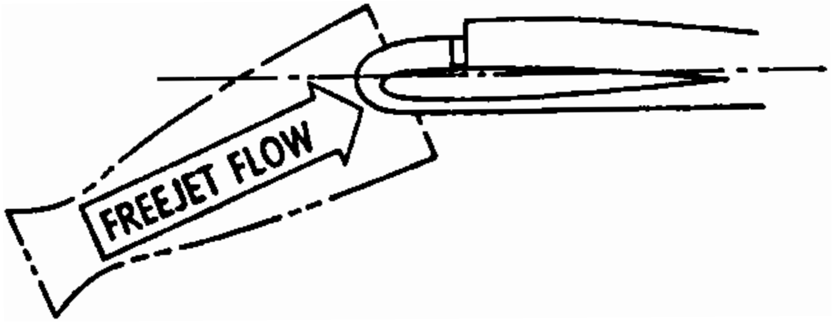
Figure 4.5 Supersonic Freejet Testing Concept for ASTF

FULL SCALE FOREBODY/INLET/ENGINE COMPATIBILITY

FLIGHT CONDITIONS



**ASTF FREEJET SIMULATION
WITH FOREBODY SIMULATOR**



- **DEMONSTRATES INLET COMPATIBILITY OF PROPULSION SYSTEMS BEFORE FLIGHT**

Figure 4.6a Free Jet Testing as Proposed for ASTF Showing the Concept and Use of a Forebody Simulator

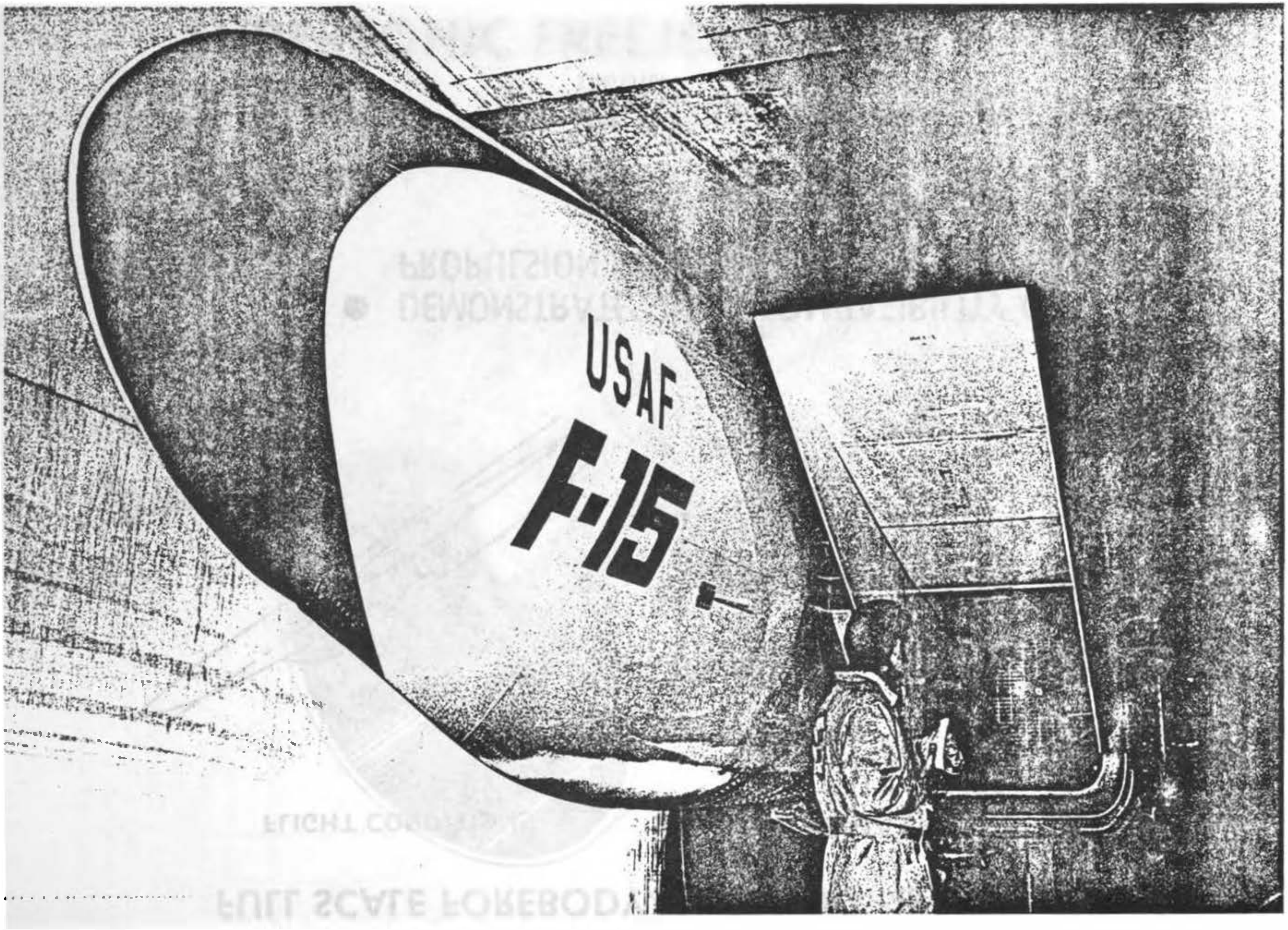


Figure 4.6b Aerodynamic Forebody of an F-15 Showing the Concept Proposed for ASTF Freejet Testing

	SUBSONIC NOZZLE	SUPERSONIC NOZZLE
MACH NUMBER RANGE, M	0.1 TO 1.0	1.0 TO 3.0
MACH NUMBER VARIATION RATE MACH DOT	+0.05/SEC	+.04/SEC TO -.06/SEC
ANGLE-OF-ATTACH RANGE, ALPHA	-10 TO +45 DEG	-10 TO +20 DEG
ANGLE-OF-ATTACH ROTATION RATE, ALPHA DOT	10 DEG/SEC	10 DEG/SEC
ANGLE-OF-ATTACK ANGULAR ACCELERATION ALPHA DDOT	25 DEG/SEC^2	25 DEG/SEC^2
YAW RANGE, BETA	-10 TO +10 DEG	-10 TO +10 DEG
YAW ROTATION RATE, BETA DOT	10 DEG/SEC	10 DEG/SEC
YAW ANGULAR ACCELERATION, BETA DDOT	25 DEG/SEC^2	25 DEG/SEC^2

Table 4.3 Design Goals for ASTF Free Jet Nozzles

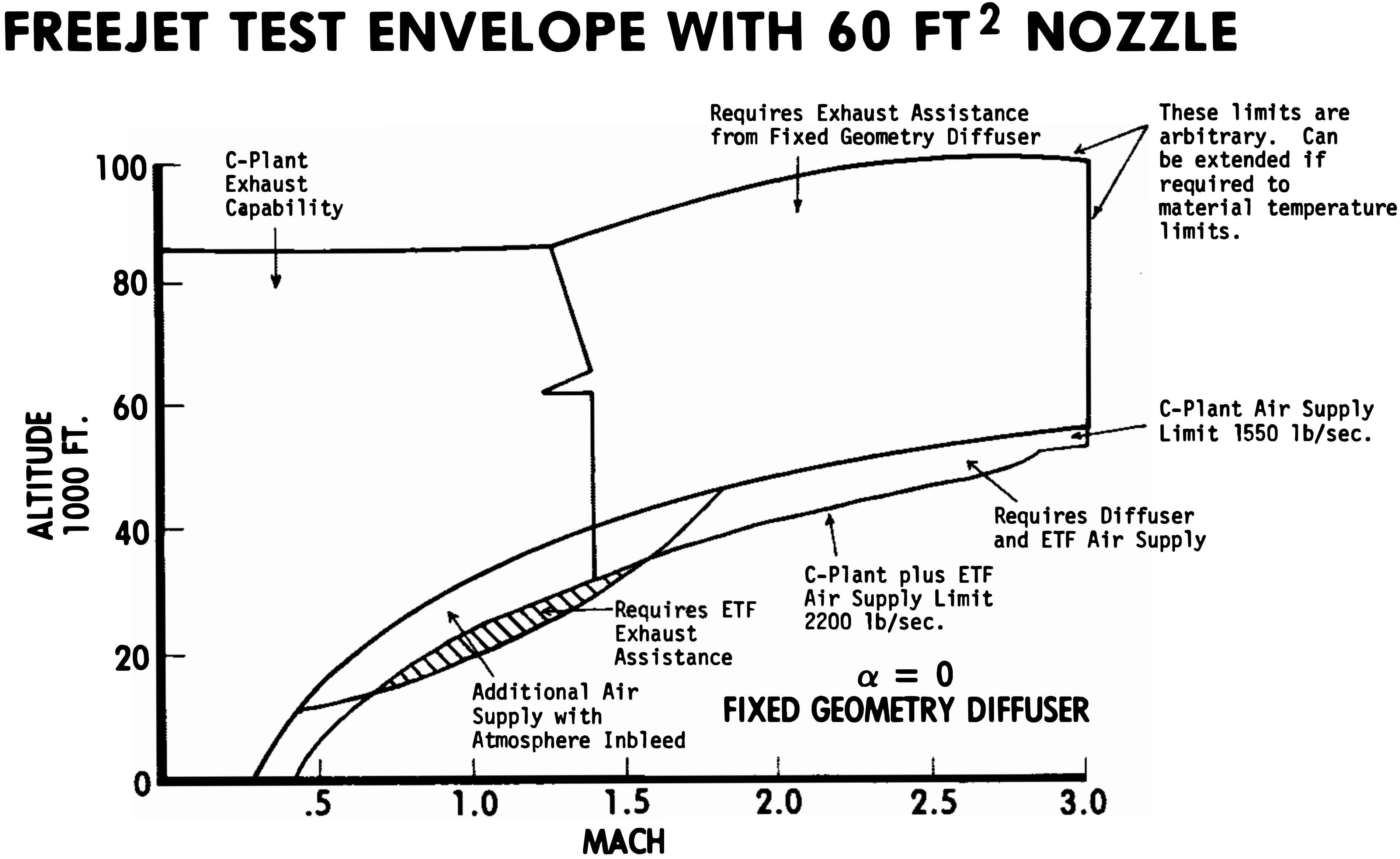


Figure 4.7 Proposed Free Jet Test Envelope for ASTF with 60 Ft² Nozzle

FREEJET TEST ENVELOPE WITH 77 FT^2 NOZZLE

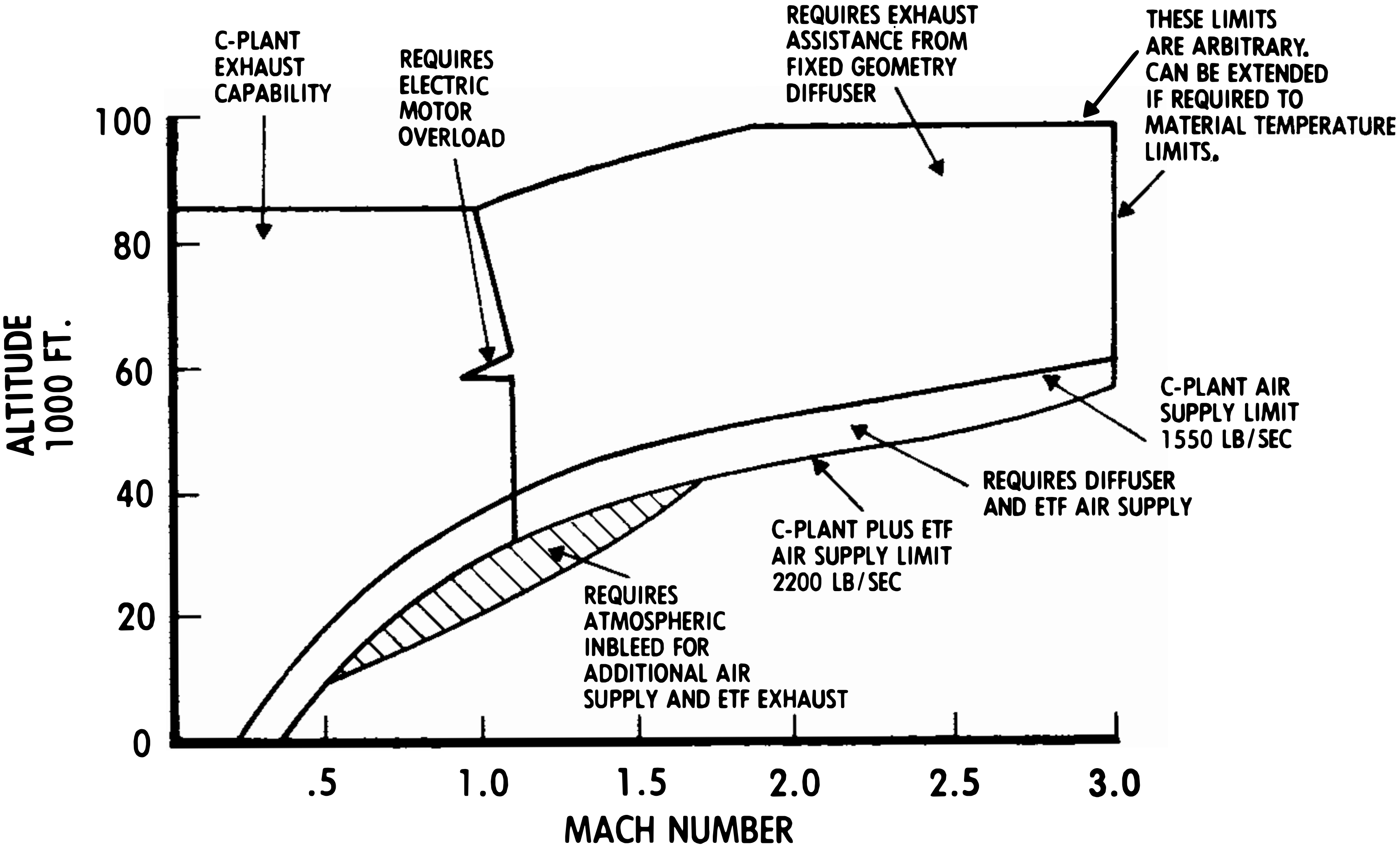
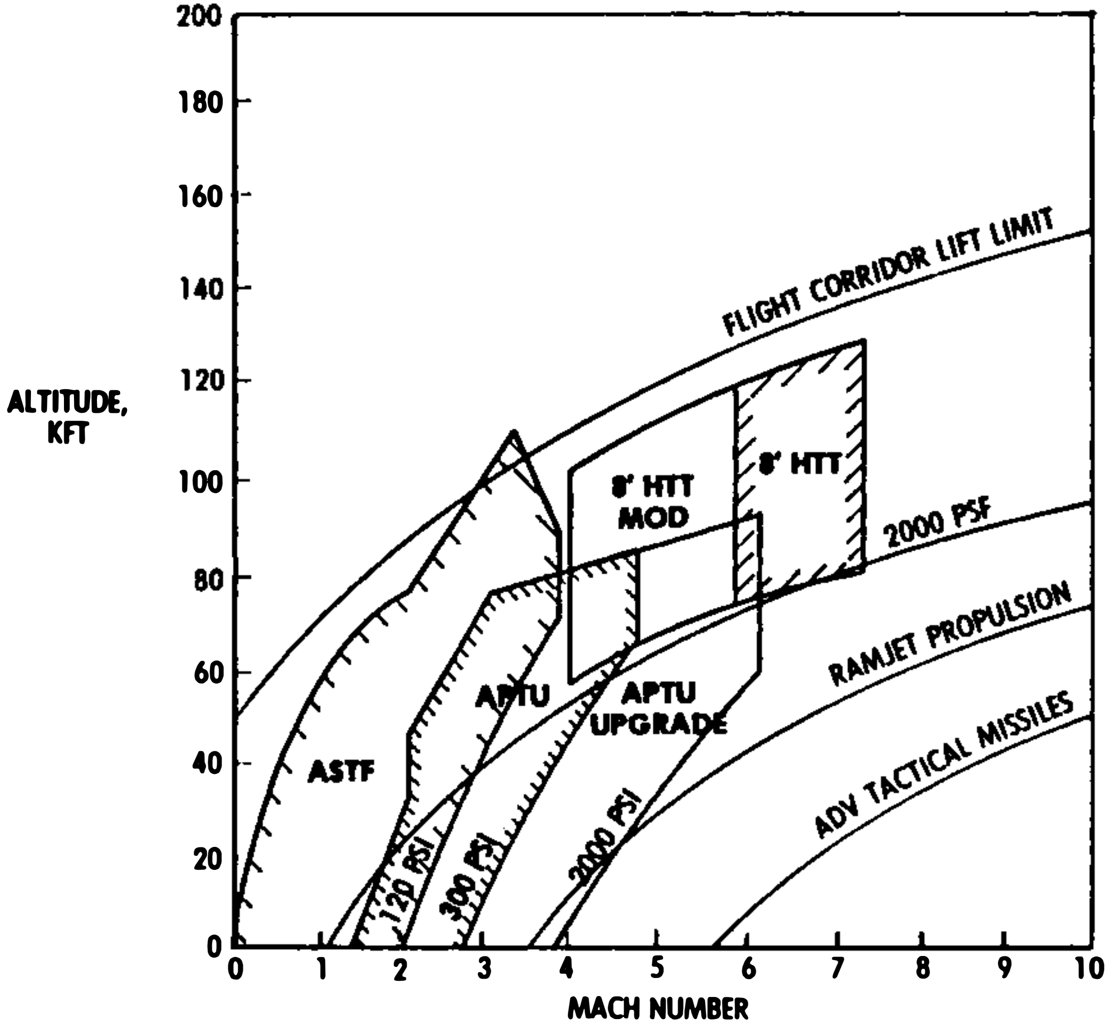


Figure 4.8 Proposed Free Jet Test Envelope from ASTF with 77 ft^2 Nozzle

TEST REQUIREMENTS VS CAPABILITIES

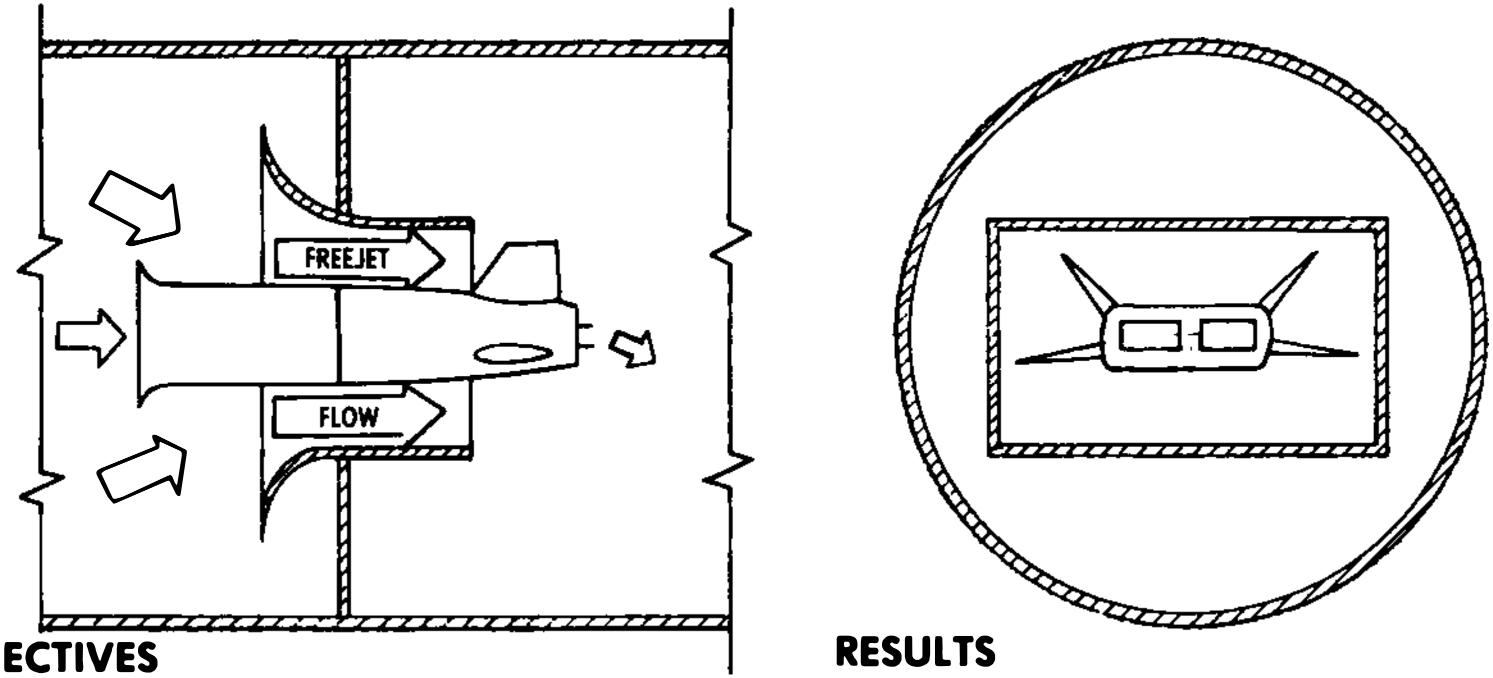


AEDC
Aeropropulsion Systems Test Facility (ASTF)
Aerodynamic and Propulsion Test Unit (APTU)

NASA Langley
High Temperature Tunnel (HTT)

Figure 4.9 Test Requirements Compared to Ground Test Capabilities

ASTF ENGINE/AFTERBODY EVALUATION



OBJECTIVES

EVALUATE ENGINE/AFTERBODY COMPATIBILITY

APPROACH

- STING-MOUNTED FREEJET INSTALLATION
- SUBSCALE ENGINE AND AFTERBODY

RESULTS

- REALISTIC PERFORMANCE TRENDS AND LEVELS
- ENGINE TRANSIENT EFFECTS
- STEADY FLIGHT AND VERY LIMITED MANEUVERING SIMULATION

Figure 4.10 Proposed ASTF Variable Geometry Exhaust Systems

ASTF AIR SUPPLY PERFORMANCE

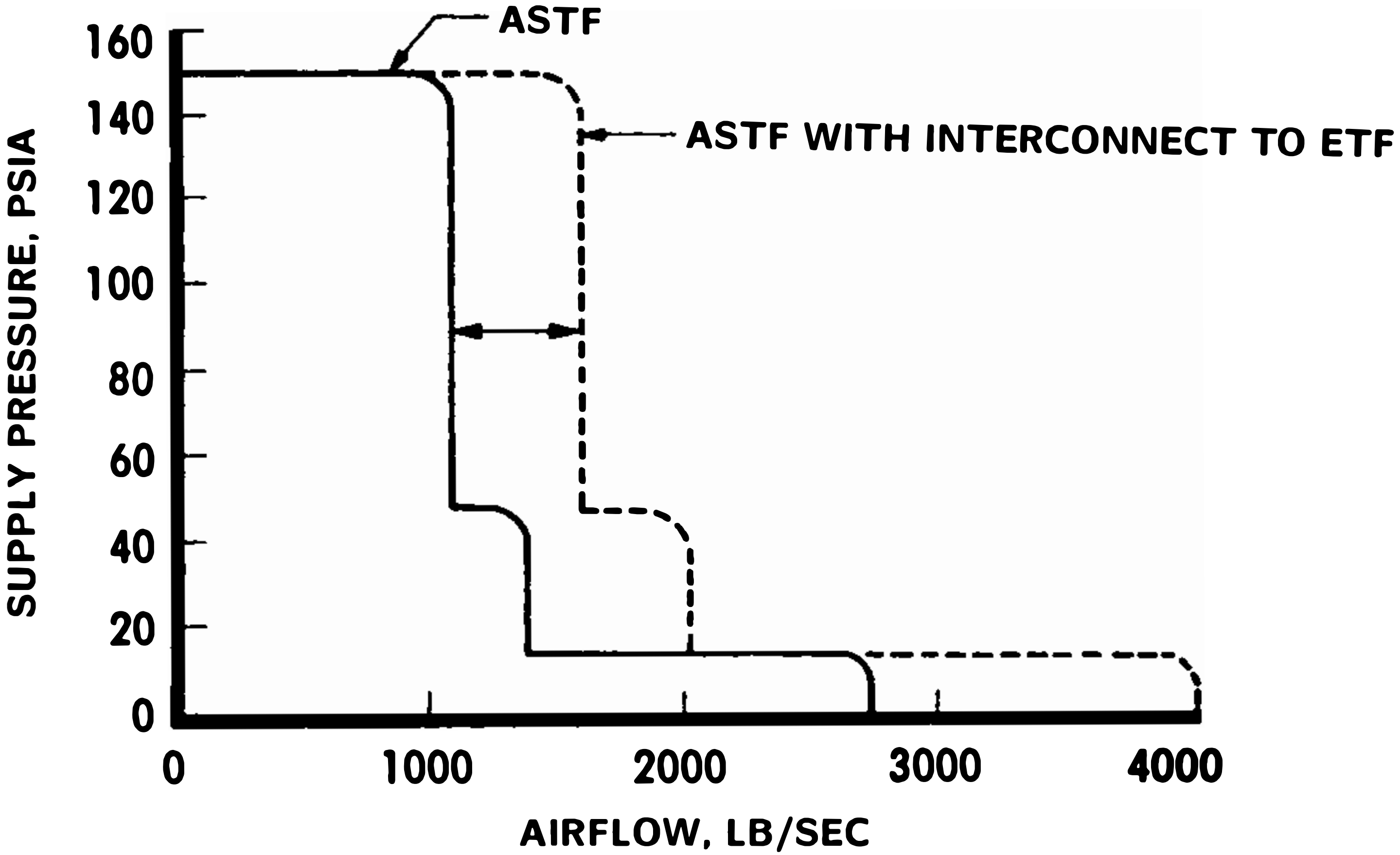


Figure 4.11 Free Jet Air Supply Capability of Major AEDC DoD Propulsion Facilities

4.4 ASTF VARIABLE GEOMETRY DIFFUSER

The ability to match the free jet flow, the engine flow, and the spill or bypass flow around the inlet could be greatly enhanced by the design and construction of a high efficiency variable geometry diffuser. While AEDC tests indicate that the current diffuser operates better than expected, future testing with angle of attack, yaw, thrust vectoring, and non-circular nozzles will generate diffuser inlet flow fields that cannot be handled by conventional diffuser design.

4.5 ASTF INSTALLED ENGINE MAPS

The relative effects of various stability factors are shown in the compressor performance schematic of Figure 4.12. The capability to investigate various aspects of installed engine performance is crucial in refining the design of advanced weapon systems.

The increased emphasis on the total integration of the flight control system with the engine controls and fire control systems requires that the installed engine maps be available earlier in the development cycle. The early availability will significantly reduce costly flight development by reducing the number of configuration iterations of the multivariable flight control system. This will be possible since the engine maps will accurately include the effects of installation and transients.

4.6 TAV FACILITIES

Rapidly emerging developments in the realm of hypersonic flight and space utilization are placing new emphasis on the development of vehicles operating at hypersonic Mach speeds. This interest is being revitalized by current efforts in the Strategic Defense Initiative (SDI) considerations and some re-thinking on the practical applications of such craft. TAVs could be operating by year 2000 if enough emphasis is placed on their development.

The required air-breathing propulsion system for this type of vehicle has an obvious weight and size impact. In fact, developing the proper propulsion system for TAVs will be the largest single design issue pacing their development. Hypersonic facilities with increased capacity will be required to bring these developments to practical operational hardware.

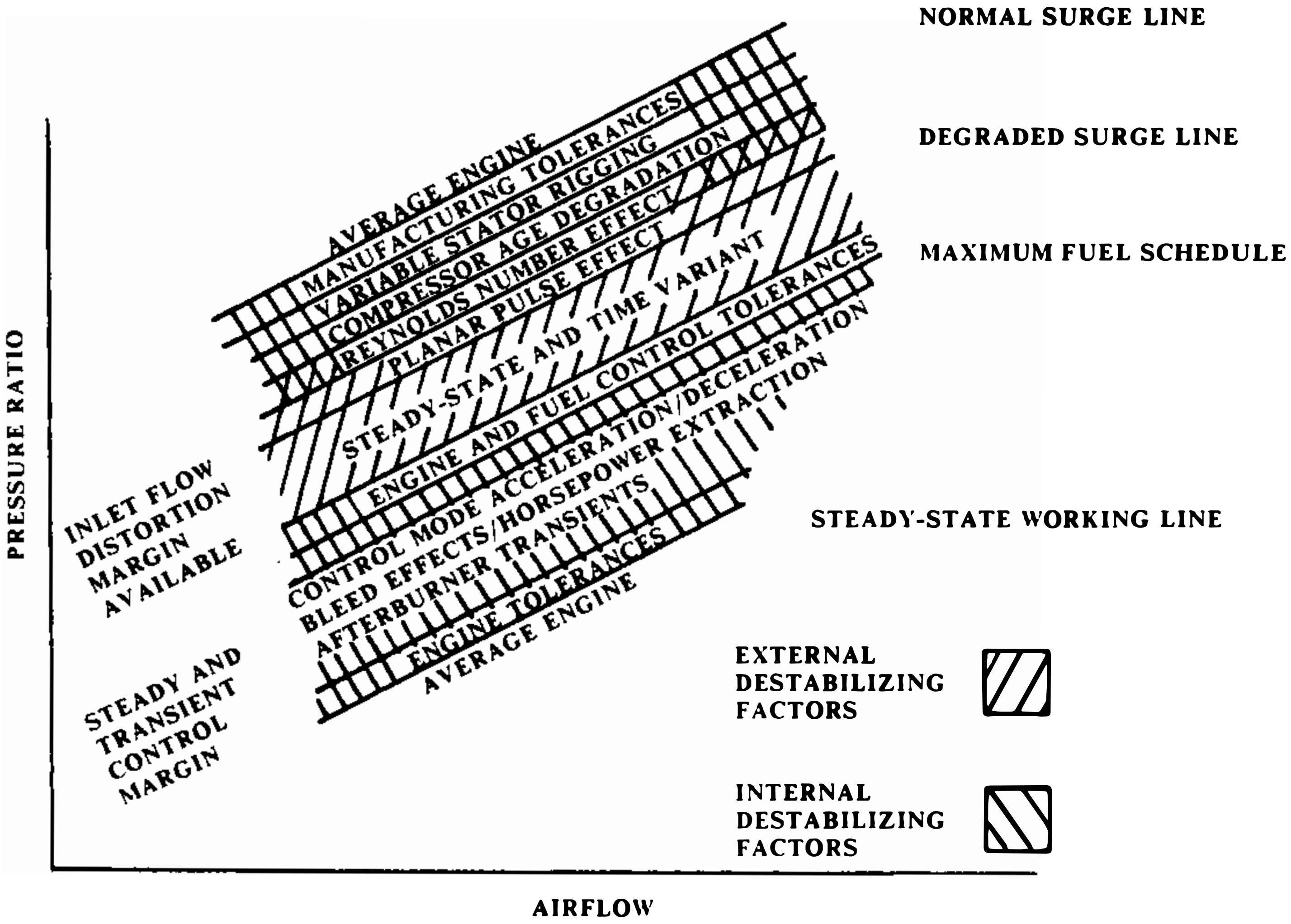


Figure 4.12 Compressor Performance Stability Degrading Factors

5.0 TEST FACILITIES AND RELATED FUNDING REQUIREMENTS

The funding of aircraft and engine development programs as related to the task outlined in Section 1.0 can be subdivided into four specific groupings. There is some overlap, but it is useful for a discussion of the impact of new facilities and integrated testing on overall costs and the contribution of ground testing. The four categories are:

1) Cost of ground test facility acquisition and such facility capability as a national technical resource

2) Cost of ground testing for an actual aircraft specific program

3) Cost of tests to correct problems detected during flight testing and the tangible and intangible related expenses of the consequent time and development penalties

4) Cost of modifications to the airframe-engine-control system to eliminate problems uncovered in flight tests.

The cost of Items 2 and 3, while substantial in absolute terms, is generally only a small part, typically less than 1% of the total program cost for a given aircraft. Consequently, substantial changes in these areas do not represent significant changes in total cost but may lead to substantial savings when compared to the costs associated with difficulties such as those discussed in Section 4.0 or even loss of flight vehicles from unexpected problems such as engine stalls. It is often the proverbial case of being "pennywise and pound foolish."

In the following subsections each of the four categories are discussed in relation to the emerging integrated aircraft designs and facility development and use.

5.1 COST OF GROUND TEST FACILITY ACQUISITION

The total cost of the national aerospace ground test facilities such as those operated by NASA and the DoD is difficult to estimate. Certainly it is in excess of several billion dollars (1986 dollars) when compared to the capital development cost for the three new facilities:

1) 80' x 120' subsonic tunnel at NASA-Ames, approximately $110 million

2) National Transonic Facility at NASA-Langley, approximately $85 million

3) Aeropropulsion systems test facility at Arnold Engineering Development Center, approximately $575 million.

These and other facilities are a national resource supported by the tax structure for the national good. Consequently, one would expect the best facility should be used for testing in any development program. However, factors such as inertia generated by past projects, several layers of bureaucracy, parochial interests, and different costing approaches have often prevented optimum facility use.[16] The dichotomy in funding of testing in Air Force facilities versus NASA facilities presents a major problem. Since Air Force facilities are industrially funded, testing costs are a direct charge to each development program. This requirement does not apply when using NASA facilities. The need for a memorandum of understanding on testing costs between NASA and DoD[17] is an artificial outgrowth of such factors.

5.2 GROUND TESTING COSTS FOR AIRCRAFT SPECIFIC PROGRAMS

While actual ground testing costs are a small percent of total program costs, they are, unfortunately, often viewed as large by those who accept the myopic view and look only at research and development expenditures. Development costs, once the flight program begins, are substantially higher, and if problems are encountered (F-111 inlets, for example), the corrective cost can be enormous or may even lead to project cancellation with its associated write-off of all costs.

With integrated designs where the possible performance problems and flight difficulties are substantially greater (the X-29 is a good example), it will be necessary to increase funding earlier in the test cycle to allow for test plans such as shown in Figures 4.3 and 5.1. This will require greater expenditures earlier in the test cycle but should not cause significant increases in overall costs, while producing better aircraft with fewer problems. Savings associated with avoiding development problems are difficult to forecast, but based on past expenditures and flight testing costs, Table 3.4, Figures 4.1 and 4.2, and Tables 4.1 and 4.2, far exceed the cost associated with improved testing procedures based on the ASTF concept.

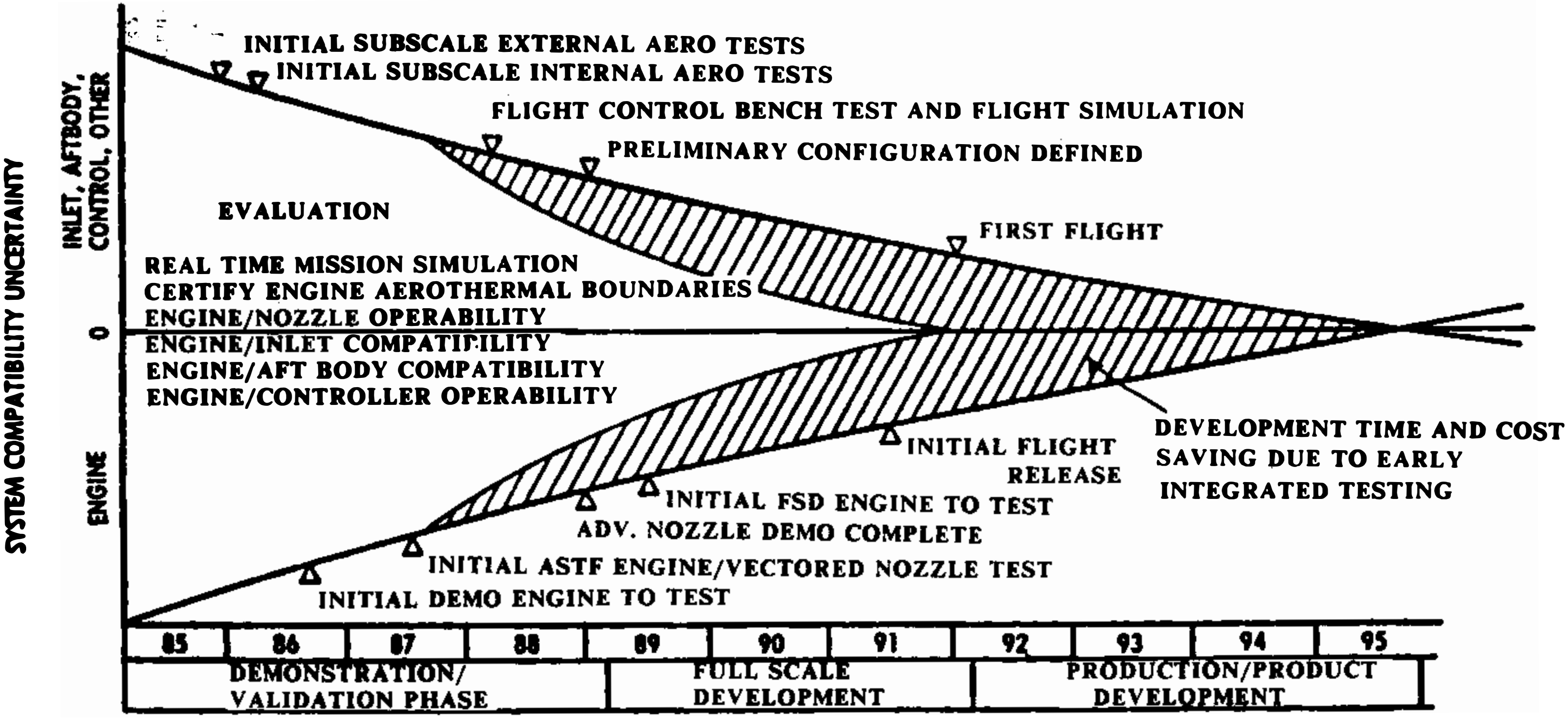
Further, steps should be taken to avoid changes in, or selection of, a test facility to minimize or meet a projected specific development budget since all the facilities are government owned and supported. This type of project accounting should be corrected to guarantee the best use of these facilities.

5.3 TESTING COST ASSOCIATED WITH CORRECTING PROBLEMS DETECTED DURING FLIGHT TESTING

Problems detected during flight testing in general require additional ground testing to determine the cause and to check possible fixes. Since flight testing is not well suited to examining flow details, etc., this corrective testing usually requires additional models and a compressed time schedule because of the pacing effect on expensive flight test schedules (see Table 3.4) and aircraft certification. These all lead to substantially increased unit costs and additional program delays when compared to tests at earlier points in the development program. Consequently, it is desirable to minimize such corrective measures, assuming corrective measures without overly severe performance penalties are possible. The only solution is improved and increased early development test programs.

5.4 COST OF FIXING PROBLEMS UNCOVERED IN FLIGHT TESTS

Modifying the actual flight aircraft after the determination of difficulties in flight tests is expensive because it is often necessary to rebuild the aircraft to reduce loads, modify control surfaces, chance nozzles-nacelle configurations, and correct inlet distortion problems such as occurred on the F-111, while



MILESTONE MARKERS (▽) ARE FOR THE INTEGRATED TESTING METHODOLOGY

Figure 5.1 Cost Savings and Funding Timing Associated with Early Integrated Testing Concepts still conforming to performance and flight envelope restrictions. The need to avoid such cost overruns is well documented in the open literature.

6.0 RECOMMENDATIONS

Based on the considerations of this report, we have concluded that the emergence of highly integrated designs in the airframe and propulsion areas, coupled with the aircraft control system, will lead to major advances in aircraft capability that can be realized only if there is a concurrent substantial increase in ground testing capability and time. Successful implementation of such highly integrated designs will require significant changes in the methods of funding aircraft and engine development. Further, the potential capabilities of the ASTF should be developed and brought to operational status as soon as possible. These points and their attendant ramifications are addressed in the following conclusions and recommendations. The final section contains brief comments based on this study, which, while not directly within the charge of the committee, will influence future Air Force programs.

6.1 CONCLUSIONS

1. Airframe, engine, and control system integration will provide major improvements in aircraft capabilities. Some projected mission profiles will be impossible without such integration. In all cases it will provide improved flight management and efficiency.

2. Integrated aircraft designs, due to the strong interactions among the various components, will lead to increased risk of development problems and the potential for expensive and time consuming corrective measures.

3. Integrated aircraft designs will impose new and difficult challenges to ground test facilities requiring changes in testing, timing, procedures, and facility development.

4. The current funding system for aircraft and engine programs inhibits use of the best facility for a given study. The present approach prevents the early testing in ground based facilities that is essential for integrated designs to avoid late identification of problems and associated penalties.

5. Integrated aircraft designs require installed engine maps, including transients, earlier in the aircraft system development cycle and certainly prior to flight tests.

6.2 RECOMMENDATIONS

The following recommendations are listed in priority order.

1. A policy incorporating advanced planning and early funding commitments for testing and test facility preparation should be implemented to greatly enhance the prospects for overall program success using the new test facilities.

2. The immediate design, development, and funding of ASTF's free jet capabilities are essential to meet the needs of current and projected aircraft and engine programs. The required free jet nozzles should be capable of provid-

ing variable Mach number, transient angle of attack and yaw, and asymmetric flows. This expanded capability is a necessary complement to the existing ASTF engine transient capabilities.

3. ASTF capabilities for testing thrust vectoring and reversing systems should be developed. The potential for studying afterbody-nozzle interactions should also be developed.

4. ASTF should be linked to the AEDC air supply systems to provide a needed significant increase of the operational envelope. Future coupling to the vacuum system should be studied.

5. The recommended free jet test capabilities should be enhanced by the design and construction of a high efficiency variable geometry diffuser for the inlet spill-flow.

6.3 COMMENTS

1. Rapidly emerging development programs such as TAVs will be seriously affected by the current weakness in U.S. hypersonic test facilities. This problem should be examined and facilities improved as soon as possible.

2. A technology base for future programs, particularly for afterbodies as thrust vector control nozzles is lacking. This will inhibit new designs if not corrected.

3. The manner in which aerodynamic testing costs are determined and charged to development programs for government owned and operated facilities such as NASA, AEDC, NSWC/WO, etc., should be closely examined to insure that the best facility for a given investigation is used regardless of funding and accounting procedures.

4. We support the conclusions of previous studies that the integration of CFD and wind tunnel testing is needed to provide test planning guidance, to increase the effectiveness of testing and to improve the interpretation of results.

5. Proper use of major test facilities such as ASTF, with their complex test programs and coordination with CFD designs and data correlations, will require a broader range of engineering and highly specialized research staff.

APPENDIX A

Attendees and Participants at Meetings of the Committee on Aircraft and Engine Development Testing

COMMITTEE MEETING 20-21 JUNE 1984
ARNOLD ENGINEERING DEVELOPMENT CENTER, TULLAHOMA, TENNESSEE

ATTENDEES

Committee
Chester W. Miller
Stuart L. Petrie
Clarence A. Syvertson
Robert L. Trimpi
Robert A. White

Air Force Studies Board
Julian Davidson
Kenneth S. McAlpine
Vernon H. Miles, Sr.

Liaison Representatives
J. W. Davis, Calspan, Arnold Air Force Station
James G. Mitchell, Chief Scientist, Arnold Air Force Station

Presentations by
Eric E. Abell, ASD/EN
Joseph J. Batka, ASD/YZEA
Col. Philip Conran, AEDC
A. C. Draper, AFWAL/FI
Col. J. D. Johnson, AFWAL/PO
James G. Mitchell, AEDC

COMMITTEE MEETING 11-12 SEPTEMBER 1984
NASA-LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA

ATTENDEES

Committee
Jack L. Kerrebrock
Frank S. Kirkham
Chester W. Miller
Clarence A. Syvertson
Robert L. Trimpi
Robert A. White

Air Force Studies Board
Lynn M. Klinger
Kenneth S. McAlpine
Vernon H. Miles, Sr.

Liaison Representatives
- John W. Davis
- James G. Mitchell

Presentations by
- Robert Bower, NASA-Langley
- R. G. Bradley, General Dynamics
- Frank W. Burcham, Dryden Research Facility
- Robert L. Grossman, Grumman Aerospace
- Gen. Robert C. Mathis, USAF (retired)
- Lt.Gen. Abner B. Martin, USAF (retired)
- Wayne McKinney, NASA-Langley
- Gary Plourde, Pratt and Whitney Aircraft Group
- Elwood Putnam, NASA-Langley

COMMITTEE MEETING 14-15 JANUARY 1985
ARNOLD ENGINEERING DEVELOPMENT CENTER, TULLAHOMA, TENNESSEE

ATTENDEES

Committee
- John L. Allen
- Frank S. Kirkham
- Chester W. Miller
- Charles V. Shank
- Clarence A. Syvertson
- Robert L. Trimpi
- Robert A. White

Air Force Studies Board
- Vernon H. Miles, Sr.

Liaison Representatives
- John W. Davis
- James G. Mitchell

Presentations by
- Frank G. Araneo, AEDC
- Allen Atkin, DARPA/TTO
- Travis W. Binion, AEDC
- David M. Bowditch, NASA-Lewis Research Center
- David A. Duesterhaus, AEDC
- William F. Kimzey, AEDC
- David J. Proferl, NASA-Lewis Research Center
- Lt.Col. J. Douglas Ridings, AEDC
- Robert L. Smith, AEDC
- Irving Victor, General Electric Company

APPENDIX B

Briefings to Committee on Aircraft and Engine Development Testing

20-21 JUNE 1984, ARNOLD ENGINEERING DEVELOPMENT CENTER, TULLAHOMA, TENNESSEE

Background of the AFSB Committee Study Request and Current Procedures	James G. Mitchell, AEDC
Topics of Discussion:	Discussions Introduced by:
How Future Aircraft/Engine Systems Requirements are Generated	Col. J. D. Johnson, AFWAL/PO
How Technologies are Identified for Insertion into New Systems	A. C. Draper, AFWAL/FI
How Technologies are Identified for Insertion into New Systems	Joseph J. Batka, ASD/YZEA
How Systems Engineering Practices are Applied to New Systems	Eric E. Abell, ASD/EN
Timing of Use of Ground Test Facilities in the Development of New Systems	Eric E. Abell, ASD/EN
AEDC Facilities Overview - Green Room	Col. Philip Conran, AEDC

11-12 SEPTEMBER 1984, NASA-LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA

Welcome to NASA Langley	Robert Bower, NASA-Langley Research Center
Engine Controls Integration	Frank W. Burcham, Dryden Research Facility
Comparative Testing Costs	James G. Mitchell, AEDC J. W. Davis, Calspan
NASA Policy and Pricing for Military Testing	Robert Bower, NASA-Langley Research Center
Delineation of Engine/Aircraft Integration Problems (Industrial Perspective):	
McDonnell Douglas	Chester W. Miller, McDonnell Douglas

General Dynamics	R. G. Bradley, General Dynamics
Pratt and Whitney Aircraft Co.	Garry Plourde, Pratt and Whitney Aircraft Co.
Grumman Aerospace Corporation	Robert L. Grossman, Grumman Aerospace Corporation
F-111, F-15, and F100 Engine	Gen. Robert C. Mathis, USAF (retired)
B-1	Lt.Gen. Abner B. Martin, USAF (retired)
Thrust Vectoring and Reversing	Elwood Putnam, NASA-Langley Research Center
National Transonic Facility Capability Integration with ASTF	Wayne McKinney, NASA-Langley Research Center

14-15 JANUARY 1985, ARNOLD ENGINEERING DEVELOPMENT CENTER, TULLAHOMA, TENNESSEE

NASA-Lewis Presentation - Introduction and Overview	David J. Proferl, NASA-Lewis Research Center
NASA-Lewis - Facilities Capabilities and Weaknesses for Engine Testing	David J. Proferl, NASA-Lewis Research Center
NASA-Lewis - Cooperation with Air Force and Costs/Cost Sharing	David J. Proferl, NASA-Lewis Research Center
NASA-Lewis - Facility Plans	David M. Bowditch, NASA-Lewis Research Center
General Electric Company Engine Development Engine-Airframe Integration Facility Usage and Requirements	Irving Victor, General Electric Company
DARPA Long Range Plans Altitude Mach Number Capability	Allen Atkin, DARPA
AEDC Test Research and Support Capabilities	William F. Kimzey and Travis W. Binion, AEDC
Aeropropulsion Testing Needs	Robert L. Smith, AEDC
Review of AEDC Technology Projects in Support of ASTF	David A. Duesterhaus, AEDC

ASTF Activiation Schedule	**Lt.Col. J. Douglas Ridings, AEDC**
ASTF Test Schedule	**Frank G. Araneo, AEDC**
Summary	**James G. Mitchell, AEDC**
USSR Facilities and Capabilities	**James G. Mitchell, AEDC**
Foreign Facilities - Capabilities and Cooperation	**James G. Mitchell, AEDC**

APPENDIX C

References

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4. The Aeronautics and Astronautics Coordinating Board, comprised of senior members of DoD, NASA, and the Department of Transportation, formed the National Aeronautical Facilities Program in 1968, which in turn did three studies on ground test facilities needed for future aircraft. Out of these studies came NTF, ASTF, and the 80' x 120' leg of the wind tunnel at Ames Research Center.

5. NTF Dedication, November 1983. NASA-Langley Research Center, Hampton, Virginia.

6. ASTF Dedication, October 3, 1984, AEDC, Tullahoma, Tennessee.

7. Air Force Studies Board. Aircraft and Engine Development Testing. Statement of Task. Washington, D.C. National Academy Press, 1986.

8. Committee on Aircraft and Engine Development Testing, Air Force Studies Board. Minutes of Committee Meeting at NASA-Langley Research Center, 11-12 September 1984.

9. Krengel, J. H. Air-Breathing Engine Test Facilities Register. AGARD-AG-269, July 1981.

10. Furlong, G. C., and L. S. Moore. AEDC Inventory of U.S. Wind Tunnels, Air-Breathing Altitude Test Cells, Rocket Altitude Test Cells, Space Chambers, Aeroballistic and Impact Ranges. August 1979.

11. Pankhurst, R.C. Dimensional Analysis and Scale Factors. The Institute of Physics and the Physical Society. 1964.

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14. Direct communication between AEDC and the Committee, June 1985.

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16. Presentations to the Committee meeting of 11-12 September 1984.

17. NASA-DoD Memorandum of Understanding on testing procedure cost. May 4, 1984.

APPENDIX D

Acronyms

AEDC	Arnold Engineering Development Center
AFWAL	Air Force Wright Aeronautical Laboratory
APTU	Aeronautics and Propulsion Test Unit
ASD	Aeronautical Systems Division
ASTF	Aeropropulsion Systems Test Facility
ATF	Advanced Tactical Fighter
AWT	Altitude Wind Tunnel
CFD	Computational Fluid Dynamics
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
HTT	High Temperature Tunnel
NASA	National Aeronautics and Space Administration
NGTE	National Gas Turbine Establishment
NSWC/WO	Naval Surface Weapons Center, White Oak, Maryland
NTF	National Transonic Facility
SDI	Strategic Defense Initiative
STOL	Short Take Off and Landing Airplane
TAV	Transatmospheric Vehicle