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AFAPL-TR-71-84

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THE NEED FOR AIR FORCE ENGINE STABILITY MARGIN TESTING FOR INLET-ENGINE INTERFACE DEFINITION

J. FRANKLIN MONTGOMERY III

TECHNICAL REPORT AFAPL-TR-71-84

DECEMBER 1971

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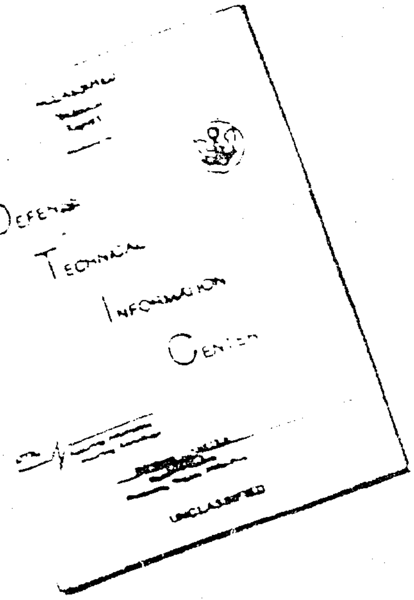

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FOREWORD

This report was prepared by the Air Force Aero Propulsion Laboratory, Air Force Systems Command. The work reported herein was accomplished in-house under Project 3066, Task 306611, "Propulsion System Flow Stability," with Frank Montgomery as Project Engineer for the Laboratory. Studies and analysis made during the period from July 1969 to September 1971 are reported. This report was submitted by the author 15 December 1971.

The author acknowledges his indebtedness to the many people whose aid and interest helped to complete this report. A partial list of these includes numerous representatives of Aeronautical Systems Division-Directorate of Propulsion and Power, Air Force Aero Propulsion Laboratory-Turbine Engine Division, Flight Dynamics Laboratory-Internal Aerodynamics Group, Arnold Engineering Development Center-Engine Test Facility, General Electric Company, Pratt & Whitney Aircraft Company, and Detroit Diesel Allison Division of General Motors. In addition, a great deal of information was drawn from the data files and histories compiled in the historical office of Aeronautical Systems Division.

Conversations and correspondence between these people and the author, and the numerous documents made available, gave the author much of the data presented in this report.

This technical report has been reviewed and is approved.

Ernest C. Simpson

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ABSTRACT

A major consideration in current Air Force engine developments consists of program approaches and time-phased engineering efforts directed to stability margin development for defined propulsion systems. Experience has shown that interface stability needs should be addressed early in developmental phases with the objective being to establish, refine, and verify engine stability margins for key operating conditions of the propulsion system.

It will be developed in this report that these needs can be met by engineering planning and programming to permit early selection and definition of engine/airframe operational interface parameters. A quantitative stability margin accountability system must be provided at the component and engine level in order to provide a basis for engine stability-related configuration refinements in development. Additionally, a data handling system is required between engine and airframe contractors in order to format and process large amounts of interface data exchanged in propulsion system development. Lastly, test and evaluation at the component level must be extended into engine testing and evaluation in order to ultimately develop and define engine stability margin for key points of system operation.

In order to better understand engine stability development needs and approaches, an examination of Air Force historical records in provided herein depicting the evolution of interface stability considerations during various system development programs over the years.

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SECTION I
INTRODUCTION AND BASIC NEEDS FOR AIR FORCE ENGINES

1.1 INTRODUCTION

The transition from reciprocating engines to gas turbine engines for military aircraft propulsion began in the years following 1946. The complexity of weapon system mission requirements also began to increase during this transition period. In combination, these factors placed new and greater demands on propulsion system performance and operational suitability. Thrust, specific fuel consumption, weight, and external dimensions, long used as engine performance parameters, were being forced to the limits of the existing state of the art. Correspondingly, engine operating characteristics under environmental conditions and life functions, such as durability, reliability, and maintainability, commonly used as measures of operational suitability, were being pushed to new levels. But the most significant aspect of this transition period was that a major change emerged in the evaluation of operational suitability; along with life functions, propulsion system stability became an important system criterion.

Stability of turbine engines was defined in ensuing years as the ability of an engine to produce continuous thrust outputs proportional to power lever settings. Correspondingly, engine-airframe compatibility came to include the capability of a propulsion system to perform during the required mission flight maneuvers and engine power modulations with "stable" propulsive output. These definitions are developed and discussed in more detail in References 1 and 2.

History shows that over the years stability problems have continually plagued propulsion system development and operation. In the most significant cases, serious system instabilities were not discovered until after the first flights of the associated aircraft. Development and operational problems with stability have been traced to several causes: (1) inadequate definition of the causes of instability, (2) inappropriate test techniques and test sequencing, (3) insufficient coordination between engine and airframe developers, and (4) utilization of inadequate descriptors of turbine engine stability and system compatibility. History also shows that improved approaches to development have evolved, and when considering all previous experience, recommendations can be made for more appropriate development techniques and programming for future systems.

Because of problems, schedules, and costs associated with stability, a review of past Air Force programs was made depicting the onset and extent of the problem on advanced high performance aircraft. Subsequent development and programming approaches that evolved over the years are also discussed and related to the basic needs of Air Force engine development needs.

In the paragraphs to follow in this section, basic needs of past Air Force engine development programs are reviewed. Section II provides a review of Air Force historical records which depict the onset of inlet-engine operational suitability problems in the early 1950's. Sections II and III examine some of the factors contributing to these problems. In addition, early efforts seeking improved propulsion interface development approaches are discussed. Section IV reviews later inlet-engine interface experiences recorded during system developments of the early 1960's. Section V briefly summarizes the significance of interface developments discussed in the earlier Sections as they relate to engine development needs. Section VI and VII discuss the evolution and status of engine interface stability approaches, criteria, and testing resources. Suggested programming methods and approaches are presented for defining the inlet-engine interface for engine developments and stability testing.

1.2 BASIC ENGINE DEVELOPMENT NEEDS

The Air Force has fundamental requirements for development programs for engines which are developed and utilized in weapon systems as Government-furnished equipment. First, baseline characteristics for each subsystem (i. e., the inlet and the engine) must be defined during the system definition phase and maintained current throughout the acquisition cycle. These baseline characteristics are contractual. Secondly, there is a need for a system of developmental and qualification tests which verify baseline characteristics prior to consignment of the engine to the weapon system contractor. And finally, a basis for defining and resolving interface problems, involving in this case elements of both inlet and engine, must be established. It will be pointed out in the following paragraphs that there is a significant interrelationship between the qualification testing and the basis established for resolving interface conflicts.

During the development of propulsion system for Air Force weapon systems, there are checkpoints prior to flight at which performance and operational characteristics of the subsystems must be functionally evaluated to verify weapon system capability. One of the key checkpoints is the definition of engine operating characteristics for the specific system integration concept. Because of the lead time required to accurately establish elements of integrated performance, this definition is normally not finalized until near the end of the development cycle during the Qualification Testing of engines. Over the years, Qualification Testing requirements have evolved through systems engineering and experience; and testing capabilities which provide evaluations of engine performance and numerous operational suitability factors indicative of systems mission operating and handling requirements have been established. However, a major aspect of operational suitability testing remains to be resolved for engine qualifications. This essential element consists of testing with engine distortion levels projected for the propulsion system inlet-engine interface and determining engine stability margins. It will be developed in this report that such testing is needed and can be programmed for accomplishment during engine development.

The basic problem to be resolved is associated with quantitative definitions of stability. Although the development of descriptors of turbine engine operational suitability (i. e., stability and compatibility) has received considerable attention and engineering effort during the past years, cirteria and approaches by which engines could be developed and qualified to operational stability needs proved elusive. In a similar fashion, criteria and approaches governing the development and verifications of satisfactory aircraft inlet flow characteristics as related to propulsion system stability proved equally elusive. Examination of some factors which contributed to the apparent lack of these criteria forms the basis of the inlet-engine interface problem to be discussed in this report.

The significance of the basic needs of Air Force engines is that the key performance and operational suitability requirements of engines must be defined at systems program onset along with processes allowing their evaluation through testing. Accordingly, a set of test procedural standards must then exist to assess engine characteristics in physically measurable terms indicative of key mission operating conditions for a particular weapon system propulsion system. The purpose of this report then is to examine needs of the Air Force relative to qualifying engines to the operational suitability requirement for engine distortion acceptance and to present engineering approaches to minimize, if not eliminate, the requirement to resolve engine inlet flow distortion acceptance and propulsion system stability problems during costly flight test programs.

1.3 PROCESSES DIRECTED TO ENGINE DEVELOPMENT NEEDS

In Air Force system acquisition programs, processes of engine definition and delivery were established and oriented toward meeting basic needs for engine developments (Reference 3). A further reason for such processes was that engine and airframe developments usually occured concurrently but under separate contractual operations. Although the contractual operations are separate, the Air Force directly encourages joint technical operations with respective contractors in efforts directed toward satisfactory definition, development, and integration of an engine into a system.

From an engine standpoint, steps arise in systems engineering of total aircraft requirements in order to arrive at definitions of propulsion system and subsystem operating requirements and characteristics. Propulsion system configurational and operational concepts can be factored down into definitions of subsystems funtional modes and correspondingly design and performance requirements for each subsystem. When development requirements are derived in this manner, engine operating characteristics and interface requirements can be established which allow for installation factors and propulsion system matching. Such criteria can then be translated to engine design and development criteria for engineering development efforts within the program's lead time to integration and flight.

These engine requirements historically have been placed in engine model specifications. While the specification is principally a technical description of the size, weight, and functions of an engine to be developed and delivered, relative to the contractual operations between the Air Force and engine contractor, it is also the baseline for aircraft performance projections. Accordingly key design and funtional requirements of an engine specification become guarantees to the Government by the engine contractor and form the basis for settlements of engine development costs. Similarly, the weapon system contractor formalizes his technical and contractual operations with the Air Force for systems design and performance guarantees on the basis of the specified engine. Since formal concurrence to this effect on the engine model specification is required between respective contractors and the Air Force, the relationship of engine to airframe is both technical and contractual in nature. Thereby the necessity of defining and establishing valid sets of engine criteria encompassing propulsion system interface functions is established.

1.4 THE SIGNIFICANCE OF BASIC ENGINE DEVELOPMENT NEEDS

The significance of the basic needs of Air Force engines is that the key performance and operational suitability requirements of engines must be defined at systems program onset along with processes allowing their evaluation through testing. Accordingly, a set of test procedural standards must then exist in order to assess engine characteristics in physically measurable terms coincident with key mission operating conditions for a particular weapon system propulsion system.

SECTION II
HISTORICAL BACKGROUND OF THE INLET-ENGINE INTERFACE (1946-1955)

2.1 INTRODUCTION

As found in Reference 4, it is a well-known fact that the military services have experienced frequent and serious problems in efforts to achieve stable engine operation throughout the flight envelopes of past advanced weapon systems. Although those systems represent a large body of inlet and engine development and integration experiences, it has been generally noted that only limited reports have been available over the years for examining the evolution and various approaches to this interface. For this section then, historical Air Force data were compiled from various sources within Aeronautical Systems Division and other propulsion development agencies as shown in the Bibliography to present a more extensive background of Air Force experience in past inlet-engine interfaces. The treatment of the information is not intended as a critique of approaches to, results of, or fixes to engine instability problems or who collectively was responsible. Moreover, a number of past developments are discussed in order to show when inlet-engine compatibility became a significant Air Force problem, what trends evolved, and other factors related to the development of operationally suitable Air Force engines in ensuing years.

2.2 IDENTIFICATION OF INLET-ENGINE COMPATIBILITY AS A MAJOR PROBLEM

In the early years of jet-propelled military aircraft developments, a number of stability related factors arose in integrating engines and airframes. Early systems encountered various inlet-engine interface-related phenomena such as engine surge, flameout during armament firing, and inlet duct rumble. While these problems appeared in various aircraft during 1946-1955, indications were that they were viewed as "normal development problems" in what might be described as first generation military jet aircraft. In due time, these difficulties appear to have been resolved with relatively minor systems impact as compared with later systems in which the situation was to change significantly.

Historical records show rather clearly that the inlet-engine interface evolved into a major problem in the early 1950's, with the advent of the 'compressor stall problem" on several advanced Air Force weapon systems as shown in Figure II-1. The reason the problem became major was basically that the "compressor stall problem" was not revealed until late in development (i. e., flight test), and flight test schedules consequently became disrupted because of flight restrictions to avoid compressor stall. In some cases, systems were so restricted that required flight and maneuvering conditions could not be achieved. At the onset of these problems (1952-1954), the Air Force and affected system contractors became increasingly concerned over the seriousness and implication of unstable engine operations in flight. During that time period, meetings were convened between those system contractors to determine the causes of engine compressor stall and remedies for its elimination. Reference 5 in 1954 was a typical example of such meetings and was significant as it was one of the earlier records of meetings convened expressly to examine "mutual inlet-engine problems" existing at that time for several advanced weapon systems. It is interesting from the standpoint of interface, that this meeting sought to determine whether inlet ducts or engine characteristics were the prime causes of "compressor stalls" in aircraft operations. Minutes of this meeting revealed the following:

1. Compressor stalls in aircraft operations had occurred across a wide spectrum of flight conditions which differed according to aircraft flight and maneuvering requirements.

2. A number of "fixes" to inlet and/or engine had been undertaken in flight testing with varying degrees of success in attempts to achieve stable engine operation.

3. A "fix" for one system would not necessarily achieve the same result for another installation or aircraft.

4. Conclusions were reached that inlet air pressure distributions (i. e., distortion) had major effects on engine stall characteristics in addition to the engine's internal matching and controlling effects.

5. Inlet-engine interface development criteria existing at that time in military specifications and design handbooks for inlet air pressure variation were considered unrealistic and in need of improvement for both inlet and engine development practices.

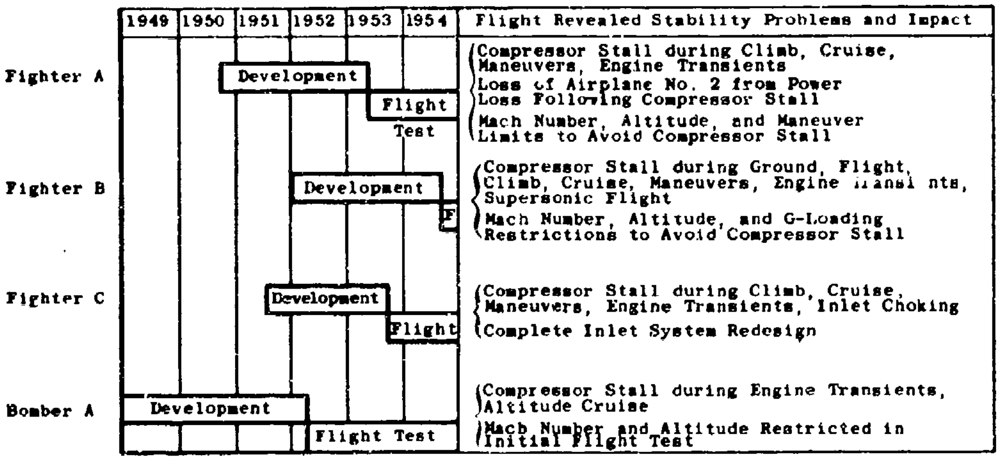


Figure II-1 Typical Air Force System Development Schedules at the Close of 1954

By late 1954, several inlet-engine problems had been revealed during flight testing of three Air Force systems when a fourth problem arose with the initiation of flight testing of Fighter B (Figure II-1). At this juncture, Air Force concern over compressor stalls and inlet-engine compatibility surfaced as shown in the letter from the Director of Weapons Systems to the appropriate development agencies at Wright Air Development Center (see Appendix I). In this letter, it was pointed out that "stability" or inlet-engine compatibility had become a major problem apparently as a result of improper development planning. Continuing, it is noted that the following tasks were defined:

1. Formation of the first known Air Force Airframe-Propulsion Compatibility Committee or Group.

2. Combined "Committee" efforts under (1) to expedite the solution of the existing problem.

3. Combined "Committee" efforts under (1) to define inlet-engine planning factors for future weapon system developments to minimize the compatibility problem.

With the occurrence of high-level Air Force concern over the inlet-engine interface, efforts began which can probably be best described in two parts. First, short-range efforts were of necessity oriented to "fix" existing problems which were impacting flight tests, production, and deployment provisions. Secondly, longer range efforts were initiated to define development planning factors to ensure inlet-engine compatibility for several evolving systems. (Some of the results of both short-range and longer-term efforts are discussed in Section III).

The need for such planning factors can be observed in Figure II-2, as at least five advanced weapon systems were either in active development or systems definition phases. In all of these cases, stringent requirements for that historical period had arisen in range, Mach number, and weapons delivery capabilities. At that point, these requirements had been recognized to some degree as factors contributing to the complexities of propulsion system integration and inlet-engine matching. Efforts then to achieve the necessary development planning factors led to many important coordinations in the following months between propulsion research and development agencies. These all sought to better identify the problem as well as steps to achieve the solution. From such events, an early and key symposium was created in the form of the first Air Force Symposium on Inlet-Engine Compatibility in June of 1955 (Reference 6) which is discussed in more detail in Section 2.4.

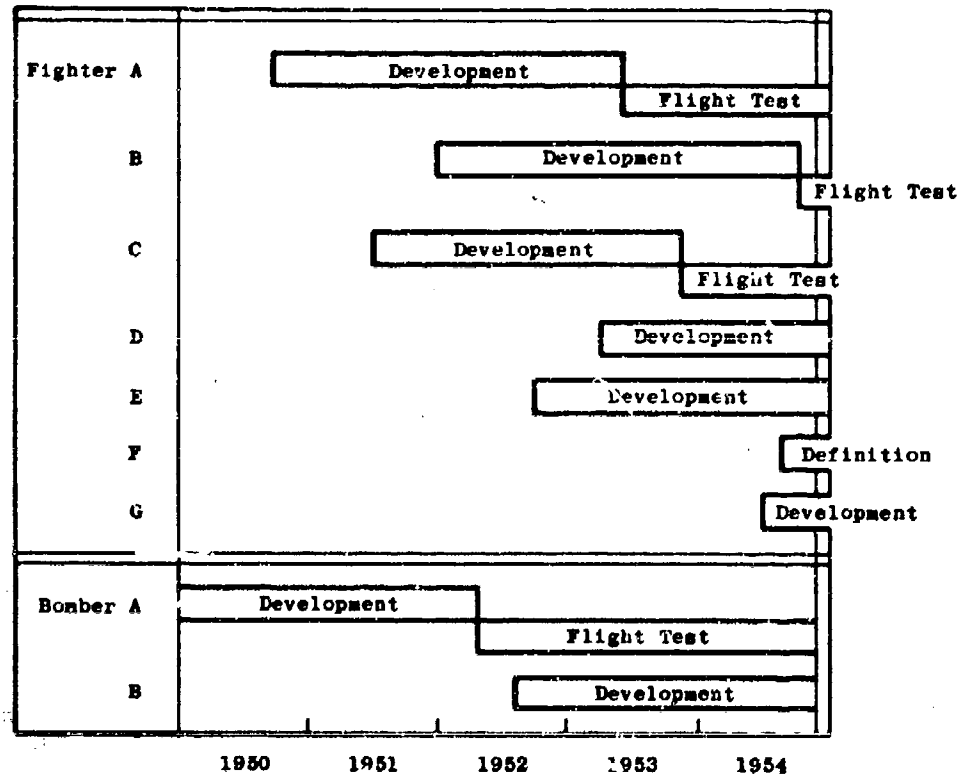


Figure II-2 Status of Air Force System Developments in Late 1954

2.3 FACTORS CONTRIBUTING TO EARLY INLET-ENGINE COMPATIBILITY PROBLEMS

The developments discussed in previous paragraphs culminated with serious inlet-engine compatibility problems, which were not revealed until flight. While many factors probably contributed to these problems, several which are considered important are summarized as follows:

It is considered significant that in the late 1940's, a new or second generation of weapon system requirements, and hence military aircraft, was evolving. While this has been described in various literature as the trend toward "bigger-faster-higher" systems, some of the important requirements in terms of propulsion systems were increased range, speed, altitude, and maneuvering envelopes. This departure from what has been described herein as first generation jet aircraft to a new or second generation can be seen in Figure II-3, which depicts general characteristics of Air Force aircraft which were to become operational in large production quantities. These increased requirements for range, maneuvering envelopes, and subsonic and supersonic operation were to significantly affect the sensitivity and complexity of propulsion system matching of inlet-engine and aircraft. Trends arising from these requirements are depicted in Figure II-3, showing inlet design treatments and engine compressor loading trends in terms of pressure ratio for these installations. In this report, increases in matching sensitivity are discussed in terms of inlet-engine airflow and distortion matching brought on by combinations of the following:

1. Increases in engine compressor loading to permit increases in pumping and overall pressure ratio to achieve (for increased aircraft range) other systems performance requirements.

2. Air induction system designs to operate without undue drag penalties, subsonically and supersonically, utilizing sharp lips, inlet shock treatment, larger range of airflow matching needs, etc.

3. Increased ranges of transient operation for inlet and engine (or mission handling).

The need for advanced weapon system capabilities and propulsion system performance posed added complexities in inlet and engine development practices. However, the status of approaches to these needs is evidenced in several areas, particularly as those existing in the Handbook of Instructions for Aircraft Designers (HIAD), military engine model specification requirements, and analytical approaches to inlet-engine matching. (References 7, 8, and 9, respectively).

First-Generation Weapon Systems

Weapon System	1943-1951					
	Mach No.*		Range		Propulsion	
Fighter	Cruise	Max	Ferry	Combat Radius	Inlet Type	Engine
I	0.65	0.81	1050	400	Side Scoop Subsonic Bifurcated	TJ
II	0.70	0.88	1000	400	Pitot	TJ
III	0.80	0.98	1200	35[illegible]	Pitot	TJ
IV	0.80	0.98	900	350	Pitot	TJ
V	0.75	0.90	1000	370	Side Scoop Subsonic	ATJ
VI	0.75	0.82	900	400	Side Scoop Subsonic Bifurcated	ATJ
Bomber						
I	0.70	0.85	1700	500	Pitot	TJ
II	0.80	0.85	2800	1350	Pitot	TJ

*Denotes Level Flight

Second-Generation Weapon Systems

Weapon System	1951-1957					
	Mach No.*		Range		Propulsion	
Fighter	Cruise	Max	Ferry	Combat Radius	Inlet Type	Engine
A	0.85	1.2	1700	500	Pitot One Shock	ATJ
B	0.85	1.7	1800	600	Wing Root External Compression	ATJ
C	0.85	1.2	1200	450	Fixed Ramp Bifurcated External Compression	ATJ
D	0.90	2.0	1200	350	Fixed Half-Cone External Compression Bifurcated	ATJ
E	0.85	2.0	1900	500	Fixed Scoop Variable Throat Bifurcated External Compression	ATJ
F	0.90	2.0	1200	550	Variable Ramp Bifurcated External Compression	ATJ
Bomber						
A	0.80	0.95	6500	3100	Pitot	TJ
B	0.95	2.0	4000	1650	Variable Axisymmetric Conical Spike External Compression	ATJ

Figure II-3 General Air Force Aircraft Characteristics (1943-1957)

First, in the HIAD (Reference 7), the design objectives (in terms of internal aerodynamics) stressed matching inlet and engine airflow and the importance of ram recovery. The engine specification (Reference 8), on the other hand, required only estimated radial and circumferential inlet air pressure distribution limits. The third document (Reference 9) stressed the importance of airflow matching and recovery and presented an airflow matching analysis technique. By looking more closely at the engine specification requirements, the requirements for inlet air pressure variation were subject to interpretation, and formal tests of inlet air pressure variation "limits" were not required. Various early records reveal that inlet air pressure variation requirements were interpreted relative to compressor blade stresses or to indicate to airframers that pressure variation required some attention in an installation. An interesting example of this interpretation is given in Appendix II. At any rate, in design documents of that time period, engine installation factors for development (and integration) of propulsion subsystems and aircraft lacked definition in the area of inlet-engine interface development criteria for inlet flow distortion and engine distortion acceptance.

Typical examples of early Air Force inlet and engine design requirements are shown in Appendix III. An example of proposed development criteria is also depicted.

As discussed previously, these "criteria" had been found lacking - "after the fact." Some early engine requirements placed the "limits" of inlet air pressure variation at ±2 percent circumferentially and ±3 percent radially in terms of inlet total pressure maximum minus the minimum divided by average (i.e., $\Delta P/P$). In Reference 5, the conference minutes revealed that these kinds of engine requirements were considered "unrealistic" in inlet design practice. The attendees at this particular meeting all indicated agreement that engine inlet air pressure variation limits should be revised to an allowable 10-percent total pressure variation or ±5-percent variation around the average inlet duct total pressure. These were felt to be "reasonable and achievable" values in inlet and engine (interface) design practices. These criteria were proposed along with a suggestion to engine designers to seek design concepts incorporating larger engine (stall) tolerances to inlet distortion.

Another factor in regard to early systems compatibility problems had to do with the limited availability of test facilities for engine and propulsion unit testing during weapon system development programs. In general, there were limited numbers of engi e altitude facilities available through about 1951, in which turbojet engines could be tested under simulated altitude environment as shown in Figure II-4. In addition to limited testing experience in terms of procedures, techniques, and instrumentation, engine altitude testing to define inlet-engine interface factors (distortion) had not been pursued prior to about 1951-1952. An early NACA report (Reference 10), for example, states that investigation into the effects of distortion had been initiated on several engines from 1952-1955. Engine models and test dates appear in the referenced report.

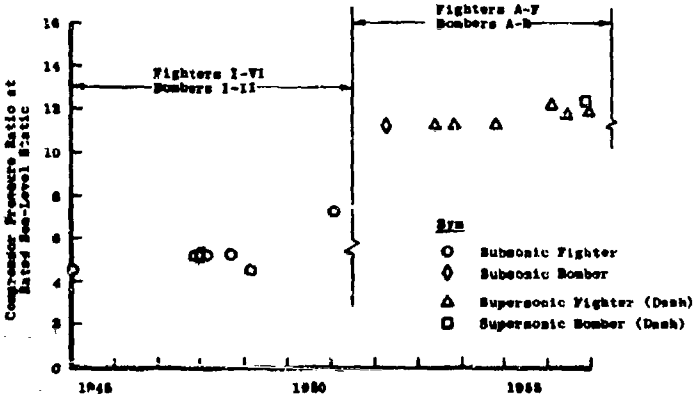


Figure II-4 Turbine Engine Compressor Loading Trends

In the area of large propulsion unit testing, large propulsion wind tunnels capable of performing free jet inlet-engine testing under simulated altitude conditions were not available until after 1955 as shown in Figure II-5. A detailed survey of other aerodynamic wind tunnels suited for inlet internal aerodynamics testing was not made although it was established that several transonic and supersonic wind tunnels were in operation at the NACA, for example. A listing of available wind tunnels in operation or under construction from 1945-1958 was found in Reference 11 and 12.

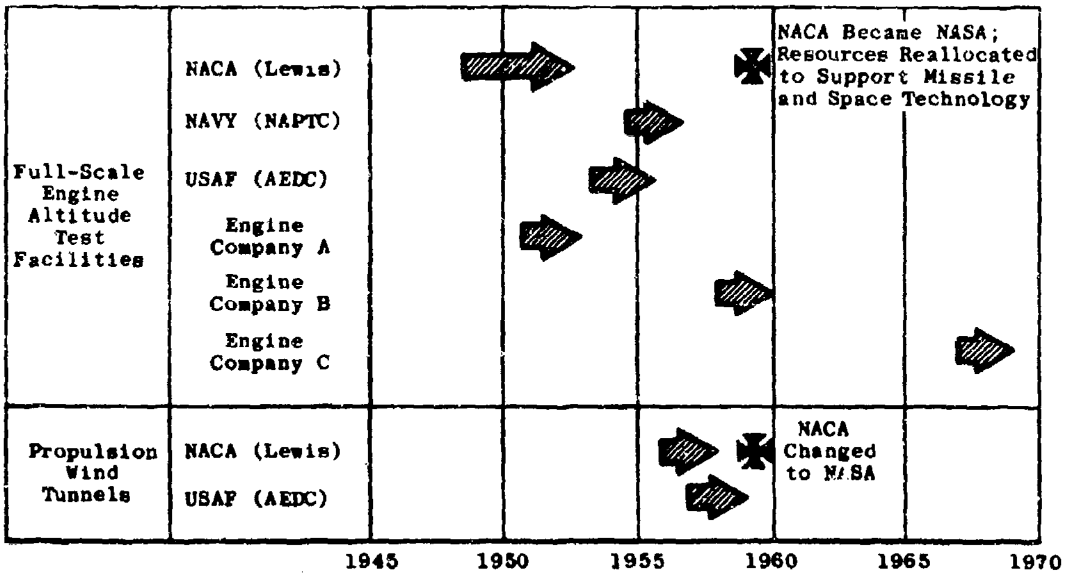


Figure II-5 General Availability of Altitude Test Facilities for Turbine Engines and Large Propulsion System Units

2.4 EARLY EFFORTS TO DEFINE INLET-ENGINE INTERFACE FACTORS

In the months following Air Force recognition of inlet-engine compatibility as a problem, actions were undertaken at Wright Air Development Center (WADC) to better define the problem and seek methods to prevent its recurrence. Such actions were reflected in a Progress Report on Engine Airframe Compatibility (Appendix IV), where inlet and engine integration factors were broken down into influence factors for further technical considerations. Outside coordinations were also undertaken to compile available research data regarding engine and inlet characteristics (principally inlet distortion and engine distortion testing results), such as the "NACA Conference on Engine Stall and Surge" (Reference 10).

As compatibility factors began to receive increased emphasis at WADC, one of the more significant interface symposia was to take shape. This was the conception and definition of the first known Air Force inlet-engine compatibility symposium. Shortly after the February 1955 Conference at NACA, a symposium was organized at WADC as the Joint Industry-Government Meeting on Engine-Inlet Duct Compatibility (Reference 13). In the late Spring of 1955, letters were transmitted to the entire aircraft and propulsion research and development community inviting participation in the Joint Industry-Government Meeting (Appendix V). The purpose for the meeting was to (1) state the Air Force concern over the seriousness of compressor stall, (2) solicit and review experiences of those present at the meeting, and (3) discuss means by which new design and test requirements could be drafted to ensure inlet-engine compatibility. The ensuing meeting was attended by representatives of the Aeronautics Bureau, NACA, USN, OSD, USAF, and all aircraft and engine companies.

As a result of the meeting, the Air Force at WADC drafted a "Technical Program for Inlet-Engine Compatibility" in September 1955 which was forwarded under letter to industry and other government agencies in November 1955 for review and comment. Constructive comments and recommendations were solicited on the scope of the program, applicability, effect on development timing, requirements for facilities, and possible additions or deletions. It was stated in the cover letter as quite probable that many of the items contained or to be accomplished in the program might later appear in contractual requirements as changes to Engine Model Specifications and Handbook of Instructions for Aircraft Design.

The program was outlined in late 1955 and is presented along with its cover letter in Appendix VI. The program contained a number of engineering approaches through research, exploratory, and advanced development efforts to establish a technical basis for improved inlet and engine distortion and flow matching criteria/methodology, testing capabilities, test procedures, instrumentation, etc. In general, the many letter replies remaining in historical files reveal that the response from the technical community was favorable and probably contributed in ensuing years to gradual improvements in understanding and approaching the compatibility problem. In addition, refinements were subsequently supported throughout industry for improved propulsion ground test capabilities and resources. Several of the responses to the drafted program are shown in Appendix VII.

SECTION III
APPROACHES TO RESOLVE INLET-ENGINE INTERFACES (1954-1958)

3.1 A BRIEF DISCUSSION OF INITIAL EFFORTS TO RESOLVE SYSTEMS STABILITY PROBLEMS DURING FLIGHT TESTS

Short-range efforts to resolve stability problems revealed in flight in the early 50's were born of necessity. Air Force historical documents reveal that at the time these major problems were revealed, aircraft production decisions had been made prior to flight during the development programs. In the case of several of these systems programs, propulsion instabilities had been so severe as to prevent or delay operational suitability testing of the aircraft with obvious implications to the overall program. Further complicating matters, there appeared to be a lack of systematic data and understanding of basic inlet-engine stability characteristics and differences in opinion as to the prime causes of engine compressor stall (see Appendix VIII).

Emphasis on early resolution of compressor stall problems in flight in the early 50's plus a lack of data on propulsion subsystems stability characteristics during development prior to flight led to a combination of multiple approaches and trial and error efforts to achieve interface resolutions. Figure III-1 shows for several systems, a table of typical problems existing at the time along with "fixes" that were tried in flight testing with varying results.

PROBLEMS	CORRECTIVE ACTIONS TAKEN	
	Inlet	Engine
Engine Stall during Climb Engine Stall during Throttle Movement Engine Stall during Cruise	Modified Boundary Layer Bleeds	Engine Control Modifications
Engine Stall during Maneuvers	Lip Shape Changes	Compressor Bleeds
Engine Afterburner Operation, Stall or Flameout	Diffusion Rate Changes	Compressor Rematch
Engine Stall Supersonic	Vanes	Compressor Modifications
Engine Stall above 30,000 ft	Rods	Afterburner Control Modifications
Engine Stall during Inlet Checking	Screens	
Engine Stall during Ground Operation	Internal Bleeds Plenum Chambers	

Figure III-1 Typical Problems and Corrective Attempts

These short-range efforts generally resulted in lengthy and costly flight test and modification programs, particularly in the cases of fighter developments. In the case of Fighter A, previously discussed, the following paragraphs were extracted from reports of Air Force operational suitability tests two years after the first flight (Reference 14):

"The F-XXX is severly restricted from optimum combat performance because of compressor stalls. Experience has demonstrated that compressor stalls may occur at any combination of altitude, power setting, and flight condition . . . Once compressor stall commences, the pilot has little or no choice except to break off any attack and regain control of the engine by all means at his disposal."

. . .

"Deficiencies in the engine limit the kill probability of the F-XXX. These include compressor stalls with throttle manipulation and afterburner failure to ignite on many selections."

. . .

"In combat it will be difficult to tell if explosive projectiles are hitting the aircraft or compressor stalls are occurring."

In yet another case (Fighter B), compressor stall was encountered shortly after first flight, and 16 months of modification and testing were required to arrive at "acceptable stall boundaries" (Reference 15). In addition, a large number of already produced aircraft required major modifications. A secondary effect was also noted in the initial flight restrictions to avoid compressor stall had resulted in the later discovery of other serious maneuvering problems in aircraft stability and control.

A brief glance at a third system (Fighter C) reveals a similar sequence of events and elapsed time to achieve stable propulsion system operation. Reference 16 reflects the results of nearly two years effort in achieving interface resolution for this system.

Several significant and related observations can be made from these early examples. First, delaying interface and propulsion stability considerations until first flight did little to ensure the compatibility of integrated systems for flight. Secondly, a lack of baseline stability data on propulsion subsystems led to multiple or trial and error testing approaches with excessive time and resources expenditures ensuing. Additionally, the pressing need for "early" resolution of flight problems and eventual stability results did not appear to significantly contribute to the understanding of causes, effects, and solutions of stability problems and translate into needed engineering approaches for propulsion system development procedures prior to flight. Reference 17 states a similar observation made in recent years as follows:

"A nontechnical observation is that compiling a catalog of past propulsion system instabilities is a frustrating task. First, it is human nature, if not policy, to remember past successes and forget past problems. Second, when a problem is encountered during flight test, the overpowering concern is to solve the problem, not understand or document it. Typically, multiple fixes are tried until some combination is sufficiently successful. Thereafter, the airframe personnel recall that the problem was solved by changes in the engine geometry, control schedule, and/or operating procedures. Similarly, the engine personnel will clearly remember that the problem disappeared when changes were made in the inlet geometry, control schedules and/or aircraft operating procedures. Thus, in all sincerity, various companies (and various groups with a company) will have conflicting versions of the cause and the cure for the same problem."

Several other Air Force weapon systems were to achieve flight in the latter 1950's as shown in Figure III-2. These aircraft were basically in the same generation of advanced systems that were in the process of evolution in the early 1950's in terms of mission definitions, propulsion system requirements, and integration concepts. Hence, compatibility improvements were apparently realized for these systems because of relatively similar propulsion system configurations, increased awarenesses of inlet distortion effects on engine stall margin, and some increased levels of emphasis on earlier propulsion systems stability related testing prior to flight. However, several of these aircraft still encountered inlet-engine interface problems in flight as shown in Figure III-2.

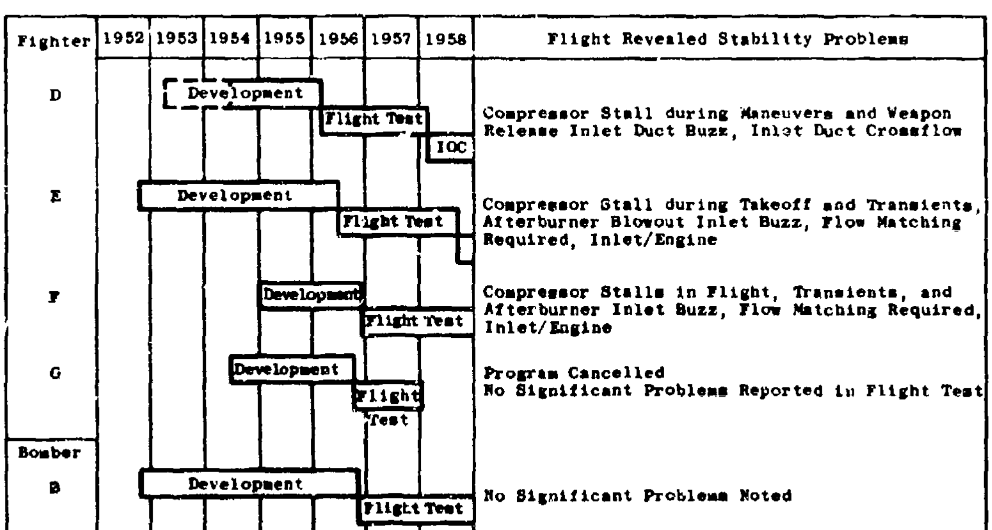


Figure III-2 Typical Air Force System Development Schedules (1952-1958)

3.2 THE COURSE OF AIR FORCE PLANS TO ACHIEVE INLET-ENGINE DEVELOPMENT APPROACHES (1954-1959)

As seen in Section II, inlet-engine compatibility problems became clearly identified in the early 1950's. Further, it was seen that the discovery and impact of serious stability problems at flight onset revealed the need for improved propulsion interface development approaches. Accordingly, early efforts at WADC had reached culmination in the Joint Industry-Government Meeting on Engine-Inlet Duct Compatibility in 1955. Based on the technical discussions and coordination up to and including this symposium, the technical plan in Appendix vi was drafted which was to provide the basis for criteria ensuring airframe and propulsion system compatibility through analysis and testing. These in turn would be translated into subsystems development approaches, requirements, and testing procedures.

However, it is of major significance at this point to place in perspective the turn of historical events that was to deter or cut short programming directed toward these engineering goals. In the years following 1955, the advent of the ballistic missile family of strategic and tactical weapon systems was to divert significant levels of funding and effort from aircraft and propulsion developments. A brief look at Figure III-3 shows that all categories of resources available for airbreathing propulsion were greatly reduced after 1955-1956, including those resources which supported programs targeted at advancing technology for propulsion development and integration.

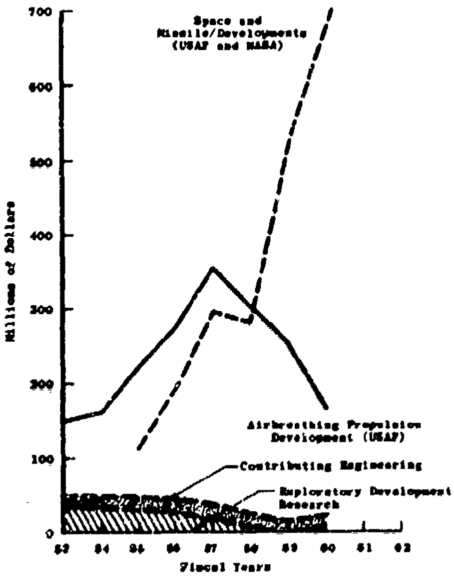


Figure III-3 Development Funding versus Years

In a similar manner, aircraft developers found mission requirements more demanding, development costs spiraling upwards, and fewer funds available for advanced aircraft programs. During this period, many aerospace contractors diverted their efforts and technical resources away from aircraft and propulsion toward the field of missiles and rockets. In addition, government research, such as that at NASA (formerly NACA), in the area of aeronautics and propulsion was reoriented to support the space and missile programs. Thus, in aircraft and engine developments alike after the mid-1950's, fewer developments were initiated and major reductions occurred in exploratory and advanced development programming. As a result, early plans to define inlet-engine development programming factors and definition of the inlet-engine interface failed to culminate as technology sources, funding, and engineering efforts dwindled.

Although the technical programs for inlet-engine compatibility were not fully realized, the coordinations with the industry at that time indicated a recognition of several basic factors:

1. The need for propulsion subsystems stability analysis and data at a much earlier time phase in systems developments was necessary to ensure airframe-propulsion compatibility in early flight testing.

2. The need existed for improved development definitions of the interface for systems developers.

3. The need existed for improved test facility capabilities (i.e., facilities, test techniques, instrumentation, etc.).

Several years after the joint industry-government coordinations in the 1955-1959 time period, modifications were made to military engine specifications (MIL-E-5007 Series) and aircraft design handbooks (HIAD) (shown in Appendix IX) as applicable to areas of airframe and propulsion interfaces. Basically, in the inlet-engine area these consisted of requirements to define engine "distortion limits" and test requirements for military engines. The HIAD on the other hand specified the need to minimize inlet duct air pressure variation and specified that circumferential total pressure variations from the mean should not vary more than ±5 percent at all required flight conditions of the air vehicle.

It has also been noted that the majority of currently available propulsion test facilities came into operation in the later 1950's, thus making available a number of engine altitude test cells, large scale propulsion wind tunnels, and other wind tunnels for airframe-propulsion subsystems testing for usage in later advanced military aircraft developments.

SECTION IV
INLET-ENGINE INTERFACE DEVELOPMENTS OF LATER AIR FORCE WEAPON SYSTEMS (1958-1965)

4.1 INCREASES AND SIGNIFICANCE OF WEAPON SYSTEMS REQUIREMENTS

Air Force weapon systems operational concepts continued to grow in scope in the later 1950's and influenced advanced propulsion system concepts and designs through their particular mission needs. Two types of such advanced weapon system concepts evolving in this time span included the long-range, sustained supersonic cruise vehicles and the mixed mission weapon systems possessing several mission range, Mach number, and high maneuverability requirements. Some of these systems and their general characteristics are shown in Figure IV-1.

Weapon System	1957-1967		Inlet Type	Engine Type
	Mach No.	Range, nmi		
Multimission Fighter I	Cruise, 0.75 Sea Level, 1.2* Altitude, 2.5*	Ferry, ~4000 Basic Mission, ~3000 (Mixed Mission Capability)	Variable Area, Mixed Compression**	Augmented Turbofan
Bomber I	Cruise, ~3.0	~6000	Variable Area, Mixed Compression	Augmented Turbojet
Strategic I	Cruise, ~3.0	(Classified)	Variable Area, Mixed Compression	Augmented Turbojet

*Dash Capability
**Later Changed in Development to Variable Area External Compression

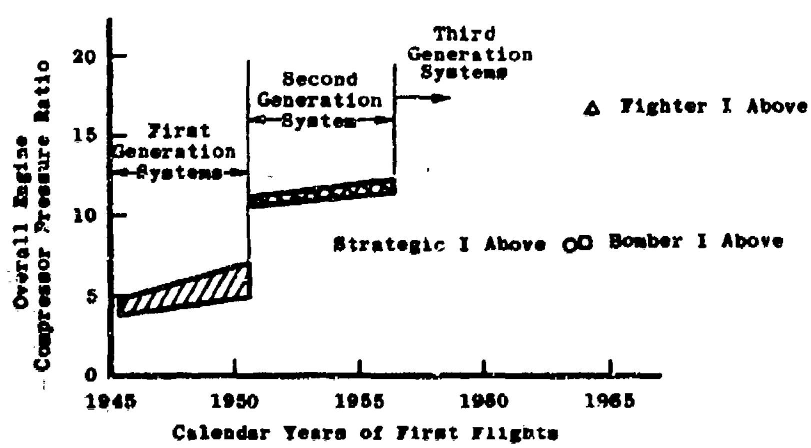


Figure IV-1 General Aircraft Characteristics (1957-1967)

Each type of weapon system requirement posed challenging engineering tasks contrasted to those of earlier systems. In the case of supersonic cruise vehicle types, the propulsion subsystems were moderate pressure ratio afterburning turbojet engines combined with variable-area, mixed-compression inlet systems. These types of weapon system propulsion systems would be required to accelerate an aircraft through takeoff and climb to cruise conditions. Upon reaching cruise altitudes and Mach numbers, efficient propulsion system cruise operations would be required for primary mission operations, which did not include requirements for wide ranges of transient maneuvers, Mach numbers, altitudes, or abrupt engine power modulations.

On the other hand, the multimission type of weapon system posed needs for efficient propulsion systems operations along several required mission trajectories varying widely in speed, altitude, and range. In addition to this desired mission flexibility, extensive aircraft maneuvering and transient capabilities were also required. These combinations of mission operations and aircraft range requirements led to propulsion subsystems consisting of supersonic, variable-area, mixed-compression inlet systems combined with high pressure ratio augmented turbofan engines.

The significance of the increased scope of these Air Force required weapons delivery capabilities became apparent in the configurational and matching complexities of resulting propulsion systems requirements and configurations. Those arising complexities became even more significant considering the status of available propulsion engineering development criteria and approaches evolving from the late 1950's, particularly those relating to integrating inlet and engine functional operations in system development.

4.2 INTERFACE DEVELOPMENT CRITERIA

It is interesting to note that all three weapon systems characterized in Figure IV-1 incorporated similar definitions in the inlet-engine interface area as shown in Figure IV-2. These definitions were consistent with Air Force design practices and criteria which had evolved by the close of the 1950's (see Appendix IX). An example of a detailed set of definitions from one of those weapon systems may be found in Appendix X.

Weapon System	Air Vehicle Specifications, Inlet and Air Induction	Engine Model Specification, Inlet Air Pressure Variation	Interface Agreement between WSC* and ESC**
Multimission Fighter I	±5% Variation about the Average Total Pressure	±5% Variation about the Average Total Pressure	Yes
Bomber I	"...The air induction system will be compatible with the engines..."	Distortion Index = 10% where DI is equal to $\frac{\Delta P}{P}$ factored by distortion shape extent and profile factors	Yes
Strategic I	Not Available	±5% Variation about the Average Total Pressure	Yes

*Weapon System Contractor
**Engine System Contractor

Figure IV-2 Typical Inlet-Engine Interface Criteria

4.3 EXAMPLES OF DEVELOPMENT CONSIDERATIONS AND APPROACHES TO INLET-ENGINE COMPATIBILITY

Air Force historical records and data from the early 1960's provide some insights into inlet-engine interface approaches for weapon systems in development at that time. From such technical records, several of which are listed in the Bibliography of this report, engineering summaries dealt with means for design and development of compatible inlet and engine configurations for advanced supersonic systems. These records reveal that the systems development experiences of the 1950's had influenced such summaries since sections related that compatibility had been first recognized and treated as a problem in the mid-1950's. Further writings stated that, after the problem had become apparent, considerable research and flight testing had been undertaken in following years to better understand the effects of inlet characteristics on engine operations.

These summaries basically reflected some of the experiences in the later 1950's as follows:

1. One of the principal effects of inlet distortion on engine operation was the increased tendency of the engine compressor to stall.

2. Levels of inlet distortion as well as geometric distribution had been found to affect engine compressor stall characteristics.

3. Compressor stall or engine flameout could be caused by high distortions resulting from poor inlet designs, pressure fluc-

tuations during flight maneuvers (inlet unstart, buzz, flow separations, etc.), and the ingestion of armament firing gases.

4. Compressor stall characteristics had been found to be affected by stage loading, stages and/or spool matching, control response (accel-decel), control operation, and Reynolds number.

5. Supersonically, shock-boundary layer interactions had been found to result in higher inlet flow distortions at the compressor face.

6. Inlet-engine compatibility problems on military aircraft had resulted in considerable difficulties and solutions had usually been found by "modifying engines."

Based on the above or preceding types of "knowns" from prior development experiences, technical summaries continued into discussions of design practices and development approaches that were felt necessary to achieve inlet-engine compatibility for new systems. From such discussions, several significant factors were identified as follows:

1. It was not felt possible to predict the character of inlet flow for a new design.

2. It was not felt possible to predict the response of a new engine under development, to (1) above.

3. Because of (1) and (2) then, the best design practice in inlet-engine compatibility was felt to be found in considering small inlet disturbances as inlet design requirements and in maximizing engine tolerance to inlet disturbances.

4. Based on earlier inlet-engine experience, it was felt that 10 to 15 percent distortion levels ($\Delta P/P$) should not be too difficult for integrating inlets and engines, and represented a resonable maximum target value in systems preliminary design stages.

5. The major aerodynamic consideration in (supersonic) inlet-design remained one of maximizing inlet performance (recovery) at the lowest level of external drag.

To carry out these approaches, Air Force systems engineers proposed that early development testing be conducted in a system program, to achieve data on inlet internal flow characteristics. Based on these results, engine tests could then be performed using screens or other devices to produce levels and patterns of inlet distortion at the engine compressor face for engine operational testing. These testing evaluations were felt necessary early in the program so that inlet and/or engine changes could be made prior to an inlet-engine compatibility test. Full-sclae inlet-engine compatibility testing was recommended in systems programs where compatibility remained questionable in design and development (prior to flight).

Further, it was felt necessary to require engine contractors to develop and furnish more meaningful estimates of allowable inlet distortion limits. It was suggested that these estimates should contain the combined effects of pattern shapes as well ad disturbance levels, and should provide estimates of the engine's response, even if allowable distortion limits were exceeded.

Concluding sections dealing with these development approaches again stated that problems of compatibility encountered in flight testing had usually been resolved by engine modifications.

4.4 PROPULSION SYSTEM COMPATIBILITY DEVELOPMENT TEST TRENDS

Some reports and data remain in Air Force historical files, from which compatibility development testing trends in the early 1960's may be examined. References 19 and 20 and other reports dealing with a strategic high Mach number cruise system show that inlet-engine matching and compatibility were recognized in some quarters at program definition and onset as potential interface engineering problems. For example, some 4000 hr of air induction system testing had been accomplished by one system contractor between 1958 and late 1961. Over 1500 hr of this included 0.25 and 0.577 scale model inlet tests. Further scale model inlet and inlet-engine tests were planned prior to flight. As a result, considerable development emphasis and resources were applied to engineering and testing of both inlet and engine subsystems. Testing initiated prior to program onset continued after go-ahead into progressively larger wind tunnel model inlet tests while the engine development program employed various inlet distortion screen tests. (Approximately 50 million dollars were spent on inlet-engine and component testing during acquisition.) A significiant portion of testing was accomplished coincident to key mission operating conditions in order to assess propulsion systems characteristics and matching through analysis and provide design refinements wherever necessary.

During inlet-engine testing in 1961-1962, a scaled inlet model and an engine were coupled and operated in an altitude propulsion wind tunnel. During this testing, an unusual problem occurred. Under certain test conditions, engine "drift stalls" were occurring. These were defined as stall occurrences after a random length of time at a stabilized test condition. Reviews of the data indicated that engine stall events were occurring randomly under low and high steady-state distortion values and on a nonrepeatable basis. However, earlier inlet test of smaller model inlets had incorporated limited amounts of high response pressure instrumentation, and similar provisions had been extended to the inlet-engine tests in anticipation of unsteady inlet flow phenomena such as buzz or inlet shock-induced perturbations. Although this early instrumentation was somewhat less refined compared with that available in recent years, sufficient dynamic instrumentation existed to indicate some insights into the driving mechanisms that resulted in unexpected engine random stalls, i. e., the turbulence or fluctuating pressures at the engine face resulting from the shock-boundary layer interactions in the inlet system (Reference 21).

Subsequently, engine testing was initiated to learn more about engine response characteristics in the "turbulence" environment, which produced the first known reports on the effects of turbulence (and some qualitative data) on turbine engines (Reference 22).

The early recognition of compatibility development needs of this system, and a continued high level of emphasis on engineering and test during developments served well in minimizing inlet engine matching and compatibility problems for this system as flight testing in later months was to demonstrate.

A second and admittedly more complex development program for a tactical system was also initiated in the early 1960's. Data referenced in the Bibliography of this report revealed some concerns over inlet-engine compatibility development based on earlier systems experiences in the 1950's but, in general, concluded that through systems development testing of inlet and engine, a compatible system could be constructed. Although at development onset test data on both inlet and engine were found lacking, Air Force personnel proposed that aircraft inlet and engine could be integrated inside the 10 to 15 percent distortion ($\Delta P/P$) levels except at Mach numbers greater than 2.2.

However, initial development testing of the mixed compression inlet system resulted in a decision to change the design operation of the inlet to external compression design (see Appendix XI). Parallel engine testing during development was performed using screens to simulate scale model inlet distortions from the changed inlet now under development and no problems were anticipated at the time that the inlet and engine were integrated for operational tests in an altitude propulsion wind tunnel. While some difficulties arose in free-jet tests, no major problems were projected since production configuration improvements had not yet been incorporated into the test article. Wind tunnel test operating restrictions and modes were also subject to question in some areas where compressor stalls had been observed. However, subsequent flight testing was to reveal inlet-engine compatibility problems of significantly larger magnitude than expected from ground testing results.

4.5 INTEGRATION AND FLIGHT

Figure IV-3 depicts the development program schedule histories for three advanced Air Force systems which were to achieve flight in the mid-1960's. Official records reveal little in the way of documented major interface problems on two of the systems, namely, the supersonic cruise design point aircraft. But in the case of the fighter system, early flight tests revealed another major problem in the inlet-engine area. It will be recalled from Figure IV-1 that this system became defined with a highly loaded engine cycle in terms of compression system pumping and was to be matched for a broad spectrum of mission operations with an advanced and complex air induction system. In terms of matching sensitivity or complexity, this system marked a major advance compared with earlier Air Force weapon systems. Flight testing into 1965 revealed unexpected and serious discrepancies in systems' stability (and performance). By mid-1965, propulsion system problems such as various modes of compressor stall and flameout had limited the flight envelope and aircraft maneuvering capability to the extent that significant delays in the flight test schedule and program were evident. Air Force task force groups convened, such as shown in Reference 23, and after some examination, stated that the system could be made to work over some of the important parts of the wide mission spectrum required, but at the expense of overall program schedule. Perhaps more importantly, considering the complexity of the overall propulsion system and the wide spectrum of systems operating requirements, it was not felt possible at that time to fully define the problems; therefore, additional diagnostic investigations, studies, and tests were recommended for identifying and understanding the operating characteristics of the inlet and engine.

Serious problems in flight testing continued and an accelerated program of flight and ground testing was implemented. With the influx of those tests and the incorporation of extensive diagnostic instrumentation (including high response pressure measuring devices), another problem surfaced. Systems for handling, reducing, transmitting, and interpreting data from tests rapidly reached an unworkable point. Along with the data density problem, another serious difficulty arose in that contractual interface definitions covering inlet and engine were basically steady-state and subject to much discussion and interpretation as related to inlet-engine interface problems.

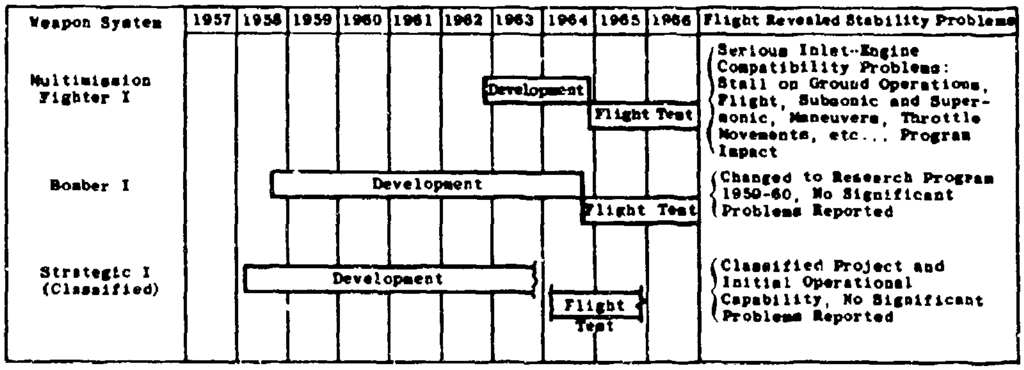


Figure IV-3 Typical Air Force System Development Schedules (1957-1966)

By early 1966, the Air Force again officially declared inlet-engine compatibility as a major problem. As in earlier times, the Air Force concern was exemplified by the letter in Appendix XII, addressed to the various airbreathing propulsion developmental agencies at WADC. This letter essentially duplicates the one written twelve years earlier. As in Appendix I, the Air Force again requested that efforts be focused on inlet-engine compatibility needs for both existing and future systems. As a result of this direction, Air Force agencies at WADC again formed Task Force efforts to seek improved interface compatibility development approaches, plans, and criteria as shown in Appendix XIII. The need for this long-range effort can be seen in Figure IV-4 because several advanced systems were nearing definition. It is interesting to note that this letter again asked for short-range and longer-range efforts in advanced and exploratory development programming as needed, to derive necessary propulsion system stability development approaches for Air Force weapon systems. It can be seen in Appendix XIII that the resulting program was similar in many respects to the 1955 program in Appendix VI.

Progress and coordination with the industry from ensuing efforts in inlet-engine development procedures were to be covered in a joint industry-government meeting in mid-1969, the Airframe Propulsion Compatibility Symposium (Reference 4).

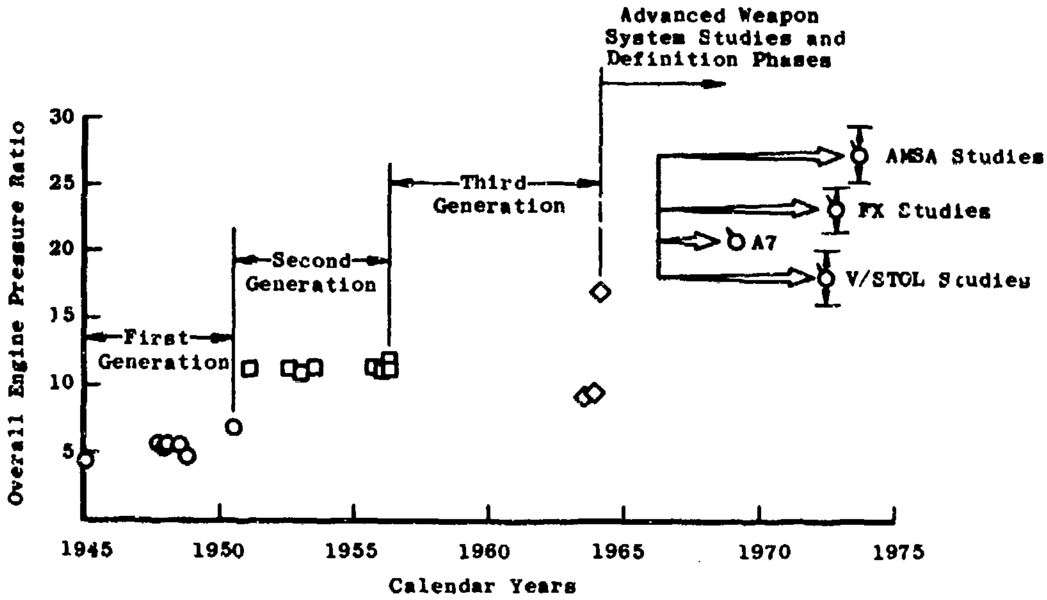


Figure IV-4 Calendar Years of First Flights and Systems Studies/Projections in 1966 versus Loading Trends in Compressor Pumping

SECTION V
INFLUENCE AND SIGNIFICANCE OF COMPATIBILITY PROBLEMS ON ENGINE DEVELOPMENTS

5.1 GENERAL TRENDS IN ENGINE DEVELOPMENT

Emerging weapon systems compatibility problems arising in flight during the early and mid-1950's clearly demonstrated the needs for improved propulsion development approaches, criteria, and test procedures. These problems led engine developers to seek improvements in testing and interface definitions for describing inlet flow effects on engine compressors.

Sets of distortion tests were subsequently initiated on compressor rig tests using distortion screens and other flow distortion producing devices. With the advent of improved turbine engine development facilities, engine testing with distorted inlet flow began and was extended into altitude tests (Reference 24). Engine manufacturers directed these test efforts toward developing means to correlate inlet flow conditions and engine compressor response characteristics in order to predict compressor stall. As a result of these efforts, various correlating factors or "distortion indices" were generated by the different companies. These indices consisted of calculation procedures which factored measured inlet flow pressures with empirically and test-derived influence coefficients to predict compressor stall (Reference 1). Test methods typically used in engine and compressor tests consisted of incrementally increasing inlet flow distortions at some steady-state set point, until compressor stall was reached. At the point of incipient stall, pressure distortions were measured and converted to distortion indices. Therefore, when inlet distortion-produced indices reached calculated values correlating to stall, a distortion "limit" was established.

Engine model specifications on the other hand required the estimated radial and circumferential inlet air total pressure distribution limits (Reference 25). (Later specifications were to require a test demonstration of these "limits".)

From this background, a concept of distortion limit calculations and definitions evolved into interface criteria and approaches employed in various later Air Force system programs.

5.2 APPLICATION OF DISTORTION LIMITS

In some engine development programs, distortion index calculation procedures and limits were established for all projected steady-state operating conditions. It was anticipated that such procedures could be utilized for compressor stall margin development and for predicting stall response as a function of engine-inlet flow distortion. Frequently, distortion index calculation procedures were extended into inlet development tests, to assess inlet distortion. (Later indices were also utilized in flight test inlet measurements.) Definitions of distortion limits were subsequently established in various system design criteria and specifications.

In developments emphasizing these approaches, however, serious problems arose during integration and flight test phases with the advent of unexpected stability problems. At the onset of these problems, interface definitions and distortion limits often became major areas of disagreement when needs existed to define and resolve interface compatibility. Schedule delays were incurred for these needs as respective contractors assembled and presented data seeking to establish compliance to contractual interface criteria. Often such interface data differences revolved around whether or not specified inlet distortion limits had been exceeded. The applicability of inlet and engine distortion testing results and subsequent interpretation were challenged. Further, contractors sometimes indicated that military specification and design requirements contributed to inadequate or inappropriate contractual definitions of interface criteria (see Appendix XIV).

5.3 DEVELOPMENT ADEQUACY OF LIMIT APPROACHES

In integration and flight experiences, distortion index calculation procedures were found inadequate in assessing stability and predicting compressor stall. In subsequent engine and systems testing, sets of data were provided in which little correlation could be made on the relationships of inlet flow distortion and stable or unstable engine operation (Figure V-1).

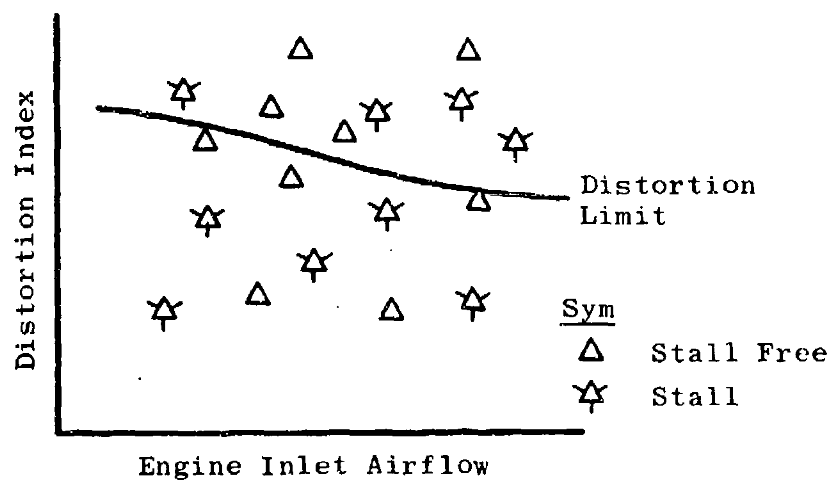


Figure V-1 Typical Correlation of Distortion Limits and Compressor Stall from Flight Data

Distortion limit concepts, as applied for such developments, proved inadequate for many reasons. In efforts to derive the general utilization of engine stability characteristics for example, distortion indices did not define the allocation or utilization rates of compressor stall margins. As the relationships of engine internal margin utilization vary in accordance with engine operating conditions, so do margins utilized by varying inlet flow characteristics and conditions. The range, effects, and variability of external destabilizing phenomena as well as internal destabilizing effects of engines did not readily yield to stability generalizations without definitions of margin utilization factors and quantities.

The range of boundary conditions involved in steady-state engine and compressor distortion testing was far exceeded in propulsion system operations. These conditions included systems transients, control tolerances, production variations, deterioration, Reynolds number effects, and inlet flow characteristics.

Distortion index definitions largely failed to characterize the physical properties of inlet flow. Conversely, a distortion index could not be translated into a flow condition for an engine or compressor rig test sequence. In addition, an index calculation was greatly influenced by the placement, frequency response, uncertainty, and quantity of pressure measuring instruments (see Figure V-2). Such sampling problems along with differing data reduction procedures in the past have yielded entire ranges of distortion indices for similar inlet pressure measurements, thus rendering correlation efforts fruitless.

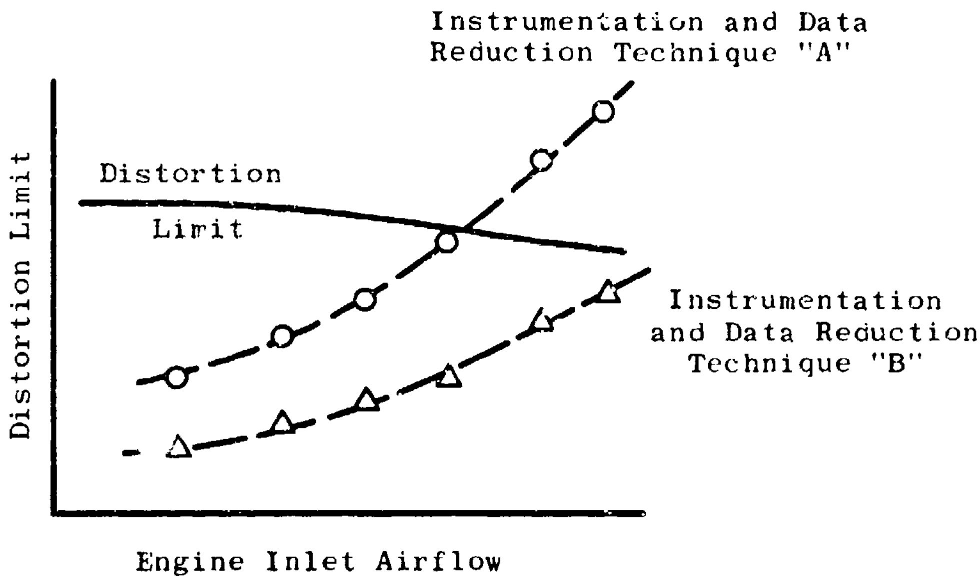


Figure V-2 Typical Comparison of Distortion Index Values Using Two Different Approaches for the Same Inlet Flow Conditions

These discussions are not meant to imply that distortion correlation efforts in themselves are totally inapplicable in development. Moreover, it is important to determine the limitations that are inherent in such procedures and to constrain their usage within such boundaries. As such, distortion indices evolving in recent years have been utilized as development tools rather than criteria for stability development or contractual agreements.

5.4 SUMMARY AND SIGNIFICANCE OF INTERFACE COMPATIBILITY PROBLEMS

By reviewing the past twenty-five years of aircraft and engine development, many similarities can be observed. A look at the generations of aircraft and engines rather than individual programs shows the trends toward increased propulsion system complexity and matching sensitivity as weapon system requirements expanded over the years. In many cases, a lack of interface development emphasis existed prior to and during inlet and engine development as a result of earlier development experiences, available engineering approaches, test resources, and the influence of national policies and objectives.

Testing and evaluation during the 1950's established the influences of destabilizing effects on engines from both internal and external sources. However, these effects were not quantified in terms of engine margin utilization elements and related to engine mission handling needs in a propulsion system.

Over the years, evolving interface criteria were inappropriate and failed to define functional propulsion systems characteristics in physical and measurable terms for engineering development purposes. Such criteria in turn were poorly suited for translation into engine development testing.

The status of interface definitions and testing processes for propulsion subsystem developments contributed to a tendency to approach engine stability margin utilization as a general case rather than a deterministic one requiring assessments of engine margins and how they were utilized for various effects in operational usage. The general utilization of engine margins was, therefore, often sought in development through the application of "distortion limit" definitions or "distortion indices" as opposed to development criteria addressing mission-related propulsion system operating characteristics. Further, distortion index calculations proved inadequate in characterizing engine-inlet airflow.

Engine development testing procedures for interface were lacking over the years in terms of normalized or accepted test techniques for assessing stability margins. Until more recent years, instrumentation, data systems, and test experience were also limited.

As a result of such interface definition and development testing shortcomings then, propulsion development testing was accomplished on a number of past systems programs in which any number of interpretations were made relative to test results and specification compliance rather than effective application to systems engineering needs.

Engine distortion test sequences, for example, were sometimes accomplished to demonstrate the validity of distortion limits or indices. Further, in many cases of engine distortion testing, engine stability was judged by the presence or absence of compressor stall.

Data handling also evolved into a problem over the years as interface testing came into practice for propulsion subsystem developments. A lack of uniform data handling and transmittal processes, in addition to subsystems test procedural problems, was finally realized with the advent of dynamic and transient propulsion testing data.

In summary then, past engine development and integration approaches have frequently resulted in delaying engine stability accessments until after first flight. The need has thus been generated to derive engine stability margin and utilization in costly and time-consuming flight test programs. Such programs have consistently shown the shortcomings of trial-and-error testing to achieve system stability and have typically yielded little in terms of understanding true cause-and-effect relationships of interface problems. This is further evidenced by the lack of applicability of experience to progressively newer and more advanced systems developments. In short, past inlet-engine interface development approaches have been inappropriate to the needs of the service in developing operationally suitable engines for advanced systems.

SECTION VI
EVOLUTION AND STATUS OF ENGINE STABILITY DEVELOPMENT APPROACHES AND TEST PROCEDURES TO ATTAIN PROPULSION SYSTEM COMPATIBILITY (1965-1970)

6.1 INTRODUCTION

In earlier sections of this report, it was shown that needs again arose in the Air Force during the mid-1960's for improved development approaches to airframe-propulsion system compatibility. In the later 1960's, objectives, similar to those of technical plans drafted in the 1950's, were again oriented toward propulsion subsystems stability development definitions, criteria, programming approaches, test procedures, and testing techniques. These objectives or needs were clearly stated in documents such as those found in Appendix XIII, or Reference 26. The needs for improved data handling and transmittal between propulsion developmental agencies and the Air Force were also identified.

This section will review briefly some of the results of engineering efforts in the late 1960's which sought and established some recent propulsion system stability development programming and procedural concepts. These stability development and programming approaches are discussed in terms of relating engine stability margin allocation and utilization concepts with recent advances in turbine engine stability margin testing in the Air Force.

6.2 DERIVATION OF PROPULSION SYSTEM STABILITY ELEMENTS AND DEVELOPMENT PLANNING CONCEPTS

Efforts initiated by the Air Force and industry in the 1965-1966 time period led to several key concepts in propulsion system and engine stability development approaches. The first of these concepts (Reference 1) discussed and presented an accounting approach for the external and internal factors which affect or degrade the stability of an engine. These elements are shown in Figure VI-1, depicting the necessary margin allocation and utilization factors and quantities that must be defined and developed for stable engine (compressor) operation at specific propulsion system mission conditions.

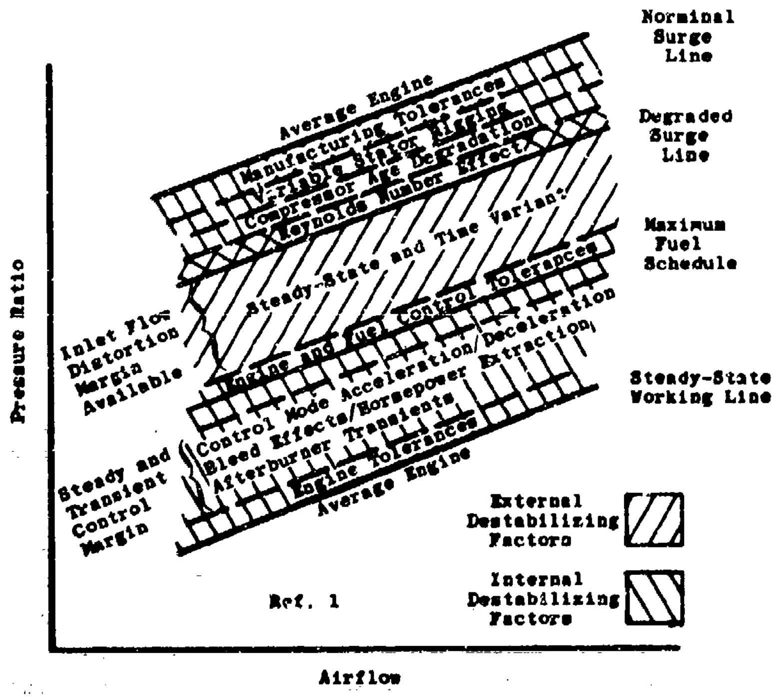


Figure VI-1 Cumulative Representation of Stability Degrading Factors on a Compressor Performance Map

Along with margin allocation and utilization elements for turbine engines, programming concepts and approaches evolved which basically sought definition, development refinement, and test verification of engine margin allocations relative to propulsion system mission operations. These concepts and approaches are more completely discussed and developed in References 2 and 19 and are illustrated in Figure VI-2. This figure portrays an inlet and engine development planning approach during predevelopment, contract definition, and systems acquisition program time phases. Inlet and engine trends are shown in terms of the time-phased matching requirements for inlet airflow distortion and engine tolerance for specific propulsion system configurations and mission handling requirements.

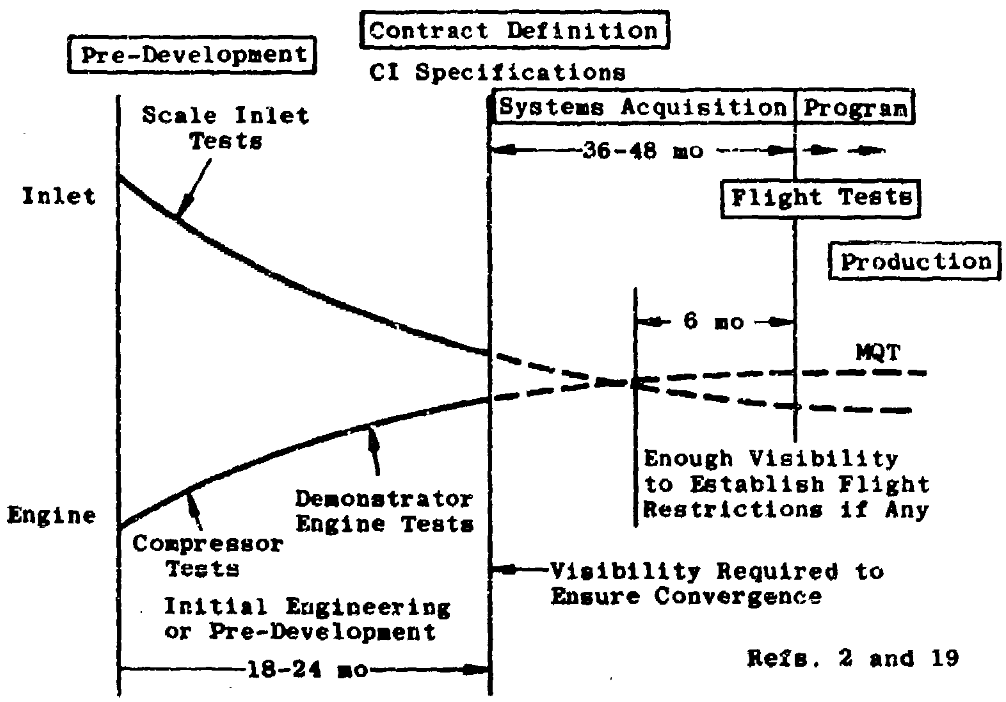


Figure VI-2 Development Plan Concept for a Typical 200-lb/sec Engine

During the formulation of these concepts and approaches, however, further needs were identified in the areas of propulsion subsystem and system development criteria and test procedure. For engine development processes, needs existed for stability criteria and turbine engine stability testing techniques and procedures. Such needs were also identified and supported by various technical and scientific panels such as the USAF Scientific Advisory Board (Reference 26). As a result, these needs were documented as shown in Appendix XV.

6.3 AIR FORCE EFFORTS TO DEVELOP ENGINE STABILITY CRITERIA AND TEST PROCEDURES

In 1966-1967, several major stability investigatory programs were initiated by the Air Force, NASA, and industry. One such program in the Air Force consisted of a 3-year stability test program on an advanced augmented turbofan engine configuration, conducted by personnel of the Aeronautical Systems Division, the Air Force Aero Propulsion Laboratory, and the Arnold Engineering Development Center. The specified objective was to develop normalized test techniques and procedures for engine stability testing. The breakdown of testing considerations is shown in Table VI-1.

TABLE VI-1
AUGMENTED TURBOFAN STABILITY TEST PROGRAM

TEST OBJECTIVE:	Develop Normalized Testing Techniques and Procedures for Turbine Engine Stability Testing
ITEM BREAKDOWN:	<u>Engine Inlet Operating Environment</u>
	Clean Inlet Techniques and Control of Variables
	Distorted Inlet Techniques and Control of Variables
	Airflow Measuring Systems
	Definition of Inlet Airflow Characteristics/Parameters
	Instrumentation and Data Handling
	<u>Engine Configuration/Operation</u>
	Pretest Data
	Instrumentation
	Engine Operating/Testing Techniques
	Data Acquisition and Handling
	Operating Environment-Pressures/Temperatures
	<u>Test Cell Hardware Configurations</u>
	Distortion Producing Mechanisms
	Engine Test Configuration Support Requirements
	Data Acquisition Systems
	<u>Simulation Ranges</u>
	Steady-State Operation
	Time-Variant Operations

Specific objectives included the following:

1. Development of controllable airflow disturbance generation techniques and criteria for producing steady and time-variant distorted engine-inlet airflow conditions. Identification of parameters which best describe and measure inlet flow characteristics,

2. Development of apparatus and techniques for acquiring data on engine compression systems throughout their operating ranges to determine aerodynamic characteristics, margin allocations, and utilization rates,

3. Development of apparatus and techniques to simulate interface flow conditions from aircraft inlet subsystems,

4. Development of testing apparatus and techniques for engine operation and control under conditions of propulsion system interface operations, (i. e., bleed, horsepower extraction, transients, inlet distortion, etc.),

5. Development of instrumentation techniques for 1, 2, and 3, and

6. Development of techniques for rapid and compact data reduction, analysis, and transmittal.

6.4 ENGINE STABILITY TESTING DEVELOPMENTS AND SIGNIFICANCE

Air Force engine stability testing experience in earlier years had been spread out in various systems developments over a number of years with different engineering teams, needs, and objectives. Some experience with steady-state distortion testing existed for example on the J-79 development and other engines. Some early dynamic distortion testing had been accomplished by the early 1960's on the J-93 development program after fluctuating inlet total pressure characteristics of the XB70 inlet system had been identified.

The Augmented Turbofan Stability Test Techniques program, however, allowed extensive investigation into all phases of engine stability testing with adequate time and resources to accumulate needed testing knowledge, definitions, and experience for the complexities of such testing. This engine test effort was programmed to proceed from clean inlet baseline testing at simulated Mach number and altitude to steady-state and ultimately to time-variant testing phases under clean and distorted inlet airflow conditions. Therefore, test instrumentation was investigated, refined, and defined around the needs of each phase. Time was available to investigate and define test hardware configurations, techniques, etc., and alternative approaches. Improvements in instrumentation and data acquisition/recording and data transmittal systems were investigated and defined.

The results of this test program are reported in Reference 27. The significance of this engineering test development program was demonstration of the feasibility of identifying and quantifying the destabilizing factors and elements of engine stability margins for defined interface conditions. By utilizing the array of testing techniques and procedures developed in this test series, it is possible in engine development testing to select test procedures allowing accessments of the complex external and internal stability margin quantities shown in Figure VI-1, with the exception of compression units' age deterioration effects (see Appendix XVI).

6.5 SUMMARY

During the 1960's, needs reappeared in the Air Force to improve the qualitative stability approaches of earlier systems. Accordingly, overall development approaches evolved in the later 1960's which sought to form a quantitative basis for engine stability margin allocation and utilization. Programming approaches and time phasing to accomplish these objectives received significant levels of emphasis and support. However, one of the essential tools required for accomplishing these objectives was identified as the urgent need for improved engine stability testing criteria, techniques, and procedures. An extensive 3-year Air Force program was created to accomplish this need. The results of this program demonstrated that engine stability testing could result in quantitative assessments of turbine engine stability margin elements for defined sets of propulsion system interface operating conditions. Also, methods for characterizing inlet flow properties were identified, thus yielding methods for stating physical, measurable parameters for system development testing criteria.

The full relevance of currently available stability margin testing capabilities is discussed in Section VII as an integral part of an overall time-phased approach to developing operationally suitable engines. Programming approaches referenced in this section form the basis for incorporating engine stability margin testing into development programming and time phasing.

SECTION VII
DEVELOPMENT PROGRAMMING APPROACHES TO ESTABLISH INTERFACE CRITERIA AND ENGINE STABILITY MARGIN TESTING

7.1 INTRODUCTION

As interface development approaches evolved, it was necessary to establish engine testing techniques and procedures in order to enlarge engine stability assessment capabilities. It was further recognized that efforts would be required to define physical and measurable interface parameters for such tests in order to provide criteria and functional definitions suitable for testing purposes. These definitions and capabilities could then be integrated into propulsion system stability development approaches and design criteria.

As part of Air Force engine stability testing discussed in Section VI, definitive interface parameters were established, and the feasibility of assessing turbine engine stability margins was demonstrated. In addition, testing criteria, procedures, and techniques were documented (Reference 27).

Utilizing the experience gained from this program in combination with established stability programming approaches (such as Reference 2) it is possible to organize and define inlet-engine criteria during early development phases. Defined test methods and procedures offer a basis for establishing a uniform and systematic interface data handling system between engine and airframe development efforts. Further, an approach is provided for deriving and defining interface operating functions for parameters and conditions that can be achieved in engine development testing.

For engine testing phases, an array of testing techniques and procedures is available for selection and application to stability margin development. In the appropriate development phases, engine stability margin testing can be accomplished coincident to mission operating conditions specified for a propulsion system. Such an approach provides a logical extension of engine component stability development efforts into engine development testing and assessment processes.

This section presents the time-phased planning approaches to define the interface, the form such definitions should evolve to in order to be tested, and finally, the programming considerations and steps for incorporating engine stability margin testing into a development program.

7.2 TIMING AND PROCEDURAL CONSIDERATIONS TO ACHIEVE INTERFACE DEFINITION

The time at which engine stability margin requirements must be established is during the systems definition phase as shown in Figure VII-1. Efforts leading to contract definition were initiated some months earlier in systems study and advanced technology phases. In the approach depicted, steps are directed to matching inlet flow characteristics with engine tolerances at required mission operating conditions so that analyses can be performed on compressor margin allocation and utilization rates or quantities.

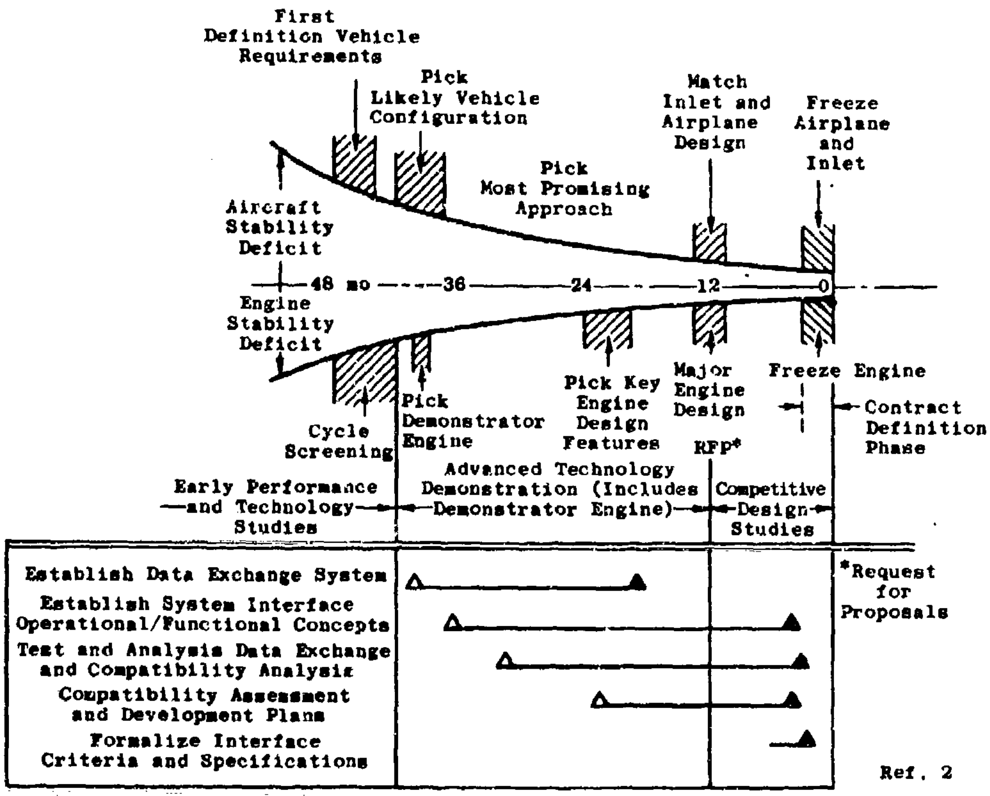


Figure VII-1 Typical Interface Timing and Decisions to CE1 Specification

Development tools available in this phase consist of the following:

Airframe - Weapon system and propulsion system requirements
Systems engineering and analysis of configuration
Scale model inlet testing and analysis
Computer data handling and modeling techniques

Engine - Available technology to address propulsion system requirements
Engine component rig test and analysis
Demonstrator engine testing and analysis
Computer data handling and modeling techniques
Stability audit and screening techniques

In order to use these development tools effectively for establishing inlet-engine functional definitions and development criteria, it is first necessary for engine and airframe contractors to establish a data handling and transmittal system. For this system, procedures should be defined in the areas of testing, instrumenting, acquiring, and reducing airflow data for respective inlet and engine development test effort. Upon this basis, the methods and applicability of stability accounting procedures and inlet flow screening parameters should be coordinated. Propulsion system operational and hence engine requirements should be identified so as to specify such items as engine transient requirements, customer power, and bleed requirements for mission interface operating conditions.

By approaching and entering the system and contractual definition phase (Figure VII-1), coordinated compatibility test and analysis data procedures for scale-model inlet and engine compression systems can be utilized to derive and define interface criteria. This process consists of iterating inlet flow characteristics, compressor characteristics, and engine operating requirements for sets of projected propulsion system operational conditions to determine areas requiring engineering development emphasis. Engine compatibility analyses can be concentrated on systematic definitions of propulsion system functional operations for stability considerations. Examples of such compatibility analysis techniques can be found in References 28 and 29.

From an engine development standpoint, the interface becomes defined in sets of projected mission operating conditions providing an inlet airflow rate and flow characteristic coupled with defined engine operating modes. For such cases, the engine compression system must allocate sufficient margins to allow for inlet flow destabilizing factors as well as those internal factors shown in Figure VII-2. Complete definition of the interface consists of physical and measurable parameters describing the inlet airflow rates and quality delivered to the engine and the engine operating conditions corresponding to some given flight conditions.

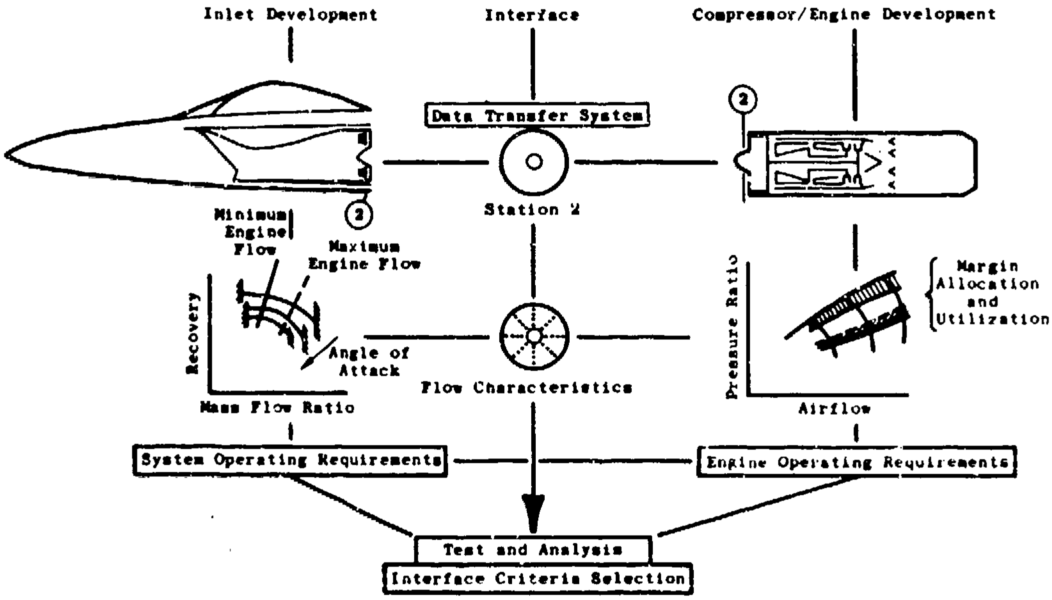


Figure VII-2 Typical Interface Development and Definition

From this type of analysis, test, and data exchange system, sets of operating definitions can be derived through compatibility analysis efforts between engine and airframe contractors to arrive at a systems compatibility baseline and development criteria. A finite number of such definitions should be placed in the appropriate section of systems specifications.

7.3 DATA NEEDS TO ESTABLISH AND DEFINE THE INTERFACE FOR DEVELOPMENT

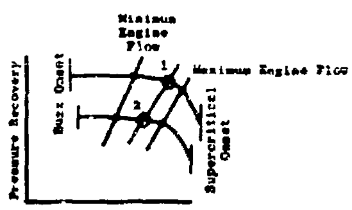
A finite number of inlet-engine interface definitions and system functional conditions must be established for engine development and test verifications required by Air Force model specifications. Operating conditions selected during system definition must be representative of projected propulsion system mission operations for which the characteristics of inlet flow have been defined and factored with engine margin allocation and utilization rates. The assessment and establishment of these conditions should be indicative of the matching and quality levels required of inlet and engine stability characteristics for specified mission operations.

In order to develop and establish interface criteria suitable for incorporation into specification processes, a suggested interface check-list and data format is presented in Figures VII-3 and VII-4. Once development is initiated, continued efforts will be required to maintain the interface data exchange system for the types of data depicted and to maximize the applicability of such data for development purposes.

Item	Coordination		
	System Contractor	Engine Contractor	Procuring Service
Geometric Location of Inlet-Engine Interface for All Inlet-Engine and Compressor Testing	x	x	x
Instrumentation for Inlet-Engine-Compressor Distortion Testing...Location, Geometric Placement, Range, Response, Uncertainty and Frequency Response	x	x	x
Interface Data Format, Data Reduction, and Data Transmittal Procedures	ICD*	ICD	
Interface Operating Conditions Quantitized	x	x	x
Interface Control Documentation	x	x	
Interface Data Format for Engine Specification		x	x
Interface Data Format for Aircraft Specification	x		x
Engine Stability Development Plan		x	x
Propulsion System Integration Plan	x	x	x
Preliminary Engine Testing Techniques		x	x
Preliminary Inlet Testing Techniques	x		x
Engine Stability Accountability Procedures		x	x

*Interface Control Documentation

Figure VII-3 Typical Interface Check List for Contractual Criteria



Flight Conditions

Altitude = __

Mach = __

Customer Bleed = __

Horsepower Extraction = __

Transient Descriptions: Where applicable, specify time-rate-of-change.

Inlet Condition	Angle		Total Flow	Average Ram Recovery	Tabulated Instrumentation Readings*	Frequency Response	Secondary Flows	Engine Control Bleed	Stability Margin**	
	Attack	Yaw							Available	Utilized
Minimum	—	—	—	—	—	—	—	—		
Match Point 1	—	—	—	—	—	—	—	—		
Maximum	—	—	—	—	—	—	—	—		
Minimum	—	—	—	—	—	—	—	—		
Match Point 2	—	—	—	—	—	—	—	—		
Maximum	—	—	—	—	—	—	—	—		

*Steady-state and high-response pressure data should be tabulated for each probe.

**Stability margin estimates from analysis techniques per interface coordination between contractors.

Figure VII-4 Typical Interface Data Format

7.4 PROGRAMMING ENGINE STABILITY MARGIN TESTING

Programming considerations for engine stability margin testing are depicted in Figure VII-5. At onset, interface functional definitions and development criteria are established. Further, the figure reveals the importance of interface data handling systems between engine and airframe contractors for the exchange of stability test and analysis data during system development lead time. The importance of maintaining this process cannot be overemphasized if proper definitions of inlet flow quality, system operating functions, and engine margin allocation/utilization factors are to be maintained and effectively utilized in systems development.

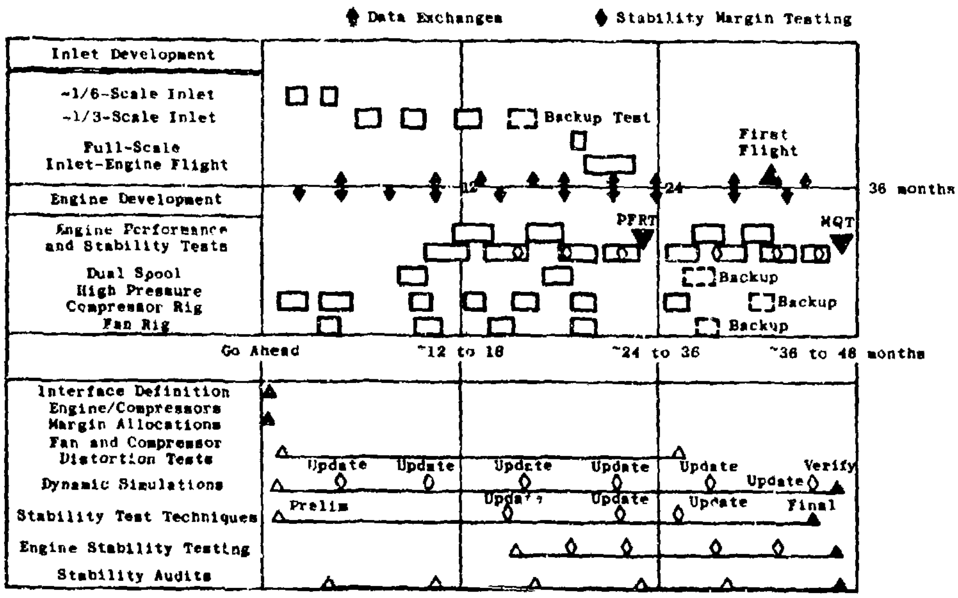


Figure VII-5 Typical Stability Development Programming Considerations

General engine development programming considerations should include time-phased engineering and test resources to develop and refine stability characteristics of engine components and the complete engine to functional requirements of a propulsion system. Through such planning, an engine can evolve through component technology incorporation to a "maturity level" satisfactory for full engine testing. At that time, sets of installation needs can be addressed more fully. A basic engine development tool is available at that point for performance and stability assessment and refinement efforts. This tool consists of the engine environmental test cell shown in Figure VII-6. Such a test cell provides testing capability to examine and define engine operating characteristics under conditions of "clean operation" as well as those occurring under required propulsion system operational modes. These test cells and engines accommodate high levels of instrumentation and specialized hardware for both performance and stability testing objectives. In suitable environmental facilities, ranges of test conditions are available to duplicate the interface conditions and functional operations, involving the rates of inlet airflow, engine power level, bleed, horsepower extraction, and altitude ambient conditions of a propulsion system. The utilization and application of this capability reflect the importance of achieving sets of propulsion system interface criteria in physical and measurable terms.

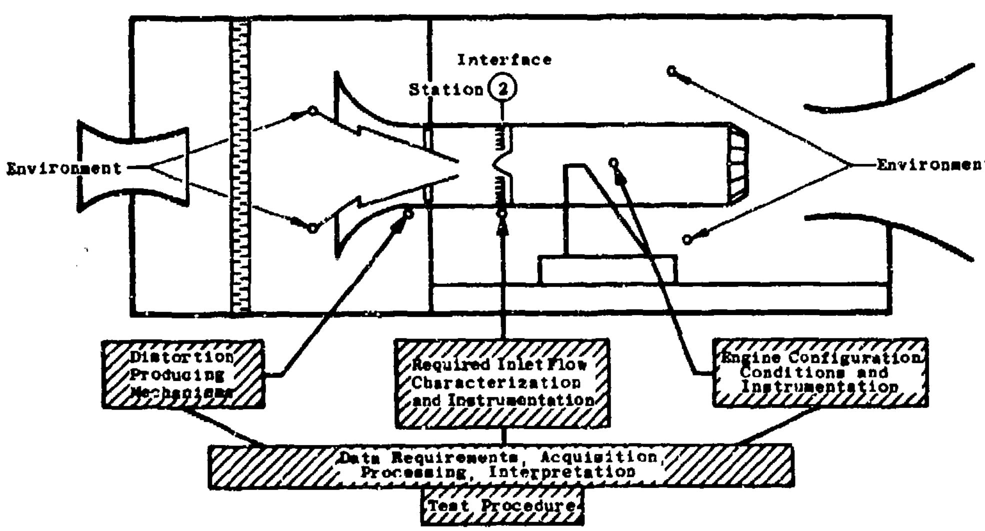


Figure VII-6 Typical Test Configuration and Coordination Requirements

For specified interface development criteria, a number of engine development testing sequences should include stability margin testing phases. From Figure VII-5, general timing needs are addressed for establishing the required testing configurations and procedures to duplicate interface conditions. Testing configurations and procedures can be selected from those available in Reference 27. In each case, interface conditions must be factored by engine contractors and the Air Force to select the test conditions, hardware, and procedures most appropriate to assess engine stability margin allocation and utilization. These items are also depicted in Figure VII-6.

Engine stability margin testing should be oriented to developing and defining engine characteristics in an organized and controlled manner. For example, it is essential to document and understand clean engine operating characteristics prior to seeking the combined effects of the installation such as inlet flow distortion, bleed flows, customer power extraction and time-variant rates. An incremental approach to interface operating complexity will lead to proper accounting for these combined variables, if testing phases are properly coordinated and scheduled from clean baseline testing phases into those encompassing installation effects.

7.5 ENGINE STABILITY MARGIN DEFINITION AT QUALIFICATION

Engine stability margin testing during systems development programs provides a quantitative accounting system for refining and verifying margin allocation concepts for projected systems operations. These testing and evaluation phases can be accomplished to determine margin availability and subsequent allocation to each destabilizing factor present for a particular propulsion system operating condition. Data from such testing can be used for stability development tracking, margin audits, and engine computer modeling techniques.

Programming emphasis on interface criteria and stability margin testing during engine development and prequalification testing phases can be utilized to complete definitions of engine stability characteristics for finalized flight engine configurations. This sequence of engine stability margin testing can be utilized in evaluating engine stability margin at qualification. Properly defined engine compressor performance and stability characteristics data applied to the qualification engine configuration can be utilized to establish this test sequence without increasing test procedural time and complexity. With proper engine configurational and operational definition occurring, a verification of engine matching, controlling, and loading is accomplished during normal qualification baseline performance testing phases. Some slight increase in test scope is required during this phase to confirm engine internal transient characteristics such as time rate-of-change of inlet airflow and compressor speed-flow-pressure-ratio relationships. Upon verification of engine/compressor characteristics, limited sets of inlet distortion characteristics specified in interface criteria can be tested at the specified engine operating conditions to verify margin allocations for distortion. A general example is shown in Figure VII-7.

Several significant benefits are possible for programs effectively utilizing engine stability margin testing and qualification: (1) For a defined set of interface functional parameters, it is possible to determine margin utilization quantities for each destabilizing factor present.

(2) Engine computer modeling techniques can be improved based on data inputs from tests conducted under projected systems interface operations. (3) Developed sets of engine stability characteristics and correlations to flight test data are possible. (4) It is possible to develop, qualify, and deliver an Air Force engine with defined stability margin levels for projected propulsion system-operational requirements rather than arbitrary or generalized stability utilization factors.

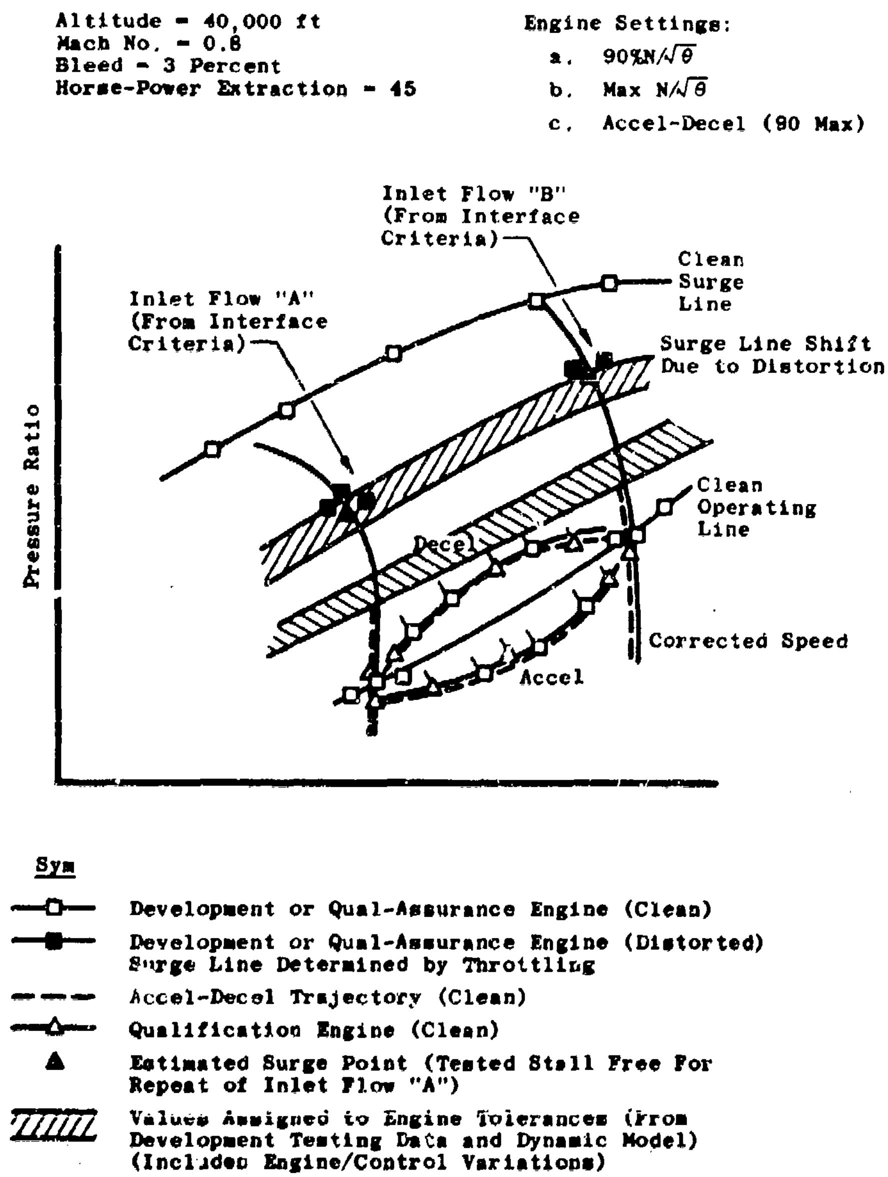


Figure VII-7 Typical Engine Stability Margin Determination

7.6 SUMMARY

Approaches leading to interface definition have been proposed based on the incorporation of recent Air Force engine stability testing experience into stability programming approaches. Further, an array of engine test techniques is available for the selection of applicable testing procedures to specific engine stability testing sequences. Programming steps have been proposed to incorporate engine stability margin testing into engine development testing sequences in a time-phased manner in order to develop and define engine margin allocation and utilization rates. This stability testing process forms the basis for engine qualifications of Air Force engines through development accountability of stability margin data from earlier development and qualification assurance tests. These test data allow for the verification of stability margins of candidate qualification engine configurations.

SECTION VIII
SUMMARY AND CONCLUSIONS

This report has endeavored to depict Air Force history and experience in developing operationally suitable engines and propulsion systems. In the years following 1945, propulsion system stability evolved into a large and continuing problem in the operational suitability of advanced turbine engine propelled aircraft.

In some respects, the approaches to engine and propulsion system developments have passed through three overlapping phases as shown in Figure VIII-1. In the first of these, there was little or no basic approach to inlet-engine matching beyond airflow rates and pressure recovery.

During the second phase, a generation of advanced systems and engines surfaced with more stringent inlet-engine flow matching needs for development. Ensuing approaches incorporated qualitative analysis and testing procedures, which, unfortunately, did not lead to stability approaches and definitions in quantitative terms. Also, during the second phase, ground testing facilities became available but lacked testing definitions and experience in stability-related testing. Toward the end of this phase, engine distortion limit concepts came into being seeking general utilization factors for engine stability margins. Stability margin tests were not required for engine qualifications during this phase because of a lack of development criteria and test standards.

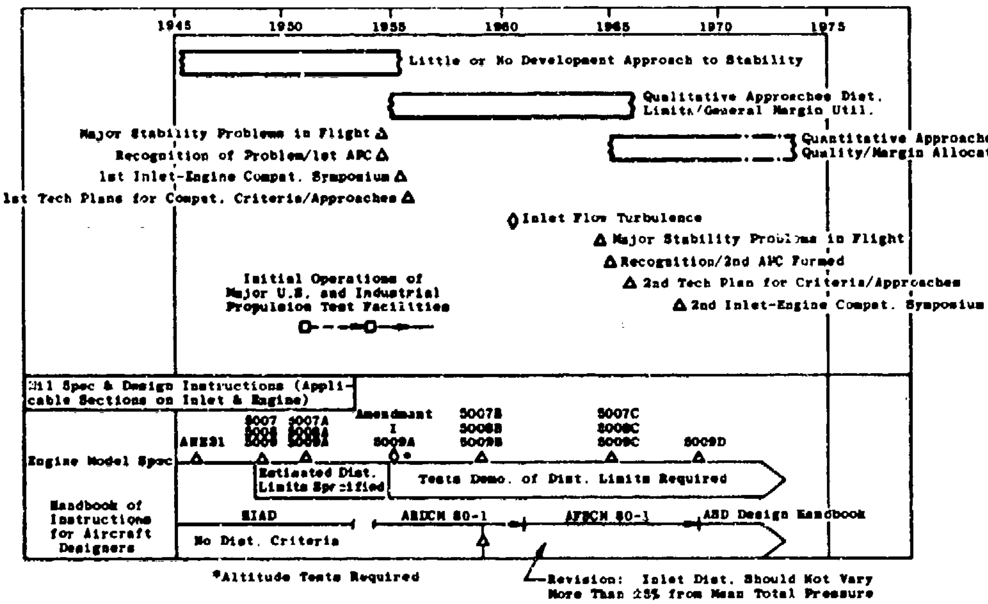


Figure VIII-1 Significant Interface Approach Phases and Events

As advanced aircraft continued to evolve in the early 1960's, a new problem arose in the interface area involving turbulent inlet airflows or fluctuating total pressures and their effects on propulsion system operation. Therefore, a system of already nonstandard data and qualitative steady-state approaches become completely inundated by the huge quantities of data from high response instrumentation employed in propulsion testing.

In the third phase, new stability programming approaches evolved encompassing testing within systems lead times, and efforts were directed at quantifying system stability factors early in development. Still, the area relating to interface criteria and engine stability testing procedures lacked definition (see Appendix XVII). Efforts were initiated in the late 1960's to develop solutions to these needs. Ensuing testing demonstrated the feasibility of assessing engine stability margins for defined interface and engine operational and/or functional conditions.

In short, the adequacy of past engine stability approaches to propulsion system needs is reflected in the large number of flight revealed problems occurring since the mid-1950's, requiring extensive time and costly efforts seeking solutions to the interface stability problem.

In the future, matching inlet and engine can be expected to remain an engineering development task of considerable size and complexity for advanced high performance aircraft. This general trend to matching is shown in Figure VIII-2. However, by combining the quantitative or stability margin element approaches that have evolved in recent years with the advances in engine stability margin testing techniques discussed in this report, engine stability development approaches more responsive to basic Air Force engine needs can be established.

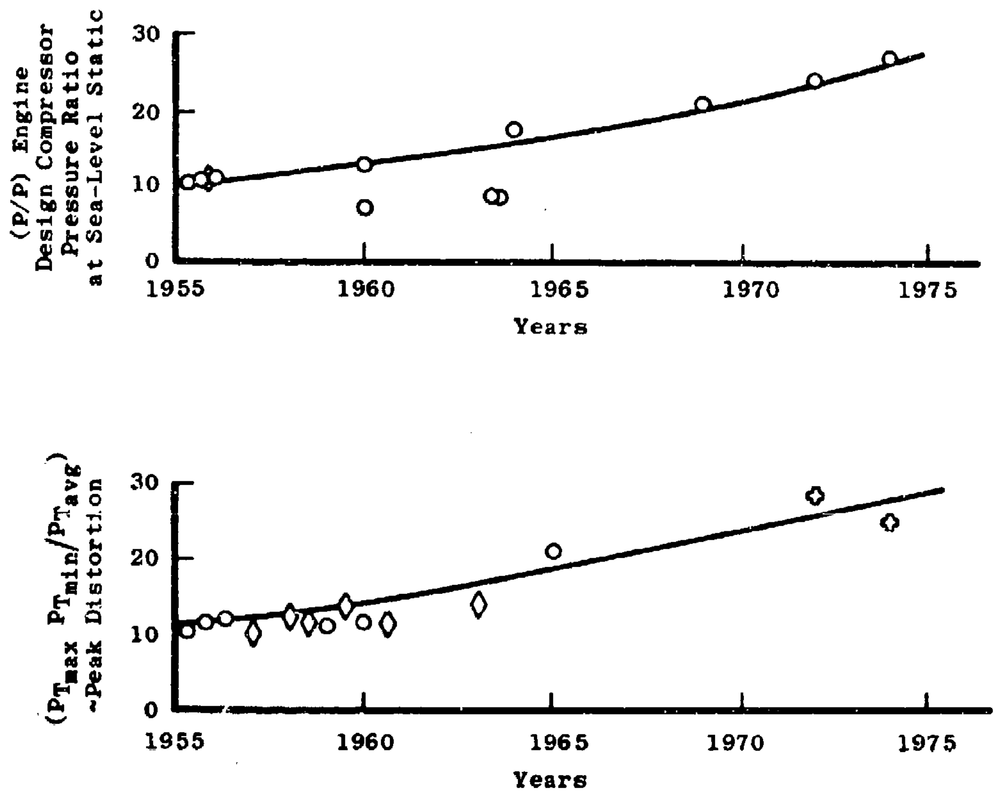


Figure VIII-2 Inlet-Engine Matching Trends

Since all development programs vary in complexity, time, and resources, engineering judgment will always be required to implement and refine the basic approaches such as those proposed in this report. But the potential for engine development approaches quantifying and test verifying stability margin elements through development and qualification can be attained with the proper degree of development emphasis and effort.

SECTION IX
RECOMMENDATIONS

1. It is recommended that Air Force engines be qualified to operational suitability needs established for the propulsion system, i. e., engine stability. It is further recommended that a stability margin assessment be made an integral part of engine qualifications.

2. It is recommended that interface definitions be established during contract definition no later than program onset. These definitions should be established so that all parameters are stated in physical and measurable terms. Further, such terms should reflect the mission operating functions and conditions rather than arbitrary limits or correlation factors. Instrumentation, test procedures, and data handling processes should be formalized to the degree required by the Air Force.

3. For Air Force engi[illegible] source selections for aircraft, it is recommended that the interface conditions selected for engine specification purposes be throughly reviewed. Further, overall development planning and phasing of engine development efforts and test programs should be evaluated in the area of stability development steps and qualification resolution programming.

4. Continued support and mainenance of the Air Force test center at AEDC is recommended. Resources, engineering coordination and test support can provide the Air Force a standardized test base in testing techniques, procedures, and future refinement. It is in this manner that development criteria and engine testing can be maintained to Air Force needs.

5. Continued support of basic research in the areas of propulsion system flow and compression systems stability is recommended. This in turn provides a continuing technical basis for improving and updating exploratory and advanced development efforts for turbine powered propulsion systems.

6. Military standards, design handbooks, and specifications for propulsion systems (inlet and engine) should establish refined interface formats incorporating operational functions and definitions in physical and measurable terms, to establish criteria coincident to projected system flight operational conditions.

7. The resources required to conduct a propulsion system development program to flight should be considered. A stability development effort for advanced high performance systems will probably

appear large depending on complexity. However, the resources required for such efforts should be considered relative to the large penalties in costs, operational capabilities, and deployment schedules that have historically occurred in the past.

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Appendix I

Appendix II

Appendix III

Appendix IV

Appendix V

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Appendix VII

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Appendix XI

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Appendix XIV

Appendix XV

Appendix XVI

Appendix XVII

Letter from B/G Howell M. Estes, Jr., dated 19 November 1954, concerning the F-XXX Inlet-Engine Problem

F- Program

WCSP
Attn: Lt Col. Keese

WCS

19 Nov 1954
Brig Gen Estes/ef
30205/1014/Kal27

1. At the present moment, we are experiencing extreme difficulty with the F- airframe-engine combination, largely the result of duct deficiency in the F- airframe. These deficiencies jeopardize the entire F- Program. It is essential that WADC thoroughly investigate the present situation to assure that every effort is being taken by WADC, McDonnell and Pratt & Whitney to resolve this problem at the earliest practical date.

2. It seems apparent that we have arrived at this situation as a result of improper planning. If, at the earliest possible point in the development plan, provisions had been made for thorough testing of the duct-engine combination, necessary duct design changes could possibly have been made prior to airframe production. In any event, had this early mating of the duct and engine been scheduled, we would not be in as serious a condition as we find ourselves at the moment.

3. Accordingly, using the F- situation as an example, it is necessary that we think through this problem of marriage of the duct and the engine at an early date in development programs for future weapon systems. The FBX is a good example in this connection.

4. It is desired, therefore, that you act as Chairman of a Weapon Systems Directorate Group, consisting of individuals from your office, the Fighter Division, and the F- Project Office, to meet with a similar working group of the Power Plant Laboratory (contact Col. Appold to obtain name of Power Plant Lab Chairman) to accomplish the following:

a. Thoroughly examine our present duct-engine situation regarding the F- and determine what measures can be taken to expedite, on a priority basis, the solution of this problem;

b. Develop planning factors from the basis of our experience with the F- to be utilized in development planning for future weapon systems to insure that this problem will be minimized on these future weapon systems.

c. Provide for General Haugen and myself, at the earliest possible date, a joint briefing on your findings under a. and b. above.

cc: WCG, Gen. Boyd
WCL, Gen. Haugen
WCLP, Col. Appold
WCSF, Col. Allen
WCSF, Lt Col. Phillips

HOWELL M. ESTES, JR.
Brigadier General, USAF
Director of Weapon Systems
Operations

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Appendix II

Aircraft Laboratory Comments on Engine-Inlet Compatibility, 15 July 1955

15 July 1955

AIRCRAFT LABORATORY COMMENTS
ON
ENGINE-INLET COMPATABILITY

The advent of turbojet powered aircraft greatly increased the importance of internal flow considerations in aircraft design. The large air flow requirements of turbine engines and the resulting large volume requirements of ducting to supply this air, meant that the aircraft configuration was more than ever before influenced by the engine installation. The aircraft designer, in designing a turbine powered aircraft, considered many items in choosing an inlet duct design, some of which are listed below:

I Drag
II Duct volume
III Weight
IV Equipment placement
V Total pressure recovery
VI Total pressure distribution
VII Complexity

The aircraft designer chose the inlet design which resulted in the best aircraft performance characteristics for a particular set of requirements. This decision was based on the best information available at the time.

The airframe manufacturer could of course, directly estimate the effect of Items I thru IV on the aircraft performance, but he was forced to rely on the engine manufacturer for data to determine the effects on engine performance of inlet duct total pressure recovery and total pressure distribution. The engine manufacturer furnished sufficient information, in most cases, to adequately evaluate the losses in engine thrust and fuel flow for inlet total pressure losses. No information, however, was made available by the engine manufacturer on the effects of total pressure distribution.

The engine manufacturers, when queried as to the compressor face total pressure distribution limits in their engine specification, stated that the limits were essentially arbitrary numbers designed to make the engine user aware that pressure distribution was something to consider, but that they had little idea of what the limits really should be. The engine manufacturers sole concern was the effect of pressure distribution on compressor blade stresses.

The inlet designer is faced with many difficult problems. Inlet lips, for instance, must operate satisfactorily over an angle of attack range exceeding 180°. This large angle of attack range is caused both by airplane angle of attack and inlet mass flow ratio. Therefore, to prevent lip separation, under all flight conditions, would require a lip in the shape of a bellmouth which would be completely unacceptable from a drag viewpoint.

Side inlets, which have come into use because of the electronic requirements on certain aircraft and because of the decreased duct volume, can have an inherent pressure distribution at the inlet due to the effect of the forward fuselage, even when completely eliminating the fuselage boundary layer. In addition, side inlets generally necessitate the presence of duct bends, the smallest of which will disturb the flow to some extent.

The engine manufacturers have, and still are, specifying total pressure distribution limits which are impossible to meet for all flight conditions. One engine manufacturer who has rather stringent distribution limits admitted that not even his flying test bed met the requirements under all conditions. Furthermore, only one engine manufacturer has made some allowance for duct boundary air in these limits. The engine users therefore have taken the attitude that an arbitrary, unrealistic requirement is no requirement at all, and have therefore given very little emphasis to pressure distribution in the past.

Recent experience with the JXX engine has demonstrated that the tendency of a turbojet engine to stall or surge can be adversely influenced by decreasing the Reynolds Number and/or increasing the pressure distributions. Engine stalls can seriously reduce the combat effectiveness and even cause structural failure by causing supersonic duct "buzz", and therefore must be avoided.

The present engine stall problems are being solved by several different approaches. In one case the aircraft manufacturer solved the problem by making engine control changes. Compressor modifications have also showed improvements as have some inlet modifications. Unfortunately very little can be done regarding Reynolds Number.

The JXX engine experience has clearly indicated that correlation of total pressure distribution does not adequately define the effects on engine stall margin. Such factors as the amount of area influenced by a high or low total pressure region, the location of a pressure distortion, the type of pressure distribution, can greatly influence the engine stall margin. To date, no satisfactory correlation exists which adequately defines the pressure distribution effects on engine operation. Until this correlation is established, the airframe manufacturer cannot possibly determine through wind tunnel tests what duct geometries are required to assure stall free compressor operation, other than compromising the entire airplane and providing a bellmouth at the engine face.

Since the engine company is the only organization which has knowledge of the internal engine performance characteristics, the airframe manufacturer has no initial knowledge of compressor stall sensitivity. Even static testing of the engine with the inlet duct does not cover engine performance at high values of referred engine speeds nor is the effect of Reynolds Number determined. Only when the aircraft has flown with a particular engine and covered the complete range of airplane performance capabilities, is there any indication of the seriousness of any compressor stall problem.

The better the airplane is, the more likely it is to run into compressor stall problems. For example, the greater the maneuverability, the greater the magnitude of inlet disturbances; the higher the ceiling, the greater the adverse effect of Reynolds Number; the higher the rate of climb, the greater the tendency for any speed sensing controls to lag behind; and the broader the speed range, the greater the opportunity for the duct flow requirements to become mismatched with compressor flow requirements.

In order to prevent the reoccurrence of engine stall problems it would be desirable to accomplish the following items:

I. Increase effort to determine a correlation between pressure distribution parameters and compressor stall margin.

II. If no adequate correlation can be found, each engine should be qualified by tests to determine its sensitivity to pressure distribution parameters.

III. The information in I & II should be translated into terms of "trade-off" data and given to the airframe manufacturer so that he may arrive at an optimum compromise for his particular aircraft.

IV. Continued emphasis be put on inlet research and development.

Appendix III

Extracts from:

1. ARDCM 80-1, 1953 Handbook of Instructions for Aircraft Designers
2. MIL-E-5007A 1951 Military Specification, Engines
   MIL-E-5008A 1951 Military Specification, Engines
   MIL-E-5007 1949 Military Specification, Engines
   MIL-E-5008 1949 Military Specification, Engines
3. Typical Proposal Data Covering Air Induction System
4. Typical Preliminary Air Vehicle Specification
   Specifying Air Induct Systems

16.6 ENGINE AIR-INTAKE SYSTEM

16.60 GENERAL

The engine air-intake system of the power-plant installation includes the necessary ducts, scoops, passages, chambers, etc., which obtain ambient air and supply this air to the engine for combustion of the fuel. Anti-icing and deicing provisions, antidust devices, and any other equipment employed in or near the intake ducts for the purpose of restricting, modulating, filtering, heating, or cooling the intake air shall be considered part of this system.

16.61 DESIGN OBJECTIVES

The effect of aerodynamic design of the engine air-intake system on turbo-jet and turbo-prop type engine performance is of considerably greater importance than for reciprocating engines. The optimum aerodynamic configuration of the air-inlet and induction-system ducting can be achieved only by exact analysis of the system requirements and parallel study and comparative wind-tunnel analysis of alternate designs. The various merits of duct and inlet configurations of different design and location depend primarily on the type of engine installation employed in the aircraft. The critical nature of duct and entrance configurations in regard to the effect of compressibility and normal energy losses at high Mach numbers makes evaluation of the engine air-intake system by individual performance testing imperative. Some guidance in the selection of inlets and ducting most suited to the various installation configurations is provided by the documents referenced in chapter 1.

There are several approved methods available for computing the effect of the air-induction system design on aircraft and engine performance. For this reason, no specific method will be recommended here. The designer may use any rational method for calculating performance. If the method selected has been published, a report which explains the method in detail should be forwarded to the Air Materiel Command for approval. (The approved methods mentioned above are listed as references in chapter 1.)

A report describing the methods employed and the results obtained in the performance testing of the engine air-intake system shall be forwarded to the Air Materiel Command for approval.

In the design or planning stage of the engine air-intake system, consideration must be given to the location of the air inlet to insure that the selected position is in an area of satisfactory air flow patterns and boundary layer characteristics at all attitudes and conditions of operation for which the aircraft is designed.

A short air-induction system is preferred. Where a choice must be made between a long tail-pipe extension for the exhaust system and a long engine air-intake system, the sacrifice of induction-system performance must be accepted because of the larger penalty imposed on engine performance by tail-pipe length, the high weight-per-unit area involved in limiting the inherent fire hazard of the tail pipe and inspection, maintenance, and replacement considerations. Special consideration must be given to locating and positioning the air inlet in an area where there is little probability of entraining foreign particles thrown up by the wheels of the aircraft.

16.62 GENERAL DESIGN REQUIREMENTS

16.620 Construction Design—The inlet and system ducting shall be of sufficient strength to withstand the maximum pressure depression encountered at maximum engine thrust with the aircraft in static condition. In addition, the strength shall be sufficient to withstand vibrations produced by air-flow variations (which may exceed the strength required to withstand pressure differentials).

Flush-type riveting shall be employed for the internal surfaces of all ducting in the system.

Construction components which may vibrate loose and enter the engine should not be employed in the engine air-intake system. If their use is unavoidable, adequate safetying of each part is to be accomplished.

All pertinent data and drawings of duct quick disconnects shall be submitted to the Air Materiel Command for approval prior to incorporation in the aircraft.

16.621 Control—Air-flow control by means of variable entrances or "suck-in" doors may prove of value for some power-plant installations. The performance estimates and design details for these devices shall be submitted to the Air Materiel Command for approval prior to incorporation in the aircraft.

16.622 Shut-off Doors or Valves—Air inlet shut-off doors or valves designed for the purpose of reducing the drag associated with an inoperative engine by preventing windmilling of the unit may be desirable for multiengine aircraft. This feature is especially applicable to multiengine, long-range aircraft for which a study on specific fuel consumption vs. engine service life proves partial-engine operation more economical and efficient than continuous total-engine operation at a reduced power.

Pertinent data and drawings of air inlet shut-off doors or valves shall be submitted to Headquarters, Wright Air Development Center prior to incorporation in the aircraft.

16.623 Ice Protection

The entrance to the air induction system shall be protected against ice formation and build-up. This is considered necessary because of the severe power losses associated with relatively small disturbances to engine air flow.

In addition, all airframe parts in the air induction system, such as engine accessory covers or air duct valves, subject to collection of ice shall be protected. The meteorological design conditions shall conform to Specification MIL-E-5007.

When an ice accretion meter is not furnished with the engine, an ice detecting device shall be installed in the air inlet duct and connected to a suitable indicator light. Cyclic operation of the indicator light will furnish the pilot with an indication of the rate of ice formation.

16.624 Dust Protection

Dust protection for the engine is considered adequate if the air inlet is not located in a high-dust-concentration area. For ground use, dust plugs shall be provided for each air inlet, and all means considered necessary shall be taken to prevent damaging the induction system by inadvertent operation of the engine with these plugs installed.

16.625 Inlet Screens

When retractable inlet screens are not provided with axial flow engines, the airframe manufacturer shall mount a retractable screen in the inlet duct of the aircraft in accordance with the following instructions.

a. Design and Construction

(1) The size of the screen openings shall be such as to prevent the entrance of a 0.25 inch sphere.

(2) No part of the screen or screen actuator shall extend into the duct when the screen is in the retracted position. Any object collected on the screen shall be retained during retraction and extension of the screen and shall not enter the engine under any condition of aircraft operation. The screen recess (for the retracted screen) shall be designed such that there is a 7/8" clearance between the face of the screen recess and the face of the screen.

(3) If the screen is composed of more than one segment, each segment shall be capable of independent retraction when any other segment is restricted in the extended position.

(4) Precaution shall be taken to insure that the screens, when extended, do not become inoperable due to icing conditions.

(5) The screen shall have sufficient strength to stop a 50 cal. cartridge case at a relative impact velocity of 600 ft./sec.

b. Performance

(1) With no blockage of the screen effective area, the screen shall be capable of retracting in three seconds against the air flow encountered at 100% engine power and maximum speed of the aircraft at any altitude up to and including the service ceiling of the aircraft. Retraction time shall not exceed five seconds with 1/3 blockage of the effective area of each screen segment. The screen shall be capable of completing 3 cycles of operation from extend to retract to extend in 5 minutes.

(2) The loss in available engine thrust with the screens in the extended position shall not exceed 3% of the available engine thrust with no screens installed. The loss of the available engine thrust with the screens in the retracted position shall not exceed 0.5% of the available engine thrust with no screens and a smoothly faired duct.

16.63 TESTS

The recommended flight and ground test procedures for turbo-jet and turbo-prop type power-plant installations are detailed in Memorandum Report WCNEI-525-460. This report includes testing procedures for the induction system.

MIL-E-5007A
27 JULY 1951

Superseding
MIL-E-5007
19 July 1949

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET, GENERAL SPECIFICATION FOR

This specification was approved by the Departments of the Army, the Navy, and the Air Force for use of procurement services of the respective Departments.

3.19.3 Inlet Air Pressure Variation.- The estimated radial and circumferential pressure distribution limits shall be specified in the model specification.

MIL-E-5008A
27 JULY 1951

Superseding
MIL-E-5008
19 July 1949

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET, MODEL SPECIFICATION FOR
(OUTLINE AND INSTRUCTIONS FOR PREPARATION)

This specification was approved by the Departments of the Army, the Navy, and the Air Force for use of procurement services of the respective Departments.

3.19.3 Inlet Air Pressure Variation.- The estimated radial and circumferential inlet air pressure distribution limits shall be as shown on curve_______. (The contractor may show these limits in other than curve form.)

MIL-E-5007
19 July 1949
Superseding
AN-E-30
14 June 1946

MILITARY SPECIFICATION

ENGINES; GENERAL SPECIFICATION FOR
AIRCRAFT TURBO-JET

This specification was approved on the above date by joint action of the Air Force and Navy Departments for use in the procurement of aeronautical supplies.

3.22.4 Inlet air pressure variation.- The estimated radial and circumferential pressure distribution limits shall be specified in the model specification.

MIL-E-5008
19 July 1949
Superseding
AN-E-31
14 June 1946

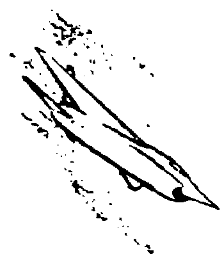
MILITARY SPECIFICATION

ENGINES; MODEL SPECIFICATION FOR AIRCRAFT TURBO-JET
(OUTLINE AND INSTRUCTIONS FOR PREPARATION)

This specification was approved on the above date by joint action of the Air Force and Navy Departments for the purpose of establishing standard aeronautical practices.

3.22.4 Allowable inlet air pressure variation.- The estimated allowable radial and circumferential inlet air pressure distribution limits shall be as shown on curve ______________. (The contractor may show these limits in other than curve form.)

AIR INDUCTION



- Ram air inlet ideally located
- Optimum inlet area
- Boundary layer bleed
- Low diffusion angle
- Gradual curvatures

INLET AREA

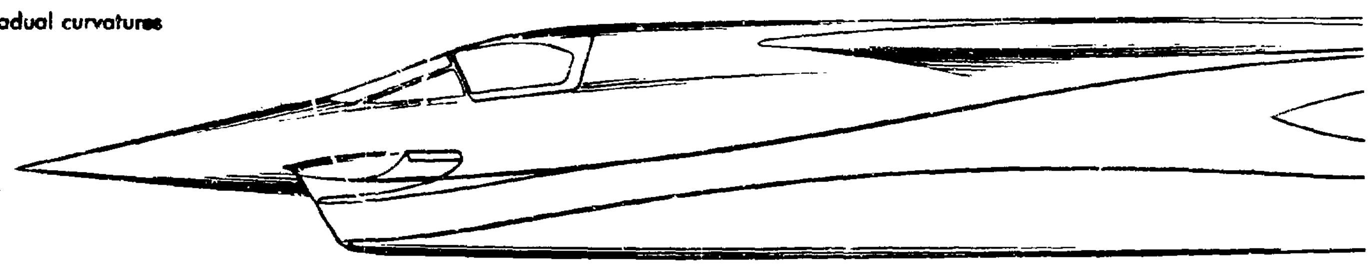
The inlet area is small enough to obtain minimum drag due to change in airplane contour caused by the inlet installation, yet large enough to prevent sonic speeds being reached in the inlet at the maximum speed of the airplane.

BOUNDARY LAYER BLEED

Flow separation and choking within the duct are prevented by bleeding off the low-energy boundary layer air at the duct entrance.

DUCT DESIGN

The duct is designed with gradual diffusion and very little curvature to minimize the pressure loss between the inlet and the engine.



INLET LOCATION

The design locates the inlet far enough aft to avoid interference with nose radar installations, yet far enough forward to allow high pressure recovery to be obtained.

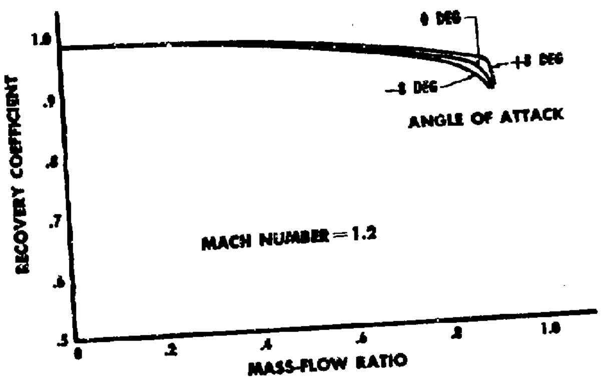
INLET TYPE

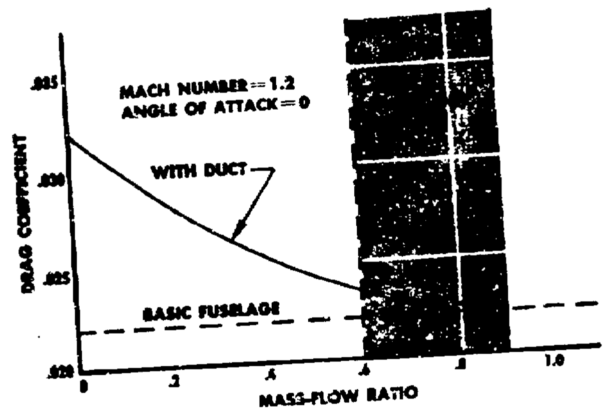
The combination of ram air inlet and gradually diffusing duct achieves highest possible pressure recoveries for an airplane designed to operate at both subsonic and supersonic speeds up to a Mach number of 1.7.

A single ram air inlet with a moderately curved and expanding duct was selected as the best combination for supplying air to the single turbo-jet engine with axial-flow compressor. This selection was made after an exhaustive analytical and experimental examination of the characteristics of various inlet types at free-stream Mach numbers between .2 and 1.7. The combination is outstanding in its ability to achieve good performance throughout the entire operational range of flight Mach numbers and angles of attack, from low subsonic speeds, through the transonic range, and up to approximately Mach 1.7.

The excellent pressure recovery and drag characteristics based on high-speed wind tunnel tests at Mach 1.2 are shown on the graphs. The normal operating range of mass-flow ratios has been selected to obtain the best balance between pressure recovery, drag, and Mach number in the duct itself. The continuous increase in recovery with decreasing mass-flow ratio gives evidence of stable flow characteristics.

The use of a boundary layer bleed prevents flow separation and choking within the duct by removing the low-energy air at the duct entrance. This method has proved to be effective in controlling the separation caused by the interaction of the normal shock wave with the boundary layer at Mach numbers up to 1.7.





3. REQUIREMENTS (Cont)

3.12.3 Auxiliary Propulsion Unit: Not required.

3.12.4 Engine-Driven Accessories: Two hydraulic Pumps and one d-c generator shall be installed on and driven by the engine.

3.12.5 Air Induction System: Air inlets, with boundary layer bleeds, shall be located on each side of the fuselage adjacent to the pilot's compartment with ducts extending aft to the engine. The air inlet duct lips shall incorporate provisions for anti-icing.

3.12.6 Exhaust System: The engine shall be furnished complete with exhaust system, including afterburner with variable area nozzle. The Contractor may modify the engine as required to provide a section of tailpipe between the engine and afterburner in order to lengthen the engine for optimum nozzle location.

3.12.7 Cooling System: Provision shall be made to supply cooling air for the engine and engine accessories.

3.12.8 Lubricating System: The engine shall be furnished complete with lubricating system including the oil tank, oil-fuel heat exchanger (oil cooler), pumps, lines, strainer and valves.

3.12.9 Fuel System:

3.12.9.1 The fuel system shall include pressurized wing integral fuel tanks of 1050 gallons net capacity. Two air-driven fuel booster pumps shall be provided in the wing tanks. Provision shall be made for pressure or gravity refueling of the fuel tanks.

3.12.9.2 Air shall be bled from the engine compressor section and passed through heated carbon contained in a tube of streamline cross section passing through the engine exhaust tailpipe and then cooled for the purpose [illegible]oviding inert gases for fuel tank purging and press[illegible]ing.

3.12.11 Propulsion System Controls: The Contractor shall provide a power control lever for the pilot and shall connect this lever with the selector furnished with the engine.

3.12.12 Starting System: The starting system shall include a cartridge type starter not requiring an external source of power. The starting switch shall be located for use by the pilot.

Aircraft Laboratory Progress Report on Engine-Airframe Compatibility, 17 January 1955 **Appendix IV**

AIRCRAFT LABORATORY PROGRESS REPORT
ON ENGINE - AIRFRAME COMPATABILITY
17 JANUARY 1955

I. Problems

A. To prevent a re-occurance of the engine surge problems presently encountered in aircraft using the J-XX engines.

B. To obtain propulsion systems which will optimize aircraft performance.

II. Items Which Influence Engine Surge

A. Engine

1. Compressor

a. Radial, axial, etc.

b. Single spool, dual spool, etc.

c. Variable speed, constant speed.

d. Blade profiles, number of stages, etc.

e. Fixes to prevent surge (intercompressor bleed valves, etc)

2. Engine matching

a. Turbine design

b. Tailpipe design

c. Power extraction and air bleed requirements

3. Reynolds number

a. Component performance

b. Change in engine matching

4. Engine controls

a. Sensitivity

b. Reliability

c. Proper location and installation

5. Production and maintenance tolerances

B. Airframe

1. Flight envelope

a. Altitude

b. Speed

c. Rate of climb and descent

d. Maneuvers

e. Acceleration

2. Total pressure distribution at compressor face

a. Radial or circumferentiel

b. Location near hub or tip

c. Number of pockets

3. Inlet control

a. Optimization of net propulsive effort

b. Avoidance of inlet buzz

4. Armament

a. Type

b. Location relative to the inlets

5. Nozzle exit shrouds

III. Items Requiring Immediate Attention

A. Effect of total pressure variation at compressor face on engine surge.

1. Lack of data.

2. Data that do exist indicate that the details of the distribution are a primary parameter.

3. No intelligent method can be used in improving pressure distributions until the effects on surge are known.

B. Preliminary Determination of Optimum Pressure Distribution

1. Need for immediate design criteria for airplanes such as the F-XXX.

2. Need some idea of penalties in weight, size, drag, thrust, and fuel flow necessary to meet various pressure distribution requirements.

C. State of the Art of Compressor Face Pressure Distribution

1. Unrealistic requirements of engine manufacturers.

2. Airframe manufacturers lack of effort on pressure distribution.

3. Engine manufacturers greatly interested in obtaining inlet pressure data.

4. Could indicate effects of various types of inlets, locations, etc on pressure distribution.

IV. Present Aircraft Laboratory Action on Immediate Problems

A. Effect of Total Pressure Variation at Compressor Face on Engine Surge.

1. Requested that weapons system obtain surge data on those airplanes not currently undergoing a surge flight test program.

2. Held conferences with North American, Convair, and Douglas to obtain information on compressor surge of F-XXX, F-XXX, FXX, and AXX.

3. Held conferences with Pratt & Whitney and Curtiss-Wright to obtain information on compressor surge.

4. Conducting correlation of flight test data to examine effect of pressure distribution on compressor surge.

B. Preliminary Determination of Optimum Pressure Distribution

1. Meeting with NACA and Republic to set up test program to investigate ways of improving pressure distribution in F-XXX.

2. Initiating purchase request to study the effect on aircraft performance of various methods of reducing the total pressure variation.

C. State of the Art of Compressor Face Pressure Distributions

1. Investigating best method of obtaining pressure distribution data on all of present airplanes.

2. Data to be condensed and transmitted to engine manufacturers.

V. Recommendations

A. The Aircraft Laboratory initiate a program to investigate methods of improving compressor face pressure distribution.

B. The Power Plant Laboratory obtain and study all data on pressure distribution effects on surge (Navy sponsored NACA program, Pratt & Whitney program, etc).

C. If present data is insufficient to determine pressure distribution effects, the Power Plant Laboratory initiate a research program to secure additional data.

D. A study be initiated by the Power Plant Laboratory to determine the engine thrust, specific fuel consumption, and weight penalties necessary to maintain a given stall margin with varying pressure distribution.

E. After recommendations A, B, C, and D have been accomplished, the Aircraft Laboratory initiate a program to determine the compromise on pressure distribution which will optimize airplane performance.

Hq WADC Letter to Industry, subject Joint Industry-Government Meeting on Engine-Inlet Duct Compatibility, dated 24 May 1955

Appendix V

WCL 24 MAY 1955

SUBJECT: Joint Industry-Government Meeting on
Engine-Inlet Duct Compatibility

TO: Douglas Aircraft Co., Inc.
ATTN: Mr. E. F. Burton
Chief Engineer, Santa Monica Div.
3000 Ocean Park Blvd.
Santa Monica, California

1. The purpose of this letter is twofold. First, to emphasize the growing concern of the Navy and Air Force over the engine-inlet duct compatibility problem. Second, to acquaint you with the details of a plan which is designed to provide the best possible exchange of technical information pertinent to this problem, and to request your cooperation in the implementation of the plan.

2. Briefly, it is the desire of the Military Services to sponsor a technical meeting, to be attended by the appropriate members of the aviation industry, the NACA, the Navy, and the Air Force. The objective of the proposed meeting is to provide for a free exchange of information between the industry and the Government while protecting the proprietary rights of industry members. In working toward this objective, the following plan has been evolved:

a. A joint conference between the industry, the NACA, Navy, and the Air Force, to be held at the Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. The conference will be divided into general and restricted phases:

(1) General Phase -- to be attended by all participants:

(a) Orientation by each of the Services on their own experience, including armament aspects.

(b) Presentation by NACA on the general aspects of the problem.

(c) Brief open discussion period.

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Hq WADC (WCL) 24 [illegible] 1955 to Douglas Aircraft Co., Inc., Subject: "Joint Industry-Government Meeting on Engine-Inlet Duct Compatibility"

(2) Restricted Phase -- attendance to be limited to members of the airframe industry, the NACA, the Services, and a particular engine manufacturer whose products are under discussion.

(a) Five two- or three-hour sessions; one for each of the major engine builders wherein his particular engines will be discussed freely with members of the aircraft industry, the NACA, and the Services. Other engine manufacturers will not be in attendance.

3. It is expected that the NACA presentation, during the general phase of the meeting, will be based as fully as possible on a presentation made to the Government Services at the Lewis Laboratory on 3 February 1955. However, in the interest of maintaining proprietary rights, reference to specific products or data will be deleted from this presentation. The restricted phase will provide an opportunity for discussion of specific data and will provide the basis for the best possible exchange of technical information.

4. It is requested that you review the attached tentative agenda and forward to WADC the extent of the comments you desire to present at the meeting, plus any other comments you may have. WADC will attempt to provide the necessary time for the airframe industry to present its views. In order to eliminate duplication, and at the same time provide each member of the airframe industry with an opportunity to present his thoughts, you are encouraged to coordinate your activities with other organizations prior to the meeting. For your convenience, a list of recipients of this letter is attached hereto. In accordance with an agreement with the NACA, it is expected that you will receive a copy of the NACA report, "NACA Conference on Engine Stall and Surge," based on the 3 February presentation. This report should be in your hands at an early date in order to allow a thorough perusal prior to the forthcoming meeting.

5. The meeting is scheduled to be held at the Wright Air Development Center Auditorium on Tuesday, Wednesday and Thursday, 14, 15 and 16 June 1955. Space available will accommodate approximately five persons from your organization. A Secret security clearance will be required for attendance. Accommodations may be obtained at the Miami Hotel, Dayton, Ohio, and bus transportation will be furnished to and from Wright Field. It is requested that you advise WADC the names of personnel who desire to attend, security clearance, date of arrival, and

Hq WADC (WCL) 24 MAY 1955 to Douglas Aircraft Co., Inc., Subject: "Joint Industry-Government Meeting on Engine-Inlet Duct Compatibility"

hotel accommodations desired. Also, please advise any requirements for presentation facilities, such as chart easels, slide or motion picture projectors, etc. Please direct your reply to Commander, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, Attn: WCLPO-1.

FOR THE COMMANDER:

VICTOR R. HAUGEN
Brigadier General, USAF
Director of Laboratories

2 Incls.
#1. Agenda
#2. List

cc: BAR

DISTRIBUTION

Boeing Airplane Company
Attn: Mr. George Martin
Seattle 14, Washington

Boeing Airplane Company
Attn: Mr. N. D. Showalter
Wichita, Kansas

Douglas Aircraft Co., Inc.
Attn: Mr. C. C. Wood
Long Beach 1, Calif.

Douglas Aircraft Co., Inc.
Attn: Mr. E. F. Burton
Santa Monica, Calif.

Douglas Aircraft Co., Inc.
Via BAR El Segundo
El Segundo, Calif.

Lockheed Aircraft Corp.
Attn: Mr. J. B. Wassall
Burbank, Calif.

Lockheed Aircraft Corp.
Attn: Mr. R. W. Middlewood
Marietta, Georgia

North American Aviation, Inc.
Attn: Mr. J. G. Beerer
Downey, Calif.

North American Aviation, Inc.
Via BAR Columbus
Columbus, Ohio

Republic Aviation Corp.
Attn: Mr. J. C. O'Brien
Farmingdale, L. I., New York

North American Aviation, Inc.
Attn: Mr. R. H. Rice
Los Angeles 45, Calif.

Glenn L. Martin Company
Attn: Mr. E. G. Uhl
Baltimore, Maryland

Northrop Aircraft, Inc.
Attn: Dr. Wm. F. Ballhouse
Hawthorne, Calif.

Grumman Aircraft Engineering Corp.
Via BAR, Bethpage
Bethpage, L. I., New York.

Chance-Vought Aircraft Div.,
United Aircraft Corp.
Via BAR, Dallas
Dallas, Texas

McDonnell Aircraft Corp.
Via BAR, St. Louis
St. Louis, Mo.

Consolidated-Vultee Aircraft Corp.
Attn: Mr. R. H. Widmer
Ft. Worth, Texas

Consolidated-Vultee Aircraft Corp.
Attn: Mr. W. W. Fox
San Diego 12, Calif.

Bell Aircraft Corp.
Thru: AF Plant Representative
Niagara Falls, N. Y.

TENTATIVE AGENDA

INDUSTRY - GOVERNMENT MEETING ON ENGINE-INLET DUCT COMPATIBILITY

WADC AUDITORIUM 14, 15 and 16 JUNE 1955

Chairman - Brig. General Victor R. Haugen
Director of Laboratories

14 June

Opening Remarks - General Haugen	0930 - 1000
Service Experience	1000 - 1130
Lunch	1130 - 1230
NACA Presentation	1230 - 1430
Break Period	1430 - 1445
NACA Presentation	1445 - 1545
Discussion Period	1545 - 1630

15 June

Pratt & Whitney Engines	0930 - 1200
Lunch	1200 - 1300
NACA	1300 - 1400
Airframe Industry	1400 - 1450
Break	1450 - 1505
General Electric Engines	1505 - 1535
NACA	1535 - 1605
Airframe Industry	1605 - 1630

16 June

Allison Engines	0930 - 1000
NACA	1000 - 1030
Airframe Industry	1030 - 1100
Westinghouse Engines	1100 - 1130
NACA	1130 - 1200
Lunch	1200 - 1300
Airframe Industry	1300 - 1330
Wright Aeronautical Engines	1330 - 1400
NACA	1400 - 1430
Break	1430 - 1445
Airframe Industry	1445 - 1515
Close of Business	1515 - 1545

Hq WADC Letter concerning Inlet-Engine Compatibility dated 2 November 1955, and Inclosure—Proposed Technical Program

Appendix VI

HEADQUARTERS
Wright Air Development Center
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

IN REPLY ADDRESS BOTH COMMUNICATIONS AND ENVELOPE TO COMMANDER, WRIGHT AIR DEVELOPMENT CENTER, ATTENTION FOLLOWING OFFICE SYMBOL:

2 NOV 1955

A loss in aircraft performance resulting from improper matching of the air induction system and engine has, in the past year, become a major problem to the military services. The NACA Lewis Flight Propulsion Laboratory recognizing the severity of the problem, provided a briefing for members of the Government services on 3 February 1955. Subsequent to that meeting on 14, 15, 16 June, the Navy and Air Force sponsored a three-day Industry-Government meeting at Wright Air Development Center to discuss the problem with Industry and NACA. Both of these meetings served to bring attention to the overall problem, and several excellent technical approaches to the problem were offered.

Attached is a proposed technical program prepared by the Wright Air Development Center which substantially is a compilation of thoughts and ideas from the aircraft and engine industries, the NACA, and the Air Force and Bureau of Aeronautics. It is requested that this program be reviewed by your organization and comments thereon be submitted to WADC. Consideration should be given to such items as scope of the program, practicability, effect on development time, requirement for facilities, effectiveness of the proposed program, and possible additions or deletions.

It is quite probable that many of the items contained in the attached program will appear as contractual requirements as changes in Military Specifications, Handbook of Instructions for Aircraft Designers, etc. As such, these items may have a rather profound effect on your operation as a member of the aviation industry. It is believed that you will welcome the opportunity to compile your comments and forward them to WADC for review and evaluation.

Comments should be directed to Commander, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, ATTN: WCLPO-1. Your cooperation will be of great benefit to the Air Force and will be sincerely appreciated.

Sincerely,

Victor Haugen

VICTOR R. HAUGEN
Brigadier General, USAF
Director of Laboratories

1 Incl
Prop Tech Prog for
Engine Inlet Compat
(n/d)

Proposed Technical Program for Engine Inlet Compatibility

I. Suggested NACA Investigations:

a. Conduct sufficient tests to determine whether a positive correlation exists between wind tunnel model testing and wind tunnel and flight full-scale inlet testing as pertains to flow profiles. For the purposes of this technical program, the term "flow profile" will exclude that portion of the boundary layer within 1/2 inch of duct walls and/or center bodies. Included in this investigation should be a determination of the importance of close Reynolds number control in model testing.

b. Conduct distortion tests on NACA designed compressors, including the transonic and supersonic designs, with a view toward determining the ultimate value of data obtained on the compressor itself and how fully this data can be used in determining the effects of flow distortions on the complete engine.

c. Continue running distortion tests on newly developed engines as the need arises.

d. Conduct studies and exploratory research with the objective of increasing the operational capabilities of power plant installations through the use of alternate means such as aerodynamic features of the inlet duct and variable area devices in the engine.

II. Tests to be Performed by Engine Manufacturers:

a. During the early experimental stages of compressor development, run distortion tests on compressor rigs to provide an indication of the sensitivity of the particular design to profile distortions. These tests should be run, in addition to the static sea level tests, at applicable altitude and Mach number conditions wherever possible. This testing should include circumferential distortions of one and of two low energy areas and radial distortions of (1) low energy at the blade tips, and (2) low energy at the hub. It would be desirable to conduct tests on as many combinations of circumferential and radial distortions as practicable. $\frac{\Delta P}{P\ avg}$ for each of these separate conditions should be run to whichever of the limiting factors occur first (heavy stall, surge, limiting blade stress) but not to exceed $\frac{\Delta P}{P\ avg} = 0.30$. Such tests should cover as fully as possible the entire range of expected engine operation. In addition, tests should be accomplished wherever practicable to determine the effects on engine operation of transient pressure distortions not to exceed $\frac{\Delta P}{P\ avg}$ of 0.50 (this should include effort to determine engine operation with respect to the length of the transient).

2

b. As early as possible, consistent with necessary engine reliability, rerun the inlet profile tests as in a. above by means of direct connect ducting to the complete engine. Determine performance, stall and surge limits, blade stress limits, or gas temperature limits as a function of $\frac{\Delta P}{P_{avg}}$ through 0.30, providing none of, the other limiting factors occur at the lower value of $\frac{\Delta P}{P_{avg}}$. Engine acceleration performance should also be determined during these tests. Such determinations should be over the entire range of engine operating conditions, including Reynolds number simulation. Any transient operations such as afterburner light-off, modulation, or shutdown should be included as applicable. Use of any variable geometry features should be tested over their full range of operation.

c. For engines intended for particular aircraft applications. Employing inlet profiles furnished by the applicable aircraft manufacturer, complete the tests outlined in b. above. Profiles may be simulated by screens or other objects installed in a direct connect duct to the engine.

d. Based on results of c. above, and using the latest inlet configuration for a particular aircraft, establish the minimum acceptable acceleration stall margin referred to stall margin obtained with a bellmouth inlet. This stall margin value would then be employed in engine production acceptance tests.

e. In the event that no positive correlation can be found to exist between scale model wind tunnel testing and full-scale inlet testing, the tests outlined in c. above should be run, in so far as facilities are available, in a free jet system (supersonic).

f. Use of the actual inlet on a sea level static basis alone is not considered adequate profile testing. However, use of the actual inlet and duct on a static test engine will be more reliable and more convenient than the use of screens and should be employed to the maximum extent possible.

g. Plan to conduct extensive flight tests on an early aircraft employing the latest inlet and engine design configuration. These tests should be extremely comprehensive in nature and should cover every possible flight condition. Some effort is needed here to determine what constitutes the minimum acceptable instrumentation. This should be in addition to the power plant performance testing accomplished by the aircraft manufacturer.

III. Studies and Experimental Research at Engine and Control Manufacturers:

a. Study and test to determine the penalties involved in fixes provided to make the engine accept poor profiles. These penalties, of course, will be manifested in terms of weight, size, performance, flexibility, etc. These determinations should be made for each engine developed and these efforts should be intimately tied into the test efforts specified in Paragraph II. During this phase inlet and engine performance data should be freely exchanged. The intent of this data exchange is that the airframe contractor will supply the appropriate engine manufacturer with inlet performance data for use in tests to determine engine performance penalties. The engine performance data, based on test results, will then be supplied to the appropriate airframe manufacturers so that aircraft performance may be calculated on a more realistic basis.

b. Conduct studies to determine the relative sensitivity to flow distortions of various compressor and engine types.

c. Conduct studies to determine engine performance and structural integrity under conditions of supersonic duct buzz.

d. Study power control systems to provide increased accuracy and sensitivity.

1. A search for, and evaluation of, new and novel ideas of sensing and control to be conducted by all agencies of the engine and control industries.

2. Conduct engine cycle analyses to determine inherently more accurate controlling principles with major emphasis on (1) effect of controlled mode over complete range of flight conditions and control established outputs, and (2) providing desired performance with intrinsic compensation for engine power section performance changes which are due to inlet effects.

3. Study means of improving the accuracy of sensors considering the expanded operating range and the effect of sensor location.

4. Provide ways to improve the accuracy of the complete control and each of its subassemblies.

5. Conduct research with a view to minimizing production and service deterioration differences which are so disastrous to scheduled engine control functions.

6. Provide more forward looking application engineering in order to realistically specify, in the beginning of engine development, all of the requirements which the control must meet, with particular emphasis on compatibility with the inlet.

7. Continue to search for compressor parameters which will ultimately allow sensing of incipient compressor surge.

8. Expand the utilization of analogue computer and simulator equipment during engine and control research and development programs.

IV. Studies and Experimental Research by Airframe Manufacturers:

a. Study the correlation between small scale inlet duct testing and flight testing as pertains to flow profiles.

b. Conduct inlet development tests as early as possible in the aircraft development program and provide flow profile data to be used in engine tests for determination of engine performance penalties.

c. Conduct early flight testing (such as Phase III) to determine inlet performance including pressure distribution data as well as pressure recovery. Some effort is needed here to determine what constitutes the minimum acceptable instrumentation.

d. Study and test the effects of inlet duct design parameters (bends, diffuser angles, lip shapes, screens, plenum chambers, etc.) on flow profiles, pressure recovery, etc.

e. Study and develop methods and devices to alleviate the adverse effects of high angles of attack and yaw on inlet performance.

f. During preliminary aircraft design, consider the effects of inlet design parameters on aircraft performance and operational limitations. (This requires engine trade-off data which may necessarily be estimated in some cases.)

g. Conduct a general study to determine the compromise in pressure distribution which will result in the best aircraft performance. This study should include analysis of engine types, inlet location and types, and engine acceleration time versus aircraft performance. (The engine acceleration time is important since instantaneous stall margin is reduced during acceleration making any adverse profile effects even more critical.)

Airframe Industry Letter Responses to USAF Proposed "Technical Program for Engine-Inlet Compatibility"

Appendix VII

CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

FORT WORTH, TEXAS

TELEPHONE: SUNSET 7311

CAS:JEF:ltt/A.Misc. 6-3337

December 19, 1955.

Subject: (Unclassified) Proposed Technical Program for Engine-Inlet Compatibility

To: Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

23 Dec 55

AF Plant Representative
GAP #4 - P. O. Box 371
Fort Worth, Texas

Attention: WCLPO-1

Via: Air Force Plant Representative
Government Aircraft Plant No. 4
Fort Worth, Texas

Reference: (a) WADC Ltr. of 2 November 1955 to R. H. Widmer (Unclassified)

Inclosure: (A) Three (3) Copies Convair (Fort Worth) Comments on Subject Program (Title and Document Unclassified)

1. As requested in your letter of 2 November 1955, we have compiled comments on your proposed technical program for engine-inlet compatibility. These comments are attached.

2. The comments have been prepared in the same format as the proposed program. In those cases where we made no comment on items of the program, we were in agreement with these items.

3. In general, we feel subject program is well thought out and very worthwhile. Convair, General Electric, and NACA have already taken many of the steps recommended, in connection with the B-58 program. We hope the results will serve as an example that close attention and coordinated effort can minimize inlet flow distortion and its adverse effects.

Very truly yours,

CONVAIR
A Division of General Dynamics Corporation
(Fort Worth)

R H Widmer

R. H. Widmer
Assistant Chief Engineer

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INCLOSURE (A)

Convair (Fort Worth) Comments on the WADC
Proposed Technical Program for Engine-Inlet Compatibility

I. Suggested NACA Investigations:

a. We recommend similar studies or tests to determine the correlation, if any, between supersonic buzz characteristics of wind tunnel models full-scale inlet-engine combinations. Some work has been done to find scale effects on model buzz characteristics, but little has been done to correlate buzz characteristics of models of any scale with those of an actual inlet-engine installation. There may be interaction between inlet buzz and comprèssor rotating stall as flight Mach numbers increase. Buzz becomes more severe and, because ram air temperature increases and thus engine corrected RPM decreases, the engine advances toward the rotating stall region.

e. (Added by Convair) NACA should obtain and publish data to set the minimum size of free-jet nozzle to test a given inlet at prescribed operating conditions. It appears that supersonic tunnels big enough to test a full scale inlet and engine will be very heavily scheduled for a long time to come. Free-jet testing could greatly relieve the test load of the large tunnels. In addition, free-jet testing has many advantages over tunnel testing, in such aspects as latitude of simulated flight conditions, ease of imposing transients, operating cost, simplicity of test article, etc. However, there seems to be a lack of data on the minimum usable ratio of free-jet area to inlet area, particularly for subscritical inlet operation. This leads to selection of a possibly over-sized free-jet nozzle for testing a given inlet, which in turn may sharply curtail the range of test conditions, or even rule out free-jet testing due to facility airflow limits.

II. Tests to be Performed by Engine Manufacturers:

a. We recommend that inlet flow profile effects on the overall engine be estimated from this compressor research and made a part of the engine performance bulletin. If feasible, preliminary bulletins issued before such compressor research should show profile effects estimated from previous experience.

b. When this data becomes available, it should replace the estimated data of a. above in the performance bulletin. We would like to see included in transient data the rates of airflow decay from throttle chop and flame-out. This information affects variable inlet design.

INCLOSURE (A)
Page 2

e. A full-scale test of the engine inlet in a supersonic free jet or propulsion wind tunnel can furnish much data besides profile effects, all of which is valuable to the airframe manufacturer. This is especially true for a variable inlet and its control system. We recommend that such a test be made a cooperative effort between engine and airframe manufacturers, with prime responsibility being taken by the most interested party.

III. Studies and Experimental Research at Engine and Control Manufacturers:

e. (Added by Convair) When a variable inlet is to be used, the inlet control manufacturer in cooperation with the engine manufacturer should conduct analogue studies on the inlet-engine combination with their respective controls.

IV. Studies and Experimental Research by Airframe Manufacturers:

f. As stated in our comments on II a. and b. above, we feel the engine manufacturer should provide engine trade-off data. In most cases, it would be difficult for the airframe manufacturer to make estimates of suitable accuracy.

g. This study again requires engine trade-off data to be shown in engine performance bulletins if the study is to be conducted analytically during early aircraft design stages. After a particular engine has been selected for an aircraft, then the exchange of model inlet profile test data and data on engine performance with these profiles can begin, and the study will proceed in that manner.

h. (Added by Convair) We recommend that the engine-inlet installation be tested in a free-jet or propulsion wind tunnel. See comment on II. e. This is especially desirable when a variable inlet is used. Such a test should precede flight testing and has these advantages over flight tests:

1. Critical regions can be investigated without endangering the lives of a flight test crew.

2. More complete and more accurate instrumentation can be used.

Westinghouse

ELECTRIC CORPORATION

AVIATION GAS TURBINE DIVISION

P.O BOX 288
KANSAS CITY MO.

December 8, 1955

WK3422L

TO: Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio
ATTN: WCLPO-1

SUBJECT: Proposed Technical Program for Engine Inlet Compatibility

REFERENCE: WADC Letter dated 2 November 1955

1. This contractor appreciates the opportunity to review and present comments on the proposed technical program for engine inlet compatibility. The program is commendable in its scope, practicality, and probable effectiveness.

2. It appears that a shorter over-all development time for the engine-airframe combination may result from the program. Incompatibilities of the duct and engine will show up sooner, at a time when modifications can be more easily introduced. But the time required to bring an engine through its qualification test and into production may be increased about six months if the tests with distortions and with the inlet duct are required prior to the qualification test.

3. Because the problem of engine-inlet duct compatibility is still relatively new and inadequately understood, we urge the Air Force to move cautiously in making provisions of the proposed program mandatory. We believe this is particularly true where new test facilities will be needed. Several of the tests described in the program require test facilities that, to the best of this contractor's knowledge, are existent only in small number.

4. Section IIa of the proposed program states that compressor rig tests should be run at static sea level, also at applicable altitude and Mach number conditions whenever possible. This contractor's compressor rig has insufficient power to test compressors at inlet conditions corresponding to altitudes below 30,000 feet. It is believed th... most existing compressor rigs have similar limitations. Inability to test at

Commander, WADC - 12-8-55

static sea level conditions on the rig has not been considered a serious limitation, inasmuch as the surge margin at static sea level is generally greater then at altitude.

5. Not all engine contractors possess engine altitude test facilities. The testing at altitude (referred to in Section IIb) would, therefore, at this time, have to be done in a government facility. It seems likely that the demand upon government facilities could exceed their capacities.

6. The studies of supersonic duct buzz, mentioned in Section IIIc, would require elaborate test facilities that, to the knowledge of this contractor, are almost non-existent.

7. Results of inlet duct testing accomplished to date indicate that the presence of an engine after the inlet duct influences the flow pattern to a considerable degree. It is suggested that Section Ia be amended to state specifically that, wherever possible, wind tunnel tests be run with an engine installed after the inlet duct.

8. It is suggested that a Section numbered Ic be added. The section may read: "From information available, devise a definition of flow distortion that is more precise than $\Delta P/P_{avg}$ and formulate a family of representative steady-state distortions to which engines should be subjected. Also obtain and disseminate information on representative transient distortions, their magnitude, their geometric pattern, and their duration of time." The problem of generating representative distortions in a compressor rig or a static engine test, by means of screens, etc., is not straightforward. A byproduct of the family of flow distortions that might be devised by NACA would be a definition of the screen or spoiler geometry required to produce each representative distortion. The transient distortions referred to are those resulting from aircraft maneuvers and gun and rocket fire.

9. It appears to this contractor that the requirement of Section IId is impractical. The section deals with the stall margin value to be employed in engine acceptance tests. Using present procedures for engine acceptance testing, it is impossible to stall the compressor and thus determine the surge margin. An exception exists when low referred RPM stall can be obtained by overriding the acceleration control. Although we agree that the objective of Section IId is highly desirable, we can suggest no simple modifications to the acceptance testing procedure to permit the stall margin to be checked.

10. We feel there is great merit in Mr. Silverstein's suggestion that the industry standardize on a small number of inlet duct configurations. The trend to pod-mounted engines in supersonic aircraft should make this approach feasible. Engines of different sizes could be accommodated by geometrically scaling a given inlet duct. Certainly in supersonic flight the flow distortions at the engine inlet will tend to become more severe.

Commander, WADC - 12-8-55

Mr. Silverstein argues that by limiting the number of inlet duct designs, it will be possible to concentrate development and thus obtain uniformly better inlet ducts than if each aircraft has a different duct geometry. We recommend that Mr. Silverstein's proposal be seriously considered.

11. The Air Force's desire to gain a better understanding of the fundamental phenomena of inlet duct compatibility is appreciated by this contractor. The meetings among the Services, NACA, airframe manufacturers, and engine companies, have gone a long way to promote a better understanding of the problem, and continuation of this approach, coupled with the excellent program proposed by the Air Force, should achieve success. We shall be pleased to cooperate.

Respectfully submitted,

Allan Chilton
Allan Chilton
Chief Engineer

AC:FS:gw

cc: BAGR - Central District
BAR - Kansas City

CHANCE VOUGHT AIRCRAFT
INCORPORATED · DALLAS, TEXAS

BUREAU OF AERONAUTICS REPRESENTATIVE
RECEIVED
DEC 1 1955
NAVAL INDUSTRIAL RESERVE PLANT
P. O. Box 5907 Dallas, Texas

NOV 30 1955

E-4976

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLPO-1

Via: Bureau of Aeronautics Representative
Dallas, Texas

Subject: Comments on Proposed Technical Program
for Engine-Inlet Compatibility

Ref: (a) WADC Ltr. WCLPO-1 dated 2 November 1955 with BAR, Dallas End-1, SerNo. 16943 dtd 14 November 1955

Gentlemen:

The proper matching of the engine and the inlet duct is considered to be of primary importance by this airframe manufacturer in the development of effective fighter aircraft and missiles. Therefore, the opportunity to comment upon the subject program of reference (a) is welcomed.

In general, this airframe manufacturer is in agreement with the proposed program. It is suggested that NACA also conduct studies to determine better criteria for defining flow distortion than the extreme variation of total pressure divided by the average total pressure. As stated at the conference on engine-inlet duct compatibility on 14, 15 and 16 June 1955 at WADC, data were presented which indicated that the distribution of the flow distortion is also of prime importance. Perhaps some statistical distribution function would be of greater value and significance. This airframe manufacturer is in accord with the suggested programs for the engine and control manufacturers, and is currently engaged in the studies and experiments suggested for the airframe manufacturer.

End-1
15 DEC 1955
FORWARDED.
18293

Very truly yours,

CHANCE VOUGHT AIRCRAFT, INCORPORATED

H. B. Gibbons

H. B. GIBBONS
Assistant Chief Engineer

OFFICIAL FILE COPY
POWER PLANT
HCR/fm

DESIGNER AND BUILDER OF HIGH PERFORMANCE MILITARY AIRCRAFT SINCE 1917

REPUBLIC AVIATION CORPORATION
FARMINGDALE, LONG ISLAND, NEW YORK

Telephone Farmingdale 2-1100

September 2, 1955
Ref: 55-5158
HJK/baj

SUBJECT: Joint Government Industry Meeting on Engine-Inlet Duct Compatibility

TO: Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attn: Major General Albert Boyd
Dept. WCG

Thru: AF Plant Representative

1. During the recent meeting held at Wright Field on June 14, 15, and 16 on the subject engine-duct compatibility, Col. Appold, Chief of the Power Plant Laboratory, requested comments and recommendations from the participants. These have been prepared and are submitted in the attached exhibit.

2. The objective of both engine and airplane manufacturers is the design of the best possible propulsion system. To realize this objective both must recognize that the induction system is assuming a far more important role in this propulsion system than it has heretofore. Supersonic flight has brought the intake ducts into equivalence with the rotating engine compressor, and at least equal consideration must now be given to the requirements and limitations of the induction system when designing future engines.

3. The joint meeting on engine-duct problems has set an example of the type of cooperation required. The evidence of existing close cooperation between some engine manufacturers and the airframe manufacturers was gratifying and it is hoped this attitude can be made to prevail in the entire industry.

4. This Contractor wishes to thank the Air Force for the opportunity of attending the meeting and will be happy to discuss any questions raised by the recommendations in the attached exhibit.

REPUBLIC AVIATION CORPORATION

A. Kartveli

A. Kartveli
Vice President-Chief Engineer

Encl: As above

NORTHROP AIRCRAFT, INC.

CABLE ADDRESS "NORAIR"

IN REPLY REFER TO: 3000-3204
RBK:ACF:fm

NORTHROP FIELD
HAWTHORNE, CALIFORNIA
26 November 1955

Subject: Inlet Distortion Effects On Engine Performance

To: Commander
Wright Air Development Center
Wright-Patterson Air Force Base
Ohio

Attention: WCLPO-1

Through: Air Force Plant Representative
Northrop Aircraft, Inc.
Hawthorne, California

Reference: (a) WADC ltr WCLPO-1 dtd 2 November 1955 (encl.)

1. Your recent letter and enclosure concerning a proposed technical program for engine-inlet compatibility has been reviewed with considerable interest. In our opinion, you are to be commended for the completeness of the program and your clear delineation of responsibility and duties of the many agencies concerned. The following comments are submitted as requested.

2. In regard to the proposed NACA tests to determine the effect of model scale on the distribution of air flow at the compressor inlet (Item I-a) we are pleased to report that such a correlation has been investigated by the engineers at Northrop Aircraft, Inc., in connection with the SM-62 missile program. Test data were obtained from a full scale wind tunnel program, a low speed 1/7 scale model program and an engine test facility program. The last of these consisted of engine operation while connected to the ducting system of the missile both with and without a pre-entrance bellmouth. In general, the data showed excellent correlation when plotted against the inlet Mach number or engine corrected air flow rate.

NORTHROP AIRCRAFT, INC.

To: Commander, WADC

Attention: WCLPO-1

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Page -2-

3. The problem of defining the distributional parameters which bear physical significance to the problem of engine stall and surge is one that will require some serious consideration. In the past it has been a burden to the people concerned in the evaluation of inlet performance to have to measure many different parametric terms. A recent survey of this problem revealed that no fewer than ten different definitions were being employed throughout the industry. It is suggested that, prior to proceeding into the proposed program at great length, some study be made to better determine just what parameters have physical significance and to then standardize this definition throughout the aircraft and engine industries.

4. Section II of the enclosure outlines the tests that would be conducted by the engine manufacturers. Subparagraphs "c" through "g" summarize tests wherein the engine manufacturer would concern himself with engine-inlet problems as applicable to a particular airplane. It is the firm opinion of this company that such tests should be carried out by the prime contractor of the airplane; namely, the applicable airframe manufacturer. While it is probably desirable to conduct these tests in close liaison with the engine manufacturer, and perhaps in some instances in his facility, the actual testing and analysis of the information obtained should be reserved for the airframe technical personnel. As a further comment, it is our opinion that airframe manufacturers would desire to know as much as possible about the particular limitations and penalties due to distortion that characterize the engine being considered prior to his engine selection and induction system design. He is then in a position to balance the penalties of weight and complexity of the inlet design against the performance which will result. The primary mission for which the aircraft is intended will probably delineate the critical flight conditions and permit a more judicious choice of powerplant which will result in the best match of airframe and engine. This procedure will also provide the necessary challenge to the engine manufacturer to design engines with greater tolerance to distortion. It is our recommendation that the engine manufacturer be required to include the distortion limits and effects

NORTHROP AIRCRAFT, INC.

To: Commander, WADC

Attention: WCLPO-1

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Page -3-

of distortion on engine performance in the engine model specification in a manner somewhat analogous to the present practice of specifying performance penalties due to inlet total pressure decrements. The proposal made at a recent conference to the effect that the inlets and engines be considered as an integral unit is in our opinion inadvisable and should not be considered in the program outlined in the enclosure.

5. Concerning the subject of static engine tests in conjunction with the air inlet ducting of a particular aircraft, it is our opinion that these tests should be performed for reasons in addition to the evaluation of engine stall problems that might occur at altitude. It appears from viewing the data that exist, and our personal experience, that the problem of engine stall and surge is much less critical to compressor face distortion under static operating conditions than under high altitude dynamic conditions. If this is a physical fact, then it is probably possible that the engine manufacturer could specify more lenient distributional tolerances under conditions of static engine run-up and take-off. As is well known, inlets possessing sharp lips experience extremely high distortion parameters during static or low flight speed operation. This fact presents a very difficult design problem to the airframe manufacturers if they are to design into their system some device which will eliminate these large distributional values under these conditions. It is hoped that the subject program will reveal that this limited range of airplane operation will be allowed more lenient distributional tolerances.

6. We sincerely appreciate the opportunity you have given us to comment on this program.

NORTHROP AIRCRAFT, INC.

Wm F Ballhaus

Wm. F. Ballhaus
Chief Engineer

DEC 8 1955

AF Plant Rep. Ofc., Northrop Acft. Inc., Hawthorne, Calif.
☑ Reviewed. No action required by this office.
☐ Concurred in.

John McGratt

CHARLES W. TENNANT, Lt. Col., USAF
AF Plant Representative

cc: OOAMA

ALLISON DIVISION

GENERAL MOTORS CORPORATION

INDIANAPOLIS 6, INDIANA

CABLE ADDRESS "ALLISONENG"

7 December 1955

IN REPLY REFER TO E1117HE

Commander
Wright Air Development Center
Wright-Patterson Air Force Base
Ohio

Via: USAF Plant Representative

Attention: WCLPO-1

Reference: WADC Letter, Brigadier General Haugen to R. M. Hazen, dated 2 November 1955.

Subject: Allison Division Comments on Proposed Technical Program for Engine-Inlet Compatibility

1. The Allison Division is well aware of the severity of aircraft performance problems resulting from incompatibilities between the engine and the air induction system. Although Allison power-plants have, to date, experienced little or no operational difficulties arising from inlet flow distortions, we recognize that a great deal of attention must be given to the compressor surge problem in the design and development phases of an engine program. We are in full accord with the objectives implied by the technical program proposed by the Wright Air Development Center, and we sincerely appreciate the opportunity to express our views on the practicability and effectiveness of the proposed program.

2. Fundamentally the WADC proposal encompasses the problem areas rather thoroughly. In specific details, however, the program appears to place a disproportionate share of the burden for alleviating duct-engine matching problems upon the engine manufacturer. At the Industry-Government meeting in June it was rather universally agreed that the matching problem is the mutual responsibility of the airframe and engine people alike. We trust that the apparent emphasis on the engine phase of the program results only from our present inability to precisely define an approach to the solution of the duct problem. Maximum effectiveness of the program will be realized from a vigorous yet studied pursuit of the program objectives. The establishment of contractual requirements

Commander
Wright Air Development Center

7 December 1955
E1N7NE Page 2

must be approached with caution, particularly in the initial phases, to prevent the program from defeating its own purpose through sheer complexity.

3. The following comments pertain to the specific details of the proposed technical program and are listed in a corresponding order:

I. NACA Investigations

a. The determination of possible correlation between model and full-scale testing is of prime importance.

b. It would be well worthwhile for NACA to try to establish a more suitable factor for describing distortion - perhaps something similar to the boundary layer form factor. Also, for optimum correlation of compressor and engine testing, it is desirable that the distortion tests be conducted on compressors which are component parts of existing engines.

c. Newly developed ducts should also be tested.

d. The exploratory research should include possible corrective devices such as free windmills, etc. Studies should also be directed toward the investigation of compressor stage action on attenuating or amplifying distortion and suitable stage design criteria.

II. Engine Manufacturer's Tests

a. While distortion testing on compressor rigs may be very useful, requirements for such testing should not interfere with the primary development of the compressor. Hence the phrase, "As soon as practicable", should be inserted at the front of line 1.

In line 4, substitute "-- Reynolds Number Indices --" for "--Altitude and Mach Number Conditions --".

$\frac{\Delta P}{P_{avg}}$ values of 0.20 for steady state and 0.35 during transients should be the maximum allowable levels induced by the air inlet system.

Commander
Wright Air Development Center

7 December 1955
E1L7NE Page 3

b. Development schedules may be such as to permit the substitution of engine testing for compressor rig testing. Under any circumstances it would not appear necessary to evaluate blade stress levels on both the engine and the compressor rig.

The capacity of available facilities will definitely limit the scope of engine acceleration testing.

c. This phase could be substituted for the investigations prescribed under item (b).

d. Item (d) is sound in principle. However, it must be recognized that a particular aircraft duct may impose such severe penalties as to prohibit compliance with various Military Specification requirements - particularly with respect to maximum acceleration time and unrestricted throttle movement.

e. The tremendous problem of facilities availability is obvious.

f. On the contrary, screens can be used quite effectively to simulate known in-flight pressure distributions whereas use of the duct alone will only provide information for the sea level static condition.

g. Except for special problems, the work outlined under this item should be performed by the airframe manufacturer since the normal course of testing calls for investigating aircraft performance over the full range of attitudes, altitudes and Mach numbers including the effects of armament firing.

III. Research at Engine and Control Manufacturers

b. This is an NACA project except insofar as a certain amount of information automatically accrues from engine design studies and from the testing effected under Phase III.

c. It appears likely that supersonic duct buzz is intolerable under any conditions.

Commander
Wright Air Development Center

7 December 1955
E1M7NE Page 4

d. We heartily endorse the projects listed under (d). It is noted that item 5 introduces the ubiquitous field cleaning problem.

IV. Research by Airframe Manufacturers

b. Early testing and development of inlet ducts are "must" items if the program of engine testing is to be conducted with any degree of rationality.

Information as to the effects on distortion patterns of such items as skids, external stores and launch racks (missiles) should also be supplied to the engine manufacturer as early as possible. Items such as these have, in many cases, imposed very serious inlet profile deficiencies.

c. Minimum acceptable instrumentation is that which will accurately define the circumferential and radial profiles prescribed for engine testing under II-a. Accurate profile determination at the engine inlet will generally require a minimum of 8 total-head rakes of 5 probes each plus suitable wall statics. In some cases even more probes may be required.

d. Values of $\frac{\Delta P}{P_{avg}}$ commensurate with those established in II-a for engine testing should also be fixed for the evaluation of inlets. Test values higher than the fixed limits would then automatically render a duct unacceptable under any circumstances.

4. We feel that items IV-f,g require some separate comments since herein lies one of the most knotty and delicate problem areas of the entire program. There can be no quarrel with the stated objectives which are basically aimed at the attainment of optimum overall aircraft performance. It is also obvious that throughout the planning of the proposed technical program, due consideration has been given to the probable necessity for accepting some compromise between peak engine performance and a degree of tolerance toward inlet distortion.

Commander
Wright Air Development Center

7 December 1955
E1M7NE Page 5

When existing engines of known characteristics are being considered for a possible application, the relative merits of stall margin vs peak performance can be readily evaluated and the engine selection can be made accordingly. On the contrary, when procurement attention is focused upon new engines still in the design phase, the tolerance toward inlet distortions and stall margin are extremely nebulous quantities and primary emphasis is placed upon the attainment of peak performance in terms of aircraft range and/or V_{max}. To maintain a competetive position the engine manufacturer must "design to the hilt". This situation poses a very real problem to which there is no quick and ready answer. Although we cannot suggest an immediate solution, we strongly believe that a frank and open admission of the existence of the problem is the first step in its elimination.

5. We hope that you find the foregoing comments useful and we will welcome the opportunity to take part in future discussions of engine-inlet compatibility problems.

Very truly yours,

ALLISON DIVISION
General Motors Corporation

D Gerdan

D. Gerdan
Director of Engineering

GEC/pf

cc: USAF PR

OFFICE OF THE AFPR
ALLISON DIVISION, GMC
DEC - 9 1955
APPROVED

Memo, F-XXX/JXX Stall-Inlet Problem

Appendix VIII

F-XXX/JXX STALL-INLET PROBLEM

Engine stalls have been encountered in the F-XXX at almost all flight conditions. It is impossible to correlate all stalls on the basis of altitude, airspeed, angle of attack, inlet duct mass flow ratio, or engine RPM. With the information available to date, it is impossible to definitely say that any engine stall encountered in the F-XXX flight testing has been solely due to pressure distribution. Since the engine stall margin is reduced by the presence of any pressure variation at the compressor face, it is apparent that low Reynolds Numbers and malfunctions of the bleed valve governor, exhaust nozzle, and fuel control are more likely to cause engine stalls when a finite pressure variation exists. It appears that only a small percentage of the engine stalls encountered in the F-XXX can be attributed to pressure distribution effects. In its initial attempt to correlate the effect of pressure distribution on engine stalls, the engine contractor thinks that the variation of circumferential total pressure at the compressor face, expressed in percentage of the average total pressure at the compressor face, is a parameter which can be used to determine the effect of pressure distribution on engine stalls. No effect of localized pockets of high or low pressure has been noted by the engine contractor.

The engine contractor states that only recently has the effect of pressure distribution on engine stall become known. He further admits that the pressure distribution limits in the engine specification (± 2 circumferential & ± 3% radial) were obtained by considering the worst possible combination of distribution on compressor blade stresses and that no consideration was given to engine stall when these distribution limits were set. The engine contractor admits that these

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pressure distributions are unrealistic, when considering inlet design, and that even their flying test bed inlet does not meet these limits. The engine manufacturer states that the stall margin of the engine was based on ± 1-1/4% circumferential pressure distribution and that even if the engine specification limit of ± 2% pressure distribution were met, that a thrust and SFC penalty will be paid to keep the same stall margin. It is also significant that the one airplane, the Navy XXX, which the engine contractor points to as having no repeatable engine stalls, does not meet the engine specification distribution limits.

In conversations with several other engine manufacturers, they have stated that the engine specification distribution limits are essentially arbitrary numbers, designed to make the engine user aware that pressure distribution was something to worry about, but that they had no idea what the numbers really should be. Almost all of the engine manufacturers have, and still are, specifying pressure distribution limits which are impossible to meet for all flight conditions. Furthermore, only one engine contractor has made some allowance for duct boundary layer in the engine specification pressure distribution limits. All the other engine manufacturers have made no allowance for boundary layer and hence have ridiculous requirements which no practical inlet duct can meet. Because the pressure distribution limits have been completely unreasonable, the airframe manufacturers have tended to take the attitude that a ridiculous, arbitrary requirement is no requirement at all.

Inlet designers in the past have concentrated on inlet total pressure recovery with pressure distribution a secondary consideration. There are several reasons why pressure distribution has taken a back seat.

1. The engine manufacturer's limits were impossible to meet in a practical installation.
2. Neither the engine manufacturer nor the airframe manufacturer realized the effect of pressure distribution on stall, and only the compressor blade stresses were considered a problem.
3. Because the inlet lip must operate over an extremely wide angle of attack range, caused both by airplane angle of attack and inlet mass flow ratio, it is impossible to design an inlet lip which will prevent lip separation under all flight conditions, without unduly compromising the airplane drag.
4. Side inlets, which have come into use because of the electronic requirements and the decreased volume of the duct, have an inherent pressure distribution at the inlet due to the effect of the forward fuselage on distorting the air entering the inlet, even when completely eliminating the fuselage boundary layer. Thus, for a side inlet configuration, not only would it be necessary to have no pressure distribution caused by the duct itself, but it would also be necessary that the duct remove the pressure distribution caused by the external aerodynamics of the forward fuselage.
5. Side inlets necessitate the presence of bends in the inlet duct. Even with the smallest practical duct bends, some pressure distribution will be caused by the bends.
6. In order to attain the best overall airplane performance it is often necessary for the inlet designer to compromise the inlet duct in order to allow for considerations of aircraft drag, weight, placement of equipment, etc.

7. In order to meet the engine specification pressure distribution limits, under all flight conditions, for any type of inlet, it would be necessary to resort to such measures as plenum chambers, duct screens, etc. These would result in lower thrust, higher specific fuel consumption, and an increase in airplane size and weight to keep the same design performance.

The engine operating line is closer to the stall line than other engines. This results in rather small stall margins and makes the engine extremely sensitive to any disturbance. To point this out there is one airplane which has flown with two different engines and has essentially the same performance capabilities with either engine. The JXX engine installation in this airplane has given stall problems which are an order of magnitude larger than the other engine.

Of all the airplanes in which the JXX is installed, the F-XXX, F-XXX, F-XXX, B-XX, FXXX, and AXXX, no airplanes are free of stalls and only one has stalls intermittently. The B-XX is currently undergoing an extensive flight test program to fix engine stalls. One airframer is currently initiating flight tests on the F-XXX airplane to fix engine stalls. Another fighter is awaiting its new inlet ducts before initiating extensive engine stall tests.

The F-XXX inlet duct has excellent pressure recovery and at least average pressure distribution when compared to other airplanes. While a new inlet duct has already been designed to alleviate the supersonic inlet stability problems it is not expected that this design will appreciably decrease the pressure distribution. This new inlet duct is currently being fitted to the #2 airplane.

Original full scale static inlet tests on the inlet duct showed extremely poor pressure distribution. Pressure distributions in the order of ± 10 to 15% were measured. The airframer immediately embarked on a program to fix this, and by modifications to a vane through the duct, were able to reduce the pressure distribution to approximately ± 5%. The Aircraft Lab told the F-XXX project office that this distribution is about as good as can be expected under static conditions. The airframer is currently engaged in an attempt to obtain better pressure distribution but little hope exists that it can be achieved without increasing the inlet total pressure loss, with a resultant decrease in thrust and increase in specific fuel consumption.

It is desired to point out here that the airframer has done a very competent job in the wind tunnel, static, and flight tests of the inlet duct.

The Air Force, of course, is interested in actual airplane performance and is not concerned with paper performance based on unrealistic assumptions. It is apparent to the Aircraft Lab that neither demanding that the inlet supply zero pressure distribution or demanding that the engine accept the maximum possible pressure distributions will result in the optimum aircraft performance. The optimum obviously lies somewhere inbetween these two extremes.

The Aircraft Lab is currently initiating a program to obtain from the engine manufacturers the effect of pressure distribution on thrust, fuel flow, and engine weight. This data is then to be turned over to the airframe manufacturers to estimate the effect of pressure distribution requirements on airplane installed thrust, airplane drag and weight. The aircraft performance can then be calculated and a pressure distribution can be determined which optimizes the airplane performance.

In summary then, it is the Aircraft Laboratory's opinion that:

1. The JXX engine is too sensitive to disturbances.
2. The present pressure distribution limits are unobtainable at all flight conditions by any practical inlet.
3. Pressure distribution limits should be set which optimize the airplane performance.

Extracts from:

1. ARDCM 80-1, 1959, Handbook of Instructions for Aircraft Designers
2. MIL-E-5007B, 1959 Military Specifications, Engines
   MIL-E-5008B, 1959 Military Specifications, Engines
   MIL-E-5009B, 1959 Military Specifications, Engines
   MIL-E-5009A Amendment I 1955

Appendix IX

SECT 7. ENGINE AIR INTAKE SYSTEM

7.1 GENERAL

The engine air intake power plant installation includes the necessary ducts, scoops, passages, chambers, etc., which obtain ambient air and supply this air to the engine for combustion of the fuel. Anti-icing and deicing provisions, antidust devices, and any other equipment employed in or near the intake ducts for the purpose of restricting, modulating, filtering, heating, or cooling the intake air are also considered part of this system.

7.2 DESIGN OBJECTIVES

The effect of aerodynamic design of the engine air intake system on turbojet and turboprop type engine performance is of considerably greater importance than for reciprocating engines. The optimum aerodynamic configuration of the air inlet and induction system ducting can be achieved only by exact analysis of the system requirements and parallel study and comparative wind tunnel analysis of alternate designs. The merits of duct and inlet configuration of different design and location depend primarily on the type of engine installation. The critical nature of duct and entrance configurations in regard to the effect of compressibility and normal energy losses at high Mach numbers makes evaluation of the engine air intake system by individual performance testing imperative. There are several approved methods available for computing the effect of the air induction system design on aircraft and engine performance. For this reason, no specific method is recommended here. Use any rational method of calculating performance. If the method selected has been published, forward a report which explains the method in detail to WADC for approval. Subsequently, forward a report describing the methods employed and the results obtained in the performance testing of the engine air intake system to WADC for approval. In the design or planning stage, give consideration to the location of the air inlet to insure that the selected position is in an area of satisfactory airflow patterns and boundary layer characteristics at all attitudes and conditions of operation for which the aircraft is designed. A short air induction system, consistent with good diffusion practice, is preferred. Where a choice must be made between a long tailpipe extension for the exhaust system and a long engine air intake system, the sacrifice of induction system performance must be accepted because of the larger penalty imposed on engine performance by tailpipe length, the high weight per unit area involved in limiting the inherent fire hazard of the tailpipe, and by inspection, maintenance, and replacement factors. Give special consideration to locating and positioning the air inlet in an area where there is little probability of entraining foreign particles thrown up by the wheels of the aircraft.

7.2.1 PRESSURE VARIATION

The air induction system total pressure profile at the engine front face has a direct relation to gas turbine engine operation as concerns compressor stall and surge. Total pressure variation from the mean should be as small as is possible with good inlet design. Radial total pressure variation does not affect engine compressor stall as much as does circumferential total pressure variation. Circumferential total pressure variation from the mean should not vary more than plus or minus five percent at all required flight operation altitudes, angles of attack, maneuvers, and speeds. Recent flight test data show that relatively wide pressure variation at a few points in the plane of the compressor face does not affect compressor stall as much as does medium pressure variation at a greater number of points. The size and location of these regions of variation of total pressure at the compressor front face appear to be the deciding factor in current inlet duct induced engine stall limits.

7.2.2 PRESSURE RECOVERY

A high average total pressure recovery at the engine front face is desirable so that opti-

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mum engine performance may be realized. Pressure recovery normally decreases with increasing aircraft Mach number. Design objectives for air inlet average total pressure recovery are as follows:

Mach	0 to 1	- 0.95
Mach	2	- 0.85
Mach	3	- 0.60

7.3 GENERAL DESIGN

7.3.1 CONSTRUCTION DESIGN

Make the inlet and system ducting of sufficient strength to withstand the maximum pressure depression encountered at maximum engine thrust with the aircraft in static condition. In addition, provide sufficient strength to withstand vibrations produced by airflow variations (which may exceed the strength required to withstand pressure differentials). Employ flush type riveting in the internal surfaces of all ducting in the system. Do not use construction components in the engine air intake system which may vibrate loose and enter the engine. If their use is unavoidable, provide safetying of each part. Submit all pertinent data and drawings of duct quick disconnects to WADC for approval prior to incorporation in the aircraft.

7.3.1.1 LOCATION

The air inlets and armament stores should both be located so that rocket and gunfire blasts or other effects will not enter the air inlets of gas turbine engines. The effect of sudden changes in inlet air temperature and pressure and subsequent compressor surge can be serious in gas turbine engine flight operation. See E.4-3.2.1.3 for location of rocket launchers and E.4-7.2.2 for information on compressor stall.

7.3.2 CONTROL

Airflow control by means of variable inlet spikes, plugs, wedges, bypass doors, or suck-in doors may be necessary on high-speed aircraft to supply engine airflow requirements over the complete range of operating conditions. See D.3-7.3.2.1 for design of the controls of these variable inlet components.

7.3.2.1 Variable Geometry Inlet Control

Design the variable geometry inlet control system to insure an accuracy of regulation consistent with the steady state and transient characteristics of the basic engine control. Make the reliability and fail-safe features of the inlet control compatible with those of the basic engine control. Submit sufficient data to WADC to permit an evaluation of the control system relative to a specific engine and aircraft installation.

7.3.2.1.1 Reliability. Use as a guide the requirements listed in this paragraph. Make the variable geometry inlet control the simplest and most reliable system which will provide the engine-aircraft combination with the specified performance and ease of operation. Design the inlet control system without special emergency features so that:

a. A failure during takeoff of any single functional part does not reduce the total thrust below 95 percent of military jet thrust on an NACA standard day plus 40°F. over the altitude range of sea level to 6,000 ft. altitude.

b. A failure of any single part does not result in the engine or airframe exceeding the structural operating limits to the extent that such failures cannot be prevented by simple corrective pilot action with a reasonable period of time.

c. Failure of any single part, when installed in the aircraft, shall not cause an abnormal operating condition such that aircraft controllability cannot be maintained by simple corrective pilot action. Incorporate only such manual and automatic safety features which have been demonstrated to be reliable and provide emergency operation under the failure conditions listed above. Incorporate no devices, in addition to those required above, for the purpose of protecting against the simultaneous failure of two control system parts, except where the first failure can cause the second.

MIL-E-5007B
22 JANUARY 1959
SUPERSEDING
MIL-E-5007A
27 JULY 1951

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET, GENERAL SPECIFICATION FOR

This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.

3.20.3 Inlet Air Pressure Variation. The estimated maximum radial and circumferential total pressure distortion limits which can be safely tolerated shall be specified in the model specification. In addition the estimated maximum radial and circumferential total pressure distortion limits which can be tolerated without adversely affecting rated engine performance shall also be specified. The estimated effect on engine performance of these distortions shall be specified in the model specification. These limits shall not include an area bounded by the duct walls and a line spaced therefrom by 1½ percent of the compressor tip diameter.

MIL-E-5008B
22 JANUARY 1959
SUPERSEDING
MIL-E-5008A
27 July 1951

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET, MODEL SPECIFICATION FOR (OUTLINE AND INSTRUCTIONS FOR PREPARATION)

This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.

3.20.3 *Inlet air pressure variation.* The estimated radial and circumferential inlet air total pressure distribution limits which can be safely tolerated shall be as shown on curve(s) .... (The contractor may show these limits in other than curve form.) The estimated effect of radial and circumferential total pressure variation on thrust, fuel flow, and air flow shall be as shown on curve(s)........ (At least 5 inlet distortion points which are to be demonstrated under 4.2.7.1.3 of MIL-E-5009 shall be specified.)

MIL-E-5009B
22 JANUARY 1959
SUPERSEDING
MIL-E-5009A
21 JULY 1951

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET, QUALIFICATION TESTS FOR

This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.

4.2.7 Altitude Tests.

4.2.7.1 Test Conditions.

4.2.7.1.1 General. An engine, not necessarily engine "A" shall be subjected to altitude tests which shall consist of operation and air starting checks at several selected thrust conditions around the operating limits envelope specified for the engine in the model specification, except that portions of these tests may be accomplished on separate engines at the discretion of the Using Service. The points covered on this envelope shall be for a standard hot atmosphere and a standard cold atmosphere as defined by tables II and III of MIL-STD-210, and the altitude rating points. The test points selected shall be the minimum necessary to demonstrate the engine operating and air starting limits envelope. Unless otherwise specified in the engine model specification, loading of the accessory drives will not be required during these tests. If a continuous duty ignition system is specified, it shall be in operation, with rated input voltage, at all times after a normal start sequence has been completed.

4.2.7.1.3 Inlet Air Pressure Distribution. For selected test points as specified in the model specification, the air total pressure distribution at the compressor inlet shall simulate conditions approximately equal to the maximum allowable percent and extent of variation of the total pressure pattern, specified in the model specification.

MIL-E-5009A
AMENDMENT-1
23 DECEMBER 1955

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET, QUALIFICATION TESTS FOR

This amendment forms a part of Military Specification MIL-E-5009A, dated 27 July 1951, and has been approved by the Department of Defense for use of the Departments of the Army, the Navy, and the Air Force.

*4.2.2.3.3 Altitude Tests.-

*4.2.2.3.3.1 Test Conditions.-

*4.2.2.3.3.1.1 General.- An engine, not necessarily engine "A," shall be subjected to Altitude tests, which shall consist of operation and air starting checks at several selected power conditions around the operating limits envelope specified for the engine in the model specification, except that portions of these tests may be accomplished on separate engines at the discretion of the Using Service. The points covered on this envelope shall be for a standard hot atmosphere, a standard cold atmosphere as defined in ANA Bulletin No. 421, and the altitude rating points. The test points selected shall be the minimum necessary to determine the engine operating and air starting limits envelope and shall be specified in the model specification.

*4.2.2.3.3.1.3 Inlet Air Pressure Distribution.- For selected test points as specified in the model specification, the air pressure distribution at the compressor inlet shall simulate conditions approximately equal to the maximum allowable percent and extent of variation of the pressure patterns specified in the model specification.

Typical Weapon System Engine and Inlet Interface Criteria

Appendix X

A. AIR VEHICLE SPECIFICATION (INITIAL)

3.12.1.2.1 ENGINE INLET DISTORTION SUITABILITY - The engine will operate satisfactorily within the compressor inlet distortion limits as specified in the ____ engine model specification.

3.12.5 AIR INDUCTION SYSTEM

3.12.5.1 DESCRIPTION - Air Inlets (one for each engine) shall be provided as specified in SPECIFICATION No. ________ (Propulsion Subsystem).

3.12.5.2 AIR INTAKES

3.12.5.2.1 AIR INTAKES (RECIPROCATING ENGINES) Not applicable.

3.12.5.2.2 AIR INTAKES (TURBOFAN ENGINES) The design of the intake inlet and duct shall be as specified in SPECIFICATION No. ______ (Propulsion Subsystems).

B. PROPULSION SUBSYSTEM SPECIFICATION (INITIAL)

3.8 ENGINE AIR INDUCTION SYSTEM - Each engine shall be provided with an induction system automatically modulated to provide high propulsion efficiency. The inlet shall be located so as to minimize ingestion of the boundary layer and angle of attack effects. The design of the intake inlet and duct shall positively prevent any erratic or adverse air flow distribution which would cause engine compressor stall or other engine malfunction at all normal operating conditions, altitudes, and attitudes including but not limited to take-off, approach, wave off, and aircraft stall conditions. The permissible circumferential and radial air pressure distribution at the engine face shall be within the limits specified in Engine Model Specification No. ____.

The inlet control system shall automatically maintain the total pressure recovery characteristics that result in optimum engine performance as necessary to meet the aircraft design mission requirements at all Mach altitude conditions.

In order to insure static and take-off engine/aircraft design performance, additional air inlet opening or openings may be provided.

C. ENGINE SPECIFICATION (INITIAL)

3.20.3 INLET AIR PRESSURE VARIATION - Revise this paragraph to read: "Engine performance shall not be affected by any circumferential and radial inlet air pressure distribution of up to $\pm 5\%$ of the average absolute total pressure except within 1/2 inch of the duct wall."

3.20.3.1 INLET AIR PRESSURE VARIATION DATA - Data from at least 5 distortion test points will be provided to the using service in the form of a report. The specific conditions tested shall be established in coordination with the weapons system contractor.

A. AIR VEHICLE SPECIFICATION (FINAL)

3.12.1.2.1 ENGINE INLET DISTORTION SUITABILITY - The engine will operate satisfactorily within the compressor inlet distortion limits as specified in the ___ engine model specification.

3.12.5 AIR INDUCTION SYSTEM

3.12.5.1 DESCRIPTION - Each engine shall be provided with an induction system in accordance with SPECIFICATION No. _______ which shall be automatically modulated to provide high propulsion efficiency. The inlet shall be located so as to minimize ingestion of the boundary layer and angle of attack effects. The design of the intake inlet and duct shall positively prevent any erratic or adverse air flow distribution which would cause engine compressor stall or other engine malfunction at all normal operating conditions, altitudes, and attitudes including but not limited to take-off, approach, wave off, and aircraft stall conditions. The inlet and its subsonic ducting shall be designed to provide circumferential and radial air pressure distribution at the engine face within ±5% of the above absolute total pressure, except within 1/2 inch of the duct wall. Pressure distribution characteristics of the inlet will be determined from test made during the development program.

The inlet control system automatically maintain the total pressur. recovery characteristics that result in optimum engine performance as necessary to meet the aircraft design mission requirements at all Mach altitude conditions.

In order to insure static and take-off engine/aircraft design performance, additional air inlet opening or openings may be provided.

B. PROPULSION SUBSYSTEM SPECIFICATION (FINAL)

3.8 ENGINE AIR INDUCTION SYSTEM - Each engine shall be provided with an induction system automatically modulated to provide high propulsion efficiency. The inlet shall be located so as to minimize ingestion of the boundary layer and angle of attack effects. The design of the intake inlet and duct shall positively prevent any erratic or adverse air flow distribution which would cause engine compressor stall or other engine malfunction at all normal operating conditions, altitudes, and attitudes including but not limited to take-off, approach, wave off, and aircraft stall conditions. The inlet and its subsonic ducting shall be designed to provide circumferential and radial air pressure distribution at the engine face within ±5% of the average absolute total pressure, except within 1/2 inch of the duct wall. Pressure distribution characteristics of the inlet will be determined from test made during the development program.

The inlet control system shall automatically maintain the total pressure recovery characteristics that result in optimum engine performance as necessary to meet the aircraft design mission requirements at all Mach altitude conditions.

In order to insure static and take-off engine/aircraft design performance, additional air inlet opening or openings may be provided.

C. ENGINE SPECIFICATION (FINAL)

3.20.3 INLET AIR PRESSURE VARIATION - Revise this paragraph to read: "The engine shall tolerate, without adverse effect on operation, any radial and circumferential inlet air flow maldistribution up to ±5% of the average absolute total pressure at the engine inlet face. The effect of flow patterns exhibiting distribution non-uniformity in excess of ±5% can be indicated only by engine and/or flight testing. Patterns to be tested should be coordinated with the engine contractor as indicated in paragraph 3.20.3.1 below. The pressure variations existing within 1/2 inch of the inlet duct wall are excluded from consideration. Within the limits of ±5% specified above, engine rated performance shall not be affected except by the level of average absolute total pressure as indicated in paragraph 3.4".

3.20.3.1 INLET AIR PRESSURE VARIATION DATA - Data from 5 distortion test points will be provided to the using service in the form of a report. The specific conditions tested shall be established in coordination with the weapons system contractor prior to initiation of qualification tests.

3.20.3.2 INLET AIR PRESSURE VARIATION CORRELATION FACTOR - The estimated maximum total inlet air pressure distortion capability of the engine without inlet pressure fluctuations is shown in Curve T-1574, sheets 135 through 139 in terms of an Inlet Distortion Correlation Factor. The definition of the Correlation Factor and the limitations on its use are given in Section XI of the Performance Calculation Section.

4.3 QUALIFICATION TESTS - Revise this paragraph to read: "Qualification of the _____ engine shall be predicted on satisfactory completion of those portions of the _____ engine qualification test specified below and satisfactory completion of tests on the _____ engine in accordance with MIL-E-5009 as modified below and approval of the test report by the using service. The specific test points required for the altitude qualification test shall be shown on Curve T-1574 sheet 113.

4.3A The following qualification tests of MIL-E-5009 shall not be conducted on the _____ engine since the _____ features and/or components listed are substantially identical to features and components which are required to be qualified for the ____ engine or are in accordance with approved changes to the _______.

4.3B The complete qualification test for the _____ engine, shall be conducted in accordance with MIL-E-5009B, as modified in the following paragraphs:

4.3B.22(4.2.7.1.3 of MIL-E-5009) INLET AIR PRESSURE DISTRIBUTION - Inlet air pressure distribution tests shall not be required as part of the qualification. (See para. 3.20.3.1)

Inlet Development Schedule and Total Aerodynamic Test Hours

Appendix XI

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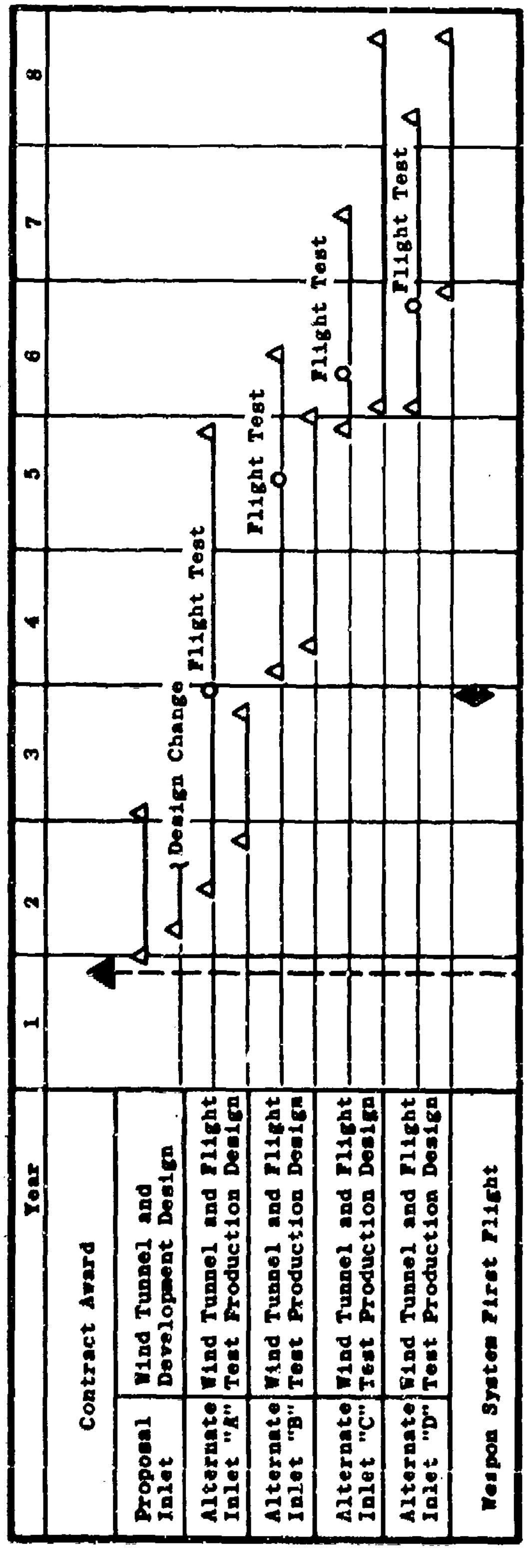
INLET DEVELOPMENT SCHEDULE



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TOTAL AERODYNAMIC TEST HOURS

	FACILITY	-1	0	+1	+2	+3	+4	+5	+6	+7	TOTAL AT 31 DEC +8
GOVERNMENT	AEDC	0	0	979.4	1,175.00	885.0	424.0	1,181.00	727.40	1,416.80	6,778.60
	AMES	41	184	2,630.0	1,795.00	318.0	0	763.00	803.00	254.00	4,421.00
	LANGLEY	394	0	2,715.0	2,487.00	1,727.0	1,055.0	1,001.00	607.00	300.00	10,286.00
	LEWIS	0	0	0	97.00	0	0	0	0	0	[illegible]
	OAL	0	0	366.5	0	0	0	0	0	0	[illegible]
	TOTAL	435	184	4,323.9	5,554.00	2,930.0	1,479.0	2,945.00	2,137.40	1,970.80	21,959.10
PRIVATE	CORNELL	0	369	1,732.9	1,063.50	0	263.0	672.25	86.50	130.00	4,317.15
	GD LSWT	738	481	825.5	833.00	129.5	430.0	1,011.00	100.00	114.00	4,662.00
	GD 4	924	298	506.5	160.70	437.0	0	1,233.70	647.90	552.40	4,760.20
	LTV	0	0	0	134.00	0	0	0	0	0	134.00
	UAC	0	0	0	0	0	0	462.00	0	0	462.00
	GRUMMAN	398	1,098	650.0	0	0	0	0	0	0	2,146.00
	TOTAL	2,060	2,246	3,714.9	2,191.90	566.5	693.0	3,378.95	834.40	796.40	16,481.35
	GRAND TOTAL	2,395	2,430	8,038.8	7,745.20	3,496.5	2,172.0	6,323.95	2,971.80	2,767.20	38,440.45
	CUM. TOTAL	2,495	4,925*	12,963.8	20,709.00**	24,205.5	26,377.5	32,701.45	35,673.25	38,440.25	38,440.25

*At Contract Award, Test Hours = 4,925
**At First Flight, Test Hours = 20,587

Note: Tabulated wind tunnel test hours include all types of aerodynamic testing. While inlet test hours are not identified, the trends and timing of test hours (including the inlet) relative to first flight can be observed.

Hq RTD Letter subject Engine-Inlet Compatibility dated 21 Jun 1966

Appendix XII

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS RESEARCH AND TECHNOLOGY DIVISION (AFSC)
BOLLING AIR FORCE BASE, D.C. 20332

RTTP 21 JUN 1966

Engine-Inlet Compatibility

AFAPL (APG) SEG (SEG) AFFDL (FDG)

1. In view of the current problems encountered in the F-111 development in this area and the requirement to insure adequate engine-inlet compatibility in future systems such as the FX, US/FRG V/STOL Fighter and AMSA, it is imperative that RTD take action now to insure resolution of this critical problem area.

2. The SAB Ad Hoc Committee on Air Breathing Propulsion recommended that the Air Force establish a compressor distortion criteria prediction method and state this along with a distortion index in an appropriate military specification. The Deputy Assistant Secretary for Research and Development has informally stated the desire for an RTD plan for implementing the SAB recommendation and has provided informal comments and guidance.

3. On 13 June 1966 at AFFDL, representatives of SEG, AFAPL, AFFDL and HQ RTD discussed the preparation of an RTD plan for implementing the SAB recommendations. As agreed upon at this meeting, it is requested that SEG assume lead responsibility for the establishment of an ad hoc group for the preparation of a plan. As discussed, the plan will cover current status of appropriate programs of both the Air Force and other government agencies, and augmentation and emphasis needed in critical areas to meet the requirements of the next generation of systems such as the US/FRG V/STOL Fighter, AMSA, and future follow-on systems. This plan should present a coordinated, unified technical approach to the resolution of the engine-inlet matching. Representatives of the Aeromechanics Division and the Propulsion and Power Division of HQ RTD will be at Wright-Patterson AFB during the week of 27 June 1966 to review the plan.

4. It is requested that you give the formulation of this plan your personal attention and support.

M. C. Demler
M. C. DEMLER
Major General, USAF
Commander

FORGING MILITARY SPACEPOWER

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RTD Integration and Management Plan for Aircraft-Propulsion Compatibility, September 1966

Appendix XIII

RTD

INTEGRATION AND MANAGEMENT

PLAN

FOR

AIRCRAFT - PROPULSION COMPATIBILITY

SEPTEMBER 1966

TABLE OF CONTENTS

FOREWORD

The correspondence following this foreword is the directive authority for the preparation of this RTD Integration and Management Plan covering the area of Airframe-Propulsion Compatibility. In view of the past history of inlet-engine-nozzle matching and problems with current systems development, this effort is considered to be of vital importance. As operational speeds increase and configurations become more complex, the problem intensifies. Unless a timely program is immediately initiated to define, solve, and document the problems of airframe propulsion compatibility, future systems will be severely penalized in performance.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS RESEARCH AND TECHNOLOGY DIVISION (AFSC)
BOLLING AIR FORCE BASE, D.C. 20332

REPLY TO ATTN OF: RTTP

21 JUN 1966

SUBJECT: Engine-Inlet Compatibility

TO: ✓AFAPL (APG) SEG (SEG) AFFDL (FDG)

1. In view of the current problems encountered in the F-111 development in this area and the requirement to insure adequate engine-inlet compatibility in future systems such as the FX, US/FRG V/STOL Fighter and AMSA, it is imperative that RTD take action now to insure resolution of this critical problem area.

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M. C. Demler
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Major General, USAF
Commander

FORGING MILITARY SPACEPOWER

SECURITY

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AIRFRAME PROPULSION COMPATIBILITY PROGRAM

I. OBJECTIVE

The ultimate objective is to develop criteria which will insure integrated airframe and propulsion system compatibility. Inherent therein is the development of data which will allow overall weapon system performance trade-offs to be made with respect to the degree of airframe and propulsion compatibility.

II. RATIONALE

Background - National experience during the past ten to fifteen years in the development of sophisticated airborne weapon systems has uncovered a problem area that is increasing in severity. This problem area is that of airframe-propulsion system compatibility both steady state and transient and has been emphasized recently by the problems encountered during development testing of new aircraft. The problem of airframe-propulsion system compatibility resolves itself not only into one of airflow distortion but the compromises and trade-offs which are involved in determining the degree of compatibility required to satisfy overall weapon system performance. This includes the definition of the critical types of distortion, steady state and transient, and the ability of adjacent components to tolerate this distortion and to perform satisfactorily throughout the anticipated flight envelope. For example, the engine must operate satisfactorily over the entire flight envelope irrespective of the amount of airflow distortion presented to the compressor face by the inlet exit; or the inlet must supply an undistorted airflow profile to the engine throughout the flight regime. There is an optimum compromise between these two extremes and it is the purpose of this project to provide criteria which will allow the prediction, determination and attainment of this optimum compromise and its relationship to overall system performance degradation.

Scope - This program will be limited to a consideration of gas turbine powered aircraft with speeds not in excess of M 4.0. There are three general classes of vehicles which will be included in the study. These are (a) long duration cruise type vehicles, (b) highly maneuverable type vehicles, and (c) V/STOL type vehicles.

Initial effort will concentrate on inlet-engine matching since there are existing programs underway for engine-nozzle compatibility. The first years of effort will be accomplished within existing manpower and funds. A working group, as described in Part IV, will support the system engineering offices by providing technical assistance and consultation on airframe-propulsion compatibility development and test programs. The working group will also review the analysis and test results to insure satisfactory performance and compatibility of the overall system. The technical advisory panel will be available for consultation and review of the overall program.

Approach - While there has been considerable effort accomplished to date in the engine-inlet compatibility area, it has been predominantely steady state, relatively isolated, and not correlated to provide commonality of solutions.

The overall approach will be to provide as much information and preliminary criteria as possible to systems engineers and managers on a periodic basis ultimately striving for a hard set of specifications completely satisfying the stated objective.

A Working Group, composed of personnel from AFAPL, AFFDL, and SEG, will be responsible for this effort. Phase I will complete discussions with advanced SPO's to determine what current criteria are being used, and when better criteria would be required to assist these programs. The Working Group will continue detailed discussions with industry and other agencies to further review the various approaches that have been and are being taken to provide inlet-engine compatiblity. Much of what is being done today is being done on a piecemeal basis looking for a specific solution to a specific problem. The group will analyze all available data to arrive at a preliminary set of criteria. Voids will be identified in fundamental understanding, performance limits under distorted flow conditions, prediction techniques, test instrumentation and test criteria. This will verify the requirements for and adequacy of the contractural activity planned herein for Phase II. Interdependent RTD Laboratory programs in aerodynamics and propulsion will be initiated and time phased to provide four distinct inputs to SEG and the System Program Offices as shown by the work schedule and technical description in Part III.

It is recognized that the complete program could be extremely expensive. In order to reach the program objective, planning and programming must be carefully done to attain efficiency in use of resources. Maximum use will be made of existing ground and flight test data as well as scheduled future flight tests so that the expense of flight testing will be minimized. No generalized flight tests are now planned for this program.

The manpower listed in Part IV (Management) is available and it is assumed that costs listed in Part V (Costs) will be programmed through normal channels and be available early in FY 68.

III. TECHNICAL INTEGRATION

The most important function of the Working Group is to identify airframe/propulsion compatiblity data and translate these into usable subsystems criteria. Airframe/propulsion compatibility criteria will be established to permit the determination of the degree of propulsion system performance degradation (thrust and sfc) for airframe inlet, engine and exhaust nozzle configurations. The causes and effects of various degrees of such degradation on specific weapon system mission performance envelopes will be established. Corrective design features and methods pertinent to planned and in-development weapon systems will be obtained to permit maximization of mission performance capability.

The criteria to be developed are:

1. Conceptual, definition and acquisition phase statements of work requirements including data, testing and reporting.

2. Data, test requirements and reports requirements for wind-tunnel airframe models and demonstrator engines.

3. Instrumentation requirements for airframe and propulsion systems testing.

4. Quantified evaluation processes for Source Selection actions.

5. Airframe and propulsion system specifications.

Firm criteria will be available at the end of CY 70 with interim criteria developed during this program being released at three major intermediate milestones. The dates for these milestones are shown on the schedule following in this part and the outputs anticipated are:

1. Preliminary inlet and engine design data, subsystem performance analysis techniques, and test data acquisition procedures will be generated to arrive at a set of compatible subsystem interface and component design requirements for designing and evaluating aerospace vehicles.

2. Establish upgraded inlet-engine performance and compatibility criteria which provide initial quantitative data for systems definition, design, test, acquisition.

3. Establish advanced interim vehicle subsystem criteria and interface requirements from the component data findings obtained from the technology program efforts, the state-of-the-art review, and data acquired from contractors developing advanced weapon systems.

4. Establish firm specifications covering vehicle subsystem design criteria and interface requirements to satisfy all contractual phases relating to the design, development, test, and acquisition of propulsion systems and related hardware.

The criteria developed and refined at the major milestone dates will be integrated into the general requirements and specification documents by the Systems Engineering Group. Reports of findings and criteria will be published for use by the System Program Offices in the Conceptual, Definition and Acquisition phases of Weapon System development and by the RTD Laboratories in establishing Advanced Technology requirements. Periodic meetings with the SPO's, SEG, RTD Laboratories, industry and other Government agencies will permit the integration of all available data and testing techniques into the planned reports and provide for general uprating of the industry-Government understanding and application of the Airframe-Propulsion System Compatibility criteria. Assistance will be provided to the Systems Program Offices for establishment of contractual work requirements, contractor interface responsibilities, source selection processes and development test programs and analyses that are conducted by the weapon systems contractors.

The source of data from which the above criteria will be established consists of the following:

Technical Review and Correlation of System Project Office experience, Industry experience, Army, Navy, FAA, and NASA Programs;

Laboratory programs in Airframe/Inlet Aerodynamics, Inlet Diffuser Design Studies, Engine Response to Pressure and Temperature Distortion, Inlet-Engine Dynamic Coupling;

Continuing Review of System Progress and Joint Flight Test with approved Advanced Systems.

The technical review and data correlation will also be important in planning and assessing the adequacy of the contractual program. Descriptions of each of the planned work elements of the Laboratory programs follow the schedule chart and are keyed to it by letter.

There are at this time no flight tests planned of a general nature. Data currently being obtained and planned from the F-111, B70, and other programs will be studied and correlated with ground test data. As new systems such as AMSA, US/FRG, or FX reach the flight test planning stage, specific test plans for airframe-propulsion system compatiblity can be incorporated. These test programs will provide data required for specific system test objectives and, in addition, will provide data which can be correlated with results from other test programs to formulate improved airframe-propulsion compatibility design criteria.

Appendix I lists those current efforts which are generally applicable to the airframe-Propulsion compatibility program.

Appendix II hereto is a list of potential contributors that may be interviewed during Phase I. The current status of the inlet-engine matching work for the F-111, XB70, C5A, AMSA, US/FRG, and FX has been summarized in Appendix III.

AIRFRAME-PROPULSION COMPATIBILITY PROGRAM SCHEDULE

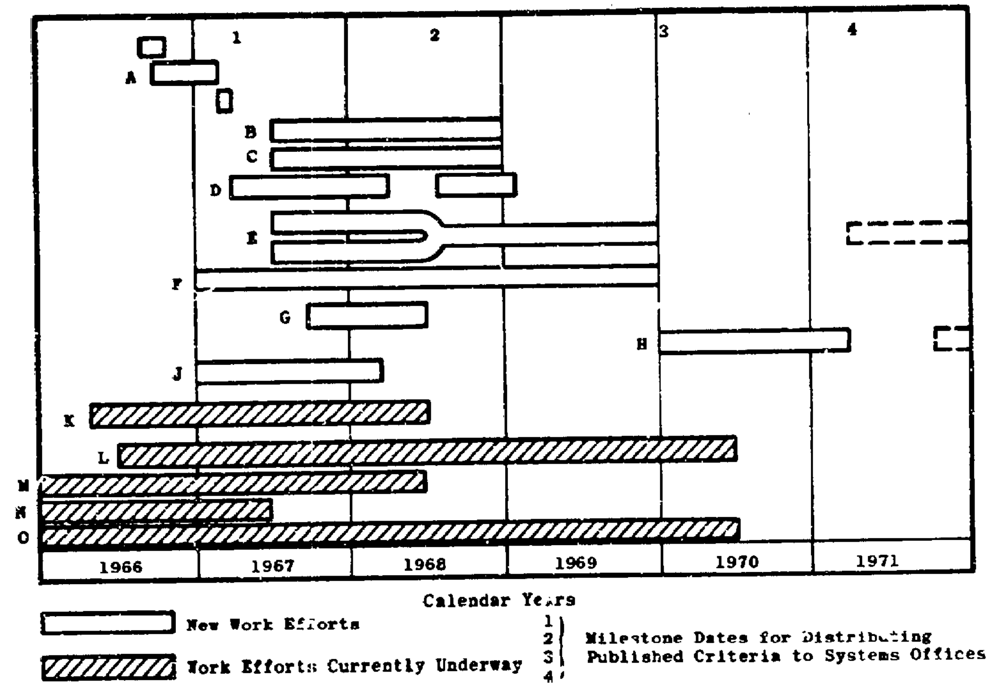
A. State-of-the-Art Review

B. Engine Pressure Distortion Effects
C. Engine Temperature Distortion Effects
D. Airframe-Inlet Interactions

E. Inlet Design Criteria

F. Engine Distortion Sensing Dynamics
G. Engine-Inlet Interactions - Generalized
H. Engine-Inlet Interactions - Systems Oriented
J. Ground-Flight Instrumentation Standardization

K. Advanced System Planning
L. Airframe-Nozzle Integration
M. Engine Nozzle Interactions
N. Duct Burning Fan-Inlet Interaction
O. Fundamental Compressor Flow Stability



Schedule Code A

STATE-OF-THE-ART REVIEW (New Program)

The in-house review of planned advanced systems and engine compatibility inlet design information, performance data, and flow distortion criteria will be continued and expanded to assess the current state-of-the-art for turbojet, turbofan, and VTOL applications. This investigation will culminate in a document for Government and industrial use which outlines basic design and evaluation criteria.

a. Briefings by various groups will be used to augment search for available information. Activities of other agencies such as NASA, Navy, and FAA will be reviewed.

b. Small contracts may be given to non-profit organizations including universities for technical advisors to assist in the assessment of information acquired.

c. Other small contracts could be let to assemble and review information in certain critical areas.

d. Output will also serve as the basic foundation for other efforts within the total inlet-engine program.

e. The Ad Hoc Working Group and Technical Advisory Panel will also provide advice to advanced systems through SEG.

f. Time Phasing

(1) Initiated on "Go-Ahead (G-A)" date.

(2) Completed in 7 months.

g. Inlet-engine review accomplished by the Working Group.

Schedule Code B

PRESSURE DISTORTION EFFECTS

Objective: To determine the relative importance of the various parameters derived from pressure measurements at the engine face in terms of compressor stability margin and performance. The approach will include re-examination of existing data in addition to compressor rig testing to arrive at a sound base from which to evaluate distortion effects.

Scope: This program will include the effects of distortion on a broad base of compressor designs including dual spool, variable geometry and various blade designs and will examine the many distortion parameters currently used (size, shape, location, magnitude, frequency, turbulence, swirl, etc) in the attempt to establish more meaningful parameters.

Output: To provide the guide lines to evaluate the steady state and dynamic compatibility of the propulsion system from diffuser exit distortion contours and establish trade-offs between performance and stability margin. Data resulting from this program will be applicable toward determining the weapon system performance trade-offs and the constraints that apply to the system design.

Time Phasing:

a. Initiated 6 months after program go-ahead.
b. Program to be completed two years.

Responsibility: AFAPL

Schedule Code C

TEMPERATURE DISTORTION EFFECTS

Objective: To establish the influence of hot gas ingestion on performance and engine stability margin by testing lift and lift cruise compressors and engines with temperature distortion including the rate of change of temperature.

Scope: This program will test lift and lift cruise compressors and/or engines with temperature and pressure distortion.

Output: To provide the guide lines to evaluate the effects of given temperature distortion in terms of engine flow stability margin and engine performance trades. The results of this program will be equally valuable in establishing the stability requirements and the performance trades during a weapon exhaust ingestion and exhaust reingestion due to thrust reversing. The data resulting from this program can be utilized as a basic tool to determine weapon system performance trades and design contraints.

Time Phasing:
a. Initiated 6 months after go-ahead.
b. Program to be completed in one year.

Responsibility: AFAPL

Schedule Code D

AIRFRAME-INLET INTERACTION (New Program)

Objective: To determine some of the most important effects of inlet placement on induction system performance and compressor face flow field distortion.

Scope:

a. For each of generic classes of vehicles such as:

(1) Cruise - Strike - Reconnaissance

(2) Tactical - Intercept - Interdiction

(3) V/STOL

(4) Transport - Logistics

b. Done in two iterations to provide data on inlet-vehicle integration.

c. For representative vehicle configurations, using different types of inlets with subsonic diffusers the distortion at the engine face for a common diffuser will be related to placement and integration on the vehicle to determine favorable locations.

d. For the VTOL engine inlets, tests will be performed with gas generators to determine the placement on the VTOL vehicles where minimum hot gas ingestion or thermal gradients exist.

Output: This effort to generally define inlet-airframe integration and define what types of flow fields must be simulated in inlet tests. Preliminary and final inlet placement data would provide information applicable to trade-off studies of system performance.

Time Phasing:

a. Initiated 6 months after go-ahead.

b. Basic program continues for one year.

c. Systems oriented effort initiated 21 months after go-ahead.

Responsibility: AFFDL with SEG input to second phase.

Schedule Code E

SUPERSONIC INLET DEVELOPMENT (New Program)

Objective: Object will be to develop configurations with a minimum of flow separation and distortion at various flight conditions, back pressures, and angles of attack or yaw. Development with objective of low distortion (especially of the critical type as defined by the engine development program) but high performance in a vehicle environment.

Scope:

a. For each of the generic classes of vehicles:

(1) Cruise - Strike - Reconnaissance

(2) Tactical - Intercept

(3) VTOL - Supersonic Mission Profile

b. Lines of the supersonic diffusers of several different types will be analyzed and tested:

(1) Axisymmetric
(2) 2-D
(3) Three-Dimensional

} External Compression / Internal-External Compression

c. Items to be accomplished for the supersonic portions of the diffusers for the different systems are:

(1) Contour

(2) Amount of variable geometry

(3) Bleed and bypass systems

(4) Define airflow characteristics

(5) Define performance and complete documentation of distortion delivered to the subsonic diffuser.

d. Extensive testing of a family of inlet configurations for each class of vehicles will be conducted over the operating Mach Number range.

Output: This program will provide candidate supersonic diffuser configurations to be checked out in the airframe interaction tests and further developed in the subsonic-supersonic diffuser program. By being systems oriented to the generic classes of vehicles, the relationship (for various inlets) of high compatibility to vehicle systems performance parameters such as weight, volume, and drag will be established so that system compromises can be performed.

Time Phasing: a. Initiated 9 months after go-ahead.

b. Output to systems-oriented-airframe interaction program. 12 Months after initiation.

c. Effort completed 18 months after initiation.

Responsibility: AFFDL.

Schedule Code E

SUBSONIC DIFFUSER (New Program)

Objective: The objective of this semi-empirical subsonic diffuser investigation is to determine the effect of diffuser geometry and subsystem design and operation on inlet performance and compressor face distortion.

Scope:

a. Effect of high dP/dx on performance and distortion.

b. Effect of ribbed diffuser designs on performance and distortion levels.

c. Effect of proximity and peripheral distribution of bypass and blow-in doors on performance and distortion.

d. Determine limitations on rapid changes in cross-sectional shapes in terms of performance and distortion.

e. Establish limits on turning angles and equivalent conical angles.

f. Designs related to missions defined for future aircraft by SEG in iterated program.

g. Investigate distortion correcting devices.

Output: Information on items a through g above will be provided to systems designers for use in configuration definition and trade-off studies. Additional information on engine face distortion and flow characteristics will be provided to the parallel engine distortion tolerance program. Diffuser configurations will be defined for use in the inlet-diffuser program to follow.

Time Phasing:

a. 15 month basic program initiated 9 months after go-ahead.

b. 9 month "systems-oriented" phase initiated at close of basic program.

Responsibility: AFFDL

Schedule Code E

INLET-DIFFUSER TESTS (New Program)

Objective: To couple results from the supersonic inlet and subsonic diffuser efforts as well as the SEG systems integration program. Combinations of the designs for systems applications will be investigated and wind-tunnel tested in relatively large scale to determine the most important inputs to steady state inlet performance and compressor face flow distortion.

Scope:
a. Parallel programs will be accomplished for short range, long range, and VTOL applications.

b. Key combinations of bleed, bypass, angle of attack, lip design, internal dP/dx to be tested for representative inlet types with adequate simulation of vehicle flow field. Performance and distortion data will be correlated with analysis.

Output: Output in terms of inlet performance and engine face distortion data will be given to the engine development programs and systems designers for use in configuration definition and trade-off studies. Most promising combinations will be incorporated in tests with advanced engines being developed with subsequent refinements for compatibility.

Time Phasing:
a. Primary 15 month program initiated 27 months after go-ahead date.

b. Refinement program (9 months) initiated as required during or after inlet-engine tests.

Responsibility: AFFDL

Schedule Code F

DISTORTION SENSING SYSTEM

Objective:	To determine the sensor, signature, control mode, and actuation mechanism requirements to maintain engine stability by direct indication of distortion level or by anticipation of a distortion level.
Scope:	To develope an engine control scheme to maintain turbine engine operation at specific points in the flight envelope where an abnormal level of non-uniform inlet flow and to establish the performance trades peculiar to such a system.
Output:	This program will result in flight worthy hardware to demonstrate stable engine operation during adverse flow conditions.
Time Phasing:	a. Initiated 1 January 1967. b. Program to be completed in 3 years.
Responsibility:	AFAPL

Schedule Code G - H

INLET-ENGINE TEST

Objective: To determine the effect of inlet-engine coupling on Airframe-Propulsion-Compatibility and to develop an integrated control system. Preliminary definition of inlet-engine compatibility will be obtained by an early wind tunnel test program in which a currently available engine will be tested with a simple inlet configuration. Important inlet operational variables known to affect flow distortion and engine operation will be investigated. Other interaction phenomena will be identified. Combinations of several inlet design types with the most advanced engines available will be investigated (for long range, short range, VTOL missions) in large wind tunnel facilities to explore in detail the interface problem and the dynamic interaction of inlet and engine. Careful analysis of results will be used in inlet and engine design iterations and, after final wind tunnel tests, will be used to establish criteria for design integration of airframe-inlet and engine in future aircraft defined by SEG systems integration studies.

Scope: Inlets investigated in the final efforts will test important combinations of placement, bleed system operation, bypass operation, and integrated control system.

Output: Information will be sufficiently general to assure flight vehicle development which is free from serious inlet-engine compatibility problems during development. To be given to SEG for development of detailed specification criteria for advanced systems. Also given to industry as airframe-propulsion system compatibility criteria for use in system design and trade-off studies.

Time Phasing:

a. Preliminary compatibility definition test program (12 month program with 3 months testing) initiated 15 months after go-ahead.

b. Inlet test with advanced engine (15 months program) initiated 39 months after go-ahead.

c. Refined inlet and engine tests (9 month program) after completion of inlet modifications.

Responsibility: AFFDL and AFAPL.

Schedule Code J

GROUND AND FLIGHT INSTRUMENTATION STANDARDIZATION

(New Program)

Analytical investigations will be conducted which are directed toward the development of a standardized instrumentation package and data reduction techniques to define inlet performance, the source of distortion, and determine the effect of nonuniform flow characteristics on propulsion system performance during wind tunnel and flight testing.

Some considerations of the analytical investigation should include the inlet and engine, type, placement, and response characteristics of the steady state and transient instrumentation and use of instrumentation to obtain a correlation between windtunnel testing and flight testing.

ADVANCED SYSTEM PLANNING

(Currently Planned Programs)

The Systems Engineering Group and the Aeronautical Systems Division continuously plan and evaluate advanced weapon systems. The Working Group working with the ASD Directorate for Advanced Systems planning will integrate these planned weapon system configurations and mission performance characteristics into the Airframe/Engine Compatibility Analyses. Basic technical data on the causes and effects of distortion will be developed for each major subsystem (airframe-inlet, engine, exhaust system) utilizing the planning data to assure that criteria are developed for realistic weapon system requirements. The criteria will be established in such a manner that effective extrapolation can be accomplished and that overall weapon system performance and final configuration (including size and weight) can be optimized by trade-offs between weapon system performance requirements, configuration, and the propulsion system and related inlet and exhaust system performance degradation effects.

The distortion criteria, their effects on subsystem performance and weapon systems performance and configuration will be utilized by ASD to permit more effective planning and evaluation of future weapon systems. Continual Working Group coordination will be accomplished with the SPO's such that the criteria and other data developed can be factored into the in-development weapon systems if mission performance capability improvements are desired. This coordination will provide the integration of the development test results from the weapon system in acquisition into the Working Group's analyses of distortion and its effects to permit an updating and improvement of the compatibility criteria.

By mid-1968, a series of representative vehicles will have been defined by ASD for those missions anticipated in the 1970 - 75 time period. This information will be used by the Working Group to orient the airframe-inlet, inlet design and engine distortion sensing technology programs being conducted by the RTD Laboratories toward the most probable configurations of near weapon systems.

AIRFRAME-EXHAUST NOZZLE

(Currently Defined Program)

Airframe-Exhaust Nozzle Integration

To develop design procedures to be used in the optimization of flight vehicle performance by proper integration of airframe and exhaust nozzle system. See Appendix I, Project 1476.

Analytical Investigation

Analytical study of nozzle flow field including internal mixing flow and effects of external flow on integrated nozzle performance. See Appendix I, Task 147601.

Integrated Nozzle Testing Techniques

To develop wind tunnel testing techniques, support equipment, instrumentation, and facility modifications for integrated exhaust nozzle systems. See Appendix I, Task 147602.

Airframe-Nozzle Testing

Experimental determination of integrated nozzle performance and correlation with analytical solution for a matrix of design data - applicable to advanced systems. See Appendix I, Task 147603.

AF 33(615)-2698

GENERAL ELECTRIC

Mathematical Modeling of Inlet/Engine Systems

OBJECTIVE: To develop the modeling techniques that will fully describe the dynamic operating characteristics of a duct burning turbofan engine coupled with an inlet over a mission profile covering Mach 3 operation at high altitudes and Mach 1.2 dash at low altitudes. This program will be completed June 1967.

AF 33(615)-3128

Exploratory Research Program for Turbo-propulsion Exhaust Systems

OBJECTIVE:

1. To develop comprehensive mathematical models for the design analysis of advanced exhaust nozzle configurations.

2. To define various exhaust nozzle configurations with known performance characteristics to meet the flexibility requirements of advanced propulsion systems.

3. To analytically and experimentally investigate the cooling design technology and perform mechanical design studies necessary for advanced exhaust systems. This program will be completed in June 1968.

AF 33(615)-3537

CORNELL AERONAUTICAL LABORATORY

Analytical and Experimental Investigation of Rotating Stall Phenomena in Turbine Engine Compressors

OBJECTIVE: To formulate a theory leading to the prediction of the inception, and the characteristics at onset, of rotating stall and thus to provide input parameters which will enable implementation of a control mode to maintain an adequate stall margin but with significant improvements in turbojet-engine performance and efficiency. This program is expected to be completed by June 1970 and ready to be integrated with a propulsion system two years later.

AF 33 (657)-9674	Continental
AF 33 (657)-16626	Allison - Rolls Royce
AF 33 (657)-15785	General Electric
AF 33 (657)-15786	Pratt & Whitney
AF 33 (657)-15787	Curtiss - Wright
AF 33 (657)-10592	General Electric

These engine demonstrator programs include distortion testing to establish stability margins and the effects of pressure distortion on engine performance.

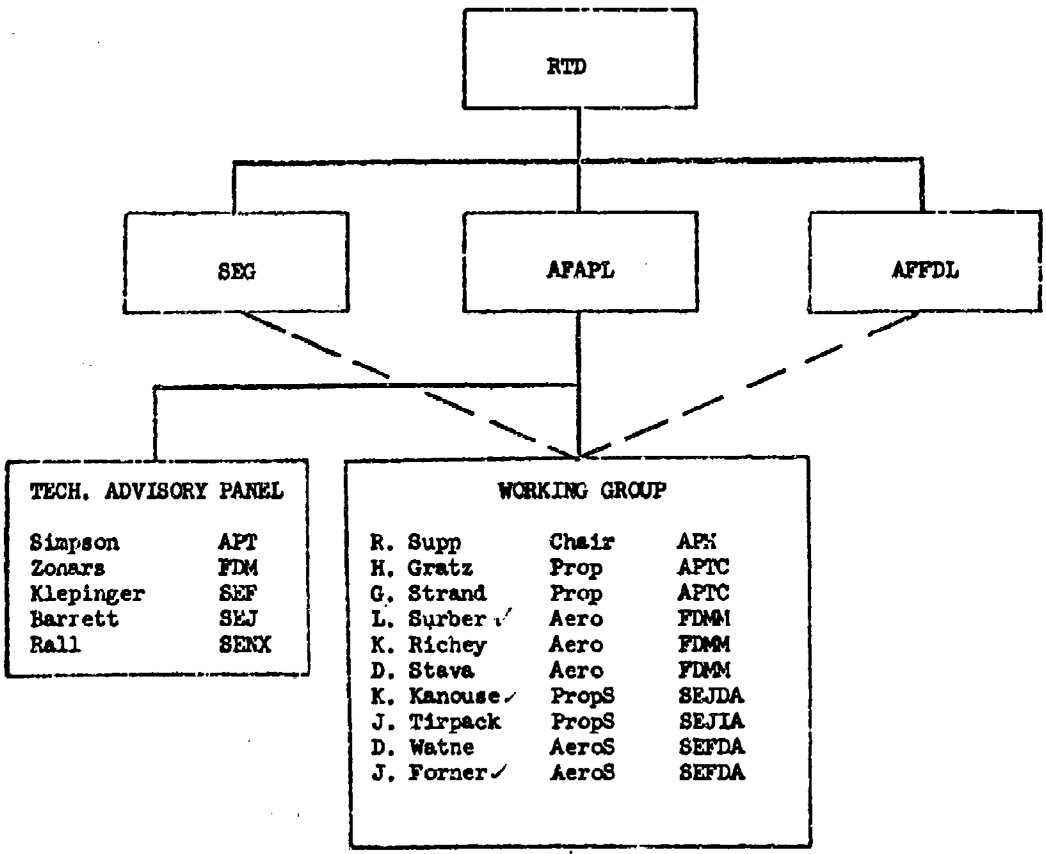
AF 33 (657)-3249	GASL
AF 33 (657)-3286	United Aircraft
NASI - 4589	Garrett

These programs to develop the blade designs for supersonic compressors include the analysis of the effects of non uniform supersonic flow at the compressor face. These contracts will be completed in February 1967.

PART IV

MANAGEMENT CHART

AIRFRAME - PROPULSION COMPATIBILITY PROGRAM



PART V

COSTS

The following fund requirements are preliminary and are based on the program as currently shown in the Part III Schedule. This program will be reviewed for adequacy after the Phase I state-of-the-art review which should occur about March 1967.

	67*	68	69	70	71
State of the Art Review	.1				
Engine Pressure Distortion Effects		.6	.4		
Engine Temperature Distortion Effects		.9	.6		
Airframe Inlet Interactions	.3	.9	.7		
Inlet Design Criteria		1.7	3.0	2.5	(1.0)
Engine Distortion Sensing Dynamics	.40	.90	.50	.30	
Engine-Inlet Interactions - General		.2	.2		
Engine-Inlet Interactions - System Oriented				2.0	1.0
Ground-Flight Instrumentation Standardization		.20			
TOTAL	.80	5.40	5.40	4.80	(2.0)

*Available within Laboratory Funds

Appendix I

EXPLORATORY AND ADVANCED DEVELOPMENT PROGRAMS RELATED TO AIRFRAME-PROPULSION COMPATIBILITY

624 05 214	
Project 3066	Gas Turbine Technology
624 05 334	
Project 1347	Flight Vehicle Structures and Stg.
1366	Aerodynamic and Flight Mechanics
1370	Dyn. Prob. Flight Vehicle
1472	Dyn. Meas. and Anal. Technology
1476	Airframe-Nozzle Integration
8219	Stability and Control
634 06 044	V/STOL Assult Transport
634 06 054	Hi Bypass Turbofan
634 06 094	Lightweight Turbojet
634 06 514	Turbo-Accelerator
634 06 694	V/STOL Aircraft Technology
634 06 704	VTOL Engine Development
634 06 824	ATEGG
634 06 834	AMSA
644 03 034	XB70
644 03 054	YF12A
644 03 064	F12
644 03 204	J58 Engine R&D
334 20 014	F-111
405 64 014	C5A

APPENDIX II

POTENTIAL CONTRIBUTORS TO ENGINE/INLET MATCHING SURVEY

Airframe

Bell
Boeing
Douglas
General Dynamics
  Fort Worth
  San Diego
Grumman
Ling-Temco-Vought
Lockheed
  California
  Georgia
McDonnell
Norair
North American
  Columbus
  Los Angeles
Republic
Ryan

Engine

Allison
Continental A&E
Garrett
General Electric
  Lynn
  Evendale
Lycoming
Pratt & Whitney
  Florida
  E. Hartford
Rolls Royce
United Aircraft Corp.
Wright Aeronautical

Government

Army
Arnold Engineering
NASA
  Ames
  Langley
  Lewis
Navy

Airlines

American
Pan American
TWA
United

Institutions

California Institute of Technology
Johns Hopkins
Massachusetts Institute of Technology
Cornell Aeronautical Laboratories

APPENDIX III

F-111 Inlet - Engine - Airframe Testing

STATUS

The F-111 aircraft has been operating with excessive performance penalties due to the problems of nozzle/airframe integration and engine-inlet mismatching. The initial flight test program encountered severe engine stalls, afterburner blowouts, afterburner lighting difficulties, and exhaust nozzle tail feather instability. Most of these problems have been significantly reduced due to design changes and refinements in the inlet and propulsion system areas.

The inlet total pressure distortion was reduced by the use of vortex generators and careful tailoring of the boundary layer bleed system to minimize the external boundary layer air entering the inlet. In addition, the environmental air sub inlet was relocated outside of the main inlet duct. Further improvement in distortion is expected to result from an increase in cross-sectional area distribution of the subsonic diffuser.

The engine has also contributed significantly to the improvements in the propulsion system operation. Numerous modifications have been made to the engine controls and to the afterburner configuration which has greatly helped the reliability of afterburner performance. Flight tests have been conducted with rematched engines which have improved the basic stall characteristics of the TF-30 engine. In addition, the use of sixth stage bleed at the higher mach numbers has allowed the flight envelope to be greatly expanded. Future improvements are expected by the use of a modified compressor design with a significant gain in distortion tolerance.

The above advances have utilized a large number of facilities and testing techniques. These include static wind tunnel, and flight tests of the inlet with both steady state and dynamic instrumentation. Recent tests have included measurement of swirl angle at the inlet exit. Engine development has been done on compressor rigs, static engine stands, altitude test facilities, flying test beds, and in the F-111. Attempts to duplicate the flight test results in ground facilities by the use of distortion screens have not given good correlation. Work is continuing in these areas. Additional wind tunnel and flight tests will be performed to investigate a number of design changes to the boundary layer diverter, inlet and diffuser geometry. Revised inlet controls and sensors are being investigated. Extensive distortion screen testing is underway on the TF-30 engine to investigate the effects of various distortion patterns on engine stall limits, stability and performance.

XB-70

INLET/ENGINE MATCHING

A follow-on flight test is being considered for the XB-70 that would include an inlet/engine matching section with the objective to establish distortion parameters, design criteria and stability characteristics of the XB-70 inlet duct and propulsion system configuration and to validate dynamic modeling analysis program for these subsystems as established by North American Aviation and General Electric.

Steady state and transient performance data at various engine airflow demands, and flight conditions, will be obtained relating inlet control, stability, and internal and external disturbances and turbulence transients to engine stability, control, and compressor inlet distortions and their effects on the A/B envelope, airstart map, throttle bursts and chops, engine surge, stall and shutdown, and inlet duct starts and unstarts, particularly during buzz.

Data points are required under steady state and transient performance during climbout and flights at various altitudes and Mach numbers (takeoff to max altitude, max Mach number conditions).

Flight data will be correlated with wind tunnel and engine altitude test cell measurements to establish inlet-engine performance simulation methods and analysis. Such data is vital to the understanding of engine-inlet distortion, as has effected the F-111A development, and to the correct engineering of future AF weapon systems (V/STOL fighter, FX, and AMSA). These data may also be valuable to the National Supersonic Transport Program.

C-5A Engine-Inlet-Airframe Testing

STATUS

The Airframe Contractor Lockheed Aircraft Company (LAC) is engaged in a closely integrated test program with the General Electric Company (GE) the engine contractor to verify the compatibility between the engine and inlet interface. The TF-39 engine (GE) and inlet (LAC) compatibility will be demonstrated by a series of testing programs continuing throughout the development program. Test hardware will be modified where suitable performance gains can be accrued. Tests have been conducted by GE on a 2/3 scale engine to demonstrate both individual and combined distortion capabilities on the major engine components and their assemblies. Several ground and wind tunnel distortion tests have been completed and the results to date have shown the engine to be highly tolerant to distortion. The engine during these tests was subjected to both radial and circumferential distortion patterns and combinations of these. These pressure patterns produced distortion levels that exceeded the Air Force's testing requirements.

Inlet distortion testing with simulated distortion patterns will be conducted on TF-39 full scale fan assemblies, compressors, and complete engines. Both steady state and transient operating modes will be investigated.

Tests have already been run on a scaled version of the fan thrust reverser both with and without an inlet. These tests although conducted on scaled hardware did show the compatibility of the inlet and thrust reverser.

Full scale inlet-engine testing will be carried out at the GE low speed test facility and initial flight testing will be acccomplished with a B-52 flying test bed aircraft. Full scale altitude testing will also be carried out in the AEDC wind tunnel and in conjunction with the flying test bed program. Full scale inlet and thrust reverser tests are scheduled throughout FY 67. The LAC inlet will be tested early in the program to uncover and correct distortion problems that may precipitate and design refinements will be incorporated to minimize installation losses. Endurance testing starting in FY 67 will include the engine with the inlet and thrust reverser attached to provide both compatibility and operating experience.

AMSA PROGRAM - ENGINE - INLET-AIRFRAME TESTING

STATUS

There are five contractors currently performing design studies and component testing. The airframe contractors are Boeing, General Dynamics, and North American. The engine contractors are GE and P&W. The present design-analysis efforts were completed in July 1966. A follow-on program is being planned to extend this effort through May 1967. One of the tasks to be undertaken during the follow-on program is to check the compatibility of the engine and inlet design and investigate the integrated engine inlet control system concept to determine it's feasibility, interfaces, and potential problem areas.

The specific effort concerning the propulsion system has been centered on investigating engine cycles, carrying out engine component tests and performing complete scale model engine tests. Preliminary designs of the engine nacelles and associated inlets have been progressing concurrently with the engine design studies. The wind tunnel inlet development tests are scheduled to begin in October 1967. The contractors are fabricating 1/8 to 1/10 scale test models of the latest AMSA inlet configuration mounted on an adequate portion of the aircraft structure to simulate actual environmental conditions. These tests will be run at AEDC to provide data on inlet recovery, flow distortion, flow stability, and other flow characteristics for each scale model inlet. These results will be used to determine the effects of flow variations on engine performance.

The AMSA engine program is a two year study emphasizing both design and test efforts. The major objective of the program is to predict the propulsion system performance capability which can be developed in the early 1970 time period. The program includes a dynamic computerized analysis to predict overall engine performance using test data for input. Several factors will be investigated in this engine simulation analysis. The important characteristics to be used in the engine analysis will be the effect of inlet distortion and flow transients on compressor performance. Both representative inlet distortion pattern flow data and engine component test data will be used to predict the engine response characteristics and performance levels. Also, other effects will be investigated by the engine contractors. These effects are inlet unstart, inlet buzz, duct turbulence and cyclic temperature changes due to hot gas ingestion. Matching the engine to the inlet over this wide range of hostile environment will be accomplished by making the inlet distortion and engine surge margins compatible to these various flow transients for all normal modes of flight operation.

US/FRG ENGINE/INLET MATCHING

STATUS

The final study reports from the US/FRG V/STOL fighter program are now being evaluated by a joint US/FRG team.

Lift and lift/cruise engine installations may point out additional engine/inlet matching problems for a V/STOL aircraft. Reingestion of recirculated hot gas and inlet performance during transition are examples of the special type of problems that may be present for V/STOL aircraft.

At this point in the program no specific testing of engine/inlet compatibility is planned or scheduled.

FX - STUDY PROGRAM -

Inlet/Engine Matching

In the FX Study most of the proposers have suggested looking at inlet size, shape, and location but not at inlet/engine matching. One company plans model tests and intends to do, as future work, an investigation of the sensitivity of inlets to variables, modification of study input data to reflect wind tunnel results, and detailed induction system design and performance calculations.

Extract from Aircraft Company Presentation to Air Force Regarding Interface Operational Problems

Appendix XIV

<u>THE AIRCRAFT CONTRACTOR'S POSITION</u>

- o THE INLET COMPLIES WITH (SPECIFICATION)
- o THE ENGINE WAS DEFICIENT
- o THE ENGINE DISTORTION TOLERANCE PRESENTATION DID NOT CORRECTLY DEFINE THE ENGINE STALL CHARACTERISTICS

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THE (____) INLET MET THE REQUIREMENTS OF (THE SPECIFICATION)

RE ENGINE STALL:	QUANTITATIVE REQUIREMENTS HAD NOT BEEN STATED. THE SWIP INLET FLIGHT CHARACTERISTICS ARE CONSISTENT WITH THE WIND TUNNEL INLET DATA WHICH THE ENGINE CONTRACTOR SAID WAS ACCEPTABLE AND WOULD PRODUCE STALL FREE OPERATION.
RE ENGINE PERF:	INLET DISTORTION LEVELS WERE LOW AND RESULT IN NO EFFECT ON ENGINE PERFORMANCE.

SPECIFIC COMMENTS ON (ENGINE DISTORTION TEST) REPORTS

	ENGINE 1	ENGINE 2
ENGINE CONFIGURATION	o NO AFTERBURNER INSTALLED o TURBINE AND PRIMARY EXHAUST NOZZLE AREAS WERE ADJUSTED o OTHER DIFFERENCES BETWEEN TEST AND PRODUCTION ENGINES? o WERE ENGINE CONTROLS SET FOR WORST TOLERANCES?	HP COMPRESSOR NOT INCLUDED IN LIST OF COMPONENTS WHICH WERE BILL OF MATERIAL? OTHER DIFFERENCES BETWEEN TEST AND PRODUCTION ENGINES? WERE ENGINE CONTROLS SET FOR WORST TOLERANCES?
TEST METHODS	o NO THROTTLE TRANSIENT TESTS o ONLY ZERO SHAFT POWER EXTRACTION o EFFECT OF "g" NOT EVALUATED o SQUARE WAVE DISTORTION PATTERN NOT TESTED o TEST CONDUCTED AT SEA LEVEL ONLY	NO THROTTLE TRANSIENT TESTS AT ALTITUDE ONLY ZERO SHAFT POWER EXTRACTION EFFECT OF "g" NOT EVALUATED SQUARE WAVE DISTORTION PATTERN NOT TESTED

- THE (ENGINE) TESTS WERE INCONCLUSIVE BECAUSE OF THE INADEQUACIES IN ENGINE CONFIGURATION AND TEST PROCEDURES

IT IS THUS OBVIOUS THAT THE ENGINE PROVIDED BY THE GOVERNMENT WAS NOT SUITABLE FOR USE AND THAT THE CONTRACTOR IS ENTITLED TO AN EQUITABLE ADJUSTMENT IN CONTRACT PRICE IN CONSIDERATION OF THE ADDITIONAL WORK ACCOMPLISHED AT THE DIRECTION OF THE CONTRACTING OFFICER IN AN ENDEAVOR TO UTILIZE THE DEFICIENT GFAE ENGINES WHICH WERE PROVIDED.

ASD Technology Need-70-5, Airframe/Propulsion System Compatibility Criteria and Performance, 2 December 1969

Appendix XV

ASD TN-70-5

Original Submission Date: 2 December 1969

Title: Airframe/Propulsion System Compatibility Criteria and Performance

Objectives:

1. Establish Design, Test, and Performance Criteria of the Airframe/Propulsion System to assure compatibility throughout weapon system mission envelopes.

2. Acquire:

   (a) Specification and Design Handbook Data

   (b) Improved Analysis/Test/Evaluation Techniques

   (c) Refined Definition of Contractor Development Efforts

End Product Required:

1. The end product should be a document or documents delineating the information specified under objectives.

Program Element: 63202F and 63216F

Priority: Vital

Problem: The problem is to establish criteria for the orderly development process of providing total integration of the propulsion system into the airframe system. Each new system is unique and as such requires that the compatibility interface of each subsystem be completely assessed to assure that the system will meet its operational mission design requirements. In this context, the Airframe/Propulsion system compatibility problem shall be considered for only the inlet/engine/exhaust subsystems. The highly complex systems presently being developed and for future requirements will depend highly on the technology base established for the inlet/engine/exhaust aspects of the weapon system. Improper integration of these subsystems may result in reduced range, reduced payload, and restricted maneuvering capabilities among other operational constraints. The technology will be used to continually assess the problem, provide for development tools necessary

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to define limitations, and to maintain the vital nature of the problem. The technology is needed today and will need to be continually updated as long as air breathing propulsion systems are used.

Suggested Approach:

1. Engine and Component Design Requirements - Establish standard definitions regarding stability parameters and the affects engine components have on these. Investigate the methods for propulsion system stability and determine the engine related characteristics.

2. Aircraft Configuration and Inlet Location Design Criteria - Establish ground rules for the optimization of the aircraft with proper propulsion system integration with regard to T-D parameters, afterbody and exhaust system optimization, and inlet placement with regard to FOD, forebody, wing effects, etc.; establish program guidelines for proper integration into the aircraft including Airframe/Propulsion system integration plans, interface control documents, test requirements, design substantiation criteria, wind tunnel models, test facilities, total full scale integration, etc.

3. Inlet/Engine Control Requirements and Interfaces - Design criteria needed includes guidelines for overall propulsion system integration with respect to controls for the engine and inlet. Integration of the control systems for gas ingestion due to weapons firing can be considered one aspect. Review current design requirements and modify as necessary to conform to current technology.

4. Improved Instrumentation for Development and Flight Test - Improve instrumentation and instrumentation techniques to provide for data gathering for development and flight test. Considerations include type of instrumentation, location in test vehicle, validation of results, handling of data, accuracy of instrumentation, etc.

Related Efforts: APC has become recognized as a necessary consideration in the development of a weapon system. Extensive effort is being exerted by the government, airframe contractors, and propulsion system contractors to establish criteria for the satisfactory integration of propulsion and airframe systems. Currently, extensive efforts are being extended in the B-1A, F-111, and F-15 weapon systems. Laboratory programs include the Airframe Propulsion System Integration (APSI) and Advanced Turbine Engine Gas Generation (ATEGG) efforts. Reports published include:

AFAPL-TR-68-30	Procedures and Suggested Programing Emphasis to Obtain Criteria Essential to Obtaining Propulsion System Flow Stability; Gratz, Harlen J.; May 1968.
AFAPL-TR-67-75	Approaches to Determine and Evaluate the Stability of Propulsion Systems; Tear, R.C. Sqd. Ldr. RAF; Feb 1968.
APTA TM-69-12	Techniques for Establishing Propulsion System Stability; Brimelow, Brian, Sqd. Ldr. RAF; Apr 1969.

Support: No funding or hardware support is available from the requesting organization. Manpower requirements will have to be established and validated prior to considering any commitment from the requesting organization. Review of reports and documentation for comments are recommended as it becomes available.

Technical Points of Contact:

Originator R. E. Grimm, ASN/ASNJI-10, 52810 REG

Lab Contact L. McKenny, AFAPL/APTP, 52278 LM
B.K. Richey AFFDL/FDMM 53528 NFK

Authentication:

James G. Barrett
22 Dec. 1969

List of AD Numbers for AFAPL Technical Reports

AFAPL TR 68-142

Part	
1	AD 857561
2	856562
3	859281
4	852182
5	851899
6A	851900
6B	851901
7	851902
8	851903
9	851904
10	851905
11	503303
12	852024
13	856225
14	503304
15	503328
16	852757
17	859282
18	856563
19	852785
20	853262

AFAPL TR 69-36

Part	
1	AD 856229
2	AD 503329

AFAPL TR 69-44

Part	
I	AD 503305
II	856259
III	858526
IV	858916
V	855767
VI	858917

TN-ASD-37-70-5-(1)

DATE OF INITIATION OR REVISION:

30 January 1971

TITLE:

Airframe/Propulsion System Compatibility Criteria and Performance

OBJECTIVE:

1. Establish design, test, and performance criteria of the Airframe/Propulsion System to assure compatibility throughout weapon system mission envelopes.

2. Acquire:

(a). Specification and Design Handbook Data

(b) Improved Analysis/Test/Evaluation Techniques

(c) Refined Definition of Contractor Development Efforts

PROGRAM ELEMENT:

63202F and 63216F

TECHNOLOGY IMPORTANCE CATEGORY (TIC):

The technology is in the class I category.

PROBLEM:

The problem is to establish criteria for the orderly development process of providing total integration of the propulsion system into the airframe system. Each new system is unique and as such requires that the compatibility interface of each subsystem be completely assessed to assure that the system will meet its operational mission design requirements. In this context, the Airframe/Propulsion system compatibility problem shall be considered for only the inlet/engine/exhaust subsystems. The highly complex systems presently being developed and for future requirements will depend highly on the technology base established for the inlet/engine/exhaust aspects of the weapon system. Improper integration of these subsystems may result in reduced range, reduced payload, and restricted maneuvering capabilities among other operational constraints. The technology will be used to continually assess the problem, provide for development tools necessary to define limitations, and to maintain the vital nature of the problem. The technology is needed today and will need to be continually updated as long as air breathing propulsion systems are used.

RELATED EFFORTS:

APC has become recognized as a necessary consideration in the development of a weapon system. Extensive effort is being exerted by the government, airframe contractors, and propulsion system contractors to establish criteria for the satisfactory integration of propulsion and airframe systems. Laboratory programs include the Airframe Propulsion System Integration (APSI) and Advanced Turbine Engine Gas Generation (ATEGG) efforts. Reports published include:

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AFAPL-TR-67-75	Approaches to Determine and Evaluate the Stability of Propulsion Systems; Tear, R.C. Sqd. Ldr. RAF; Feb 1968.
APTA TM-69-12	Techniques for Establishing Propulsion System Stability; Brimelow, Brian, Sqd. Ldr. RAF; Apr 1969.

SUGGESTED APPROACH:

1. Engine and Component Design Requirements - Establish standard definitions regarding stability parameters and the affects engine components have on these. Investigate the methods for propulsion system stability and determine the engine related characteristics.

2. Aircraft Configuration and Inlet Location Design Criteria - Establish ground rules for the optimization of the aircraft with proper propulsion system integration with regard to T-D parameters, afterbody and exhaust system optimization, and inlet placement with regard to FOD, forebody, wing effects, etc.; establish program guidelines for proper integration into the aircraft including Airframe/Propulsion system integration plans, interface control documents, test requirements, design substantiation criteria, wind tunnel models, test facilities, total full scale integration, etc.

2.

3. Inlet/Engine Control Requirements and Interfaces - Design criteria needed includes guidelines for overall propulsion system integration with respect to controls for the engine and inlet. Integration of the control systems for gas ingestion due to weapons firing can be considered one aspect. Review current design requirements and modify as necessary to conform to current technology.

4. Improved Instrumentation for Development and Flight Test - Improve instrumentation and instrumentation techniques to provide for data gathering for development and flight test. Considerations include type of instrumentation, location in test vehicle, validation of results, handling of data, accuracy of instrumentation, etc.

SUPPORT:

No funding or hardware support is available from the requesting organization. Manpower requirements will have to be established and validated prior to considering any commitment from the requesting organization. Review of reports and documentation is recommended as they become available.

TECHNOLOGY PRODUCT DESIRED:

The end product should be a document or documents delineating the information specified under Objective.

TECHNICAL REVIEW:

BRANCH CHIEF:

SIGNED

H. A. KLEIN
Chief, Auxiliary Equipment Branch
Installations Division
Directorate of Propulsion & Power
Subsystems Engineering

DIVISION CHIEF:

SIGNED

F. A. WRIGHT
Chief, Installations Division
Directorate of Propulsion & Power
Subsystems Engineering

3.

POINTS OF CONTACT:

ORIGINATOR: Ralph E. Grima, Sr. Project Engineer, ASD/ENJIA,
ext. 55457

SYSTEM CONTACT: None

LABORATORY CONTACT: T. J. Sims, APSI Program Mgr., AFAPL/TBP
ext. 52278

VALIDATION:

SIGNATURE:

SIGNED

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4.

Extract from AEDC-TR-71-249

Appendix XVI

STABILITY MARGIN AUDIT

The stability margin allocation of a qualification test engine is shown in Fig. XVI-1. An example, based on a typical augmented turbofan engine, is used to illustrate the quantitative stability margin assessment capability available using the test techniques and building block concepts established. The margin utilization attributed totthe primary factors affecting engine stability is shown for defined boundary conditions representing a typical flight condition (intermediate and maximum engine power at 55,000-ft altitude, Mach number 1.6).

The compressor stability margin is evaluated using the critical compressor component. The critical component is defined as the compressor component in which complete flow breakdown is initially experienced and is established using the technique discussed in Section 3.2.4 of Ref. 1.

The compressor stability margin audit must be derived using stability data obtained during engine development and prequalification testing in conjunction with qualification engine test results. Altitude qualification test engines are not normally subjected to intentional surge because of the hazard of structural damage and unnecessary delays in engine qualification testing. The compressor surge line and the totalIstability margin audit must be determined during engine development and prequalification testing conducted with qualification engine compressor components. Limited verification of the operating line excursions caused by the primary factors such as control requirements and distortion effects must be obtained during the qualification test. In addition, surge-free operation should be verified at the maximum predicted operating line excursions during the qualification test. Verification that the development and prequalification test results are applicable to the qualification engine is based on the standard Air Force quality control parts accounting procedures and on the comparison of operating line data (speed, flow, pressure) from prequalification and qualification engine, test programs.

Surge limit data for the stability margin audit should be obtained using a consistent specified compressor loading technique for all engines/configurations. For the example shown, compressor loading is specified at constant corrected rotor speed and at constant corrected rotor speed ratio (rotor match) to establish the surge limit at quasi-steady-state conditions using the test procedures discussed in Section 3.2.4 (Ref. 1).

Carefully selected and defined engine and environmental boundary conditions are required for a meaningful stability audit (Section 3.1, Ref. 1). The boundary condition criteria selected for the example are listed in Fig. XVI-2. The inlet-engine interface condition criteria are based on a projected flight condition (mission requirement) and are specified using the point-by-point definition discussed in Section 3.3.6 (Ref. 1). Other environmental conditions which require definition are the projected aircraft installation interface conditions (aircraft service requirements such as compressor bleed and power extraction). Engine operating conditions are defined in terms of corrected rotor speed, corrected rotor speed ratio, the engine service bleeds, and the control mode of operation. Each boundary condition used to define the surge and operating lines requires precise definition as shown by the matrix presented in Fig. XVI-3. The condition matrix is organized to illustrate the building block concept. Baseline data are established first using the techniques discussed in Section 3.2 (Ref. 1); the various destabilizing factors (Reynolds number, inlet distortion, control mode, and aircraft service requirements) are then quantitatively defined.

Stability margin, as a function of high-pressure compressor airflow, is presented in Fig. XVI-4. The margin allocation required for each of the primary factors is indicated by the "stability stack" presentation. Quantitative assessment provides the information required to verify the development of engine stability margin to levels required for projected mission operating conditions.

REFERENCE

1. Tate, Jack T. and Smith, R. E., Jr. "Normalized Testing Techniques to Determine Turbine Engine Stability Margins." AEDC-TR-71-249.

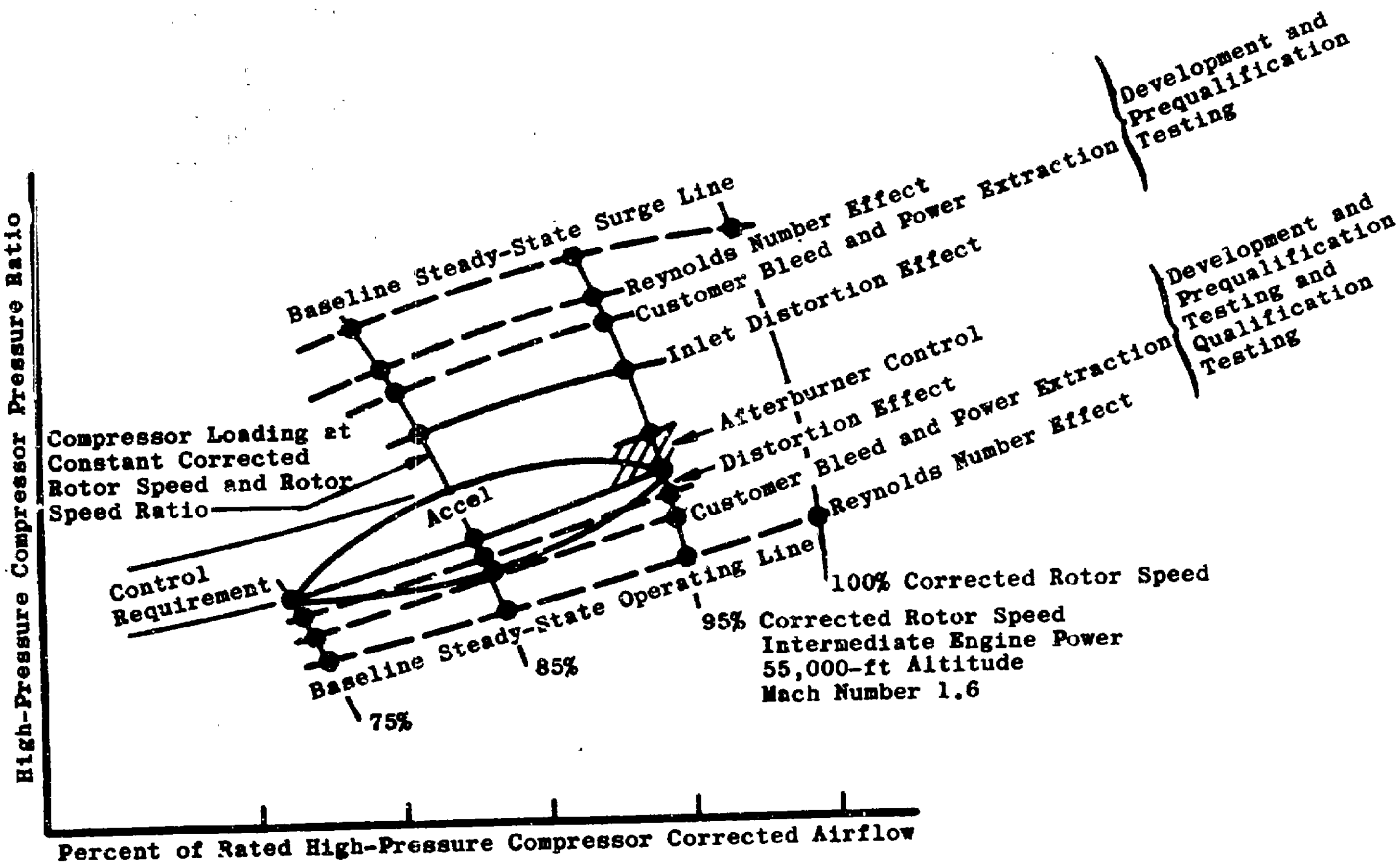
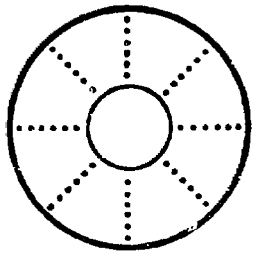


Fig. XVI-1 Example of Quantitative Assessment of Stability Margin Utilization (High-Pressure Compressor Assumed to be Critical Component)

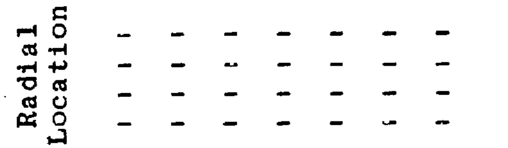
INLET-ENGINE INTERFACE CONDITIONS

INLET	ENGINE
Corrected Airflow	Corrected Airflow
Altitude	Altitude
Mach Number	Total Pressure
Ram Recovery	Total Temperature
Angle of Attack	Distortion Pattern (Point by Point Definition)
Angle of Yaw	



Instrumentation Definition

Circumferential Location



Individual Probe Values, P_{local}/P_{avg} at Corrected Airflow Value

Installation Interface Conditions (Aircraft Service Requirements)
- Customer Bleed
- Power Extraction

Engine Operating Conditions
- Corrected Rotor Speed
- Corrected Rotor Speed Ratio
- Engine Service Bleeds (Intercompressor, Anti-Ice)
- Control Function - Steady-State (SS), Transient
- Control Operating Mode - Afterburning, Nonafterburning

Fig. XVI-2 Engine and Environment Boundary Condition Criteria for Quantitative Assessment of Stability Margin Utilization

	Inlet-Engine Interface						Installation Interface		Engine Operating Conditions						Compressor Loading
	Altitude, ft	Mach No.	Ram Recovery	Total Pressure, psia	Total Temperature, °R	Distortion Pattern	Customer Bleed	Power Extraction, hp	Corrected Rotor Speed, percent rated	Corrected Rotor Speed Ratio	Inter-Compressor Bleed	Anti-Ice Bleed	Control	Operation	
Baseline	Sea Level	0	1.0	14.7	518.6	Uniform	0	0	100 95 85 75 100 95 85	Normal Operating Line Value (NOL)	0	0	Steady State (SS)	No Afterburning (A/B)	Op Line Op Line Op Line Op Line Surge Surge Surge
Reynolds Number Factor	55,000	1.6	0.95	5.329	590.7	Uniform	0	0	95 85 75 95 85	NOL	0	0	SS	No A/B	Op Line Op Line Op Line Surge Surge
Installation Factor	55,000	1.6	0.95	5.329	590.7	Uniform	Max Max Max Max Max	50 50 50 50 50	95 85 75 95 85	NOL	0	0	SS	No A/B	Op Line Op Line Op Line Surge Surge
Inlet Distortion Factor	55,000	1.6	0.95	5.329	590.7	Dist 1 Dist 2 Dist 3 Dist 1 Dist 2	0	0	95 85 75 95 85	NOL	0	0	SS	No A/B	Op Line Op Line Op Line Surge Surge
Control Factor	55,000	1.6	0.95	5.329	590.7	Uniform	0	0	95 95 75 to 95 95 to 75	NOL	0	0	Transient SS Transient Transient	A/B Light A/B Accel Decel	Op Line Op Line Op Line Op Line

Note:
1. Distortion pattern established using fixed screens at defined corrected airflow.
2. Customer bleed established using fixed geometry metering system sized for maximum allowable customer bleed flow at intermediate power.
3. Power extraction established using speed dependent loading system set for 50 hp at intermediate power.

Fig. XVI-3 Engine and Environmental Boundary Condition Matrix

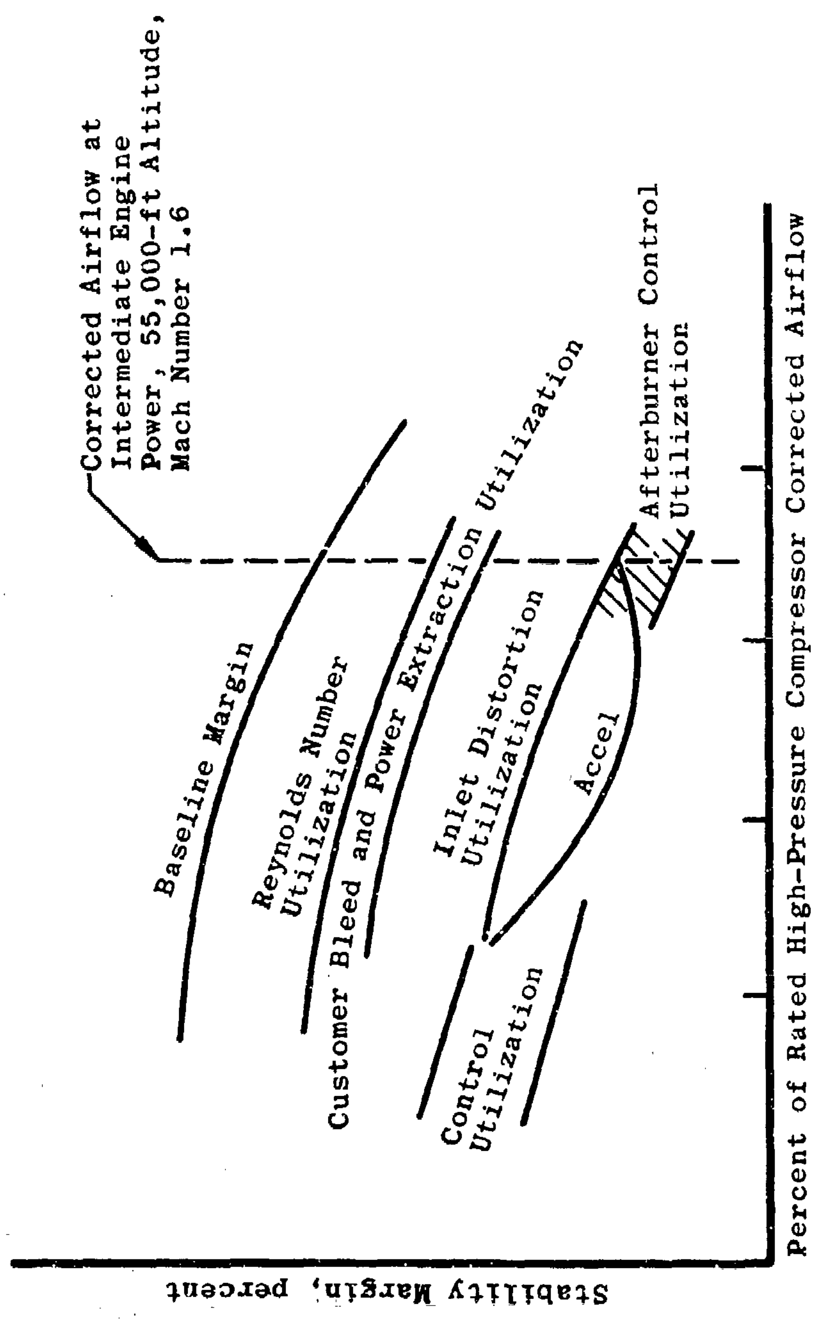


Fig. XVI-4 Quantitative "Stability Stack" of Factors Affecting Stability Margin

Extracts from:

1. AFSC Design Handbook Series 2-0, Section 2-3, Propulsion & Power, 1 March 1969, and Military Specification Requirements for Engine Inlets
2. MIL-E-5007C, 30 December 1965
   MIL-E-5008C, 30 December 1965
   MIL-E-5009C, 30 December 1965
   MIL-E-5009D, 13 November 1967

DESIGN NOTE 4F1 SYSTEM COMPONENTS

1. INTRODUCTION

Anti-icing and deicing provisions, antidust devices, and any other equipment employed in or near the intake ducts for the purpose of restricting, modulating, filtering, heating, or cooling the intake air are also considered part of this air intake system.

2. DESIGN OBJECTIVES

The effect of aerodynamic design of the engine air intake system on turbine type engine performance is of considerably greater importance than for reciprocating engines. The optimum aerodynamic configuration of the air inlet and induction system ducting can be achieved only by exact analysis of the system requirements and parallel study and comparative wind tunnel analysis of alternate designs. The merits of duct and inlet configuration of different design and location depend primarily on the type of engine installation. The critical nature of duct and entrance configurations in regard to the effect of compressibility and normal energy losses at high Mach numbers makes evaluation of the engine air intake system by individual performance testing imperative. There are several approved methods available for computing the effect of the air induction system design on aircraft and engine performance. For this reason, no specific method is recommended here. Use any reasonable method for calculating performance. If the method selected has been published, forward a report which explains the method in detail to the procuring activity for approval. Subsequently, forward a report describing the methods employed and the results obtained in the performance testing of the engine air intake system to the procuring activity for approval. In the design or planning stage, give consideration to the location of the air inlet to ensure that the selected position is in an area of satisfactory airflow patterns and boundary layer characteristics at all attitudes and conditions of operation for which the aircraft is designed. A short air induction system, consistent with good diffusion practice, is preferred. Where a choice must be made between a long tailpipe extension for the exhaust system and a long engine air intake system, accept the sacrifice of induction system performance because of the larger penalty imposed on engine performance by tailpipe length, the high weight per unit area involved in limiting the inherent fire hazard of the tailpipe, and by inspection, maintenance, and replacement factors. Give special consideration to locating and positioning the air inlet in an area where there is little probability of entraining foreign particles thrown up by the wheels of the aircraft.

2.1 Pressure Variation

The air induction system total pressure profile at the engine front face has a direct relation to gas turbine engine operation as concerns compressor stall and surge. Total pressure variation from the mean should be as small as possible with good inlet design. Radial total pressure variation does not affect engine compressor stall as much as circumferential total pressure variation. Circumferential total pressure variation from the mean should not vary more than ±5% at all required flight operation altitudes, angles of attack, maneuvers, and speeds. Recent flight test data show that relatively wide pressure variation at a few points in the plane of the compressor face does not affect compressor stall as much as medium pressure variation at a greater number of points. The size and location of these regions of variation of total

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pressure at the compressor front face appear to be the deciding factor in current inlet duct induced engine stall limits.

2.2 Pressure Recovery

A high average total pressure recovery at the engine front face is desirable so that optimum engine performance may be realized. Pressure recovery normally decreases with increasing aircraft Mach number. Design objectives for air inlet average total pressure recovery are as follows:

Mach 0 to 1	- 0.95
Mach 2	- 0.85
Mach 3	- 0.60

3. CONSTRUCTION DESIGN

Make the inlet and system ducting of sufficient strength to withstand the maximum pressure depression encountered at maximum engine thrust with the aircraft in static condition. In addition, provide sufficient strength to withstand vibrations produced by airflow variations (which may exceed the strength required to withstand pressure differentials). Employ flush type riveting in the internal surfaces of all ducting in the system. Do not use construction components in the engine air intake system which may vibrate loose and enter the engine. If their use is unavoidable, provide safetying of each part. Submit all pertinent data and drawings of duct quick disconnects to the procuring activity for approval prior to incorporation in the aircraft. Locate both the air inlets and armament stores so that rocket and gunfire blasts or other effects will not enter the air inlets of gas turbine engines. The effect of sudden changes in inlet air temperature and pressure and subsequent compressor surge can be serious in gas turbine engine flight operation. See E.4-3.2.1.3 of HIAD for launchers and E.4-9.6 of HIAD for information on compressor stall.

4. CONTROL

Airflow control by means of variable inlet spikes, plugs, wedges, bypass doors, or suck-in doors may be necessary on high speed aircraft to supply engine airflow requirements over the complete range of operating conditions. See Para 4.1 for design of the controls of these variable inlet components.

4.1 Variable Geometry Inlet Control

Design the variable geometry inlet control system to ensure an accuracy of regulation consistent with the steady-state and transient characteristics of the basic engine control. Make the reliability and fail-safe features of the inlet control compatible with those of the basic engine control. Submit sufficient data to the procuring activity to permit an evaluation of the control system relative to a specific engine and aircraft installation.

4.2 Reliability

Use the requirements listed in this paragraph as a guide to reliability. Make the variable geometry inlet control the simplest and most reliable system which will provide the engine-aircraft combination with the specified performance and ease of operation. Design the inlet control system without special emergency features so that:

a. A failure during takeoff of any single functional part does not reduce the total thrust or shaft horsepower, as applicable, below 90% of the intermediate power/thrust level normally available on a standard day over the range of sea level to 10,000 ft geometric altitude. Standard day is defined in Ref 1451.

b. A failure of any single part does not result in the engine or airframe exceeding

MIL-E-5007C
30 DECEMBER 1965

SUPERSEDING
MIL-E-5007B
22 JANUARY 1959

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET AND TURBOFAN, GENERAL SPECIFICATION FOR

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

3.21.2 *Inlet air pressure variation.* The estimated maximum radial and circumferential total pressure distortion limits which can be safely tolerated shall be specified in the model specification. The estimated effect on engine performance of these distortions shall be specified in the model specification. Compressor stall under any condition of operation within the operating envelope shall be considered a flight safety item and shall not be tolerated. The estimated maximum radial and circumferential total pressure distortion limits which can be tolerated without adversely affecting rated engine performance shall be specified. These limits shall not include an area bounded by the duct walls and a line spaced therefrom by 1.5 percent of the compressor tip diameter. Back pressure effects on the fan shall be included in the process of establishing inlet air pressure distortion limits. The instrumentation location shall be specified for inlet air pressure distortion determination. Using representative values obtainable from this instrumentation, the method and sample calculations for determination of inlet air pressure distortion shall be specified.

MIL-E-5008C
30 DECEMBER 1965
SUPERSEDING
MIL-E-5008B
22 JANUARY 1959

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET AND TURBOFAN, MODEL SPECIFICATION FOR (OUTLINE AND INSTRUCTIONS FOR PREPARATION)

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

3.21.2 *Inlet air pressure variation.* The estimated radial and circumferential inlet air total pressure distortion limits which can be safely tolerated without compressor stall and the effect on engine performance shall be shown on curve(s) __________. The estimated maximum radial and circumferential distortion limits which can be tolerated without adversely affecting rated engine performance shall be shown on curve(s) __________. (The contractor may show these limits in other than curve form.) The estimated effect of back pressure on the fan and of radial and circumferential total pressure variation on thrust, fuel flow, and airflow shall be shown on curve(s) __________. (At least five inlet distortion points which are to be demonstrated under inlet air pressure distribution (4.3.12.1.3) of MIL-E-5009 shall be specified.) The method and sample calculations used for determination of inlet air pressure distortion shall be shown on the curve No. __________.

MIL-E-5009C
30 DECEMBER 1965
SUPERSEDING
MIL-E-5009B
22 JANUARY 1959
MIL-E-5010B
22 JANUARY 1959
MIL-E-5156C
22 JANUARY 1959

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET AND TURBOFAN, TESTS FOR

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

4.3.12 *Altitude tests.*

4.3.12.1 *Test conditions.*

4.3.12.1.1 *General.* An engine, to the same parts list as the qualification test engine, shall be subjected to altitude tests which shall consist of operation and air starting checks at several selected thrust conditions around the operating limits envelopes specified for the engine in the model specification, except that portions of these tests may be accomplished on separate engines at the discretion of the using service. The points covered on these envelopes shall include standard hot atmosphere and standard cold atmosphere as defined by tables II and III of MIL-STD-210, and the altitude rating points. The test points selected shall be the minimum necessary to demonstrate the engine operating and air starting (hot starts and cold starts) envelope(s). Unless otherwise specified in the engine model specification, loading of the accessory drives will not be required during these tests. If a continuous duty ignition system is specified, it shall be in operation, with rated input voltage, at all times after a normal start sequence has been completed.

4.3.12.1.3 *Inlet air pressure distribution.* For selected test points as specified in the model specification, the fan back pressure and the air total pressure distribution at the compressor inlet shall simulate conditions approximately equal to the maximum allowable percent and extent of variation of the total pressure pattern, specified in the model specification.

MIL-E-5009D
13 NOVEMBER 1967

Superseding
MIL-E-5009C
30 December 1965

MILITARY SPECIFICATION

ENGINES, AIRCRAFT, TURBOJET
AND TURBOFAN, TESTS FOR

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

4.3.12 Altitude.-

4.3.12.1 Test conditions.

4.3.12.1.1 General. An engine substantially identical (as approved by the using Service) to the endurance test engine shall be subjected to altitude tests which shall consist of operation and air starting checks at several selected thrust conditions around the operating limits envelopes specified for the engine in the model specification, except that portions of these tests may be accomplished on separate engines at the discretion of the using Service. The points covered on these envelopes shall include standard hot atmosphere and standard cold atmosphere as defined by tables II and III of MIL-STD-210, and the altitude rating points. The test points selected shall be the minimum necessary to demonstrate the engine operating and air starting (hot starts and cold starts) envelope(s). Unless otherwise specified in the engine model specification, loading of the accessory drives will not be required during these tests. If a continuous duty ignition system is specified, it shall be in operation, with rated input voltage, at all times after a normal start sequence has been completed.

4.3.12.1.3 Inlet air pressure distribution. For selected test points as specified in the model specification, the fan back pressure and the air total pressure distribution at the compressor inlet shall simulate conditions approximately equal to the maximum allowable percent and extent of variation of the total pressure pattern, specified in the model specification.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY AFAPL WPAFB, Ohio

13. ABSTRACT

This report addresses the need for improved inlet-engine interface definitions and engine stability development approaches. Historical data are reported depicting the onset of interface stability problems in past Air Force developments. Various approaches and factors related to the development of operationally suitable engines are discussed for different time periods since the late 1940's. More recent Air Force experiences and development efforts directed toward improved stability development approaches are compiled as a basis for proposed engine development programming considerations. Inlet-engine interface definition and stability margin testing procedures are related.

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Inlet Distortion						
Turbine Engine Stability Margin						
Engine Stability Development						
Stability Margin Assessment						

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Security Classification