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DEFINITION STUDY FOR VARIABLE CYCLE ENGINE TESTBED ENGINE AND ASSOCIATED TEST PROGRAM

FINAL REPORT

November 1978

For

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16 Abstract

The product/study double bypass variable cycle engine (VCE) was updated to incorporate recent improvements. The effect of these improvements on mission range and noise levels was determined. This engine design was then compared with current existing high-technology core engines in order to define a subscale testbed configuration that simulated many of the critical technology features of the product/study VCE.

Detailed preliminary program plans were then developed for the design, fabrication, and static test of the selected testbed engine configuration. These plans include estimated costs and schedules for the detail design, fabrication and test of the testbed engine and the definition of a test program, test plan, schedule, instrumentation, and test stand requirements.

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1.0 SUMMARY

This report describes the supersonic cruise VCE propulsion work accomplished under Contract NAS3-20582A in each of the three main program tasks:

SCAR Double Bypass Product/Study VCE Update

Updating the Double Bypass VCE engine defined under previous NASA Lewis sponsored studies (NAS3-19544) was performed in the areas of component and weight improvements, cycle refinements and engine/airframe matching. The effect of these improvements on mission performance and noise levels was determined.

Testbed Engine Definition and Preliminary Design

The product/study engine design was compared with current existing high-technology core engines in order to define a subscale testbed configuration that simulates many of the critical technology features of the double bypass product/study VCE, including a coannular plug nozzle, 2X1 split-flow fan with core-driven third stage, front and rear fan duct variable area bypass injectors (VABI's) and a variable area low-pressure turbine.

Two configurations of the testbed engine incorporating these features were studied in considerable detail. These were the close coupled and uncoupled configurations of the core driven concept. The former (selected) arrangement is most costly but similar to an ultimate product study engine, whereas the latter employed maximum utilization of available hardware with compromises in system length and complexity, resulting in a lower cost configuration.

Phase II Program Plans

Detailed preliminary program plans were then developed for the design, fabrication, and static test of the selected testbed engine configuration. These plans include estimated costs and schedules for the detail design, fabrication and test of the testbed engine and the definition of a test program, test plan, schedule, instrumentation, and test stand requirements. It was concluded that the required test program should include two integrated steps: first, the evaluation of the core-driven fan stage on a core engine and, second, the incorporation of the low-pressure turbine, front fan block and exhaust system to provide a testbed demonstrator engine.

2.0 INTRODUCTION

Engine studies conducted under NASA Supersonic Cruise Airplane Research (SCAR) contracts have shown that an advanced Variable Cycle Engine (VCE) can best meet the requirements for a supersonic cruise airplane which can produce a good economic return on investment for the airlines while simultaneously meeting severe noise and pollution constraints. The most promising VCE concepts depend on the efficient and coordinated function of several critical and unique components which are theoretically attractive for this application but which require a significant technology advancement and considerable experimental testing.

To implement VCE development, NASA has planned a program to focus component technology for a limited number of the most critical unique VCE components. This program is divided into two phases. Phase I included screening of critical component technology features with a rig testing of some of the most promising designs followed by an engine definition and preliminary design of a testbed engine incorporating these selected critical technologies. A program plan and a testing plan, together with facility and instrumentation requirements, were also prepared. These plans led to the design, fabrication and test in May 1978 of a testbed engine which demonstrated the feasibility of the forward bypass control valve (VABI). The coannular acoustic nozzle was then added to the forward VABI demonstrator engine to determine the acoustic suppression benefits of this inverted flow nozzle under the Early Acoustic Test (Contract NAS3-20582B). The Phase II work of the program will encompass the detail design, fabrication/assembly, and testing of a testbed engine which not only retains the critical technology features of the Early Acoustic Test Demonstrator but achieves even greater aeromechanical similarity to the Product/Study engine by incorporation of a core driven third stage fan design.

The experimental testing of the testbed engine will determine the compatibility and interaction of the selected unique VCE components with the other engine components.

This report covers the work conducted under Contract NAS3-20582A for the Phase II Engine and Program Definition Study which defined and provided for the preliminary design of the testbed engine, determined the test facilities and instrumentation to be used, and provided an overall Phase II program plan and a test plan for the testbed engine.

3.0 SCAR DOUBLE BYPASS PRODUCT/STUDY VCE UPDATE

3.1 INTRODUCTION

The baseline product/study double bypass variable cycle engines at the end of the Phase III SCAR Study (Contract NAS3-19544) were:

- 10% High-Flow Fan - GE21/J11 Study B5
- 20% High-Flow - GE21/J11 Study B3

These engines were designed for supersonic cruise at Mach 2.32 (standard ambient temperature +8° C (+14.4° F) and were reported in an all supersonic (Mission A) and an initial 1111 km (600 nmi) subsonic leg mission (Mission B). Both missions included a FAR121.648 reserve fuel allowance. Further experience in operating the double bypass VCE cycle and later matching to the Airplane Systems Contractors' airplanes resulted in performance improvements which have increased mission range by a large amount.

Some of these performance improvements were caused by an improved cycle definition, improved components such as the front block fan, and more experience in running the double bypass VCE cycle. This study will show the improved VCE cycle and the resulting improvements in mission range for both 10% and 20% oversize fan VCE's. The percent high flow defines the increase in front block airflow in the double bypass mode at T/O shaft speed relative to the nominal airflow obtained when the front block is operated at the reduced speed sufficient to just satisfy the rear block fan sea level static design airflow requirements in the single bypass mode.

The engines being compared in this study are:

Baseline Phase III Study Engines

10% High Flow - GE21/J11 Study B5
20% High Flow - GE21/J11 Study B3

Current Improved Phase IV Study Engines

10% High Flow - GE21/J11 Study B9
20% High Flow - GE21/J11 Study B15A

3.2 SUMMARY

Improvements to the SCAR Double Bypass VCE at the end of the NASA Lewis SCAR Phase III and IV Studies were:

- Component Improvements
- Exhaust Nozzle Weight Improvements

- Cycle Refinements
- Careful Airframe/Engine Matching

The combination of these improvements has amounted to an increase in all supersonic Mach 2.4 range of 370 to 740 km (200 to 400 nmi) when the engines are sized to meet FAR Part 36 (1969) noise levels at balanced field lengths of 3200 to 3780 m (10,500 to 12,400 ft.).

3.3 VCE CYCLE IMPROVEMENTS

One of the items that has improved the double bypass VCE performance is the oversize front block fan which has been defined in NASA Contract NAS3-20041. This fan definition has the desired flow-speed relation for the double bypass VCE application and operates at approximately 30 m/sec (100 ft/sec) lower tip speed than the previous J101 aerodynamic design VCE fan. This lower tip speed, coupled with the higher technology available today, has resulted in higher fan efficiency ($\sim$ 2%).

A reduction in turbine cooling flow was attained by introduction of a cooling-air cooler which also resulted in slightly improved turbine efficiencies with the lower cooling flows. The major cycle performance improvement was a decrease in cycle bypass ratio from 0.35 to 0.25 and a reduction in overall cycle pressure ratio. This reduction in bypass ratio resulted in higher dry (non-afterburning) specific thrust at the supersonic cruise point and, when combined with higher corrected airflow capability from the lower cycle pressure ratio, gave about 23% higher thrust. This thrust increase allows the engine to be scaled down in size and still meet the aircraft thrust requirements. Table 3-1 compares both 10% and 20% high-flow double bypass VCE's and shows the major cycle differences, with the resulting supersonic cruise thrust and specific fuel consumption improvements. The nominal condition listed in the table refers to single bypass operation with the front block fan speed reduced to supply only the airflow required by the second block fan. This nominal condition is also the design point for the second block fan. The front block is designed for higher flow in the double bypass mode.

3.4 MISSION RANGE RESULTS

The engines were flown in the NASA SCAR arrow wing airplane as defined in NASA CR 132347, with a 345, 643 kg (762,000 lb) takeoff gross weight and 292 passengers. Figures 3-1 through 3-4 provide a range comparison of 10% and 20% high-flow variable cycle engines of the latest technology and operation with the baseline VCE's (GE21/J11B5 and J11B3) from the Phase III study. These curves are plotted against high-flow (takeoff) airflow corresponding to front block design conditions on Table 3-1. Figure 3-1 shows the difference in range between the Phase III baseline 10% and 20% high-flow VCE's. At the high airflow sizes, the 20% shows higher range capability than the 10%. This occurs because the 20% engine has a smaller core than the 10% for the same takeoff airflow and is thus lighter. The larger thrust capability of the 10% VCE is mismatched to the airplane cruise thrust requirements at the high takeoff airflow sizes, and the 10% VCE is always heavier than the 20% at the same

Table 3-1. Comparison of 10% and 20% High-Flow Double Bypass VCE's.

	10% High-Flow		20% High-Flow	
Engine, GE 21	J11B5	J11B9	J11B3	J11B15A
Engine, BPR (nominal, SLS)	0.35	0.25	0.35	0.25
Engine, Overall PR	17.3	16.1	17.3	16.2
Fan Overall PR	4.0	3.7	4.0	3.7
Fan - Block I				
SLS Design Corrected Airflow				
kg/sec	340	336	372	372
(lb/sec)	(750)	(740)	(821)	(821)
Design PR	2.88	2.88	3.17	3.17
SLS Airflow kg/sec	318	318	318	318
(lb/sec)	(700)	(700)	(700)	(700)
SLS PR	2.7	2.7	2.7	2.7
Fan - Block II				
Design Airflow kg/sec	140	140	140	140
(lb/sec)	(308)	(309)	(308)	(309)
Design PR	1.48	1.36	1.48	1.36
Supersonic Cruise				
M= 2.32, Std + 8° C (14.4° F)				
T_3 ° C	597	606	600	606
° F	(1133)	(1150)	(1137)	(1150)
T_{4_1} ° C	1468	1468	1468	1468
° F	(2700)	(2700)	(2700)	(2700)
Corrected Airflow kg/sec	214	231	214	231
(lb/sec)	(472)	(510)	(472)	(510)
FNIN, N	73,459	90,205	73,396	86,976
(lbs)	(16,515)	(20,280)	(16,501)	(19,554)
SFCIN, kg/Nc/N	0.1414	0.1364	0.1419	0.1370
(lb/hr/lb)	(1.387)	(1.338)	(1.391)	(1.343)
Engine Max Dia, M	2.0	1.86	2.0	1.94
(in)	(78.8)	(73.2)	(78.8)	(76.5)
Engine Weight, kg	5801	5693	5965	5965
(lbs)	(12,800)	(12,550)	(13,150)	(13,150)

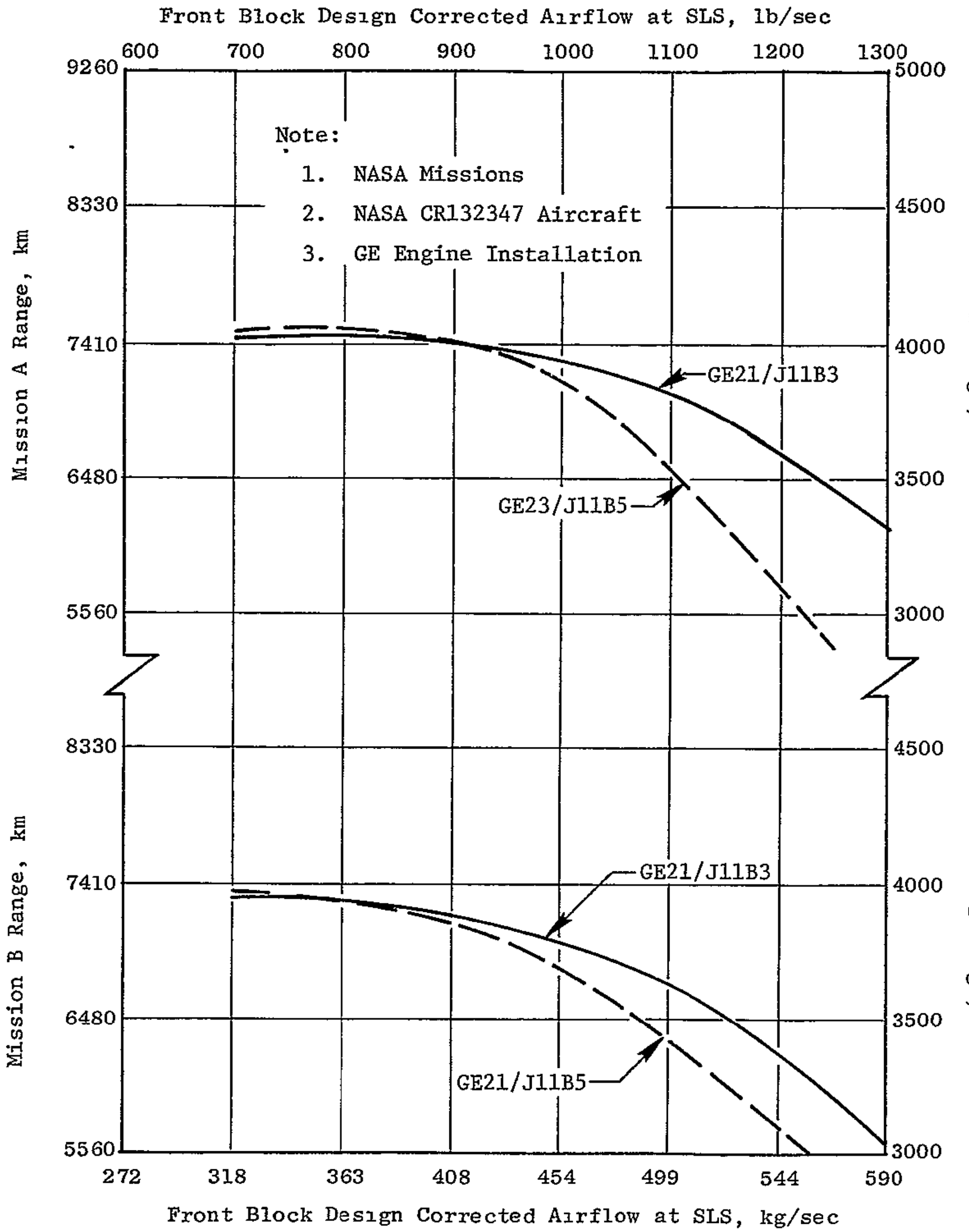


Figure 3-1. Comparison of SCAR Phase III 10% and 20% High-Flow Variable Cycle Engines.

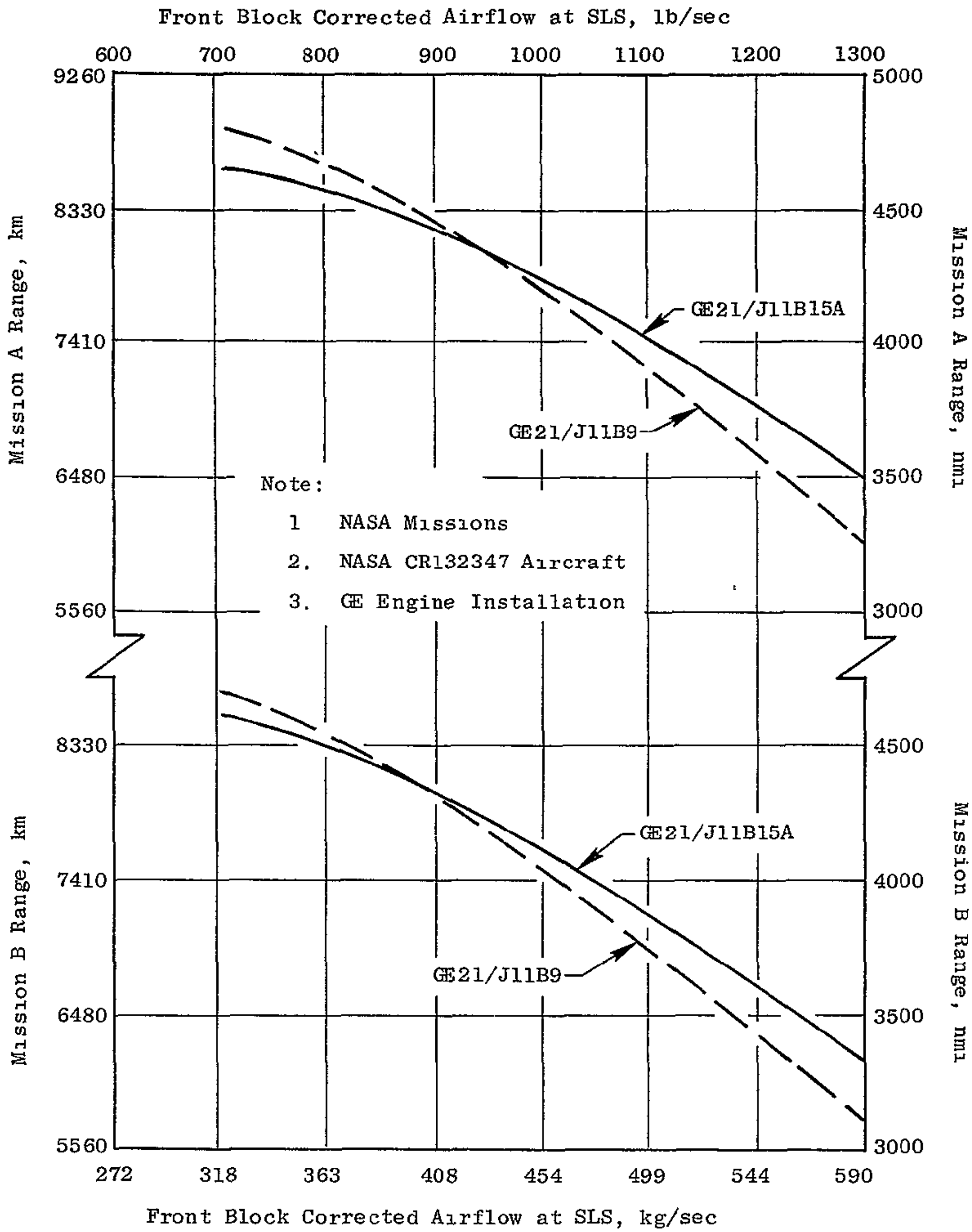


Figure 3-2. Comparison of Current 10% and 20% High-Flow Variable Cycle Engines.

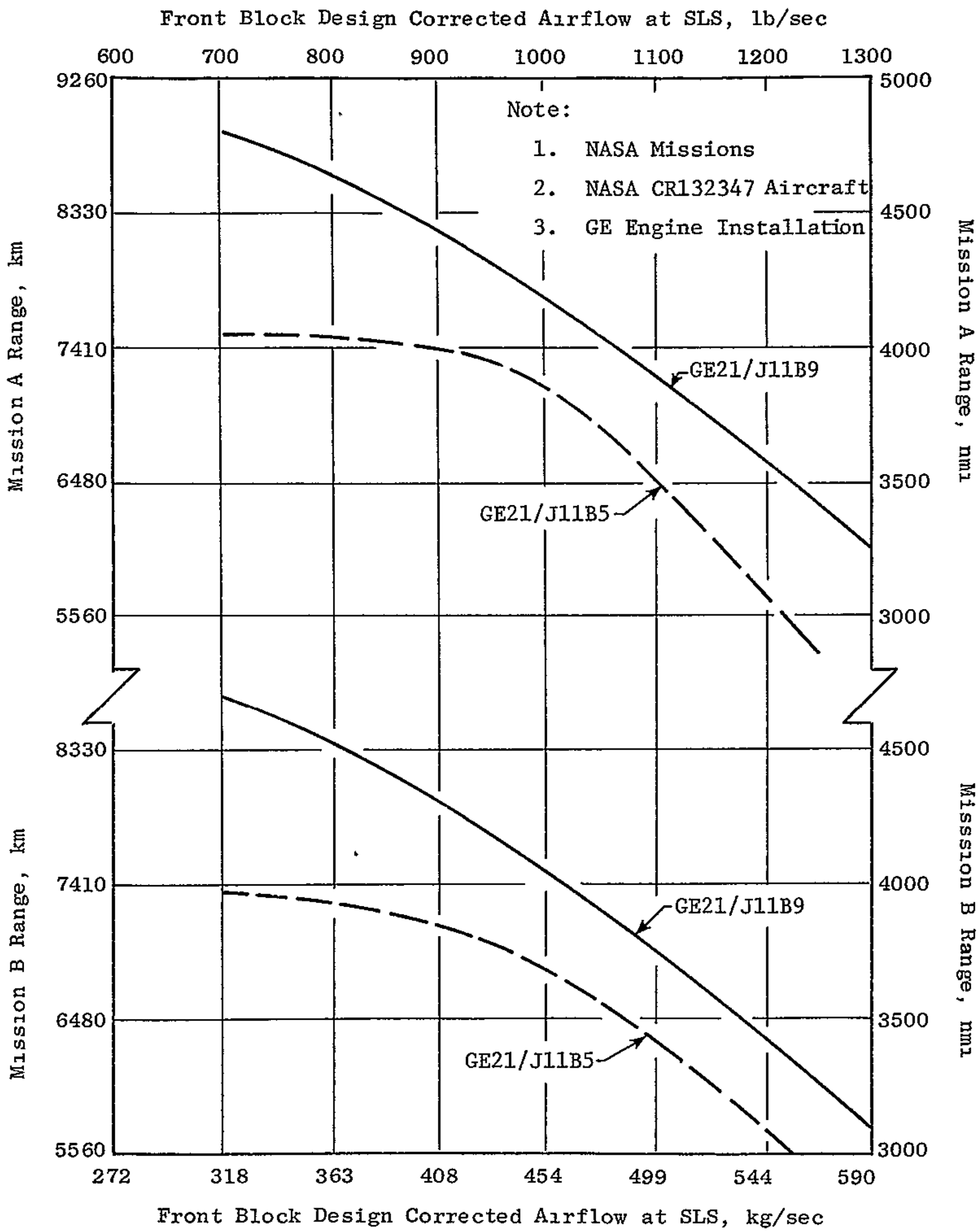


Figure 3-3. Comparison of SCAR Phase III and Current 10% High-Flow Variable Cycle Engines.

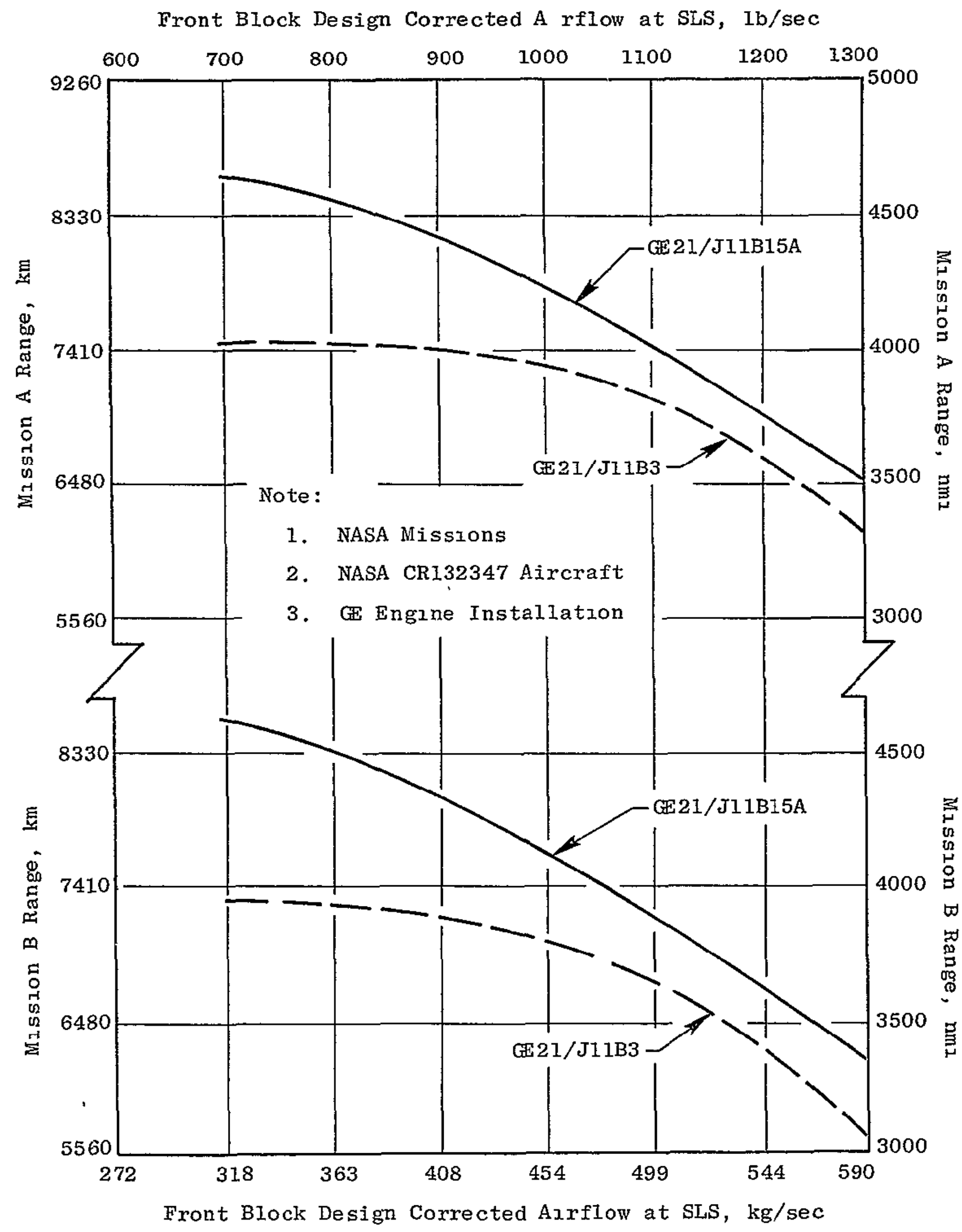


Figure 3-4. Comparison of SCAR Phase III and Current 20% High-Flow Variable Cycle Engines.

takeoff airflow. The higher thrust potential of the 10% high-flow VCE (at the same takeoff airflow) overcomes the weight advantage of the 20% VCE at the lower airflows and results in the 10% high-flow VCE being better at the smaller sizes.

Figure 3-2 shows the same comparison for the latest VCE's and the same trends are apparent. In this case, the range capability for each VCE at all airflow sizes has increased dramatically over Figure 3-1, showing the benefits of the performance and cycle improvements. Figures 3-3 and 3-4 compare directly the 10% high-flow VCE (Figure 3-3) and the 20% high-flow VCE improvements (Figure 3-4). At the smallest takeoff airflow size, these improvements are from 1111 to 1296 km (600 to 700 nmi). The increased slope (at low airflow sizes) of the new engine curves results from the lower engine pressure ratio and increased supersonic cruise airflow capability which decreases the need for afterburning operation and thus improves sfc.

The performance improvements incorporated in both the 10% and 20% VCE's were accomplished for the same or even slightly lower weight (Table 3-11) in spite of a reduction in bypass ratio and the addition of a turbine cooling-air cooler. This was accomplished mainly in the exhaust nozzle through reductions in length and diameter caused by a careful re-evaluation of the exhaust nozzle requirements and design.

3.5 NOISE SIZING

All of the VCE's studied utilize a coannular acoustic exhaust nozzle with no mechanical suppressor. The takeoff airflow size to meet the takeoff thrust requirement and FAR 36 (1969) noise levels is shown on Figures 3-5 and 3-6 for the 10% and 20% high flow engines respectively.

The airflow size is shown for traded FAR 36-0 (1969) for both the 273, 207N (61,400 lb.) thrust takeoff [3200M (10,500 ft) Balanced Field Length, BFL] and 237,968N (53,500 lb.) thrust takeoff [3780M (12,400 ft.) BFL]. The airflow size for each takeoff thrust is about the same for all engines since the mass weighted average jet velocity is essentially fixed for a constant jet noise. This actually is affected slightly by variables such as area ratio, radius ratio and flow ratio, but these are second order effects. The overall engine noise is also affected by other engine noise contributors which have not been considered in this study. Figures 3-5 and 3-6 also show that the 20% high-flow VCE is clearly better than the 10% version at the 3200M (10,500 ft.) BFL, [222 km (120 nmi) range superiority, all supersonic] but at the 3780 M (12,400 ft.) BFL the range difference has dropped to 37 km (20 nmi). These curves tend to confirm the results of the Langley System Contractors' results, which show that the delta range between the 10% and 20% high flow VCE's, at the smaller takeoff sizes of 295-340 kg/sec (650-750 lbs/sec), is about 185 km (100 nmi) in favor of the 10% high-flow VCE. If a noise level lower than FAR 36 (1969) became the goal, the 20% oversize fan would show more advantage, since the takeoff airflow would become larger (lower exhaust velocity at the same thrust), and move the engine size to the region where the 20% tends to give a better range than the 10% engine.

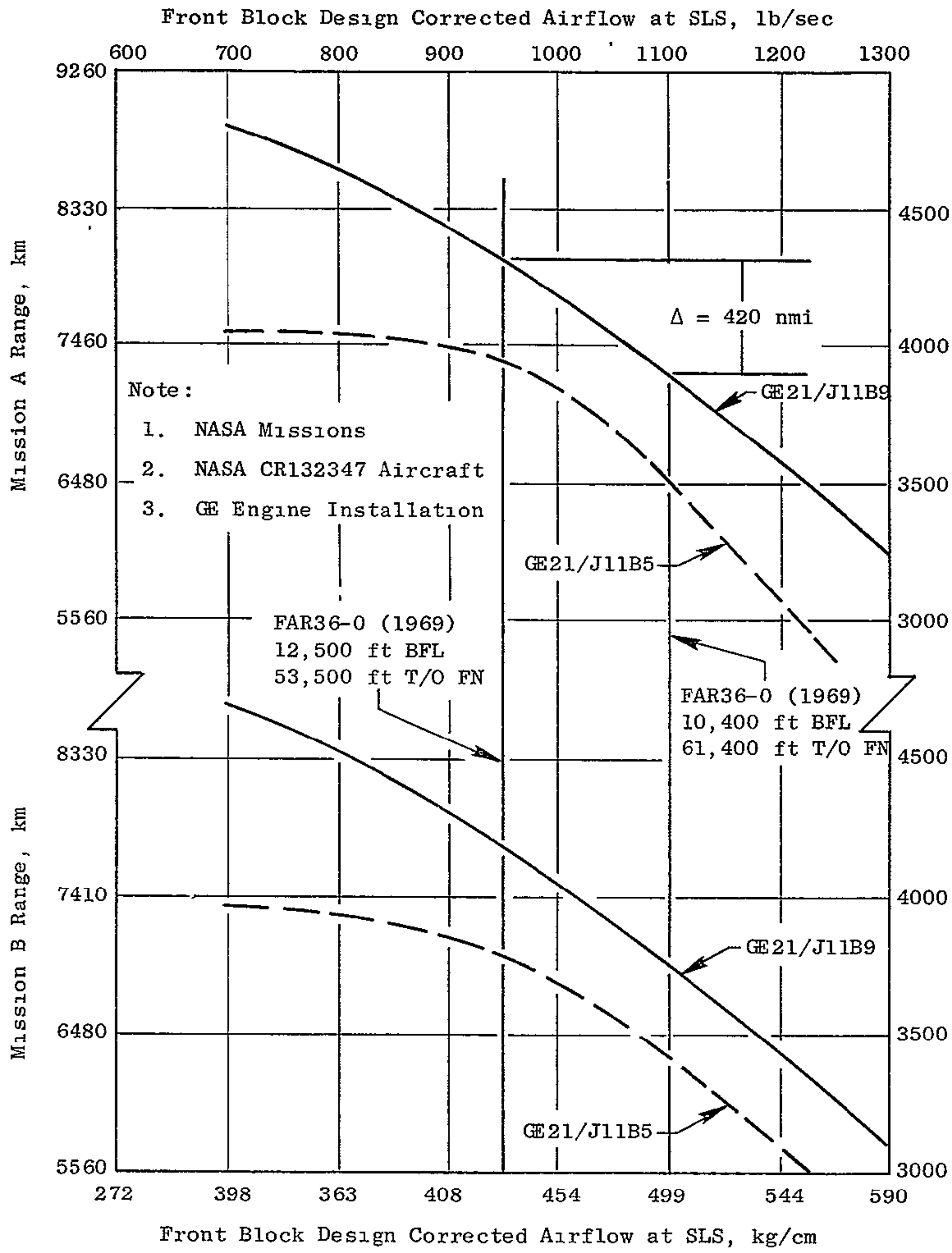


Figure 3-5. Comparison of SCAR Phase III and Current 10% High-Flow Variable Cycle Engines

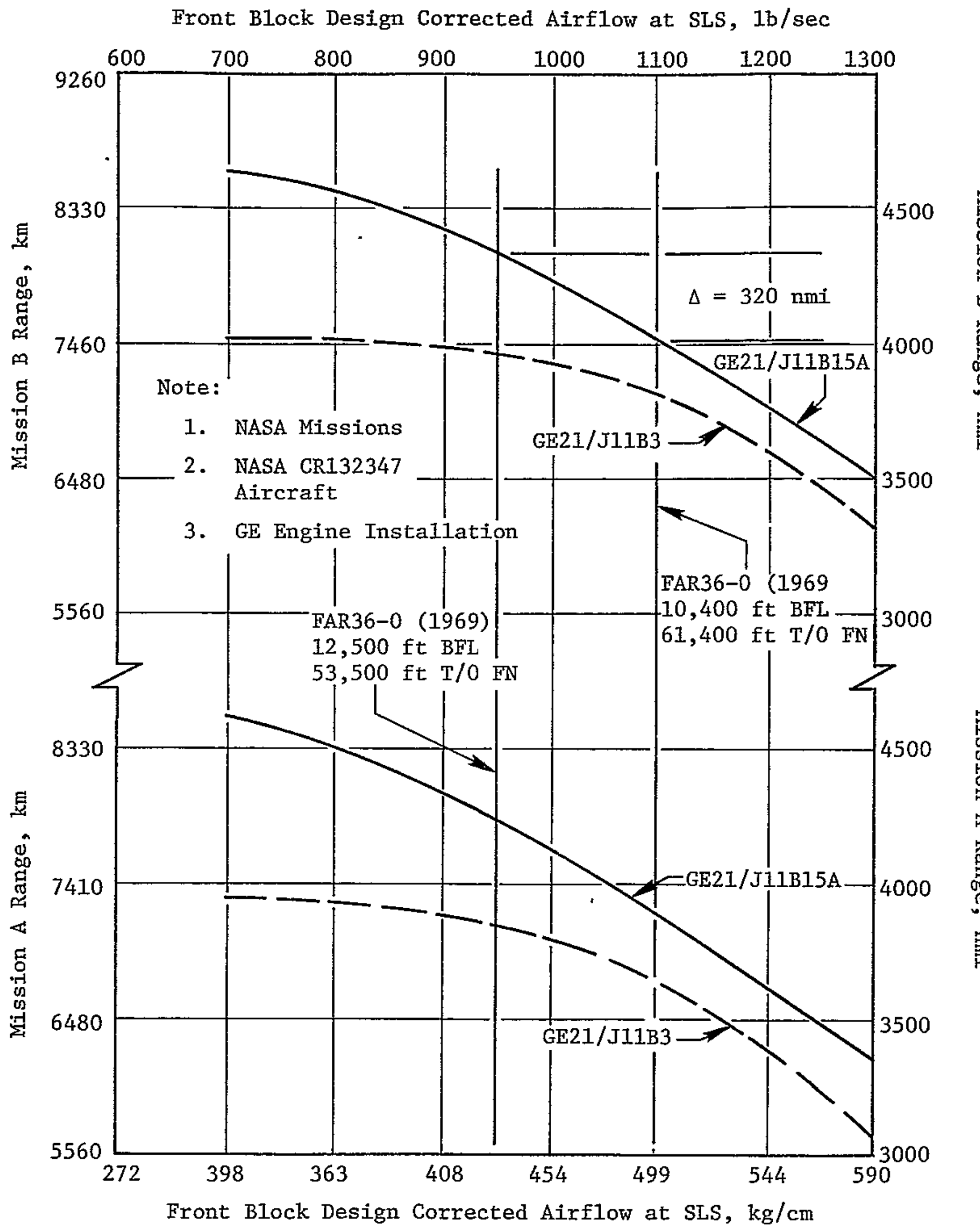


Figure 3-6. Comparison of SCAR Phase III and Current 20% High-Flow Variable Cycle Engines

4.0 TESTBED ENGINE DEFINITION AND PRELIMINARY DESIGN

4.1 INTRODUCTION

In the initial phase of the Core Driven Fan Stage (CDFS) design, two engine configurations were studied: Configuration C, an "Uncoupled Design" (U/C), and Configuration D, a "Close Coupled Design" (C/C). These configurations differ in design philosophy as follows:

- Configuration C - Uncoupled Design
  This design maximizes the use of existing YJ101 and VCE hardware. In order to accomplish this, the flow path and engine length are substantially increased (hence, the definition - uncoupled).

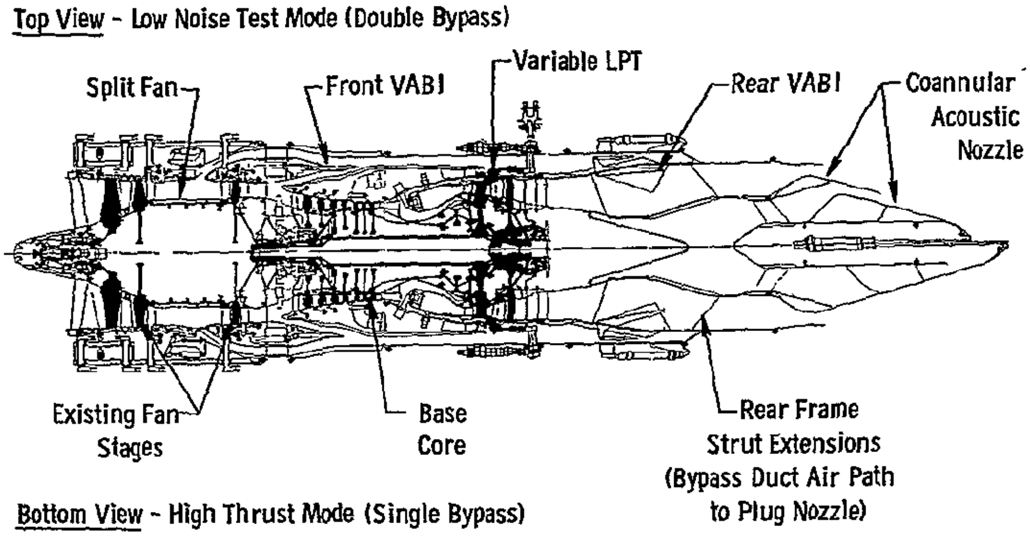
- Configuration D - Close Coupled Design
  This design is aimed at simulating a product type CDFS configuration to the maximum practical extent. This provides for a shorter/more compact flowpath and engine length (hence, the definition - close coupled).

For both configurations, the aerodynamic definition of the aft fan block stage is the same insofar as the IGV and rotor are concerned.

Although the U/C design was less expensive due to a greater commonality of parts with the YJ101 engine and the existing 2X1 Forward VABI Demo Engine, The C/C configuration was selected as the VCE Testbed Demo engine because it more closely resembles a product engine, better incorporates the significant aerodynamic features of a product design aft fan block and Forward VABI ducting, and has a simpler and lower risk bearing system (i.e. one less bearing).

Technology derived from the 2X1 Forward VABI/Early Acoustic Test Demo has been incorporated in the VCE Testbed Demonstrator. Figure 4-1 shows a comparison of these two demonstrator engine layouts. The Testbed Demonstrator Engine differs from the Forward VABI/Early Acoustic Test Demonstrator Engine in that the 3rd fan stage (aft fan block) of the 2X1 split fan is attached and driven by the high speed (core) shaft, permitting the engine to be shortened approximately 0.178 m (7 in.) and the diameter at the forward engine mount to be decreased by approximately 0.305 m (12 in.). The strut-mounted flap type selector valve for the Forward VABI is located axially in the plane of the structural frame and is comprised of multiple flaps between struts, rather than being a 360° translating ring selector valve of the type used in the NASA 2X1 Forward VABI Demonstrator Engine. The aerodynamic and mechanical features of the inner bypass modulating valve of the Forward VABI are used in the Testbed Engine Demonstrator design with only slight modifications for flowpath adaptation.

INITIAL DOUBLE BYPASS VCE NOISE TEST CONFIGURATION



CORE DRIVEN 3rd STAGE CONFIGURATION

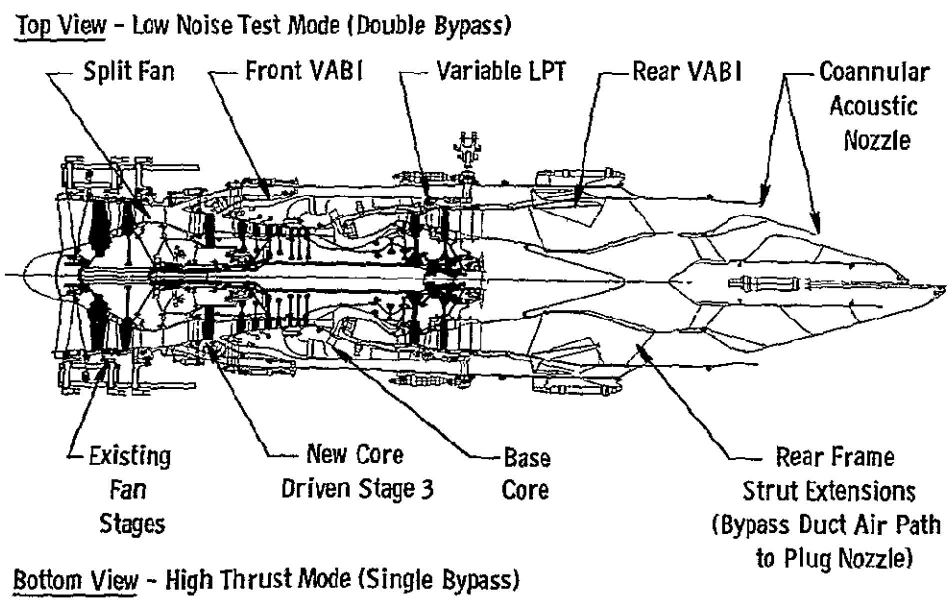


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Figure 4-1. Early Acoustic Test and Testbed Demonstrator Engines.

4.2 OBJECTIVES

The design objectives for the Testbed Demonstrator are the following:

1. To define a YJ101 VCE demonstrator engine configuration which most closely resembles the proposed SCAR/VCE double bypass product engine design.

2. To incorporate the advanced aerodynamic feature of the core-driven fan stage in conjunction with previously demonstrated VCE features.

3. To select a demonstrator engine configuration which minimizes risks in mechanical and aerodynamic design and engine dynamics.

4. To incorporate technology derived from prior VCE demonstrator test experience to improve aerodynamic and thermodynamic performance.

5. To incorporate, to the maximum extent practical, the available hardware from previous VCE demonstrator engines and thus minimize design and hardware cost and risk.

6. To utilize commercially available raw materials (AMS) and associated subcomponent hardware fabrication of the Testbed Engine components to minimize costs.

7. To design and fabricate a simple detachable suppressor for incorporation in the outer stream of the coannular acoustic nozzle.

The design effort will culminate in sequential procurement, assembly, instrumentation and test of a core engine and a complete engine. These tests will verify the performance characteristics of the core-driven fan stage concept and further evaluate the acoustic benefits of the coannular nozzle concept, including the noise reduction benefits achievable with a simple outer stream mechanical suppressor.

4.3 SUMMARY

The Testbed Demonstrator Engine is a modified version of the VCE Early Acoustic Test Demonstrator (EATD). Features to be retained from the EATD are:

- Forward Fan Block (two stages of 2X1 split fan).
- Forward VABI - Principal aerodynamic and mechanical features.
- Variable Area LP Turbine - Same as in forward VABI and acoustic nozzle demonstrator.
- Rear VABI - With modifications as may be required.
- Acoustic Nozzle - Based on test results from the Early Acoustic Test.

The rear fan block (core-driven fan stage) will be attached to and driven by the core rather than the LP system to take advantage of the improved turbine work split in this arrangement. The high-pressure turbine loading increases with a corresponding decrease in low pressure turbine loading. In the product/study engine this reduces the inlet temperature to the LP turbine and reduces the LP turbine cooling requirements. Thus an overall cycle performance and sfc improvement will be realized by this HP/LP loading arrangement in the product engine design.

4.4 PRELIMINARY CDFS AERODYNAMIC DESIGN AND ANALYSIS

The aerodynamic design point for the core-driven fan stage is at the single bypass, high specific thrust point at sea-level static conditions. At this condition the maximum airflow point is attained for the core fan stage as it must pass the entire front block flow. In the test bed engine, the YJ101 high pressure compressor operates at 91 percent of its aerodynamic design corrected speed.

The corresponding principal design point aerodynamic parameters for the core-driven fan stage are tabulated below:

Physical rpm		14,767	
Corrected Tip Speed (ft/sec)		381 m/sec (1250.7 ft/sec)	
Stage Total Pressure Ratio		1.37	
Inlet Radius Ratio			
Physical Airflow (lbm/sec)		46.2 kg/sec (102 lb/sec)	
Corrected Airflow (lbm/sec)		23.4 kg/sec (51.6 lb/sec)	
Corrected Flow-Annulus Area (lbm/sec ft^2)		175.7 kg/sec m^2 (36.0 lb/sec ft^2)	
Design IGV Pre-Swirl Angle, deg.			
	O.D.	10	10
	I.D.	0	0

The flowpath, specific airflow, inlet radius ratio, and tip speed were largely determined by the exit Mach number from the front fan block, and the entering Mach number of the high pressure compressor. It is desirable to avoid any large acceleration or deceleration of the flow between the front block fan and the high pressure compressor. The flow Mach number leaving the front fan block is about 0.49 and the Mach number entering the high pressure compressor is approximately 0.41 at the rear block design conditions. The specific airflow of 175.7 kg/sec m^2 (36 lb/sec ft^2) chosen for the core-driven fan stage represents a Meridional Mach number of about 0.5 which is essentially the same as that leaving the fan front block and requires only a modest change in axial velocity across the fan to get the flow to the required high pressure compressor inlet Mach number. The choice of the flow per annulus area and the inlet radius ratio determined the fan tip diameter. Since the physical rpm was set by the core compressor, the core-driven fan rotor tip speed was automatically set. Analysis using the General Electric stall prediction procedure indicated that this tip speed would provide ample stall margin.

Thirty-eight fan blades with a radially constant chord of 0.06 m (2.37 in.) were selected for the preliminary design. This results in a rotor aspect ratio of 1.4 and a tip solidity of 1.286 and hub solidity of 1.83. The aspect ratio of 1.4 is concluded to be sufficiently low to avoid aeromechanical flutter problems without shrouds.

A variable inlet guide vane (IGV) is required to low-flow the fan during double bypass operation. A flap type, or articulated, IGV was selected to minimize the losses when the guide vane is closed a large amount. The front portion of the vane is fixed and only the aft portion moves. This configuration keeps the incidence angle nearly constant when the flap is closed, thus avoiding extremely high incidence angles in the closed position which would occur with a conventional single piece guide vane.

A preswirl of 10° at the O.D. decreasing to zero degrees at the I.D. was selected since efficiency predictions indicated that the reduced Mach number on the rotor resulted in about 1.5 points improvement in efficiency at the aero design point relative to a no preswirl configuration. The resulting rotor inlet relative Mach number and the rotor Diffusion Factor are shown in Figure 4-2. Rotor Diffusion Factor is defined as follows:

$$\frac{1 - V_2^1}{V_1^1} + \frac{R_2 V\theta_2 - R_1 V\theta_1}{2\sigma \bar{R} V^1}$$

where: V_1^1 - relative velocity at the rotor inlet (fps)

V_2^1 - relative velocity at the rotor exit (fps)

$V\theta_1$ - circumferential velocity at the rotor inlet (fps)

$V\theta_2$ - circumferential velocity at the rotor exit (fps)

R_1 - radius at the rotor inlet (feet)

R_2 - radius at the rotor exit (feet)

$\bar{R}$ - Average of the rotor inlet and exit radii (feet)

σ - Cascade solidity (chord divided by circumferential spacing)

A flow splitter located a short distance downstream of the core-driven fan rotor divides the flow between the core, or high pressure compressor, and the inner bypass duct. The inner (core portion) stator actually serves a dual purpose; it is both a core fan stator, and a high-pressure compressor variable guide vane (IGV). There is approximately 22.6 degrees of swirl left in the flow leaving this vane at the fan aero design point, which is consistent with

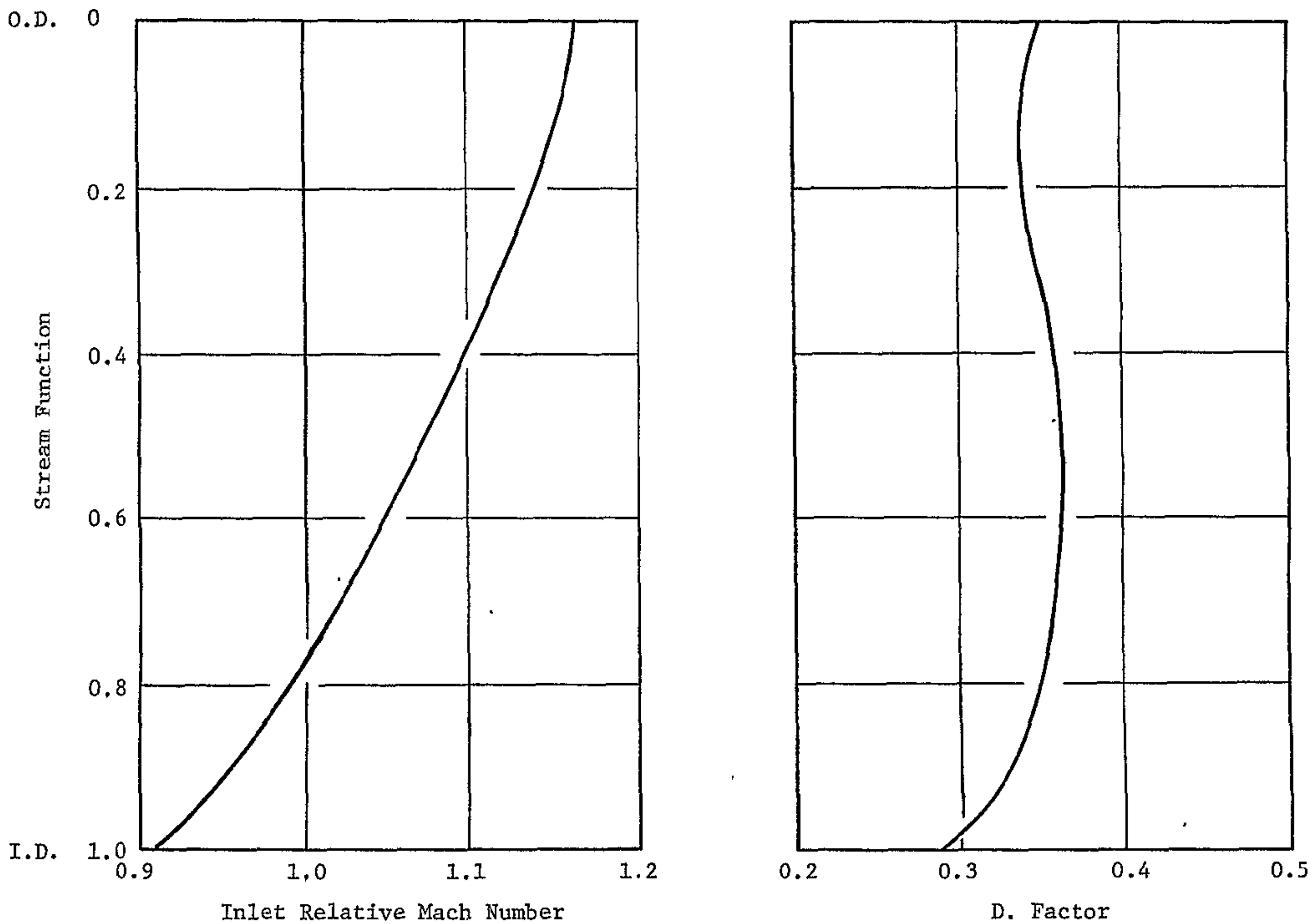


Figure 4-2. YJ101 AST Testbed Engine, Core Driven Fan Rotor, Single Bypass.

the requirements of the YJ101 IGV when operating at this condition (91% aero speed). A solidity of 1.25 was selected for this vane. The inlet Mach number and the Diffusion Factor for this core portion vane is shown in Figure 4-3.

The inlet Mach number and the Diffusion Factor loading parameter for the bypass outlet guide vanes at the single bypass aerodynamic design point are shown in Figure 4-4.

During double bypass operation, the outer bypass selector valve is opened and almost one-third of the front block fan flow passes through the outer bypass duct. The rear block fan variable inlet guide vanes are closed about 33 degrees from their design setting to make the CDFS pumping characteristic compatible with the reduced flow requirement. The inlet relative Mach number and the Diffusion Factor for the core-driven fan rotor during double bypass operation are shown in Figure 4-5. There is a significant radial redistribution of the axial velocity behind the core fan IGV when it is closed a marked amount. This leads to a redistribution of the relative flow angle entering the rotor blade. Figure 4-6 compares the rotor relative inlet air angle (measured from axial) during double bypass operation with the design values.

The inlet Mach number and Diffusion Factor for the core portion stator/IGV are shown in Figure 4-7. The closed IGV increases the swirl behind the rotor, tending to increase the aerodynamic loading of the stator. However, for the core stream, this is partially offset due to the fact that the high pressure compressor is operating at a lower corrected speed, and with a more closed IGV than in the single bypass operation.

The inner bypass ratio is considerably lower during double bypass operation than it is in single bypass. As a result, the flow exiting the inner bypass duct undergoes considerable diffusion between the rotor exit and the entrance to the bypass outlet guide vanes. This diffusion results in a considerable increase in the swirl angle between the rotor exit and the entrance to the outlet guide vanes.

To overcome this very high incidence angle and aerodynamic loading of the OGV's, unique "delta-wing" shaped, part span vanes are planned for use just aft of the fan rotor. These vanes will be designed for zero turning of the flow at the single bypass aerodynamic design point, but in double bypass they will be subjected to a significant increase in angle of attack. However, because of their proximity to the rotor trailing edge, the flow has not yet diffused much and hence the delta-wing vanes will not be subjected to nearly so large a swing in incidence angle as would the bypass OGV's (located further downstream in the inner bypass duct) in the absence of such vanes. Since the delta-wing cascade will remove some of the swirl in the double bypass operation, the bypass OGV's will not be subjected to as large an incidence angle as they otherwise would.

Even though the losses will probably be high in the inner bypass stream during double bypass operation, this flow represents only a small percentage

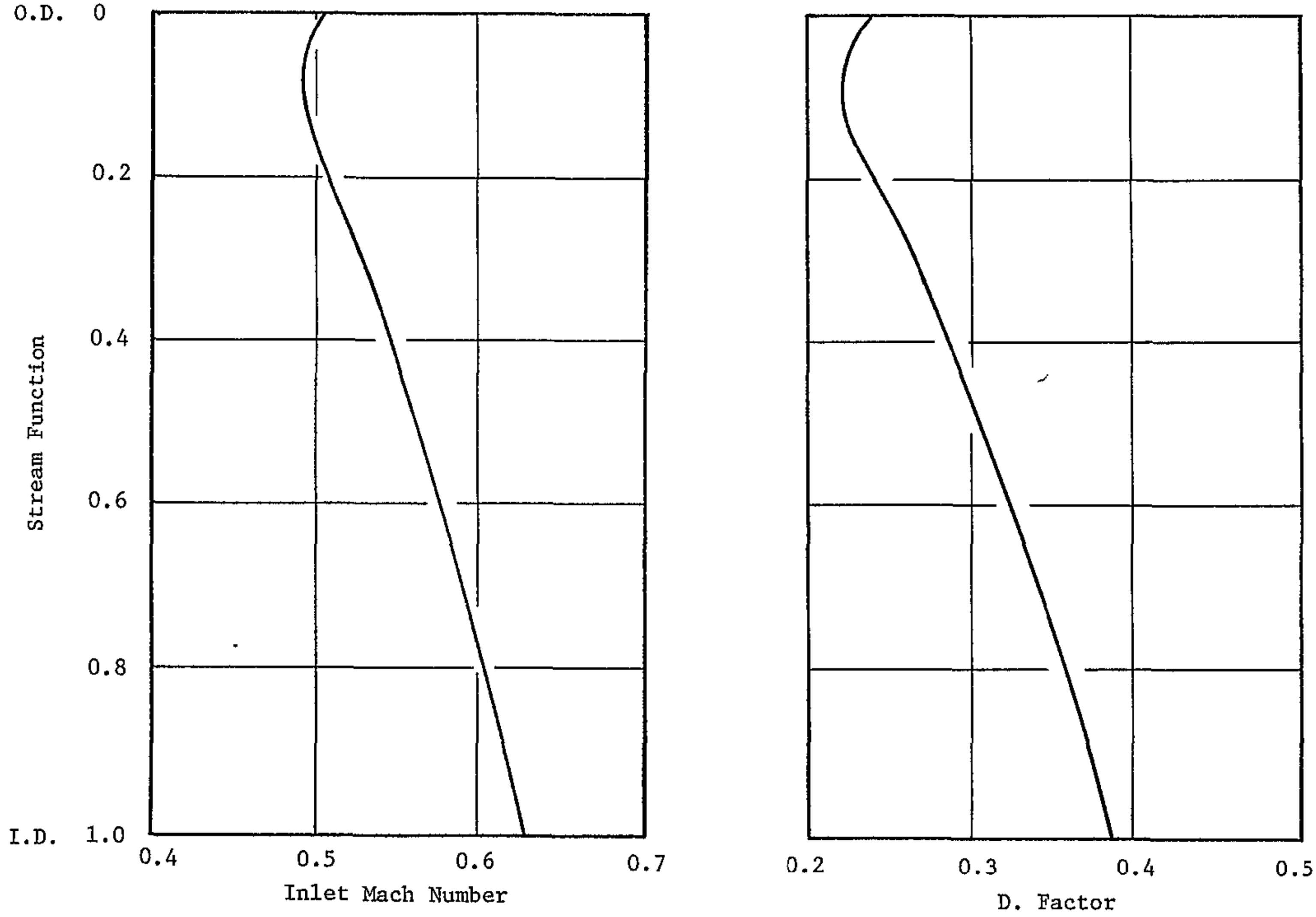


Figure 4-3. YJ101 AST Testbed Engine, Core Fan Stator/IGV (HPC), Single Bypass.

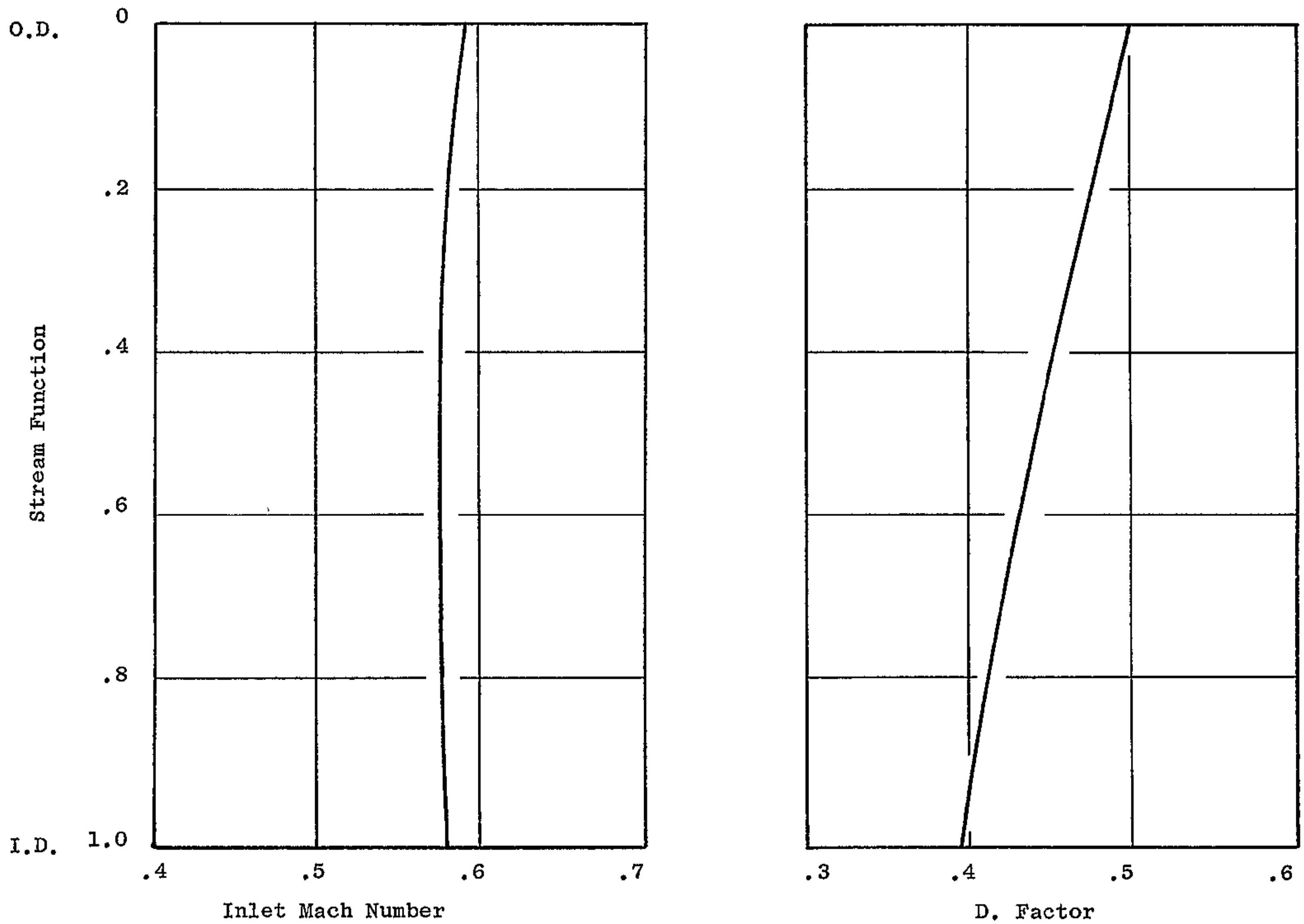


Figure 4-4. YJ101 AST Testbed Engine, Inner Bypass OGV, Single Bypass.

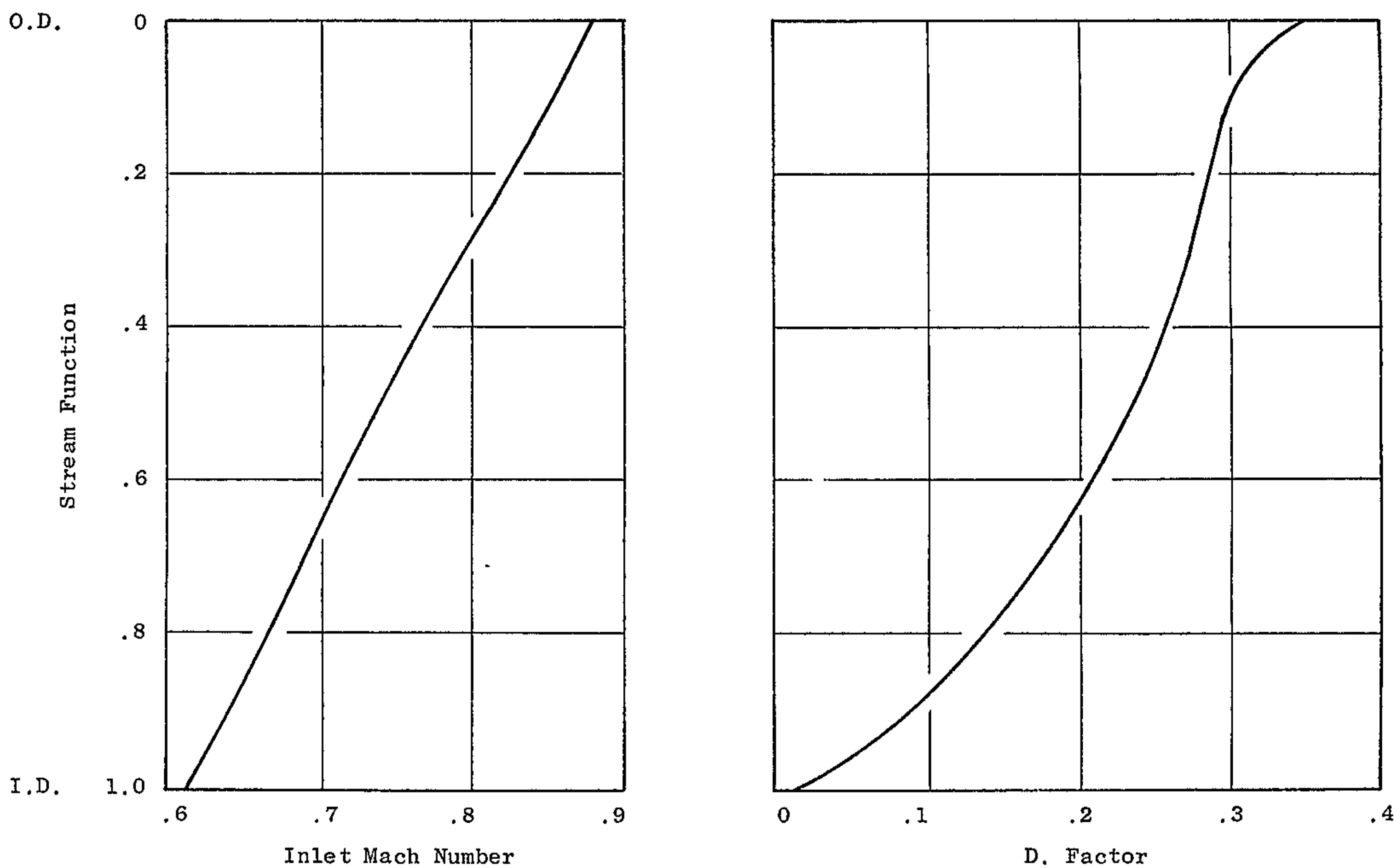


Figure 4-5. YJ101 AST Testbed Engine, Core-Driven Fan Stage Rotor, Double Bypass Operation.

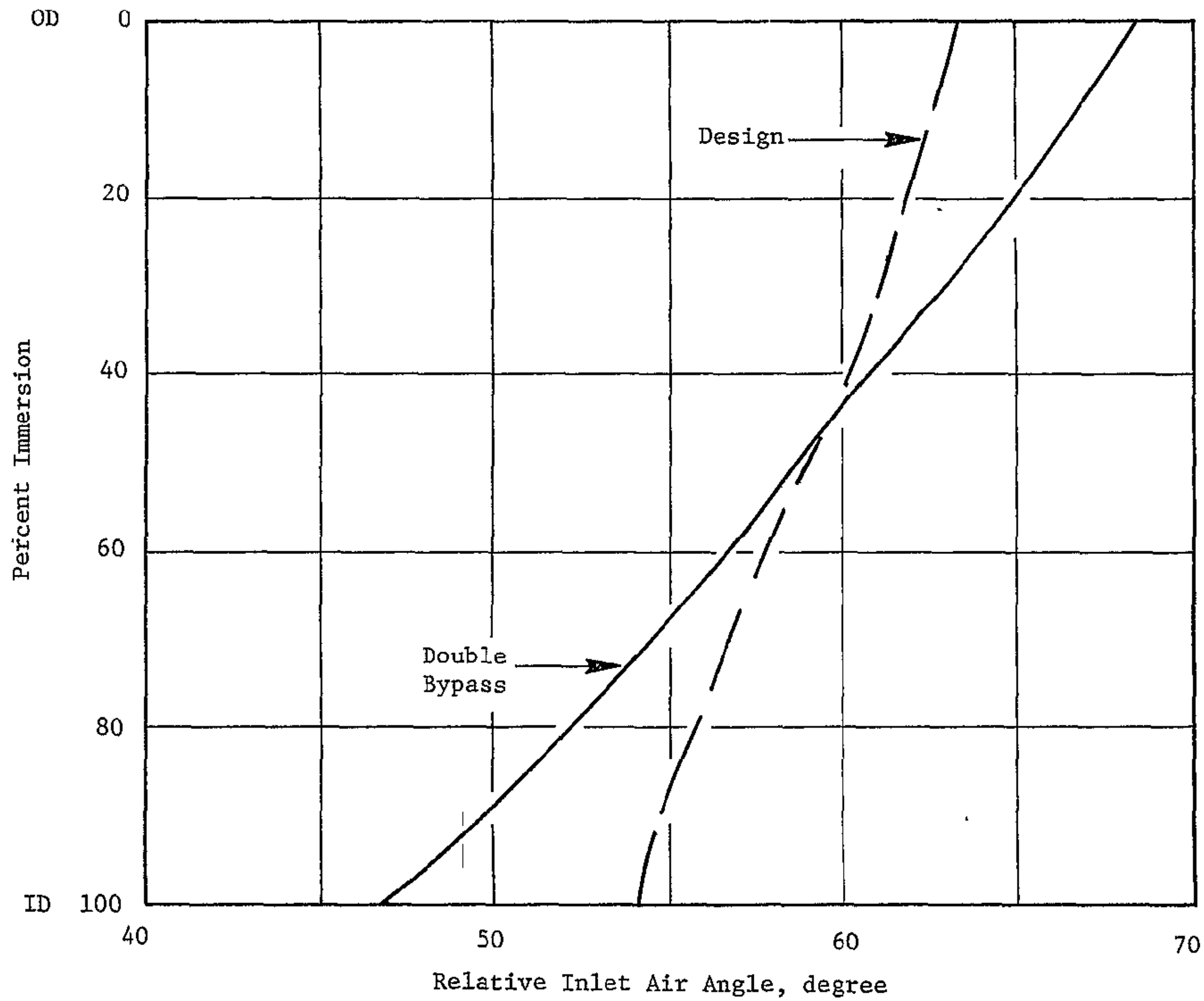


Figure 4-6. YJ101 AST Testbed Engine, Core-Driven Fan Rotor, Double Bypass.

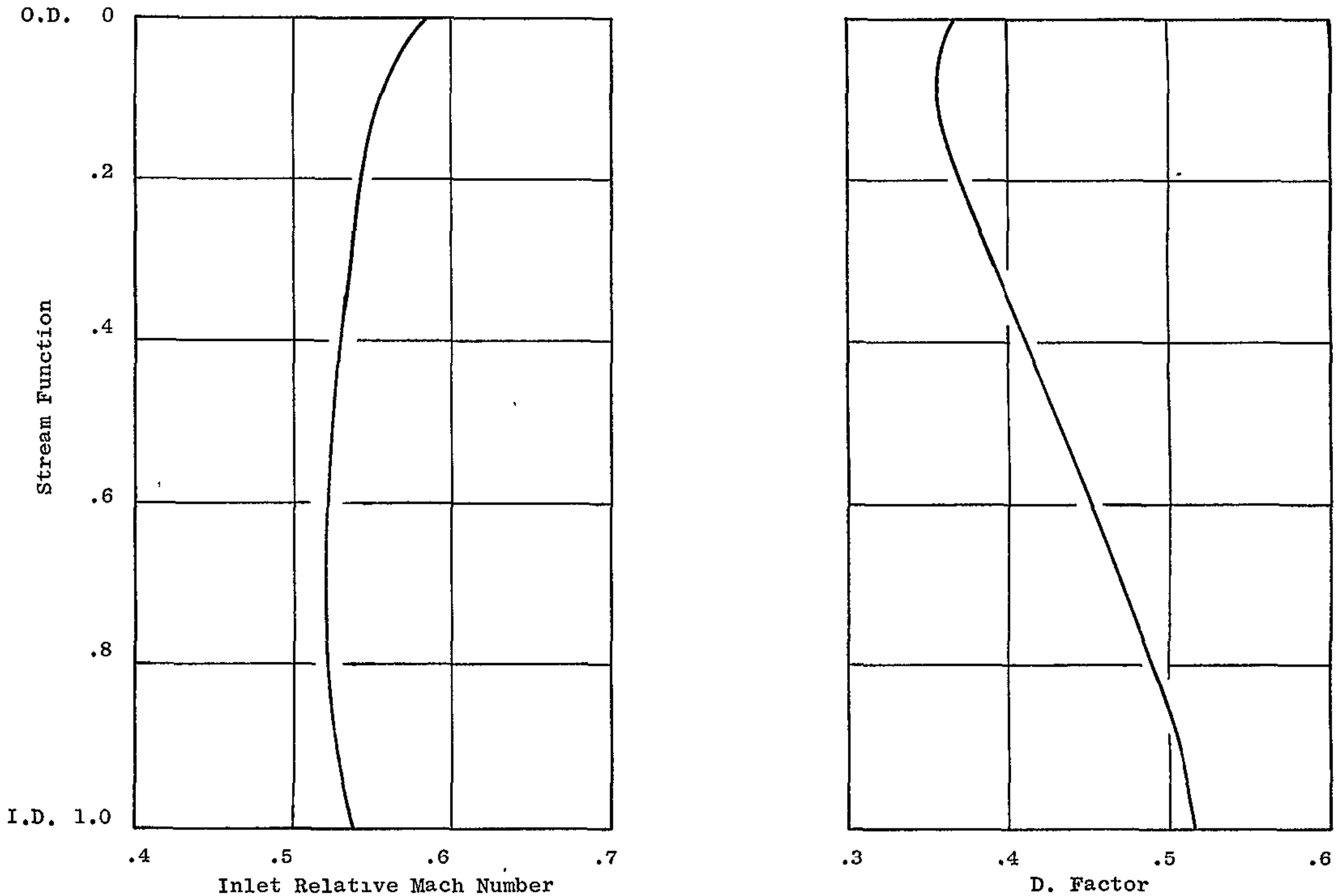


Figure 4-7. YJ101 AST Testbed Engine, Core Fan Stator/IGV (HPC), Double Bypass Operation.

of the total airflow. Calculations have shown that these losses will have a minimal effect on the overall engine performance.

4.5 PRELIMINARY FLOWPATH DEFINITION

The VCE Testbed Demonstrator (TBD) Engine CDFS flowpath configuration has been preliminarily defined and is illustrated in Figure 4-8. The first two fan stages of the standard YJ101 engine are used with adaptive hardware required to facilitate the new flow path and engine dynamic requirements. The flowpath definition satisfies both the CDFS aft fan block and forward VABI ducting requirements. Additional details of the forward VABI aerodynamic definition are shown in Figure 4-9.

4.6 ALTERNATIVE CONFIGURATION DESCRIPTIONS

The overall flowpath schematics for both the uncoupled and close coupled design configurations are compared in Figure 4-10.

The key mechanical sub-components of the selected configuration (Configuration D - close coupled) are individually described in Table 4-1. The corresponding description of Configuration "C" - the Uncoupled design is given in Table 4-2.

In both cases, utilization of existing hardware is employed to the maximum extent possible. However, this is the controlling consideration in Configuration C - particularly with respect to utilization of the existing structural frames. For both designs, materials used for fabrication of the new/special and adaptive hardware are commercially available AMS materials, where possible. Since the demonstrator engine weight is of minor importance relative to cost and aerodynamic concept verification, the mechanical design of the major sub-components is conservative with regard to stresses, deflections, etc. The mechanical design is consistent with prior YJ101 VCE concept demonstrators and is principally directed toward ease of manufacture and assembly, dimensional stability and low mechanical risk. Materials selected for the close coupled configuration reflect the capability for high temperature testing that may be desired in follow-on test programs.

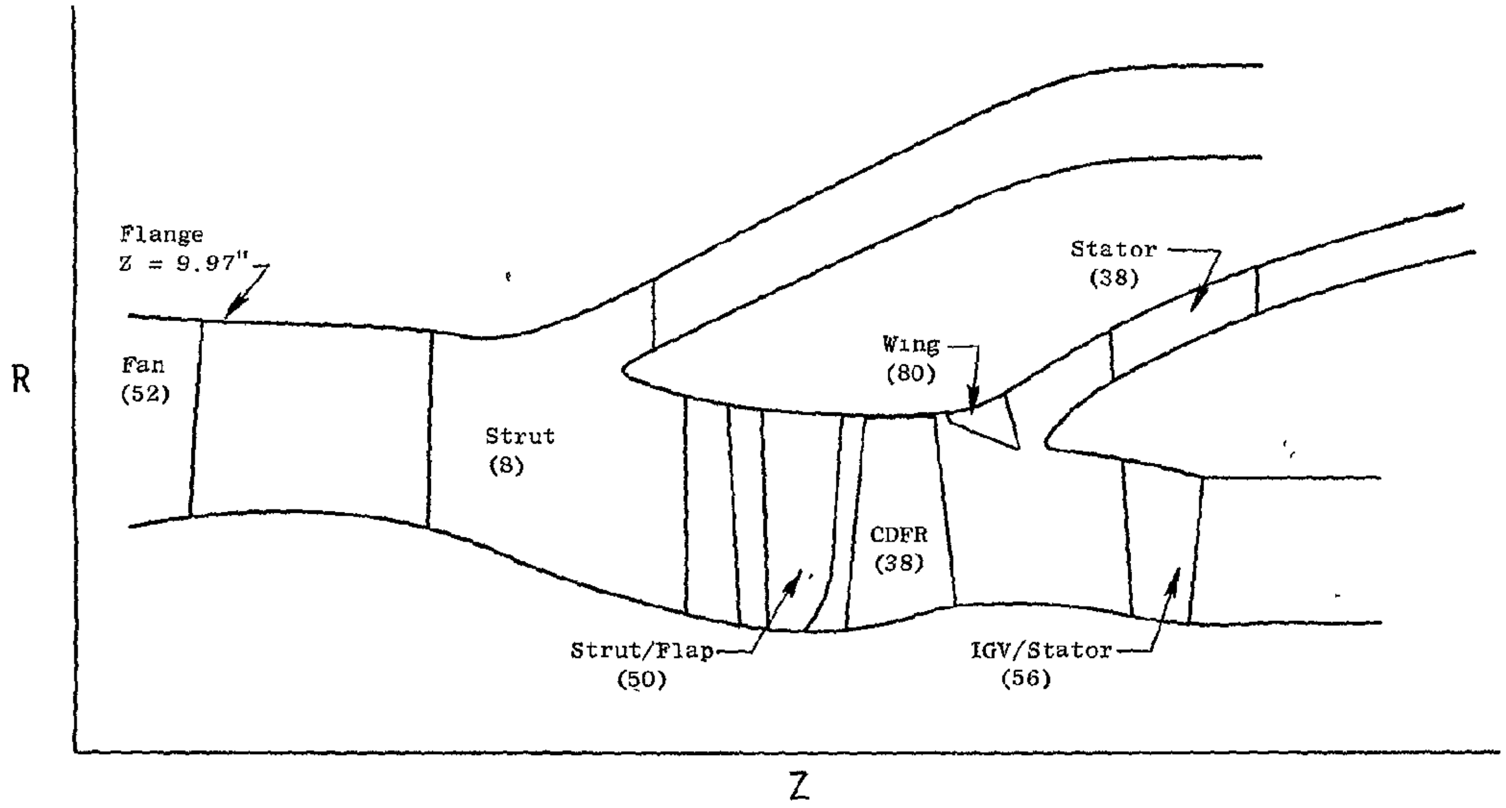


Figure 4-8. VCE Testbed Demo Core Driven Fan Stage Flowpath.

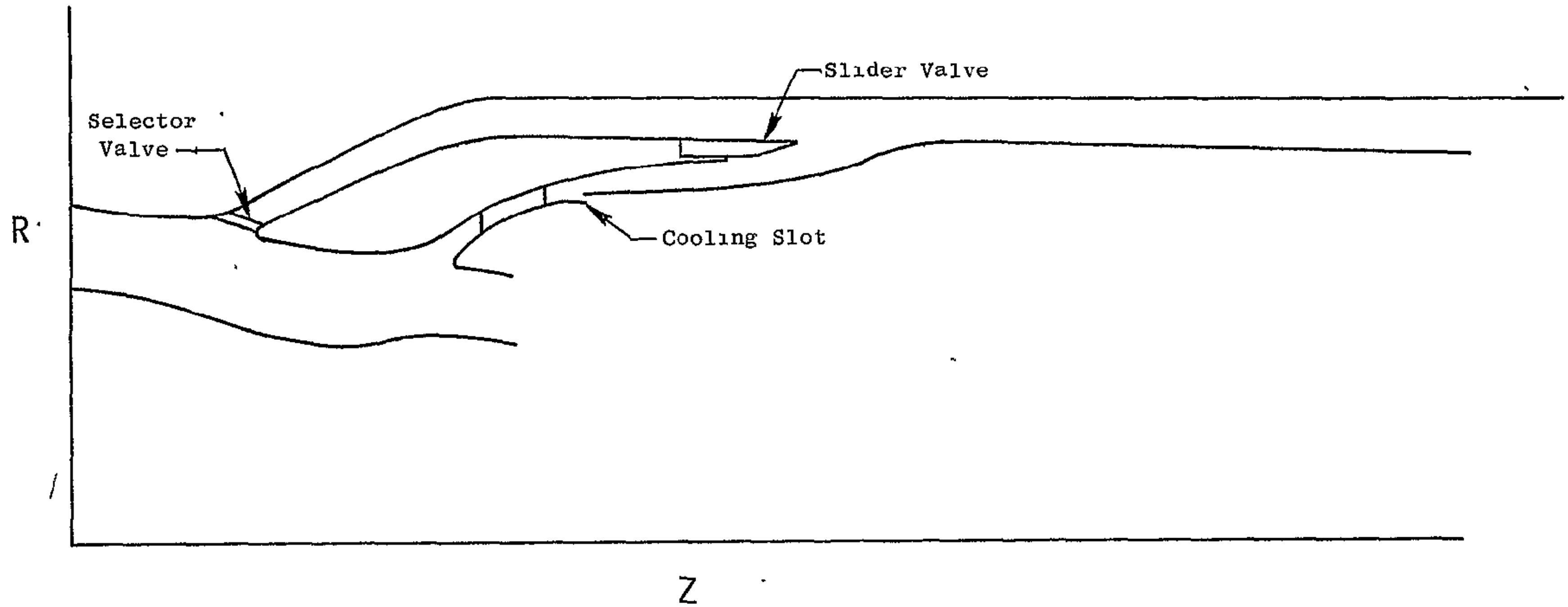
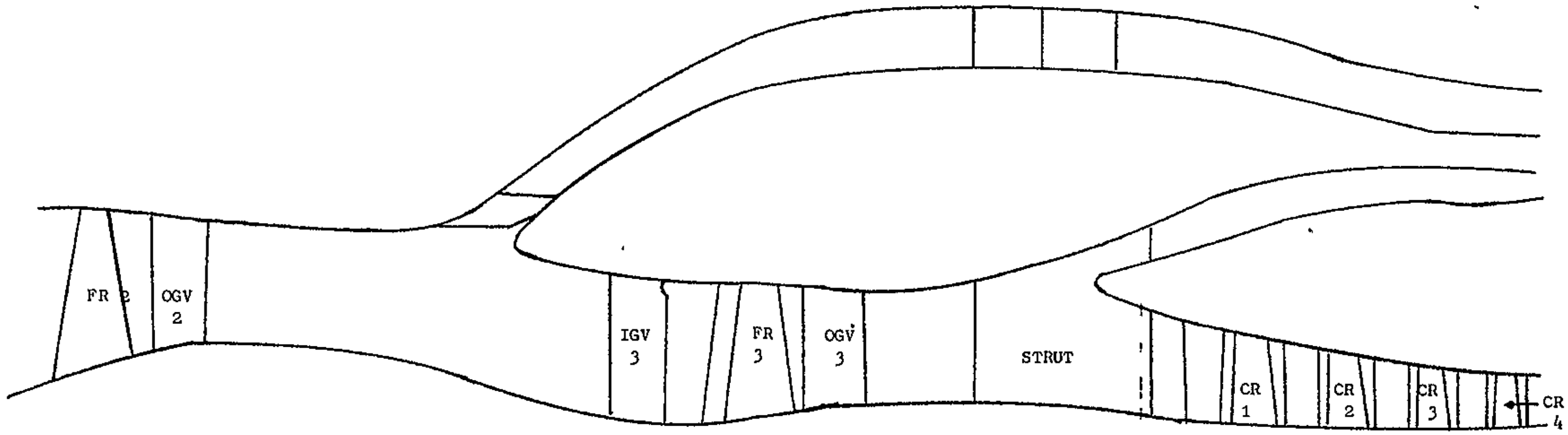
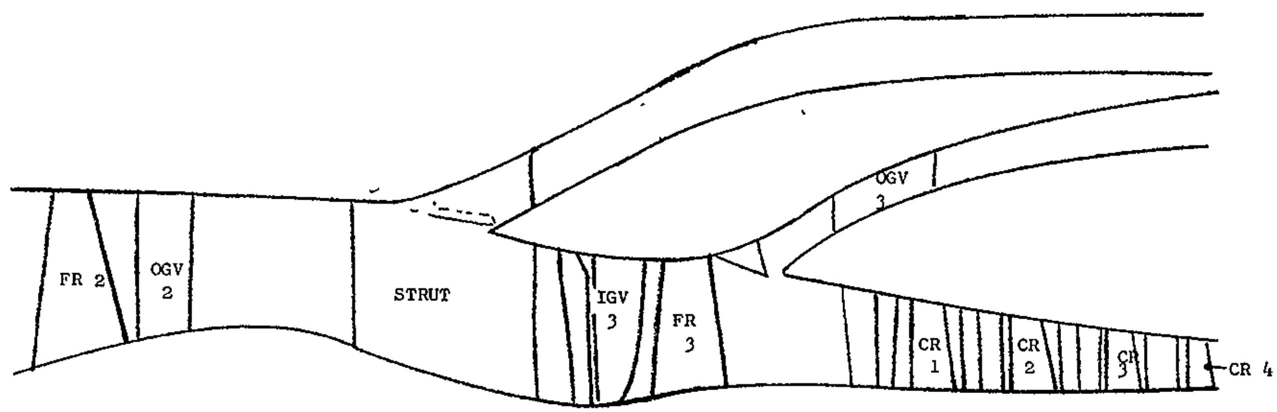


Figure 4-9. VCE Testbed Demonstrator Forward VABI Flowpath.



Configuration C - Uncoupled Design



Configuration D - Close Coupled Design

Figure 4-10. Close Coupled and Uncoupled Engine Flowpath Comparison.

Table 4-1. Mechanical Design - Configuration D, Close Coupled.

The proposed engine will utilize the current YJ101 2X1 VCE with the following new or modified hardware required.

PART NAME	FEATURES
Mid-frame	Engine mid-frame consisting of provisions for: No. 2 sump, forward selector valve, engine thrust mounts, gearbox, instrumentation mounting, and engine casing axial loadings. Material: Fabricated 321SS
Fan Discharge Inner Flowpath Wall	Provides inner flowpath wall for the fan discharge air. Material: 321SS
Selector Valve	Eight synchronized valves mounted between struts to transition fan flow from single bypass to double bypass (and vice versa). Material: 321SS
Selector Valve	Valve actuated by 2 actuators synchronized through a 360° unison ring and associated levers/linkages.
Forward Bypass Outer Forward Casing	Axially split casing to permit assembly/removal of core driven fan stage (CDFS) IGV actuation, system, delta-wing stator actuation system and removal of the delta-wing stators. Material: 321SS
Forward Bypass Inner Forward Casing	Axially split casing (for same reasons as outer casing). Material: 321SS
Intermediate Outer Casing	Split casing to permit repair/inspection, assembly of the inner bypass VABI vane area. Material: 321SS
Center Bypass Casing	Split casing (for same reasons as intermediate outer casing) - engine accessories and instrumentation mounted on casing periphery. Material: 321SS
VABI Actuation System	Two actuators

Table 4-1. Mechanical Design - Configuration D, Close Coupled (Continued).

PART NAME	FEATURES
CDFS IGV	Approximately 50 flapper type IGV for the CDFS. IGV mounts into split outer casing. Inner axial support furnished by mid-frame.
IGV Casing	Split casing supporting CDFS IGV's. Material: 321SS
Partial OGV & Casing	Provisions for supporting delta-wing OGV, and OGV removal. Material: 321SS
Inner Bypass Frame	Frame supports core engine gas loads through integral CDFS OGV struts. Material: 321SS
Outer Bypass Intermediate Inner Fairing	Fairing split to facilitate assembly/removal of VABI valve. Material: 321SS
VABI Valve	Similar to current 2X1 Forward VABI demo. valve except material to be Ti and actuated external to engine.
VABI Support	Supports VABI valve at ID and furnishes inner bypass outer wall. Material: 321SS
Inner Bypass	Split to facilitate assembly/inspection. Material: 321SS
VABI Actuation	Associated linkages/bellcranks for translating valve.
CDFS IGV	Two hydraulic actuators with linkages and 360^{o} unison ring for positioning IGV.
Fan Discharge Seal	Spacer/seal for drive and support of fan rotor. Integral crated seal teeth.
Bearing Support	Supports forward bearing of HP rotor. Material: 321SS
Bearing	New bearing for forward support of HP rotor and bevel gear.

Table 4-1. Mechanical Design - Configuration D, Close Coupled (Continued).

PART NAME	FEATURES
Bevel Gear	Same as current YJ101 gear except spline size larger.
Coupling Shaft	Spacer shaft for coupling LP shaft to fan aft shaft. Material: Inconnel
Coupling Tiebolt	Tiebolt features differential thread for attaching coupling shaft to LP shaft.
Bevel Gear Forward Drive Shaft	Shaft used to support PTO bevel gear.
Bevel Gear Aft Drive Shaft	Supports differential bearing
Differential Brg.	New roller bearing required for LP system dynamics.
LP Shaft	Shaft reworked to contain threaded ID for coupling tiebolt.
HPC Forward Shaft	Shaft reworked for new LP differential bearing and PTO bevel gear.
HPC Variable Geometry Actuation System	IGV 1, stator 1 and stator 2 to be independently actuated for core testing to determine HPC stator schedule.
CDFS Blade	Thirty-eight unshrouded Ti blades features current YJ101 stage 2 fan dovetail attachment.
CDFS Disk	Ti-17 disk supported by current HPC rotor.
Seal	Ti seal retains CDFS blading and minimizes cavity area forward of CDFS.
Spacer	Ti spacer between HPC and CDFS. Retain CDFS blading, seals cavities between blade shanks and provides rotating inner flowpath between CDFS and IGV 1 to minimize aerodynamic losses.

Table 4-1. Mechanical Design - Configuration D, Close Coupled, (Concluded).

PART NAME	FEATURES
HPC Rotor	Rotor reworked by adding body bound bolts for drive and support of CDFS.

Table 4-2. Mechanical Design - Configuration C, Uncoupled.

The following hardware (new or modified) is required for the YJ101 Uncoupled Configuration CDFS.

PART NAME	FEATURES
Casing	Split casing having selector valve and provides outer wall of forward bypass flow-path. Material: Aluminum
Fairing	Provides smooth wall for selector valve. Material: Aluminum
Selector Valve	Full 360° ring positioned to determine single or double bypass mode of operation. Material: Aluminum
Actuator	Four commercial actuators to position selector valve.
Actuation System	Miscellaneous linkages, brackets, etc., for actuator.
Forward Bypass Inner Flowpath	Provides inner flowpath wall for forward passage air. Material: 321SS
CDFS IGF Actuation Mechanism	Linkages, etc., for actuation CDFS IGV.
CDFS Actuation System	360° unison ring with associated stand-offs and linkages for positioning CDFS IGV.
Mid-Frame (Rework)	Rework of mid-frame consists of re-shaping splitter nose contour.
Fan Dischrage Seal	Rotating lab. seal with coated teeth. Material: Ti 6-4
Fan OGV Shroud	Shroud required for flowpath transition. Material: 321SS
Fan Discharge Inner	Provides inner gas passage for fan discharge air from fan to CDFS IGV frame Material: 321SS

Table 4-2. Mechanical Design - Configuration C, Uncoupled (Continued).

PART NAME	FEATURES
Front Frame	New frame supporting No. 2 bearing sump and frame fan CDFS IGV. Material: 321SS
CDFS Flapper	Approximately 50 flapper IGV's for CDFS. IGV mounts into front frame and is supported at hub and tip. Material: 321SS
EGV Casing	321 casing to support CDFS EGV's.
EGV Support Ring	Ring required to support CDFS EGV. Material: 321SS
EGV	Approximately 40 EGV's required to deswirl air from CDFS Rotor. Material: 321SS
EGV Inner Flowpath	Provides gas passage wall from EGV to mid-frame and supports CDFS rotor seal seat.
CDFS Disk	Ti-17 CDFS rotor blade disk with F404 stage 2 fan dovetail fans.
CDFS Blade	Ti-6-4 airfoils (38) with F404 stage 2 fan dovetail forms.
LPC Torque Cone	Ti-6-4 cone to support/drive LPC rotor system.
CDFS Discharge Seal	Labyrinth Seal with coated teeth to meter CDFS leakage flow and minimize cavity size behind CDFS stage. Material: Ti-6-4
CDFS Torque Cone	Torque cone required to support/drive CDFS stage. Material: Ti-6-4
HPC Forward Shaft	New shaft required to support: front of HPC rotor, LP/HP differential bearing and CDFS shaft. Material: Ti-6-4

Table 4-2. Mechanical Design - Configuration C, Uncoupled (Concluded).

PART NAME	FEATURES
LPT Drive Shaft	Same as YJ101 LP shaft except longer to adapt to new configuration and diameter decreased in front end. Material: Inco 718
CDFS Locknut	Required to retain CDFS rotor torque cone.
No. 2 Bearing and Seal Support	Support required to permit assembly of No. 2 bearing and seal compartment.
(Forward) Carbon Seal	New Vendor furnished seal required for No. 2 bearing.
Seal Runners	Runners for forward carbon seal.
Roller Bearing	No. 2 bearing required to support LPC rotor system.
Carbon Seal	New seal and runner required to seal off section of No. 2 bearing compartment.
Locknut	Required to clamp LPC torque cone to LP shaft.
Lube System	Miscellaneous lines, brackets, lube jets, etc., for No. 2 bearing compartment.

4.7 CDFS AEROMECHANICAL DESIGN

The CDFS rotor blade has an aspect ratio of 1.4, 0.70 R/R and a physical tip speed of 438 m/s (1437 fps) at the 14,767 rpm aero design point and is similar in aerodynamic and aeromechanic design to the YJ101 LP compressor 3rd rotor. The basic airfoil design presents no significant challenge for frequency control or for satisfying airfoil stress requirements as noted in Section 4.4. Due to these high airfoil loads, an axial dovetail attachment is required for maximum stress margin. A non-shrouded airfoil design has acceptable instability margin based on reduced velocity* and blade/air incidence angles relative to expected VCE operating trends. Although aerodynamic data concerning velocity-incidence as a function of corrected speed is not available, comparisons of the CDFS blade to other stage 1 blades have been used to predict behavior for the instability analysis.

Figure 4-11 gives composite torsional and flexural instability boundaries in terms of reduced velocity and incidence angle for several stage 1 blades with the anticipated VCE CDFS migration shown in dashed lines. The left hand extremities of the dashed curves represent operation of the CDFS blading at design conditions. As speed is reduced along a typical operating line, blade relative velocity goes down and incidence angle goes up because of the reduction in air flow, causing migration down and toward the right on this plot. Based on this preliminary analysis (no intersections of the dashed lines with the boundaries in Figure 4-11), no vibration instabilities are anticipated for the CDFS, and there is no need for shrouding or including damping for this blade.

Table 4-3 is an airfoil design summary for the proposed VCE CDFS. Table 4-4 provides further details of the airfoil design relative to overall vibration characteristics. This design is aeromechanically acceptable for the test-bed configuration. Figure 4-12 shows the centrifugal stress of the CDFS blade related to height at 14,767 rpm. The steady stresses are well within accepted design practice.

Figure 4-13 is a Goodman Diagram for Titanium 6Al-4V material. Shown on this diagram are the airfoil stresses in the 1st flexural, 1st torsional and 2nd flexural/modes, respectively. The steady stress is shown on the absissa, and the vibratory stress on the ordinate. Although vibratory stresses are expected to be much lower than as shown, they are purposely set on the Goodman Diagram limit or at 45 ksi (1st flex), 51 ksi (1st torsion and 2nd flex) to whow that in the event of an unexpected blade vibratory failure the CDFS blade will fail in the airfoil and not in the dovetail per design intent. Clearly, Figure 4-13 shows that both the blade dovetail and disk dovetail are well below the material stress limits with the blade at the stress limit, thus, demonstrating dovetail fatigue margin. The least margin occurs in 2nd flex in the blade dovetail. The vibratory stresses of the CDFS blade will be established in the Core Engine Test Program. The dovetail selected for this

*Reduced Velocity is a dimensionless term defined as the blade inlet air relative velocity divided by the product of the blade semichord times the blade oscillatory frequency or $V_{rel}/C/2 \times f$) = 1/K where K is commonly known as the Strohal Number.

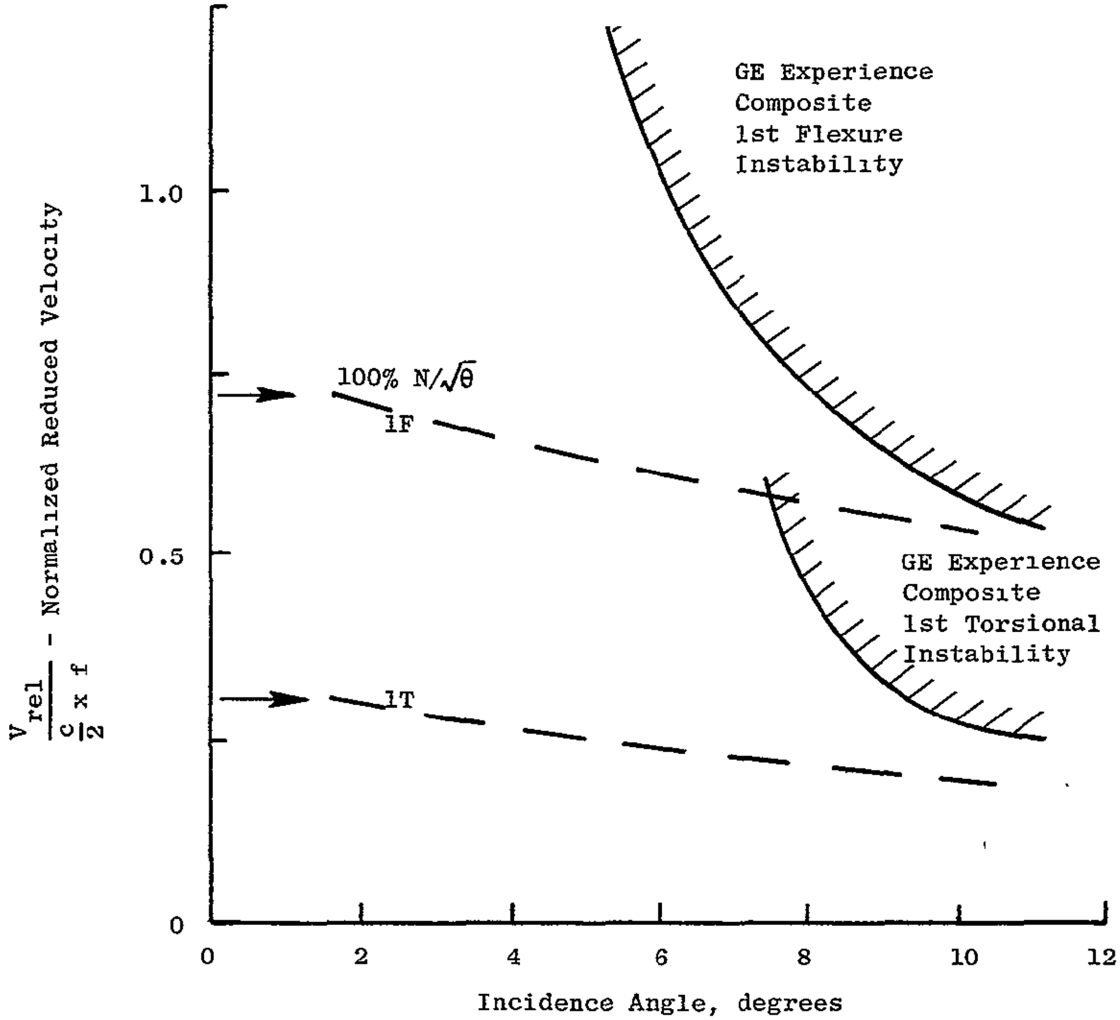


Figure 4-11. YJ101/VCE Core Driven Fan Stage Anticipated Incidence Migration - Reduced Velocity Behavior.

Table 4-3. Airfoil Design Summary.

PARAMETER		VCE CDFS
Material		Ti-6-4
Airfoil Type		BiCvx
No. of Blades		38
Tip Speed, fps		1437
Root Aspect Ratio		1.40
Average Radius Ratio		0.70
Chord (in.)	Hub	2.371
	Pitch	2.371
	Tip	2.371
tm/c	Hub	0.088
	Pitch	0.046
	Tip	0.030
Camber (Deg.)	Hub	22.5
	Pitch	3.5
	Tip	3
Mech Stagger (Deg.)	Hub	51
	Pitch	37.5
	Tip	30
Solidity	Hub	1.83
	Tip	1.29
Design Speed, rpm		14,767

Table 4-4. Aeromechanical Design Status Summary.

PARAMETER	
• IF-4/rev resonant speed	71% N_2
• IF-3/rev freq. margin at 103% N_1	7.1%
• Nominal root CF stress	19.1^K
• Max airfoil stress at SLTO	35.0^K
• 1-2S mode resonant speed upstream vane downstream vane	41% N_2
• 1-3S mode resonant speed upstream vane downstream vane	80% N_2
• Design Speed (100%)	14,767 rpm

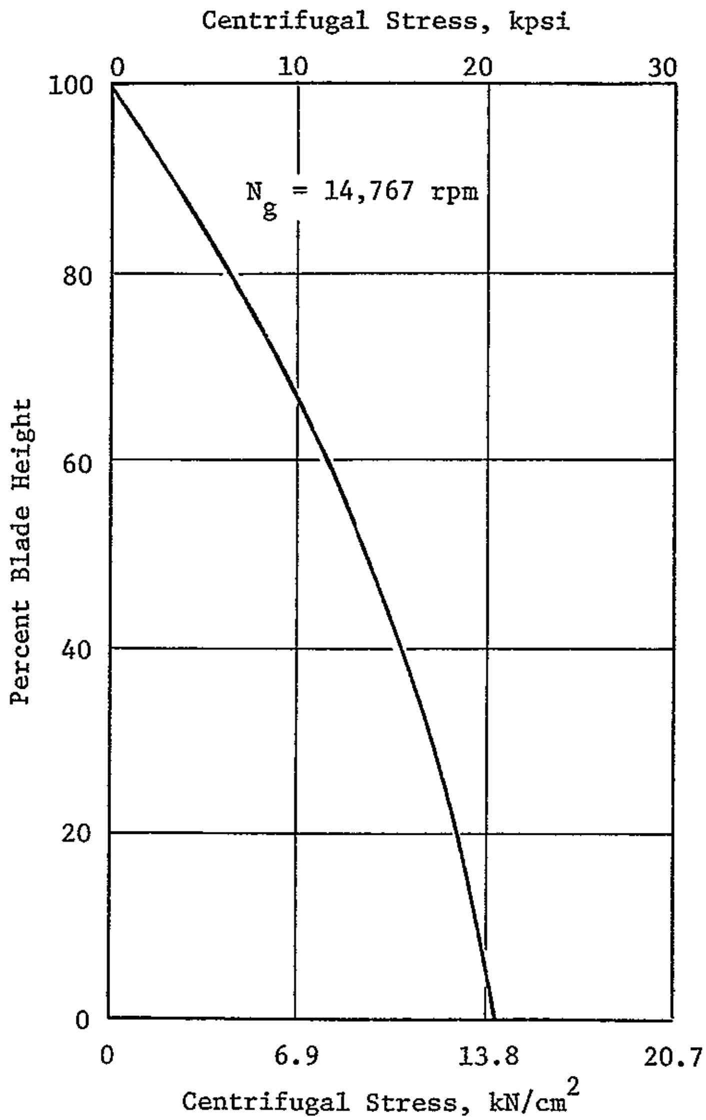


Figure 4-12. Core Driven Fan Stage Rotor - Airfoil Centrifugal Stress.

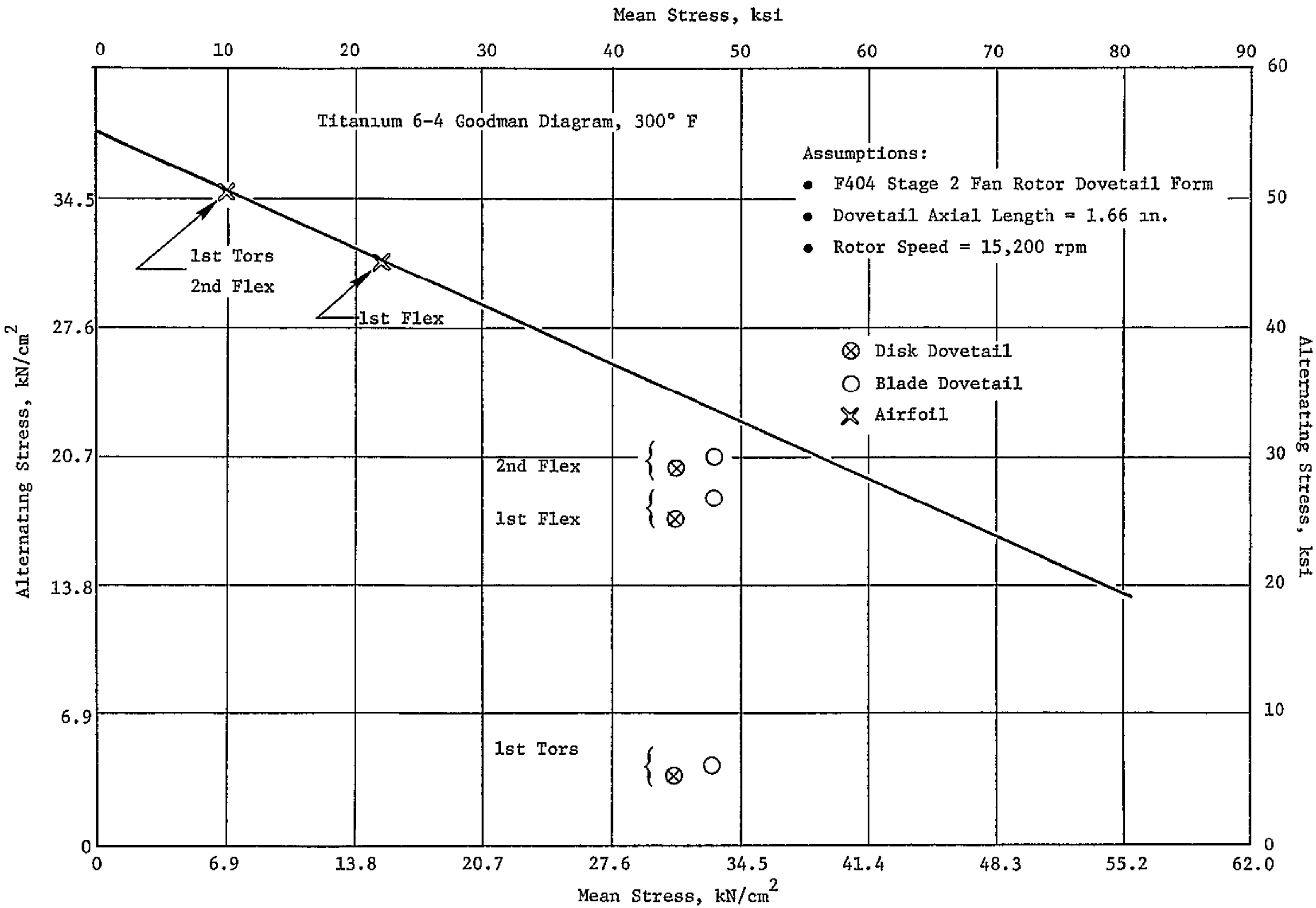


Figure 4-13. VCE Core Driven Stage 3 Fan Rotor Airfoil/Dovetail Strength.

design is the F404 stage 2 fan rotor since this axial dovetail most nearly satisfies the attachment for this stage without creating a new broach.

The CDFS Inlet Guide Vane Design is a flap type supported at the airfoil hub and tip. The hub portion of the IGV supports a seal seat mating with the CDFS rotor to reduce the cavity size between rotor and stator. Flap type IGV's are used to reduce the losses (due to high leading edge incidence) when the guide vane is closed a large amount. The front portion of the vane is fixed and only the aft portion moves. This keeps the incidence angle essentially constant when the flap is closed, thus avoiding high incidence angles in the closed position that occur with single piece guide vanes. Flap type IGV's similar in concept are employed on the YJ101 and F404 low pressure compressors.

A new HP compressor IGV is required with the CDFS to accommodate the swirl from the rotor. (Swirl from the stage 3 fan was removed by the stage 3 stator on previous VCE/YJ101 engines). For initial core testing, the HPC IGV, S1 and S2 will be independently variable to derive the required schedule for a "ganged" stator design. This new design is to be tested and proven prior to use on the full engine.

4.8 DYNAMIC ANALYSIS

The Close Coupled (C/C) Configuration was chosen as the Testbed Demonstrator design principally on the basis of its greater similarity to a product engine design and less risk relative to engine dynamics. Also, one less differential bearing is required versus the Uncoupled (U/C) Configuration. Figure 4-14 describes the bearing arrangements for the uncoupled and close coupled rotors relative to a standard YJ101 design.

The principal dynamic characteristics of the Close Coupled Configuration are shown in Table 4-5. The "boxed" vibration mode values identify the particular resonances most responsive to engine unbalance. Low response to unbalance is expected on the HP and LP rotor systems. The increased distance between the engine mount points (main frame to rear frame) resulting from locating the CDFS rotor between the YJ101 HPC and the mid-frame necessitated that the No. 2 LP rotor bearing be made a differential type. This configuration will permit the span between the No. 2 and No. 3 LP bearings to remain the same as on the standard YJ101 engine and other VCE demo. engines, thus reducing and/or eliminating LP shaft dynamic problems.

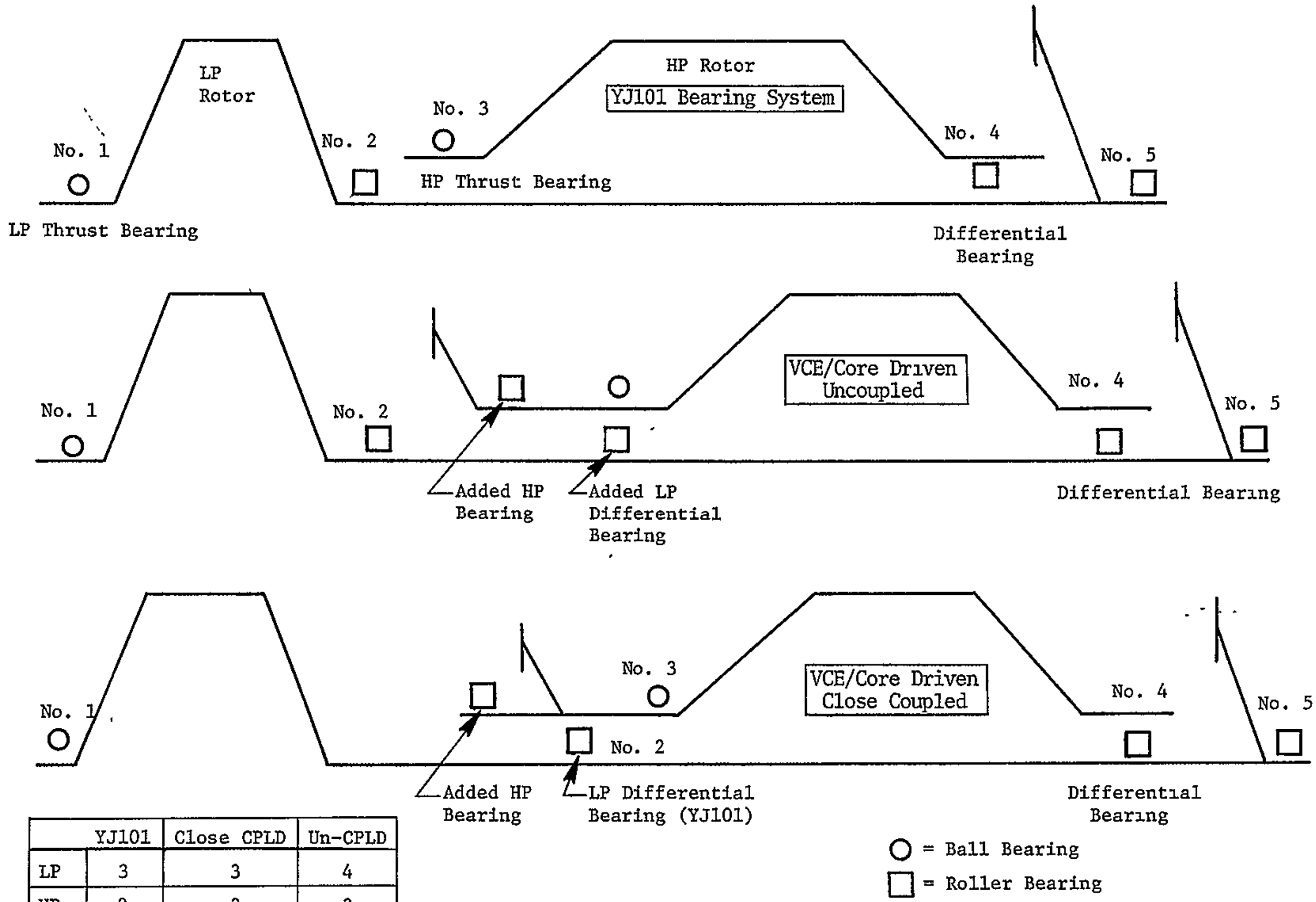
A corresponding dynamic analysis was done for the uncoupled configuration (C), including extensive studies aimed at aimplifying the required bearing arrangement. The initial analysis showed that the low pressure rotor shaft bending mode occurred in the operating range (9351 rpm N_1). Studies were made to increase this vibration mode by adding a differential bearing to the LP rotor at the HP rotor thrust bearing station, see Figure 4-14. In addition, two more studies were made to evaluate the elimination of the No. 2 bearing and its support to reduce cost and preclude skidding of a redundant bearing and to reduce the sensitivity of the core-driven fan resonance encountered during an engine start.

Table 4-5. Close Coupled Configuration D Dynamic Analysis Summary.

VIB. MODE	PREDICTED RESONANT SPEED (rpm) HP EXCITED		LP EXCITED	
Eng. Pitch/Aft Mount	1912		1799	
Eng. Pitch/Fwd Mount	2393		2386	
Rotors/Casings	3412		3382	
HP Casing/Acoustic Nozz.	6127		6148	
No. 3 Brg. Support/Compr./Casings	7696	(A)	7751	
Fan Rotor/LP Shaft/Compr./Casings	7927		8079	(B)
Casings	14089		14409	
Casings	16262		16438	
Turbines Out of Phase	17330		17786	
LP Shaft Bending	19105		19351	

Oper. Range

- OUTLINED — Resonances most responsive to engine unbalance
- (A) – Response 1.9 mils/10 GM/IN Unbal.
  – Similar to F404/Good Compr. Bal. Reqd.
- (B) – Response 4.0 mils/10 GM/IN Unbal.
  – Similar to 1X2 Fan/Good Fan Bal. Reqd.



	YJ101	Close CPLD	Un-CPLD
LP	3	3	4
HP	2	3	3

Figure 4-14. Bearing Configurations.

Results of the study to eliminate the No. 2 bearing showed that fan rotor resonance was lowered by 4647 rpm (from 10,737 rpm) to 6090 rpm and the sensitivity to fan unbalance increased by a factor of 4x. The result is unacceptable. Another possible solution was a larger diameter fan aft cone with a steeper angle and increased thickness, but this was also found to be unacceptable because of the response to resonance at 6983 rpm. Based on these studies, it is concluded that the No. 2 bearing and its support structure cannot be eliminated in the uncoupled configuration.

Two studies were also made to reduce the sensitivity of the core-driven fan stage resonance to unbalance. These studies included the provision of a fluid film to the bearing aft of the core-driven fan stage and doubling the thickness of the cone supporting it. This configuration lowered the core-driven fan resonance by 1047 rpm (from 6458 rpm to 5411 rpm) and increased the sensitivity rather than decreasing it. Therefore, the overall softening of the bearing support caused by the combination of the fluid film bearing and the thickened support cone overpowers the increased damping of the fluid film.

The thicker core-driven fan cone alone produced a core-driven fan resonance 828 rpm higher (from 6458 rpm to 7286 rpm), but the sensitivity to unbalance is essentially unchanged.

A dynamic analysis summary for a final configuration of the Uncoupled Design is shown in Table 4-6. It should be noted that this design required a more complex bearing system (7 bearings) including an additional low pressure shaft bearing. Also, a high response to unbalance is expected during start up on the HP rotor, and a relatively high response to unbalance is also expected in the LP operating range. On the basis of the system dynamics, the Close Coupled Configuration (Configuration D) was recommended.

4.9 FORWARD VABI AREODYNAMIC DESIGN

A Forward VABI design is proposed for the SCAR Testbed Demonstrator VCE having a HPT-driven 3rd Stage Fan Block. There are few design restrictions for this engine since the production hardware is still in the preliminary design stages. The bypass duct inlet and splitter nose coordinates were generated based on fan design specifications; otherwise, the ducting and VABI match plane geometry were designed totally from aerodynamic considerations.

An overview of this proposed design and how it adapts to the fan duct flowpath is presented in Figure 4-15. Station A_{15} is the entrance to the bypass duct. A detail of the static pressure match plane ($A_{14.8}$) geometry is provided in Figure 4-16.. The existing LPT Driven Forward VABI Demonstrator hardware is similar to his scheme in the region of the match plane and should provide representation of how the Forward VABI system will operate on the testbed engine. There may be slight iterations and modifications to this flowpath when mechanical and aero considerations are finalized; however, these will not significantly alter the flowpath intent nor affect basic similarity between the Forward VABI/early acoustic demonstrator and core-driven testbed.

Area distributions for both ducts, based on a 1032 cm^2 (160 $in.^2$) match

Table 4-6. Uncoupled Configuration (C) Dynamic Analysis Summary.

VI. MODE	PREDICTED RESONANT SPEED (RPM) HP EXCITED	LP EXCITED
Engine Pitching/FWD Mount	1514	1515
Engine Pitching/AFT Mount (IP)	1885	1880
Engine Pitching/AFT Mount (OP)	3286	3314
Inner Flow Path Trans.	4304	4388
Core Driven Fan	$\boxed{6458}$ (A)	6600
Core Driven Fan/Casings	$\boxed{6833}$	7004
HP Compressor	8798	9005
Fan Rotor	10698	$\boxed{10737}$ (B)
HP Casing/#3 Brg. Supp.	13526	13574
HP Casing/#3 Brg. Supp.	14590	14615
Turbines-Out of Phase	$\boxed{17768}$	18000
Outer Duct Bending	19376	19385

HP · LP · OPER. RANGE

- $\boxed{\text{OUTLINED}}$ — Resonances Most Responsive To Engine Unbalance
- (A) — Response 9.5 Mils/10 GM/IN Unbal. High CD Fan Resonance Would be Encountered During Starting
- (B) — Response 5.0 Mils/10 GM/IN Unbal. Requires Good Fan Balance

A_{15} = .1032 m^2 (160 in.^{2})

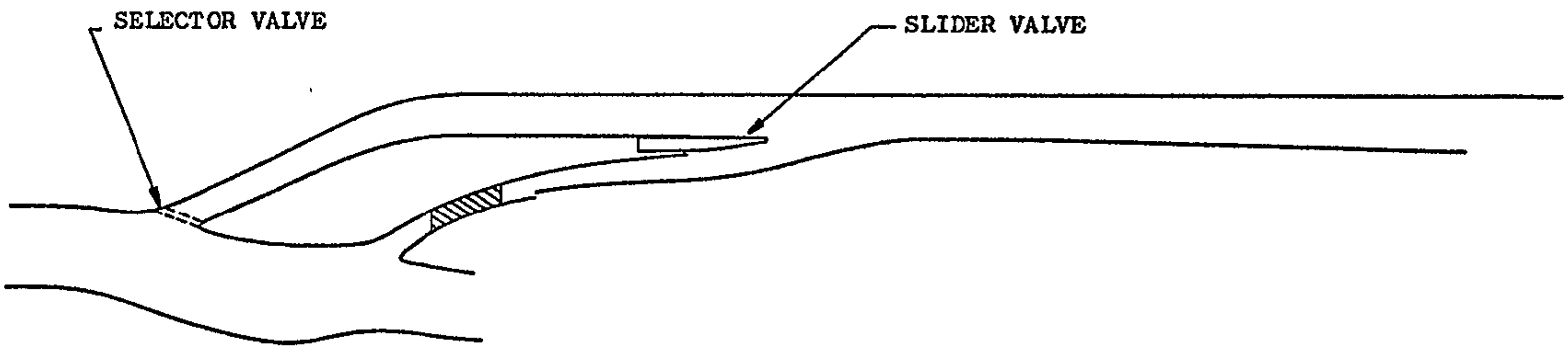


Figure 4-15. VCE Testbed Engine, Forward VABI Schematic.

$A_{15} = .1032\ m^2\ (160\ in.^2)$

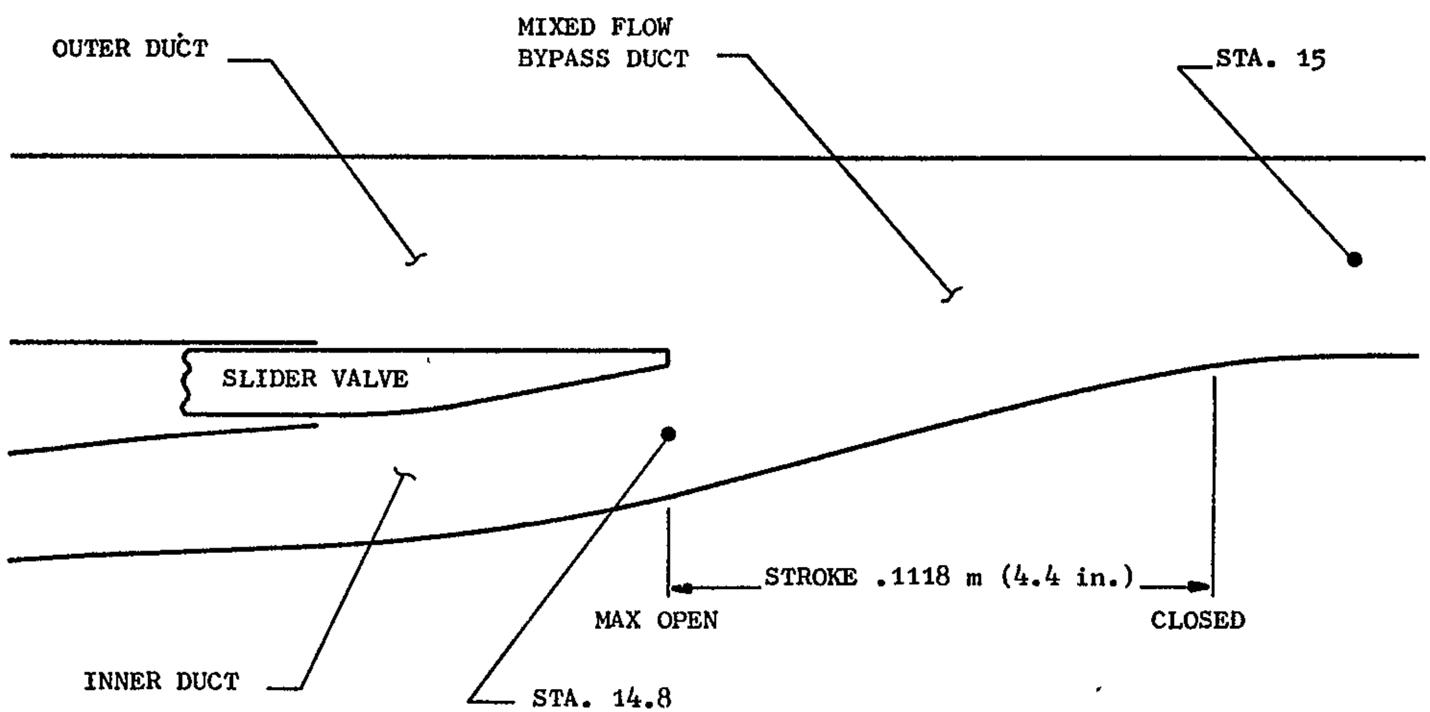


Figure 4-16. VCE Testbed Engine, Forward VABI Slider Valve Schematic.

plane area, are shown in Figure 4-17 with inner duct match plane area variation presented in Figure 4-18. An inner duct design was selected that (1) minimized diffusion through the duct at maximum stroke (full open) and (2) maintains as nearly linear a relationship of area with stroke as possible. This second consideration, as mentioned previously, helps maintain an accurate flow area schedule.

Streamtube Curvature (STC) computer program flowfield plots and separation characteristics are shown in Figures 4-19 to 4-22 for single bypass (high thrust mode) and double bypass (low noise mode/part power mode) operating conditions.

As noted, separation will not occur for either single or double bypass design operation. During single bypass extended airflow operation, the flow would separate due to higher Mach numbers in the inner duct (i.e., choked flow). The inner duct geometry could be changed to give less duct diffusion, but the diffusion problem would then be shifted forward to the fan stream. This is not currently a viable solution and other alternatives should be investigated in the future. This condition is somewhat academic since single bypass airflow extension is not a key (SCAR) mission point for a double bypass VCE. Should this point become a requirement, duct redesign trades would be required. Plots for the inner duct during double bypass operation are not available; however, the entrance Mach number and diffusion for the inner duct at double bypass operation are less than during single operation and since the analyses showed no separation for single bypass operation, no separation is expected for the double bypass mode. Corresponding Mach number distributions are presented in Figure 4-23. These studies provide preliminary aerodynamic flowfield information necessary to define a Forward VABI bypass system for the core-driven testbed demonstrator VCE.

A preliminary outer duct selector valve design is proposed in Figure 4-24. Evaluation of this concept is summarized in Figures 4-25 to 4-28. This flowpath evolved from similar analyses using STC and SABBL programs. The spike in the FSEP curve (Figure 4-26) does not indicate separation but is a result of modeling sudden surface contour changes at the juncture of the valve when it is closed. It can be seen that FSEP quickly drops to zero after the spike. If there were true separation, FSEP would remain high!

The results from the foregoing analyses indicate that the VABI design can be improved relative to the fan-driven VABI design, primarily by eliminating potential separation regions and designing a more compact, thus lower weight system. Results of the initial fan-driven studies, and verified in the Forward VABI test results, indicated that an increased bypass duct size was required to reduce bypass flow pressure losses in the VATN actuator and linkage region. A larger bypass duct was designed and built for the fan-driven VABI. The same design criteria will be used for the core-driven VABI to keep the duct Mach number and pressure losses low.

Reference Figures 4-16, 4-19, 4-20

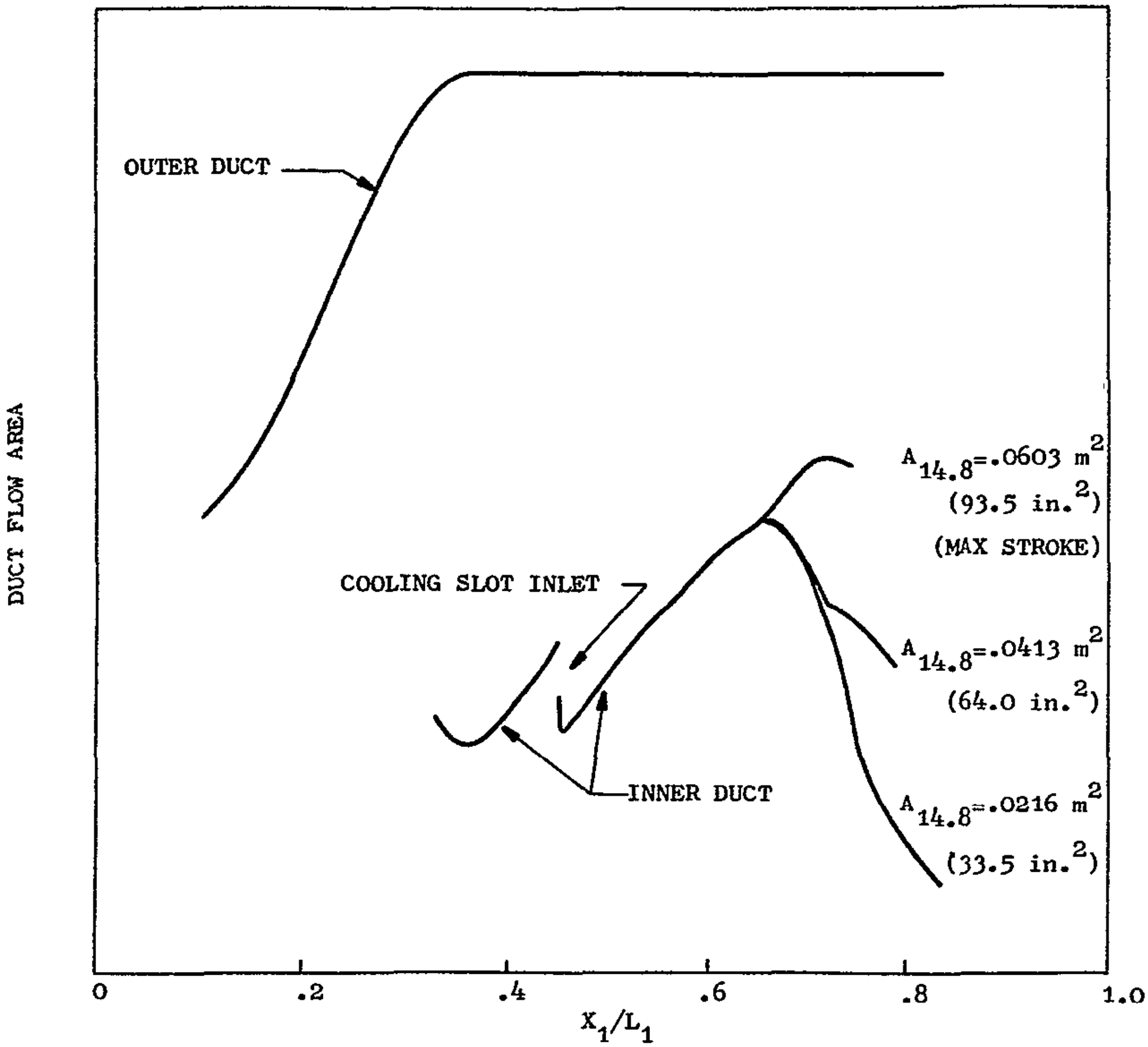


Figure 4-17. VCE Testbed Engine, Forward VABI Area Distribution.

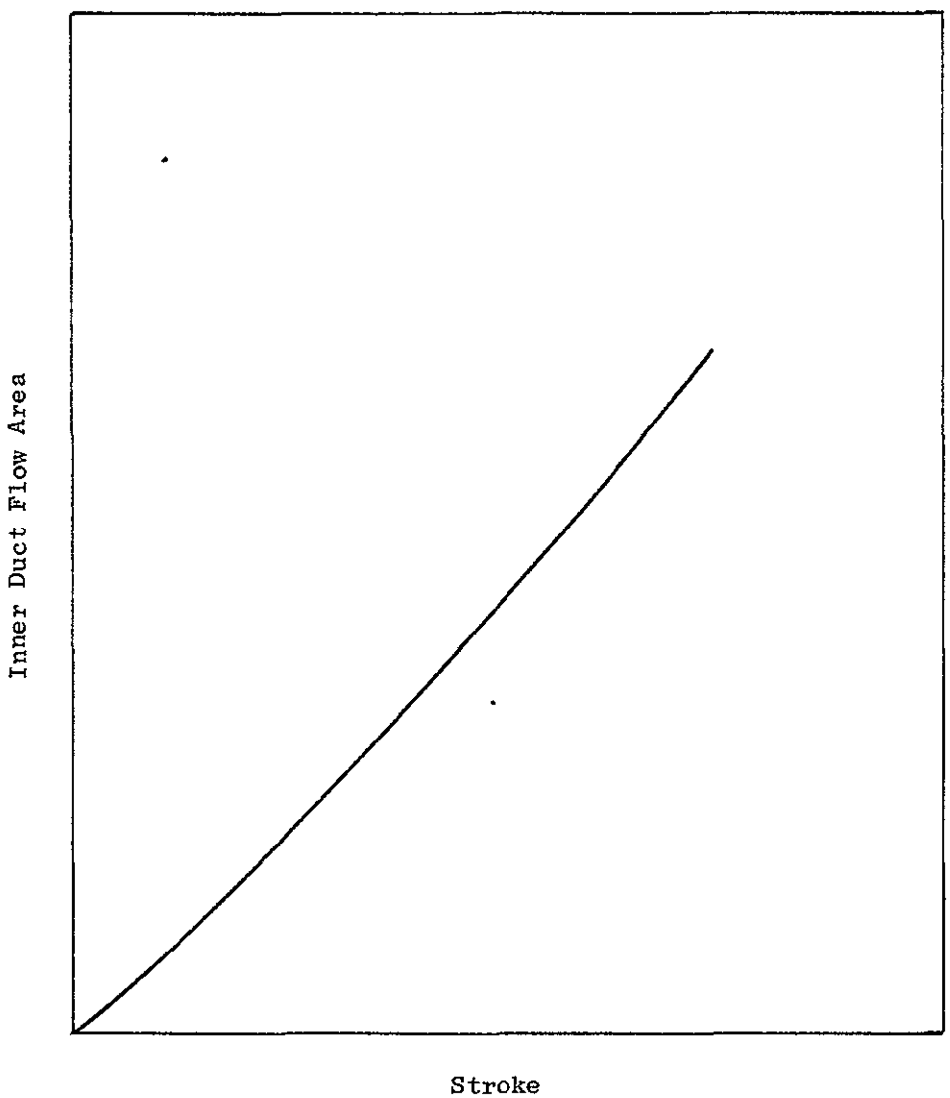
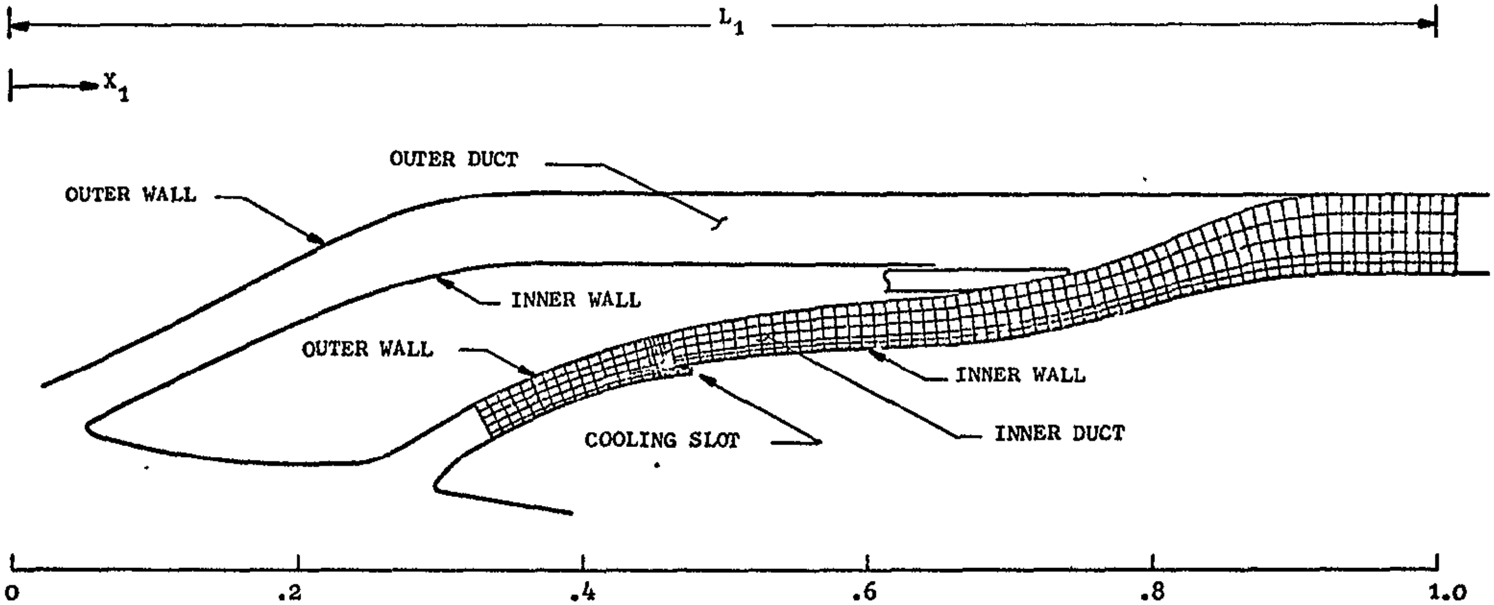


Figure 4-18. VCE Testbed Engine, Forward VABI Aero Concept, Inner Duct Match Plane Area Variation for $A_{15} = .1032\ m^2$ (160 in.^{2}).



HIGH THRUST MODE

FLOW CONDITIONS - INNER DUCT

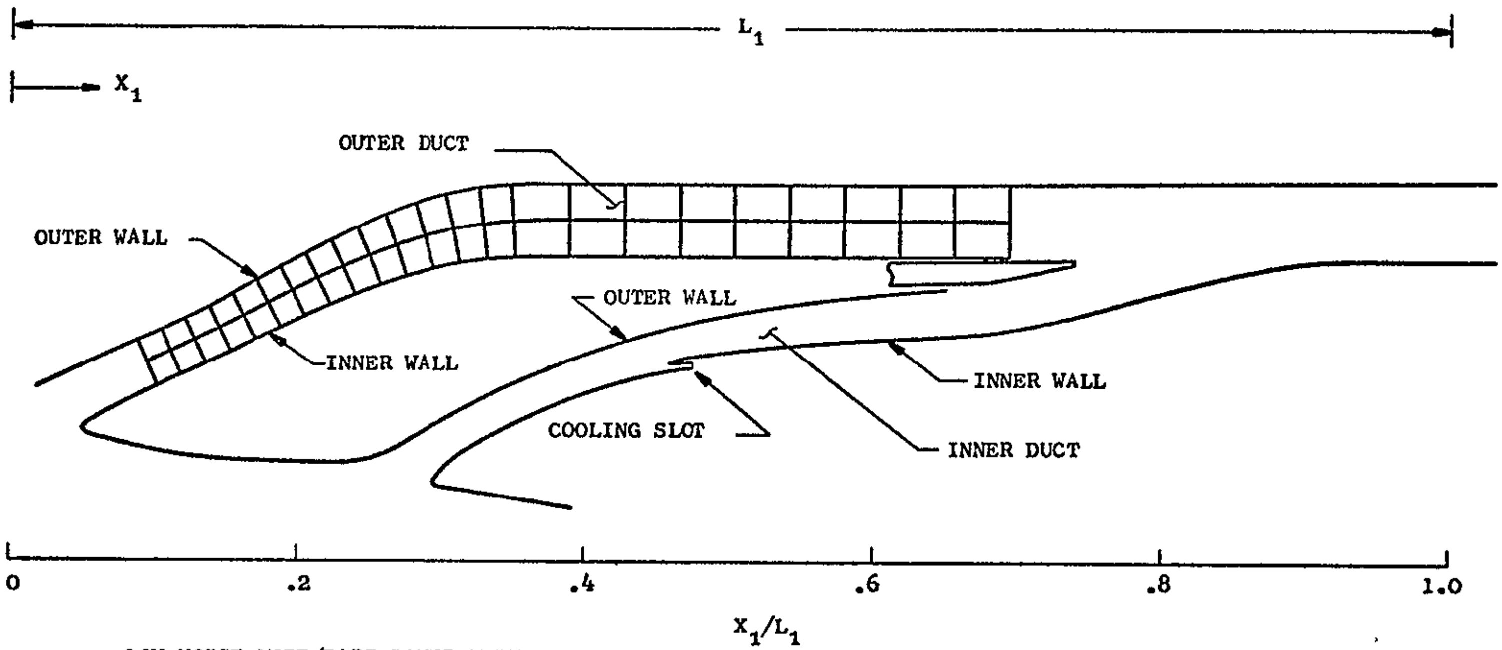
W_T = 1.44 kg/sec (31.66 #/sec)

P_T = 307.58 kPa (44.61 PSIA)

T_T = 421.4 K (758.5^{o}R)

$W_{COOLING\ SLOT}$ = .10 W_T

Figure 4-19. VCE Testbed Engine, Inner Duct STC Flowfield Study, Single Bypass Mode.



LOW NOISE MODE/PART POWER MODE

FLOW CONDITIONS - OUTER DUCT

W_T = 1.82 kg/sec (40.08 #/sec)

P_T = 265.65 kPa (38.53 PSIA)

T_T = 399.9 K (719.89°R)

Figure 4-20. VCE Testbed Engine, Outer Duct STC Flowfield Study, Double Bypass Mode.

Reference Figure 4-19.

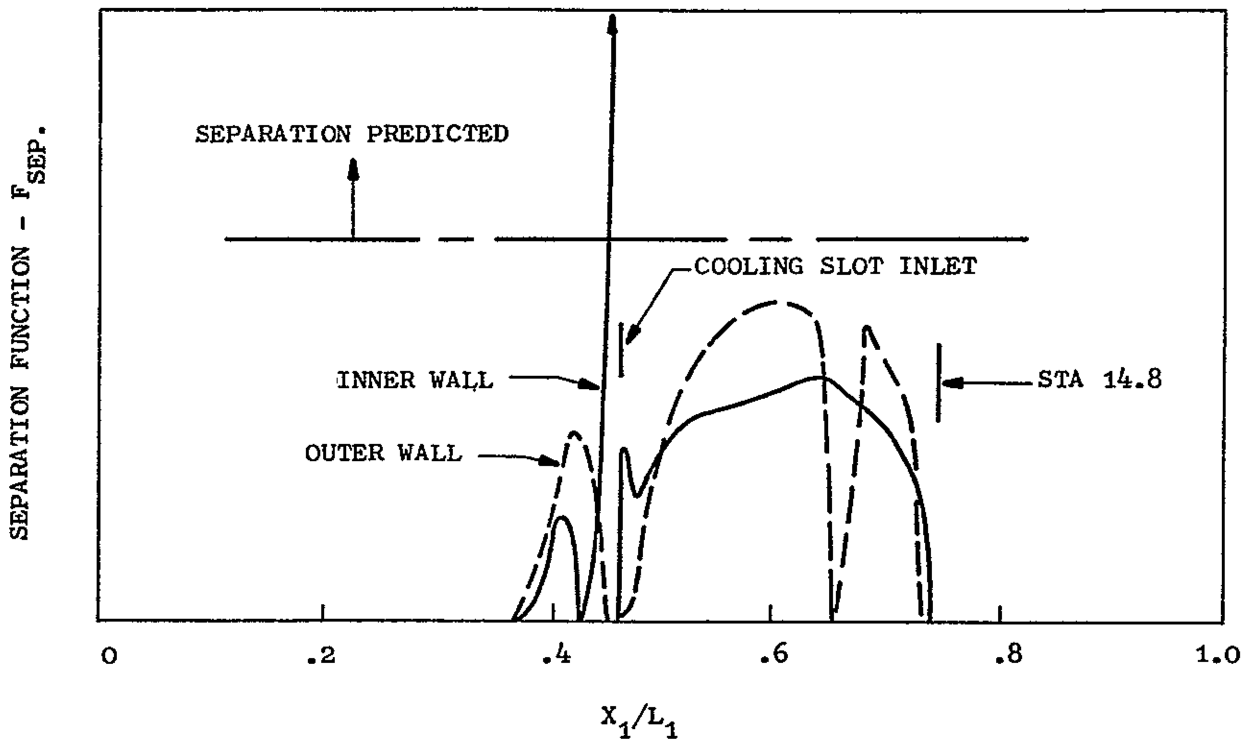


Figure 4-21. VCE Testbed Engine, Forward VABI Inner Duct - Separation Function, Single Bypass Mode.

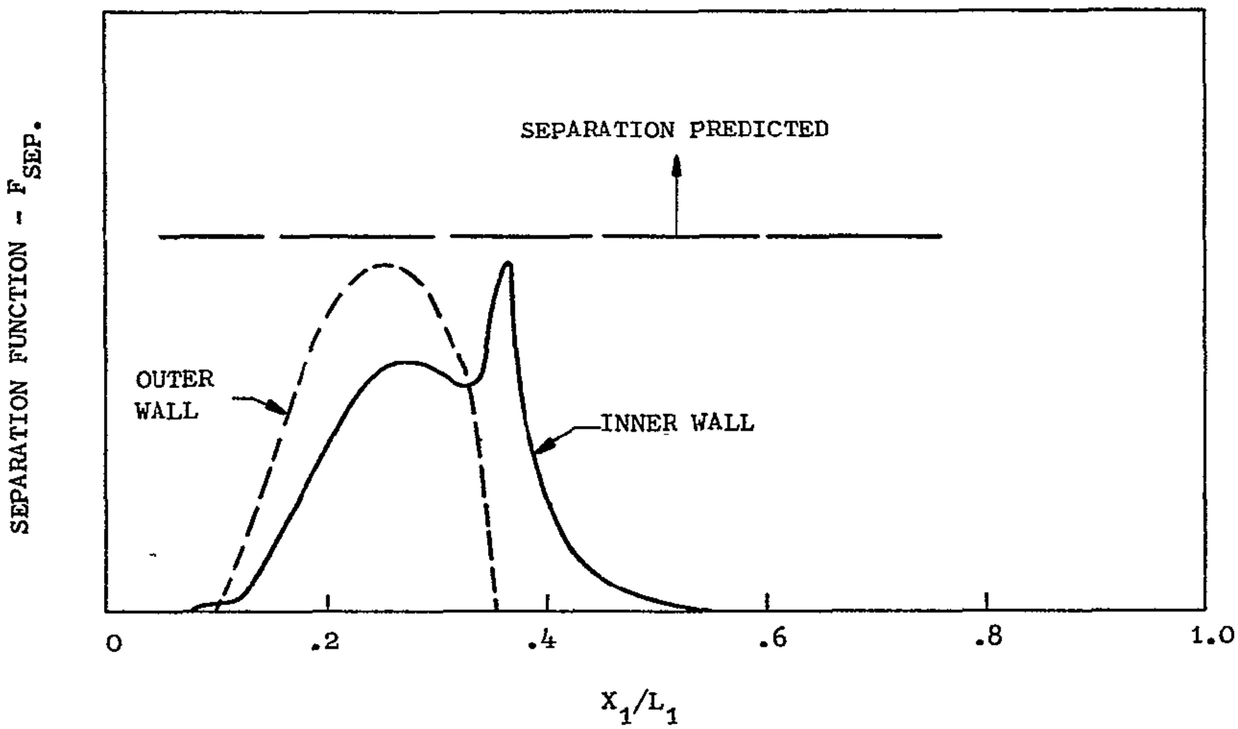


Figure 4-22. VCE Testbed Engine, Forward VABI Outer Duct - Separation Function, Double Bypass Mode.

Reference Figures 4-19, 4-20

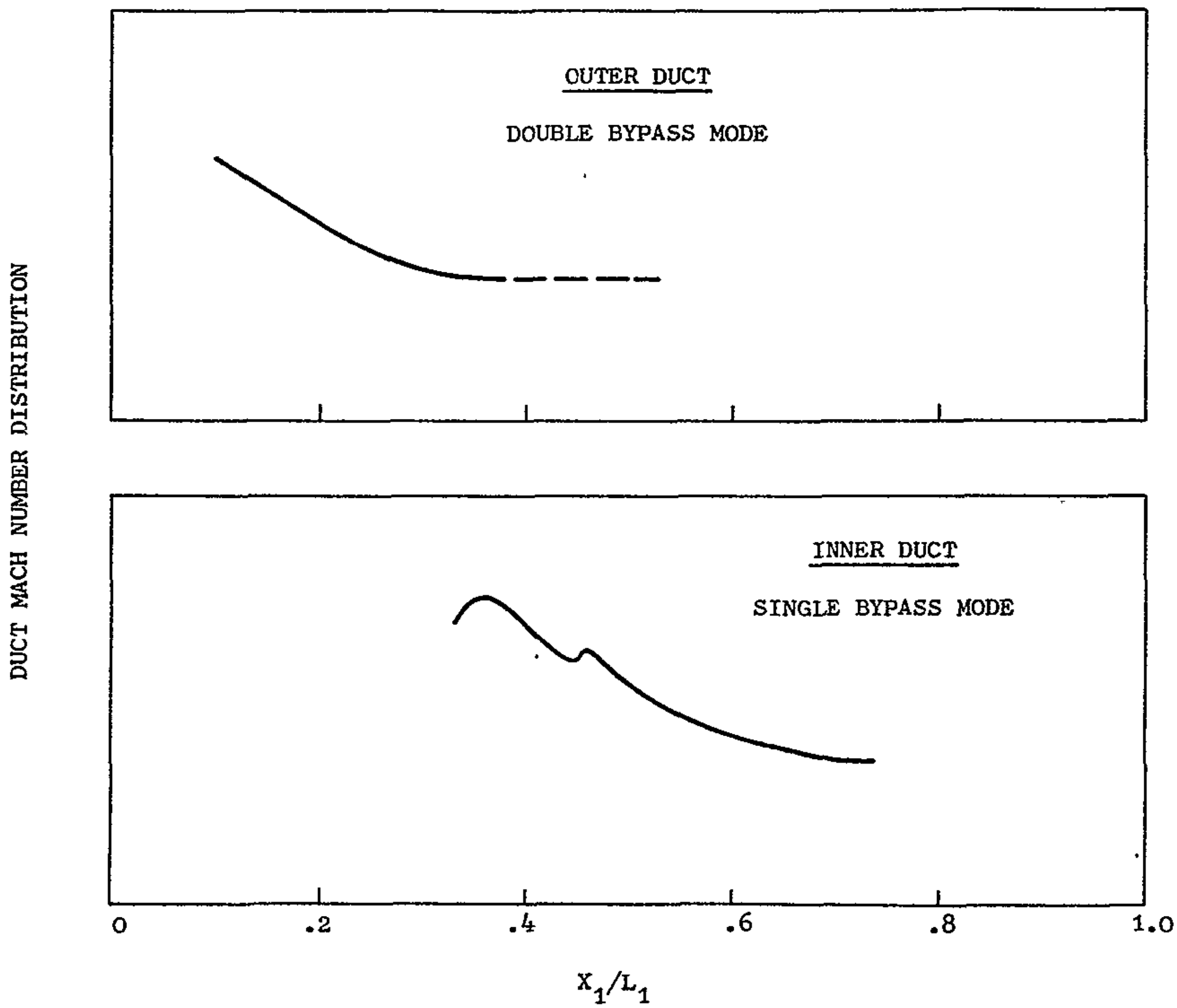


Figure 4-23. VCE Testbed Engine, Forward VABI Duct Mach Number Distribution.

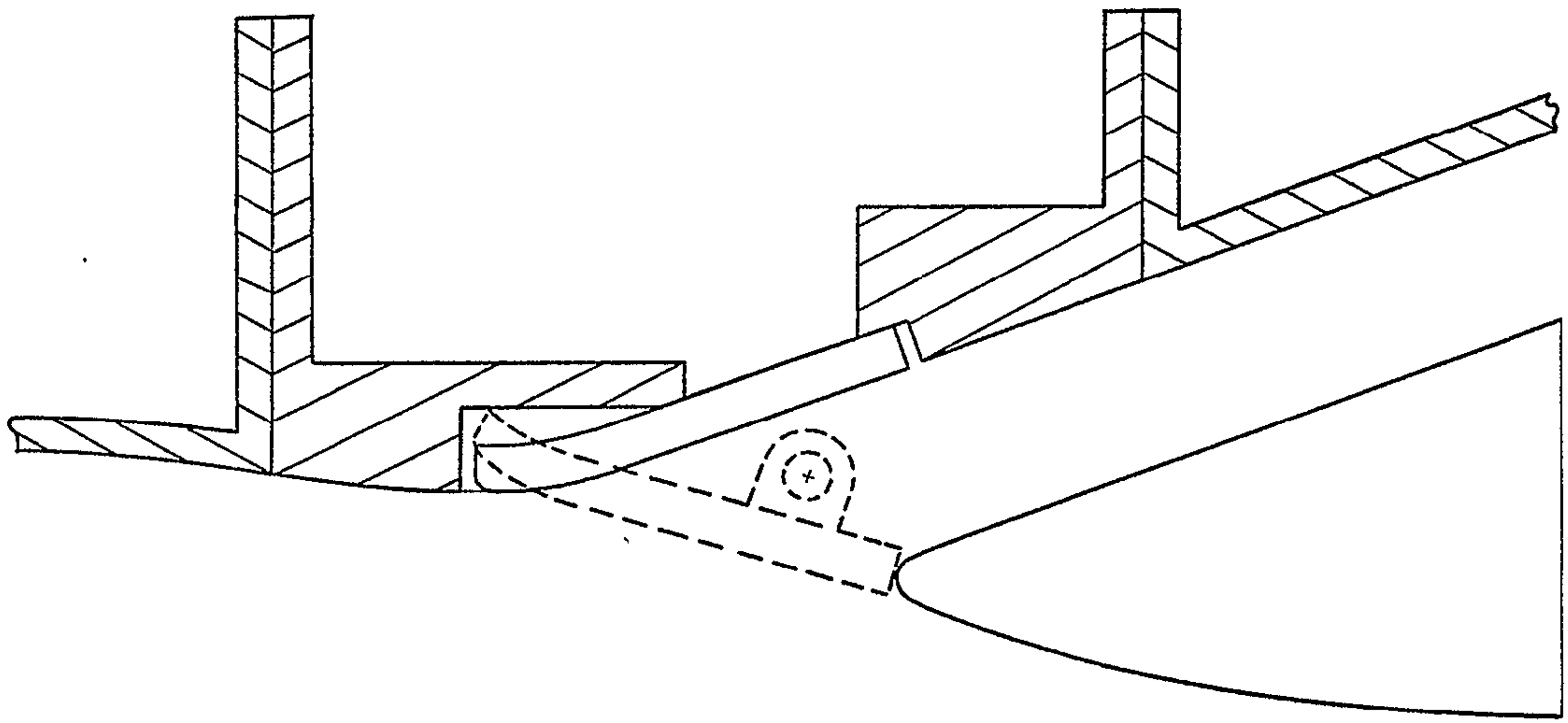


Figure 4-24. VCE Testbed Engine, Double Bypass Selector Valve Schematic.

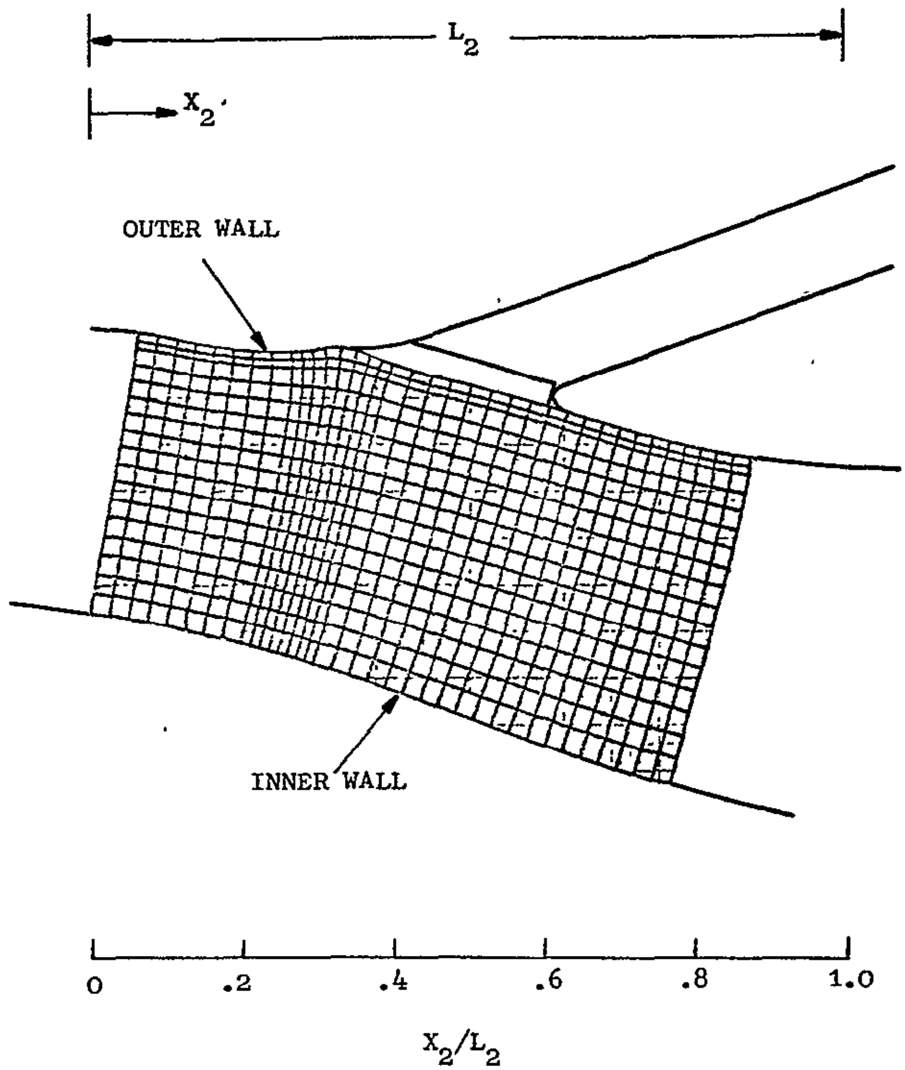


Figure 4-25. VCE Testbed Engine, Double Bypass Selector Valve STC Flowfield Study.

Reference Figure 4-25

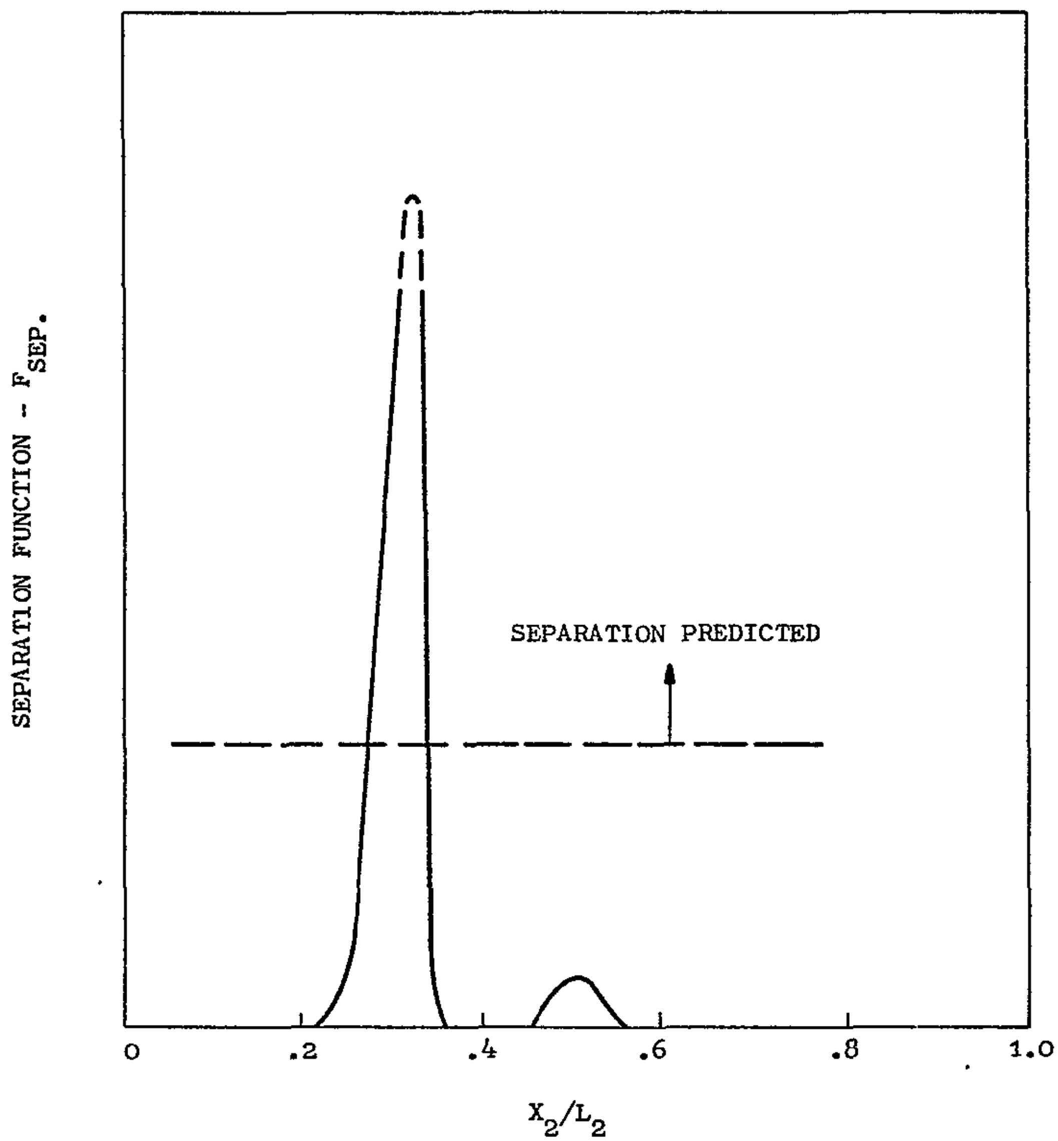


Figure 4-26. VCE Testbed Engine, Double Bypass Selector Valve Outer Wall Separation Function, Single Bypass Mode.

Reference Figure 4-25

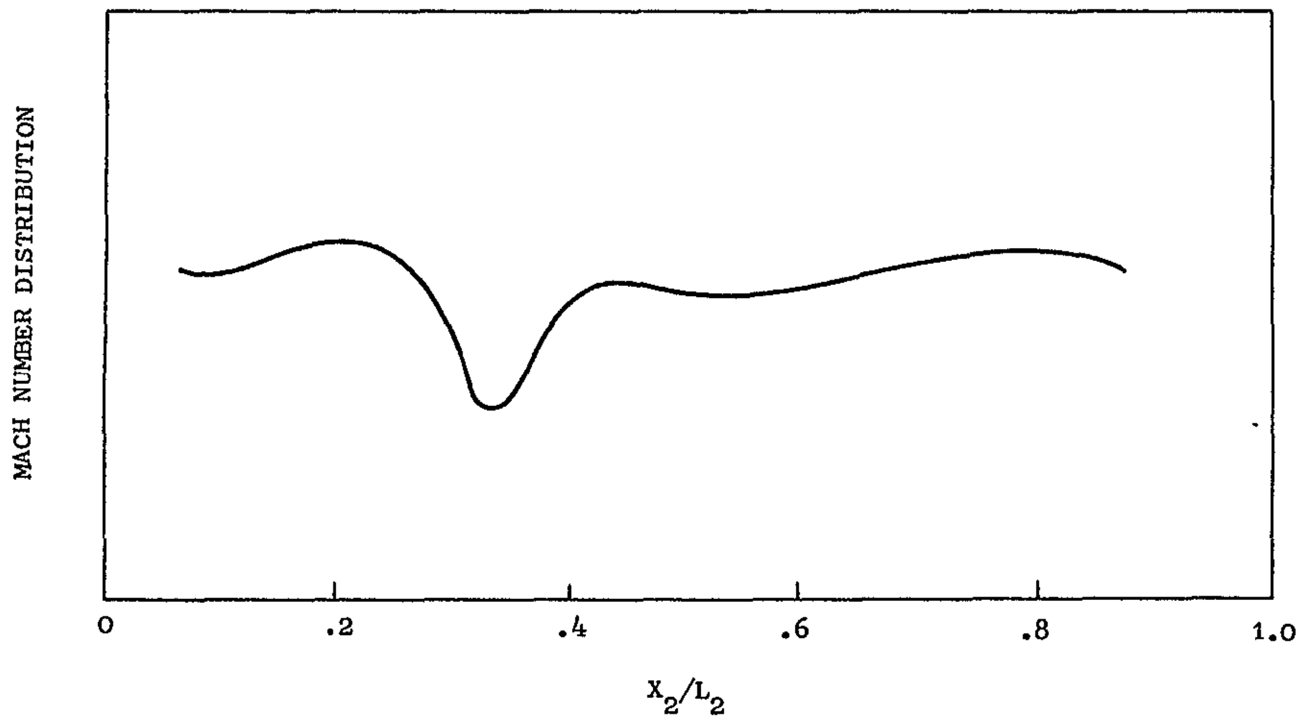


Figure 4-27. VCE Testbed Engine, Double Bypass Selector Valve Outer Wall Mach Number Distribution, Single Bypass Mode.

Reference Figure 4-25

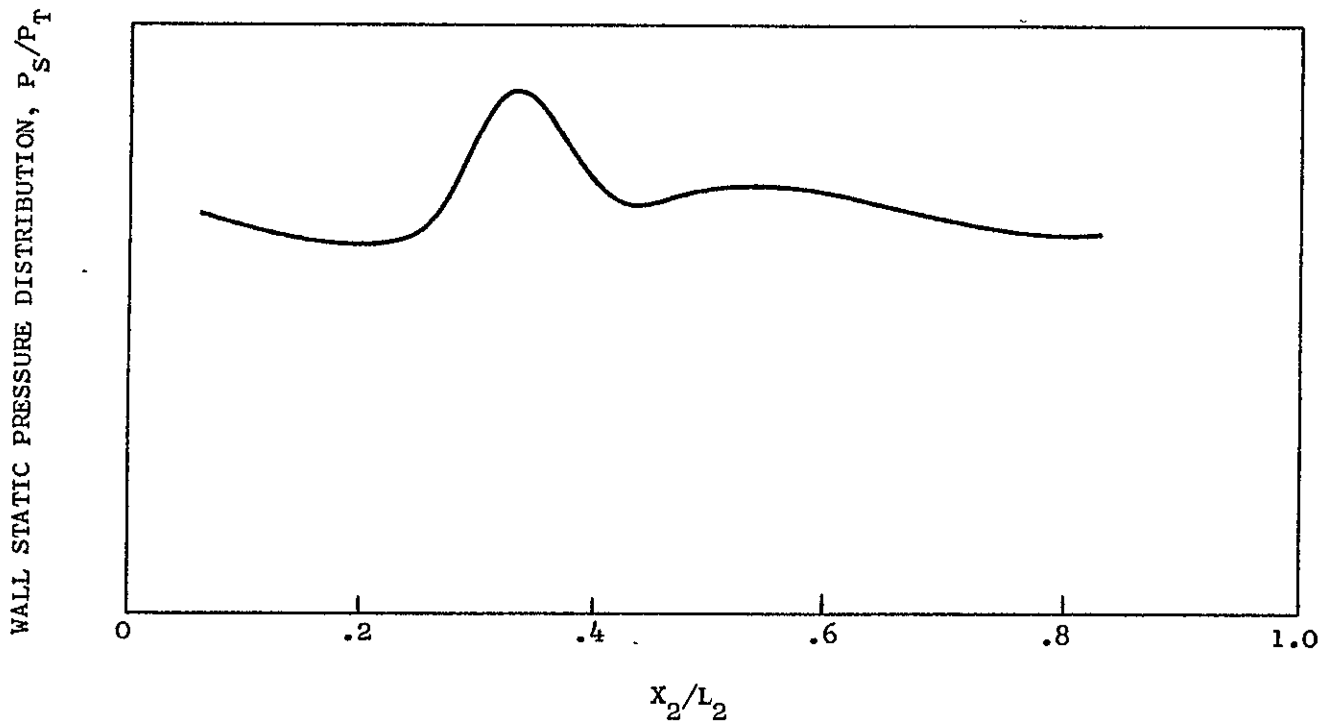


Figure 4-28. VCE Testbed Engine, Double Bypass Selector Valve Outer Wall Static Pressure Distribution, Single Bypass Mode.

4.10 FORWARD VABI MECHANICAL DESIGN

The Forward VABI mechanical design for the Testbed Demonstrator will be a design similar to that on the Forward VABI Demo except for flowpath improvements and modifications to the actuation systems to improve actuation reliability. The design of the selector valve, however, is now complicated by the fact that in the close coupled design it is in the axial plane of the frame struts and thus can no longer be a continuous translating ring. The modulating valve is of the translating sleeve type and is similar in aerodynamic and mechanical design to that demonstrated on the NASA Forward VABI VCE Demonstrator Engine.

The selector valve is of a multi-flap type with individual openings and door-type flaps between the frame struts, eight in all. Initial studies employed a cartridge-type flap valve with side walls, but a later refinement study showed that the design could be simplified and the side walls could be removed.

The Testbed Demo Forward VABI design employs externally positioned hydraulic actuators for the selector and modulating valves as a design requirement for test reliability/accessibility. This feature was verified in the recent NASA Forward VABI VCE Demonstrator Test.

4.11 ROTOR MECHANICAL DESIGN

The CDFS rotor is supported and driven by the current YJ101 HPC rotor. A spacer which bolts the CDFS to the current stage 1 HP compressor disk serves also as a rotating inner flowpath to reduce hub aerodynamic losses.

Preliminary analysis of the stage 1 HPC disk with holes added for bolting the CDFS indicates a minimum low cycle fatigue life greater than 2000 cycles to crack initiation, which far exceeds the anticipated cycles to be experienced during engine testing under current test planning.

The CDFS disk design is similar to the proven TF34 stage 1 of the high pressure compressor. As mentioned in Section 4.7, an axial dovetail attachment was selected for the disk to provide the required strength. The disk design itself is a self-supporting ring design to allow for the expanded sump area. The spacer attachment is configured to reinforce the disk ring and, thus, minimize any tendency for coupled disk/blade resonant conditions.

The aft shaft of the YJ101 fan has been retained, and a new adaptor piece which includes the seal has been designed to attach to the existing stage 2 fan instead of the YJ101/eliminated stage 3 disk.

4.12 DESIGN SELECTION

Based on the afore defined aerodynamic, aeromechanical, dynamic and mechanical design considerations applied to the two contending configurations, a technical assessment was made of both, along with a detailed hardware cost estimate. This assessment provided the basis for the recommendation to select the Close Coupled Configuration for the NASA VCE Testbed Engine Demonstrator.

The details of this assessment follow, and are summarized in tabular form with a qualitative evaluation for each. The relative merits of each factor were assessed as plus (favorable) or minus (unfavorable).

Aerodynamic/Performance Factors

Relative to aerodynamic/performance factors, as described in Table 4-7, the fan front block is identical for both configurations and is the same as previously employed on the USN 2X1 VCE YJ101 concept demonstrator (and also the Forward VABI and acoustic coannular nozzle NASA VCE demonstrators).

The forward VABI for the Close Coupled Configuration has a more favorable flowpath, particularly with regard to the outer bypass duct. This is characterized by a smaller radial offset and lower turning (and associated local separation) in the outer bypass duct. This reduced radial offset results in lower duct pressure losses, but not of a magnitude to materially affect the overall engine performance. This configuration also provides for a more compact installation envelope and, of course, is more representative of the product engine configuration.

The interfan duct of the Close Coupled Configuration embodies less outer wall discontinuity in the single bypass mode with the selector valve in the closed position. Interfan block duct losses were a significant factor in the split fan performance measurements obtained on the USN 2X1 configuration, due principally to the relatively high reference Mach numbers. This interblock duct loss was determined to be a principal area for split fan performance improvement.

The configuration of the core-driven third fan stage is essentially the same for both configurations. Both designs employ a flap type inlet guide vane for reduced losses (another result obtained from the USN 2X1 testing). The flap type IGV will provide lower losses with large closures in double bypass mode operation. A 40-vane configuration is selected for the preliminary design. The rotor embodies a low aspect ratio blade of relatively high radius ratio with 38 blades. Aeromechanical studies and comparison with the blade geometries in other applications have shown that a shroud will not be required for blade stability assurance.

The close coupled configuration, as the name implies, features a shorter distance between the fan rotor discharge and the high pressure compressor inlet plane. The distance is, in fact, 65% shorter in Configuration D. This spacing for the uncoupled Configuration C design is the same as employed in the fan driven configurations, since for all of these the main structural frame is located between the fan third stage and the compressor.

Perhaps the most salient fan aerodynamic issue relative to the two alternative configurations is that concerning the treatment of core-driven stage exit swirl. The high IGV_3 closure required for high front block bypass ratios and increased airflow handling in double bypass operating mode results in an increase in third-stage fan exit swirl. This is common to both designs and is a natural result of low flowing the aft block. In the uncoupled design, this

Table 4-7. VCE Testbed Engine Alternative Design Considerations - Aerodynamic/Performance Factors.

	Close Coupled (Configuration D)	Uncoupled (Configuration C)
A. Fan Front Block	Similar ------------------------------→ (Same as Forward VABI and Early Acoustic Test Demonstrator Engines)	
B. Forward VABI		
• Outer Bypass Duct	• Lower Turning/Radial Offset • Reduced Local Sep. • Lower Pressure Losses ⊕	• Similar to Forward VABI Demonstrator Configuration
• Inner Bypass Duct	Similar ------------------------------→	
C. Inner Fan Duct	• Lesser Outer Wall Discontinuity - Single Bypass Mode ⊕	
D. Core-Driven Stage 3 Fan	• Flap Type IGV (40) -----------------→ - Reduced Losses in Double Bypass Mode (Same for Both Designs)	
	• Low Area Ratio, High Radius Ratio Unshrouded Blade (38) (Same for Both Designs)	
	• Closer Spacing (65%) (Rotor Exit - HPC Inlet - Reduced Duct Losses	• Same Spacing as Fan-Driven Stage 3 on Forward VABI Demo
	• Partial (Bypass Stream) EGV's - Preceded by Delta Airfoils	• Full Span EGV Req'd to Avoid High Incidence Frame Struts (Rotor Exit Angle Swings over Wide Range (~ 20°) ⊖
E. HP Compressor	• New IGV Design Req'd - HPC IGV Functions as Straightening and Guide Vane	• IGV Same as YJ101 ⊕

high exit swirl is accommodated by a full span EGV which prevents high incidence flow angles on the structural struts. This high incidence angle swing on the fixed EGV's is expected to produce no significant problems in the core duct but will produce a relatively high loss coefficient on the inner bypass flow; however, this is predicted to have small effect on engine part power sfc performance, mainly because the proportion of engine flow affected is small. Furthermore, the passage connecting the fan discharge and HP compressor inlet contracts to accelerate the flow and reduce the swirl angle at the HP compressor inlet guide vane plane. In the close coupled design, this rotor exit angle variation is treated in another fashion. Not only are the delta wing airfoils included in the inner duct to reduce the incidence angle on the partial EGV's, but the HP compressor inlet guide vane in Configuration D also acts in a double function, both as a straightening vane and as a conventional flow angle setting device for the first stage rotor.

Mechanical Design Factors

Mechanical Design Factors pertinent to engine configuration selection are summarized in Table 4-8. The blade aeromechanics risk for the core driven rotor is low due to the low aspect ratio/high radius ratio and is essentially the same for both designs. The HPC Stage 1 rotor represents a problem/risk area for both designs (particularly in light of the S-1 blade failure experienced on the USN 2X1 VCE Demo). In the close coupled design, the new dual-function IGV will result in new flow conditions on the Stage 1 HPC blade which will require evaluation in the planned core test with strain gauged HPC blading. In the uncoupled design, the structural frame flow incidence can cause wakes superimposing on the Stage 1 compressor blade and attendant resonance excitation potential.

The forward VABI selector valve in the uncoupled arrangement is very similar to that employed in the forward VABI NASA demonstrator engine (i.e., a simple translating annular ring valve). The close coupled design requires the axial location of the selector valve to be coplanar with the structural struts. This requires individual flap type valves nested between the struts in a manner somewhat similar to the flaps of conventional iris-type exhaust nozzles or the rear VABI of the NASA acoustic coannular nozzle. This multiflap arrangement embodies more sealing perimeter and more leak susceptibility. The modulating (VABI) valve is of the translating ring type for both configurations and is similar in concept and design approach to that evaluated in the forward VABI demonstrator.

Relative to engine structures, the close coupled design requires two new structural frames. These frames do not pose any technical unknowns per se but do represent relatively high cost, long procurement time subcomponents. The uncoupled design utilizes a rework of the existing YJ101/VCE midframe. The frame differences largely account for the cost differential between the two configurations.

Considerable effort has been devoted to the dynamics/vibration analysis of the two alternative configurations and the results of these studies are contained in prior sections. Overall results are summarized in detail and the

Table 4-8. VCE Testbed Engine Alternative Design Considerations - Mechanical Design Factors.

	Close Coupled (Configuration D)	Uncoupled (Configuration C)
A. Blade Aeromechanics		
• Core-Driven Fan/ Rotor Blades	• Aeromech Risk Low - Essentially Same for Both Designs ——————→	
• HPC Rotor 1	• New IGV/New Blade Inlet Conditions to be Verified ⊖	• Same as YJ101 • Blade Subject to Frame Strut Resonance Excitation ⊖
B. Forward VABI - Selector Valve	• New Design - Multi Flap Type - Between Frame Struts (8) • More Sealing Perimeter/ More Difficult to Seal ⊖	• Simpler Translating Ring Valve (Similar to Forward VABI Demo) ⊕
• Modulating Valve	• Translating Ring ——————→ Valve (Similar to Forward VABI Demo)	
• Actuation	• External - Both Valves ——————→ (Reliability)	
C. Structural Frames	• New Auxiliary Frame Req'd ⊖	• Modified YJ101/VCE Main Frame ⊕
D. Vibration Analysis • HP Excited	• Low Response to Unbalance (Starting Range) ⊕ • Similar to F404	• High Response to Unbalance (Starting Range) ⊖
• LP Excited	• Moderate Response to Unbalance in Operating Range - Good Balance Req'd ——————→	
E. Bearing System	• Requires 1 Additional HP Bearing (6 Total)	• Requires 2 Additional Bearings (1 HP/1 LP) ⊖

salient points are listed in Table 4-8. Both configurations can be satisfactorily accomplished; however, the close coupled design poses a lower sensitivity to unbalance in HP excited vibration modes. The bearing system is simpler for the close coupled design with one added bearing relative to the YJ101/F404 design, rather than two for the uncoupled design. The close coupled design is preferred also on that basis.

Other Factors

Other factors, such as similarity to the product configuration, are, of course, in favor of the close coupled design (Table 4-9). This similarity was in essence the reason for pursuing that configuration. Conversely, from a demonstrator program standpoint, the uncoupled configuration represents less change from the current NASA YJ101 demonstrators, and hence, less cost in hardware and tooling. This factor was predominantly the reason for considering the uncoupled configuration as a contender. The hardware and tooling costs for both designs have been determined by a summation of part-by-part manufacturing cost analysis and the overall cost differential amounts to approximately $425,000 at selling price.

Table 4-9. VCE Testbed Engine Alternative Design Considerations - Other Factors.

	Close Coupled (Configuration D)	Uncoupled (Configuration C)
• Similarity to Product Configuration	High +	Low −
• Demo Program Requirements	• Higher Engineering Cost − • Higher Hardware/ Tooling Cost − • More Extensive Core Test Required (VG Optimization) −	• Highest Hardware Commonality to Early Acoustic Test Demo Engine +

5.0 PHASE II PROGRAM PLANS

5.1 INTRODUCTION

This section describes the program plans for design, hardware procurement, assembly, instrumentation and testing of the NASA VCE Testbed Engine. Preliminary design studies of two alternative configurations - uncoupled (Configuration C) and close-coupled (Configuration D) - were previously completed and the results were reviewed with NASA, with the recommendation for selection of the close-coupled configuration for the testbed engine design (as described under Section 4.0).

The detailed design effort will be based on the preliminary design described under Section 4.0 of this report and hardware and tooling will be procured for the following two sequential test phases:

(1) A core test in a Lynn ram test facility to determine the core-driven aft fan block aerodynamic performance and integration with the high pressure compressor.

(2) A complete engine test at the Peebles or Edwards facility for concurrent evaluation of overall engine aerodynamic characteristics/performance and coannular exhaust nozzle acoustic testing. This acoustic testing would present the second phase of full-scale inverted flow coannular nozzle testing and would also evaluate the effects of a mechanical suppressor added to the high-speed outer stream of the coannular nozzle.

5.2 OBJECTIVES

The objectives of the work described in this program can be summarized as follows:

(1) To design, procure and fabricate hardware for the VCE testbed engine employing the "close-coupled" core-driven third stage fan concept in a modified YJ101 engine.

(2) To test the operating characteristics of the core-driven third stage concept in a core (i.e., high-pressure spool) test to evaluate aerodynamic and aeromechanical performance. This testing will establish the aft fan block performance and variable geometry schedules required for integration with the YJ101 core engine.

(3) To test the operating characteristics of a VCE demo engine employing the core-driven third stage fan core engine from (2). This would require the addition of the front block of the fan, low pressure turbine and exhaust system. This testing will establish the overall feasibility and performance characteristics of the core-driven fan concept, in conjunction with previously demonstrated features including the split fan, forward variable area bypass injector, variable area LP turbine, rear variable area bypass injector and coannular acoustic exhaust nozzle.

(4) To design and procure hardware to modify the coannular acoustic nozzle assembly, to integrate one selected exhaust suppressor, and to design and procure the required suppressor hardware. Based on the initial phase of testing, limited modification to the coannular acoustic nozzle procured under Exhibit B1 of Contract NAS3-20582 is expected. The selected suppressor configuration will be based on prior scale model acoustic results.

(5) To test the complete VCE testbed engine system in an outdoor test facility to measure aerodynamic and acoustic performance characteristics. This testing will be done in conjunction with the testbed engine performance testing described in (3).

5.3 SUMMARY

The VCE Testbed Engine Program includes the design, hardware procurement and testing of the VCE YJ101 engine, which demonstrates many of the features particularly desirable for an advanced SST application. This testbed engine will be an extensively modified version of the engine tested under Contract NAS3-20582, Exhibit B1 (VCE Early Acoustic Test).

The following Early Acoustic Test vehicle VCE concepts will be retained in this Testbed Engine configuration:

- Split Fan
- Forward VABI
- Variable Area LP Turbine
- Rear VABI
- Inverted Flow Coannular Plug Nozzle

However, the rear fan block of the new configuration will be core-driven, as opposed to the Early Acoustic Test vehicle which has the third stage fan driven by the LP system. Thus, this Testbed Engine program will demonstrate the feasibility of all of those features currently employed in the Contractor's Double Bypass VCEE (Variable Cycle Experimental Engine) concept (see NASA CR 159419) and similar but more advanced SST product line conceptual engine designs with the exception of the "oversize" front fan block.

The Testbed Engine will use as its basic building block the Early Acoustic Test concept demo Variable Cycle Engine (VCE) configuration with the 2X1 fan-stage split. The rear (third) stage of the fan will be driven by the high-pressure (core) spool to take advantage of the improved high/low pressure turbine work split capabilities of this arrangement. The high-pressure turbine loading is increased and the low-pressure turbine corresponding decreased, which in turn reduces LPT inlet temperature and thus LPT cooling requirements. This configuration provides an increase in the overall cycle performance with a consequent decrease in the projected supersonic cruise fuel consumption.

A forward Variable Area Bypass Injector (VABI) mixing valve similar in concept to that developed and tested under Exhibit B1 of Contract NAS3-20582 will be utilized in the core-driven configuration. This forward VABI allows the outer and inner bypass streams to be combined into a single stream downstream of the last fan stage. In the low-noise mode, this combined bypass stream will exhaust through the acoustic nozzle plug centerbody while the primary stream exhausts from the annulus surrounding the plug. The variable forward control valve can also be adjusted to reduce the amount of bypass flow for a high specific thrust engine operaing mode. In such a mode, essentially all exhaust flow would be designed to go through the annulus surrounding the plug. The rear VABI mixing valve permits the bypass flow to combine with the primary flow in this mode to obtain an approximately uniform exhaust velocity profile.

The configuration of the selected core-driven testbed engine to be built and tested under this Testbed Engine Program is the so-called "close-coupled" version defined under the Exhibit A of this Contract NAS3-20582. Both the aerodynamic flowpath and aeromechanical arrangement of the components of the close-coupled configuration offers a better simulation of the ultimate product/design study engine as well as lower losses than the "uncoupled" version which was also an option considered. The more desirable "close-coupled" version, however, has less hardware commonality with the Early Acoustic Test configuration and requires relocation and fabrication of engine main and auxiliary frames.

The core-driven testbed engine would also use the variable area LP turbine nozzle (VATN) and rear VABI utilized in the Early Acoustic Test demo engine. The acoustic benefits of the unique inverted flow coannular plug nozzle will also be measured in this program and compared to the results attained from the Early Acoustic Test Engine. Additionally, a mechanical suppressor will be designed, procured and tested on the testbed engine in conjunction with the coannular nozzle. The suppressor design will be selected based on prior scale model acoustic tests.

The NASA core-driven fan Testbed Program is to be well integrated and coordinated with both the military VCE programs and with other related NASA VCE/SCAR programs. The results of the Early Acoustic Test (NAS3-20582) will be carefully analyzed and all pertinent knowledge gained from that program will be integrated into the VCE testbed program, as appropriate.

5.4 OVERALL PHASE II PROGRAM PLAN

5.4.1 Program Elements and Timing

The schedule for the total technical effort of the VCE testbed engine program, is twenty-seven (27) months (excluding reporting requirements). The work to be performed has been broken down into the following elements:

Design

- Aerodynamic Design - Core-Driven Fan and Forward VABI
- Aero/Acoustic Design - Exhaust System/Suppressor
- Mechanical Design - Core-Driven Fan and Forward VABI
  - Exhaust System/Suppressor
- Cycle and System Analysis

Hardware and Tooling

Test Setup and Testing

- Core Engine Test
- Engine System Test

The scheduled completion of these various elements is shown in Figure 5-1 (including the associated reporting requirements).

5.4.2 Design

Design Engineering in the following sub-tasks, in addition to providing for the design of the indicated components, also provides for the support coverage during subsequent fabrication, test setup, and testing.

5.4.2.1 Aerodynamic Design Core-Driven Fan and Forward VABI

The Contractor shall define the flowpaths for the "close coupled" core-driven third stage fan including fan interblock ducting between the existing YJ101 Stage 1 and 2 fan front block and the core-driven third stage, ducting between the third stage fan and the high-pressure compressor, inner and outer as well as aft bypass ducts, and the forward VABI selector and modulating mixing valve. The airflow geometry of the third stage fan inlet guide vane, rotor blade and exit guide vane will be defined. The inlet guide vane for the high-pressure compressor applicable to this third stage core-driven fan design will also be defined. The ducting is to be designed to provide the lowest practical pressure losses within the constraints imposed by the product engine studies. The Contractor shall define these flowpaths in such a way as to maintain compatibility, to the extent practical, with the existing two-stage front block fan and the mounting ring and aft VABI of the existing coannular plug nozzle. This design shall be based on the selected "close-coupled" configuration that the Exhibit A work of Contract NAS3-20582 showed to have the greatest aero-dynamic similarity to the projected product design.

5.4.2.2 Aero/Acoustic Design - Exhaust System/Suppressor

The Contractor shall define the necessary exhaust nozzle flowpaths and

PAGE 1 OF 2 PAGES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT PERFORMANCE ANALYSIS REPORT

Form Approved
Budget Bureau No 104 R0011

2 REPORT FOR PERIOD ENDING AND NUMBER OF OPERATING DAYS

TO: NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

FROM: General Electric Company
Aircraft Engine Group
Cincinnati, Ohio 45215

3 CONTRACT VALUE
a COSTS $ | b FEE $

1 DESCRIPTION OF CONTRACT
a TYPE: Definition Study
b CONTRACT NO AND LATEST DEFINITIZED AMENDMENT NO: NAS3-20582A
c SCOPE OF WORK: VCE Testbed Engine and Associated Test Program
d AUTH CONTR REP (Signature) DATE

4 FUND LIMITATION $

5 BILLING
a INVOICE AMTS BILLED $ | b TOTAL PYTS REC'D $

CUM COSTS/HOURS THROUGH CURRENT PERIOD

6 REPORTING CATEGORY	7 PLANNED VALUE OF WORK: SCHEDULED a	7 PLANNED VALUE OF WORK: ACCOMPLISHED b	8 ACTUAL COSTS/HOURS	9 VARIANCE: SCHEDULE (Col 7b-7a) a	9 VARIANCE: COSTS/HOURS (Col 7b-8) b	10 CONTRACTOR'S ESTIMATED FINAL COST
Submit Work Plan						
Aerodynamic Design - Core						
Aerodynamic Design - Exhaust System						
Acoustic Design						
Mechanical Design - Core						
Mechanical Design - Exhaust System						
Cycle and System Analysis						
Preliminary Design Review						
Material Release (Critical Components)						
Detail Design Review						
Hardware Procurement - Core						
Hardware Procurement - Exhaust						
Core Engine Assembly and Instrumentation						
Core Engine Test Plan Review						
Core Engine Test						
Core Test Oral Report						
Core Test Topical Report						
Engine Assembly and Instru						
Engine Test Plan Review						
Engine Test						

11 TECHNICAL ASSESSMENT OF PROGRESS — a SCHEDULE AND STATUS

6 REPORTING CATEGORY	1978						1979												1980												1981		
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Submit Work Plan	▽																																
Aerodynamic Design - Core	▽					▽																											
Aerodynamic Design - Exhaust System						▽									▽																		
Acoustic Design	▽						▽																										
Mechanical Design - Core	▽								▽																								
Mechanical Design - Exhaust System						▽									▽																		
Cycle and System Analysis	▽																						Core ▽				Engine ▽						
Preliminary Design Review				▽																													
Material Release (Critical Components)					▽																												
Detail Design Review											▽																						
Hardware Procurement - Core					▽										▽																		
Hardware Procurement - Exhaust												▽									▽												
Core Engine Assembly and Instrumentation															▽					▽													
Core Engine Test Plan Review																			▽														
Core Engine Test																				▽		▽											
Core Test Oral Report																							▽										
Core Test Topical Report																								▽									
Engine Assembly and Instru																							▽		▽								
Engine Test Plan Review																								▽									
Engine Test																									▽		▽						

NASA FORM 533P SEP 71

Baseline Plan Identification (Col 7a) Revision No ________, Dated ________

NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE

NASA APPROVED SCHEDULE DATE ________

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Figure 5-1. SCAR/VCE Testbed Engine Program Milestones.

PAGE 2 OF 2 PAGES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT PERFORMANCE ANALYSIS REPORT

Form Approved
Budget Bureau No 104 R0011

2 REPORT FOR PERIOD ENDING AND NUMBER OF OPERATING DAYS

TO: NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

FROM: General Electric Company
Aircraft Engine Group
Cincinnati, Ohio 45215

3 CONTRACT VALUE
a COSTS $ | b FEE $

1 DESCRIPTION OF CONTRACT
a TYPE: Definition Study
b CONTRACT NO AND LATEST DEFINITIZED AMENDMENT NO
c SCOPE OF WORK: VCE Testbed Engine and Associated Test Program
d AUTH CONTR REP (Signature) DATE

4 FUND LIMITATION $

5 BILLING
a INVOICE AMTS BILLED $ | b TOTAL PYTS REC'D $

6 REPORTING CATEGORY	CUM COSTS/HOURS THROUGH CURRENT PERIOD: 7 PLANNED VALUE OF WORK – SCHEDULED a	ACCOMPLISHED b	8 ACTUAL COSTS/HOURS	9 VARIANCE – SCHEDULE (Col 7b – 7a) a	COSTS/HOURS (Col 7b – 8) b	10 CONTRACTOR'S ESTIMATED FINAL COST	11 TECHNICAL ASSESSMENT OF PROGRESS – a SCHEDULE AND STATUS
Engine Oral Report							
Comprehensive Data Reports							
Final Report Draft							

Schedule months: 1978: J A S O N D; 1979: J F M A M J J A S O N D; 1980: J F M A M J J A S O N D; 1981: J F M

NASA FORM 533P SEP 71

Baseline Plan Identification (Col 7a) Revision No ________, Dated ________

NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE

NASA APPROVED SCHEDULE DATE ________

Figure 5-1. SCAR/VCE Testbed Engine Program Milestones (Concluded).

perform the aerodynamic design of a representative acoustic suppressor configuration for the outer (main) stream of the existing coannular plug nozzle. The design of the suppressor shall be based upon results available from FAA/DOT Contract DOT-OS-30034 and shall conform to the main exhaust flow system designed previously on Contract NAS3-20582 in order to use those existing struts and hydraulically-actuated center plug system. The Contractor shall also define any aerodynamic modifications needed on the existing coannular nozzle to integrate the selected suppressor. As part of the suppressor design effort, the Contractor shall perform acoustic predictions based on the Contractor's preliminary design prediction methods available at the time of the design. These predictions shall cover the spectrum of nozzle/suppressor configurations considered and shall be incorporated as a part of the Test Plan (see Section 5.4.4.2).

5.4.2.3 Mechanical Design

5.4.2.3.1 Core-Driven Fan and Forward VABI

The Contractor shall do the design, stress analysis and drafting work required to release manufacturing drawings for all hardware needed to modify the Early Acoustic Test engine configuration per Exhibit B1 to the "close-coupled" core-driven third stage fan testbed engine configuration defined in Exhibit A. These drawings shall be in conformance with the schedule article entitled "Conceptual and Developmental Design Drawings (Level 1)". Furthermore, the design work, including the stress anslysis, drawings, and materials specifications, shall be in conformance with NASA Mechanical Design and Analysis Requirements.

The hardware to be designed in this task, as currently planned, shall include the core-driven third stage rotor disk, rotor blading, and third stage fan inlet guide vane assembly with articulated trailing flaps, an exhaust guide vane for the inner bypass stream, and a structural frame to support the forward end of the high pressure compressor casing. Additionally, the hardware shall include a casing for the third stage fan, actuation linkage for varying the aft fan block inlet guide vanes, as well as shaft adapters to drive the aft fan stage from the core spool and adapters to drive the existing two-stage front fan block from the low-pressure spool, with associated bearing and power takeoff gearing modifications.

Structural and dynamic analysis to assure absence of vibration during test operation will be accomplished. The Contractor shall also design hardware for the inner fan block ducting and for the ducting between the aft core-driven fan stage and the HP compressor as well as a new inlet guide vane and associated linkage for the HP compressor. Aeromechanical design analyses shall be conducted to assure adequacy of all the required fan and compressor blades and vanes unique to the core-driven third stage concept. Additionally, the Contractor shall design a new forward VABI, including both (1) an axially translating modulating valve (similar in concept to the valve to be tested under Exhibit B1 of Contract NAS-20582) to maintain equal static pressures between the inner and outer bypass streams and (2) a new flap-type selector valve nested between relocated forward frame struts, both of which are adaptable to the core-driven third stage flowpaths. The Contractor shall also design the aft ducting to adapt the bypass duct to the existing rear mounting ring and low-pressure VATN actuation linkage.

The Contractor shall specify and select hydraulic actuators to provide the motive force to translate the forward outer bypass selector valve and modulating area bypass mixing valve. The Contractor shall also specify and select hydraulic actuators to provide the motive force to vary the position of the inlet guide vanes of the core-driven aft fan as required for transition from single to double bypass operation. Additionally, means to provide adjustment of front block fan exit guide vanes will be provided (if required). The new inlet guide vane for the high-pressure compressor will be adapted to the HPC variable geometry actuation system. To the extent practical, the actuators as well as conncting pins, brackets, nuts, bolts, etc., shall be "off-the-shelf" items.

5.4.2.3.2 Exhaust System/Suppressor

The Contractor shall do all the design, stress analysis and drafting work required to integrate the selected representative suppressor design into the existing acoustic coannular nozzle. The suppressor configuration shall be a fixed, non-retractable design for the purpose of this program.

5.4.2.4 Cycle and Systems Analysis

The Contractor shall modify a cycle performance and acoustic prediction computer deck(s) to simulate the core test and complete testbed engine test configurations. The Contractor shall make pretest performance predictions with this computer deck for inclusion in the Test Plans for the core test (Section 5.4.4.1) and engine test (Section 5.4.4.2). The existing fan front block and new rear block fan maps corresponding to the core-driven third stage shall be incorporated in these predictions. Test results obtained from the NASA forward VABI and NASA early acoustic test VCE configurations shall be incorporated in the pretest predictions included in the Test Plan submitted under Section 5.4.4.2, Engine Test, along with any required revisions defined by the core test under 5.4.4.1.

In addition, the Contractor shall prepare a data reduction program to provide on-line calculations of the engine and component performance during testing under this engine program. The Contractor shall also provide to NASA a posttest analysis of the date acquired in the tests for both the core testing (Section 5.4.4.1) and engine testing (Section 5.4.4.2).

5.4.3 Hardware and Tooling

The Contractor shall procure and fabricate the components designed and specified under Sections 5.4.2.1 and 5.4.2.2 after receiving approval from the NASA Project Manager. This shall include any special hardware that is required to adapt the core-driven third stage core test vehicle to the Contractor's test facility.

5.4.4 Test Setup and Testing

The demonstration of the core-driven third stage concept will be accomplished in two integrated sequential phases. First, the aerodynamic and aeromechanical characteristics of the core-driven third stage aft fan block with forward VABI selector and modulating valves will be combined with the modified YJ101 HP core for evaluation in a Contractor test facility. Subsequently, the core-driven third stage, forward bypass control valves, and core engine from the first phase will be assembled with the existing forward fan block, aft bypass ducting, existing LP turbine (including VATN) and modified rear VABI/coannular exhaust nozzle/suppressor into an integrated testbed engine for overall aero/acoustic performance evaluation in a Contractor outdoor test facility.

5.4.4.1 Core Engine Test

The Contractor shall perform disassembly and inspection of the existing YJ101 VCE Early Acoustic Test vehicle hardware to assure its readiness for further testing. The Contractor shall also accomplish any required refurbishment of standard performance instrumentation installed in the available YJ101 VCE Early Acoustic Test vehicle.

The Contractor shall submit a detailed written Test Plan and present an oral review to the NASA Project Manager for the core test at least thirty (30) days prior to the scheduled start of testing. Types of testing, predicted performance, instrumentation details, test schedules, emergency shutdown procedures, and facility and on-line computer requirements shall be defined in the Test Plan.

The core Test Plan shall include mechanical checkout throughout the required speed range, variable guide vane schedule evaluation of the fan and HP compressor performance mapping, distortion testing and performance demonstration with the selected fan/HP compressor variable guide vane schedule. The variable geometry actuation systems will allow independent remote variation of fan inlet guide vanes, the HP compressor inlet guide vanes and HP compressor stators 1 and 2, either individually or ganged.

The Contractor shall assemble, instrument and evaluate a core test vehicle comprised of the core-driven third stage aft fan coupled with a modified YJ101 core engine to measure aft fan block aerodynamic performance in both single and double bypass operating modes. The Contractor shall evaluate the performance of the core-driven third stage fan block coupled with the HP core and verify fan and HP compressor aeromechanical characteristics under both clean and distorted inlet conditions. For this testing the test vehicle will be comprised of a bellmouth and inlet duct adapter attached to the main structural frame which is forward of the core-driven aft fan block, a modified aft turbine frame to accommodate high-pressure turbine discharge swirl variation, and existing slave exhaust duct and variable nozzle. The new forward VABI modulating and selector valves with associated actuation designed under Sections 5.4.2.1 and 5.4.2.2 will be assembled with the core test vehicle and used as a throttle valve for the core-driven fan in this test. Testing will be conducted in the Contractor's ram test facility to simulate front block fan outlet conditions in this test.

The Contractor shall instrument the core-driven third stage and core compressor to measure aerodynamic performance with both clean and distorted inlet conditions. Distortion testing will be accomplished with several patterns of distortion screens. The Contractor shall instrument the core-driven aft fan rotor blades and the rotor blades of the forward stages of the high-pressure compressor to evaluate aeromechanical characteristics under conditions of simulated single bypass and double bypass operation. Fan aft stage inlet and discharge instrumentation and compressor inlet instrumentation to measure the aerodynamic flow fields entering and discharging from the fan and entering the aft bypass duct and high-pressure compressor will be incorporated. Pressure transducers, static pressure taps, and total temperature and pressure rakes shall be located at appropriate stations to map the fan and compressor performance. After receiving the NASA Project Manager's approval of the Test Plan, the Contractor shall conduct core engine testing at the Contractor's test facility.

5.4.4.2 Engine System Test

The Contractor shall perform visual and borescope inspection of the core test vehicle to assure its readiness for further testing. This will include refurbishment of the performance instrumentation utilized in the core testing under Section 5.4.4.1.

The Contractor shall submit a detailed written Test Plan and present an oral review of this Plan to the NASA Project Manager for the aero/acoustic test of the core-driven double bypass testbed engine at least thirty (30) days prior to scheduled start of testing. Types of testing, range of system parameters to be varied, predicted performance and acoustics, instrumentation and control system requirements and procedures, testing procedures including provisions for emergency shutdown, and test schedules shall be included in the Test Plan.

The Contractor shall assemble and instrument the VCE testbed engine comprised of the core test vehicle described in 5.4.4.1 with addition of the existing two-stage forward fan block, associated shaft adapters to drive the front block with the variable area LP turbine, and required power take-off gearing. The Contractor shall assemble the forward VABI system to the aft bypass ducting leading around the VATN linkage to the modified rear VABI and acoustic nozzle described in Sections 5.4.2.1 and 5.4.2.2. Additional aerodynamic instrumentation shall be incorporated to measure front block fan performance and forward VABI performance. The rear VABI and coannular exhaust nozzle instrumentation from the test setup evaluated under NAS3-20582 Mod. 2 Exhibit B1 will be refurbished and modified based on results of the initial acoustic nozzle tests.

The Contractor shall make any necessary modifications to the test facilities in order to adapt the testbed engine to the Contractor's outdoor test stand and fulfill required test program and objectives.

After receiving the NASA Project Manager's approval of the Test Plan, the Contractor shall begin the specified test program. The order of testing and calibration procedures shall be specified by the Contractor based on experience obtained under Contract NAS3-20582, but, in any event, should be clearly defined in the written Test Plan.

Upon completion of a mechanical checkout, the Contractor will accomplish aerodynamic performance evalutaion of the testbed engine, including simulation of single and double bypass operation at steady state conditions. The Contractor shall establish operating and performance characteristics, as well as any critical aeromechanical or duct stability limits. In addition to steady state testing, the Contractor shall determine component and system behavior during transition from single to double bypass modes and vice versa. Tests shall be conducted simulating the transition from the takeoff to the reduced-throttle subsonic cruise modes. Inlet distortion testing using two distortion patterns shall also be conducted. The aerodynamic tests of the complete engine system will be conducted at the Contractor's outside test facility.

Upon completion of the engine aerodynamic performance tests, acoustic tests will be accomplished with several exhaust configurations, including the acoustic coannular nozzle with a selected radius ratio, conic baseline nozzle with standard engine inlet bellmouth, conic baseline nozzle with treated engine inlet bellmouth and acoustic coannular nozzle with outer stream suppressor. The acoustic tests will be conducted at the Contractor's outside test facility.

Instrumentation shall be provided so that jet exit average conditions may be calculated for velocity, temperature, and pressure, based on measured nozzle entrance conditions. In addition, the Contractor shall perform nozzle profile measurements on the Contractor-selected coannular plug nozzle suppressor configuration. These velocity profile measurements shall be performed using the Contractor-developed laser velocimeter (LV) system at Contractor-selected test conditions, subject to approval of the NASA Project Manager. Although successful measurements have been made for model scale tests and limited engine tests, it is understood that LV measurements techniques, as applied to engine exhaust systems, are considered as advanced applied research measurement techniques. Therefore, the LV velocity profile measurement shall be performed by the Contractor on a best effort basis.

Thereafter, engine tests shall be conducted by the Contractor utilizing and evaluating all of the acoustic nozzle variations approved and designed under Section 5.4.2.3 of this engine program. Exit average conditions for velocity, temperature, and pressure shall be calculated for each nozzle configuration based on measured nozzle entrance conditions. The testing shall explore coannular high flow modes ranging from 10 to 20 percent above the nominal low-flow mixed exhaust condition for a wide spectrum of throttle conditions. In the event that a model scale acoustics program is being carried out in parallel to this Contract, at least one test point for the coannular plug nozzle suppressor engine configuration shall, to the extent practical, simulate the exhaust thermodynamic conditions tested under the model tests.

The Contractor shall provide far-field acoustic measurements at 0^{o} and 15^{o} and at 10^{o} angular increments from 20^{o} to 160^{o} from the engine inlet axis. In addition, and based on the engine test results under Contract NAS3-20582, the Contractor shall consider the necessity of performing near-field acoustic measurements. In the event the near-field acoustic measurements are necessary, and upon approval of the NASA Project Manager, either a microphone traverse system or an array of stationary ground microphones may be used.

In addition to acoustic test data, engine operating characteristics and performance data (e.g., nozzle discharge and thrust coefficients, airflow from a calibrated bellmouth, metered fuel flow, etc.) shall also be obtained. The Contractor shall also evaluate total system stability and operational characteristics in both the high and low-flow modes of front block fan operation as well as during transition between these operating modes. The Contractor shall, in particular, evaluate both the steady-state flow characteristics and the dynamic interaction between the fan and forward bypass control valve by means of appropriate internal pressure and temperature measurements. Similarly, the Contractor shall evaluate both the steady-flow characteristics and dynamic interaction of the rear bypass control valve/acoustic plug nozzle subsystem.

The Contractor shall provide to NASA a posttest analysis of the performance and acoustic data required in the VCE system aero-acoustic test at an agreed to date after test completion. This shall include EPNL projections to product/study size at thrust/altitude/flight speed compatible with FAR 36 (1969) or other mutually agreed conditions. The SPL spectra measured in the VCE system acoustic test shall be extrapolated and scaled to provide in-flight EPNL at the appropriate measuring stations for engine sizes and thrust ratings scaled up to those representative of the product/study engine(s) (i.e., within the matrix of such size and thrust data generated earlier for the product/study engine(s) under the Exhibit A of Contract NAS3-20582.

These acoustic predictions shall be based on the Contractor's acoustic prediction procedures, as well as theoretical acoustic techniques developed by the Contractor. The methodology for these prediction procedures shall be documented in an appendix to the Test Plan.

5.4.5 Estimated CDFS Demonstrator Engine Hardware Costs and Schedule

Based on the design definitions accomplished as reported in Section 4.0, detailed manufacturing cost and timing estimates were prepared for both configurations. These are summarized in Table 5-1. As previously described, the recommended close coupled configuration hardware has a higher cost due to the more extensive engine modification required for that configuration. Nevertheless, the recommendation was made and accepted to adopt the design which more closely simulates the SCAR product engine and avoids the dynamic/bearing problems of the alternative design. The manufacturing study also assessed the

Table 5-1. VCE Testbed Engine Hardware Cost Estimates for Close Coupled Vs. Uncoupled Configurations.

Close Coupled Configuration	
Shop Cost	Tooling Cost
$712,000	$404,000

Uncoupled Configuration	
Shop Cost	Tooling Cost
$469,000	$225,000

Costs are in Then Year Dollars at Selling Price lead time requirements for manufacture of principal long lead time subcomponents and these are shown in Table 5-2 together with the recommended program schedule for the initiation of the Testbed Engine VCE demonstrator program based on hardware lead times. Other salient proposed milestones are defined in Figure 5-1.

5.4.6 Estimated Program Costs

The following Tables (5-3 through 5-10) present preliminary estimated program costs by calendar quarter, which were compiled in May 1978. Since that time a formal request for proposal was received from NASA (RFP 3-838455Q) and more detailed cost estimates can now be found in General Electric's Proposal P78-96, "A Proposal for Additional Effort Under Contract NAS3-29582 for VCE Testbed Engine - Exhibit C", Volume II, Business Management Proposal. A summary of the program costs is shown in Table 5-11.

Table 5-2. Long Lead Time Hardware and Recommended Program Schedules.

VCE Testbed Engine Long Lead Time Hardware

(Lead Time Greater Than 6 Months)

- Main Frame
- Intermed. Frame
- Outer Bypass Casing
- Fan Discharge Seal
- Fan Disk
- Fan Blades
- Shaft Spacer
- Bevel Gears

Recommended Schedule

–	Refined Aft Flowpath	-6/78
–	Start VCE Engine Design	-7/78
–	Material/Advanced Releases	-12/78
–	Complete Design Releases	-3/79
–	Core Hardware Available	-9/79
–	Core Test Complete	-4/80
–	Remaining Engine System Hardware Available	-2/80
–	Full Engine System Test Complete	-9/80

Table 5-3. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS-ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Program Management - Overall program management to ensure achievement of all technical objectives within budgeted cost and timing. Publication of monthly and final reports as required. Coordination with NASA on design reviews, oral presentations and informal working discussions, as necessary to achieve program objectives.

MILESTONES	STATUS		1978				1979				1980			
LINE ITEM	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4
Overall Program Management														△
Monthly technical, schedular and financial														△
reporting											△			△△
Topical, final reports and CDR's														

Work element cost - $78,000 in then year $ at CPFF selling price.

Table 5-4. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS-ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Aerodynamic Design (Section 4.2.1) - Define the flow paths for the third stage fan, inner and outer bypass ducts and forward VABI. Complete detailed aerodynamic design of these components and integrate the final design with mechanical design effort. Support fabrication, build and test of core and engine system vehicles and conduct post test analyses.

MILESTONES	STATUS		1978				1979				1980											
LINE ITEM	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4								
Aerodynamic Design																						
Detail Design & Program Support																						
Test Support and data analysis																						

Work element cost - $493,000 in then year $ at CPFF selling price.

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Table 5-5. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS–ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Aero/Acoustic Design - Exhaust System/Suppressor (Section 4.2.2). Define the flow path for the rear VABI and integrate the rear VABI, acoustic nozzle and suppressor designs. Perform detail aero design for acoustic nozzle and suppressor hardware. Support fabrication, build up and test of the core and engine system vehicle and conduct post test data analyses.

MILESTONES LINE ITEM	STATUS %	STATUS SCHED	1978 1	1978 2	1978 3	1978 4	1979 1	1979 2	1979 3	1979 4	1980 1	1980 2	1980 3	1980 4
Aero/Acoustic Design														
Nozzle and Suppressor Design														
Detail Design and Program Support														
Test Support and Data Analysis														

Work element cost - $435,000 in then year $ at CPFF selling price.

Table 5-6. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS-ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Mechanical Design (Section 4.2.3) - Conduct design, analysis and drafting effort required to release manufacturing drawings for the core driven fan, forward VABI, exhaust system, mechanical suppressor and other hardware needed to modify the VCE concept demo to the AST testbed configuration. Provide manufacturing, assembly and test coverage support and coordination for both the core and engine system builds and tests.

MILESTONES	STATUS		1978				1979				1980			
LINE ITEM	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4
Mechanical Design - Core							△							
Mechanical Design - Exhaust System									△					
Hardware Procurement Support											△			
Engine Assembly & Test Support														△

Work element cost - $1,869,000 in then year $ at CPFF selling price.

Table 5-7. VCE Testbed Engine, Phase II Program Plans.

WBS-ABC

WBS PLANNING SHEET

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Cycle and Systems Analysis (Section 4.2.4) - Modify the cycle deck to simulate the core and engine system test configurations. Generate pretest predictions for inclusion in the test plans. Prepare a data reduction program for on-line engine performance calculations. Conduct post test data analysis for both core and engine system tests.

MILESTONES	STATUS		1978				1979				1980											
LINE ITEM	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4								
Cycle Systems Analysis								△														
Design Support										△												
Core Engine Test Support and Analysis													△									
Engine System Test Support and Analysis														△								

Work element cost - $590.000 in then year $ at CPFF selling price.

Table 5-8. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS-ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Hardware Procurement (Section 4.3) - Procurement and fabrication of those components specified and designed under the aerodynamic and mechanical design portions of the program. This includes any special hardware required to adapt the core driven third stage core test vehicle to the Lynn test facility.

MILESTONES	STATUS		1978				1979				1980											
LINE ITEM	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4								
Procure Core Engine Hardware						———	———	———	△													
Procure Engine System Hardware									———	———	△											

Work element cost - $1,355,000 in then year $ at CPFF selling price.

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Table 5-9. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS-ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV			WBS REF

SCOPE Core Engine Test (Section 4.4.1). Disassemble, inspect and refurbish the Early Acoustic Test Demo Engine. Rebuild with core driven third stage fan and new forward VABI and associated instrumentation. Conduct core test including mechanical checkout, fan and compressor performance mapping and fan and HP compressor VGV schedule evaluation.

MILESTONES	STATUS		1978				1979				1980											
	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4								
LINE ITEM																						
Fabricate Instrumentation											△											
Rework and Install Instrumentation											△											
Assemble Core Engine											△											
Conduct Core Test												△										

Work element cost - $958,000 in then year $ at CPFF selling price.

Table 5-10. VCE Testbed Engine, Phase II Program Plans.

WBS PLANNING SHEET

WBS–ABC

TITLE	RESPONSIBLE	ISSUE DATE	BASELINE REF	IDENT NO
VCE Testbed Engine - Phase II Program Plans	APPRV		*	WBS REF

SCOPE Engine System Test (Section 4.4.2). - Inspect and refurbish instrumentation on core test vehicle. Assemble the AST nozzle, forward VABI and front block fan to the core engine and prepare for test. Conduct acoustic test, including LV measurements.

MILESTONES	STATUS		1978				1979				1980			
LINE ITEM	%	SCHED	1	2	3	4	1	2	3	4	1	2	3	4
Prepare Laser Velocimeter											△			
Refurbish Engine & Instrumentation												△		
Assemble Engine												△		
Conduct Acoustic Test													△	

Work element cost - $918,000 in then year $ CPFF selling price.

Table 5-11. VCE Testbed Engine - Program Cost Summary

Work Element	Cost * (1000's $)
Program Management	60.0
Aerodynamic Design	379.0
Aero/Acoustic Design	335.1
Mechanical Design	1437.5
Cycle and Systems Analysis	454.0
Hardware Procurement	1042.2
Core Engine Test	737.2
Engine System Test	705.2
TOTAL	5150.5

* Total manufacturing cost - does not include G&A, Fee, etc.

5.5 PHASE I TEST PLANS

Outlines of the proposed core and system engine tests are provided in Section 5.4.4. In general, the VCE testbed test program will closely parallel the Early Acoustic Test Program established under NASA Contract NAS3-20582. The core engine test will be conducted at the General Electric Company's Lynn Mass., plant in the same test complex that was utilized during the forward VABI demonstrator program.

The full engine system test will be conducted at an outdoor acoustic facility, either Peebles, Ohio, or Edwards Air Force Base, California. These test sites are essentially equivalent in terms of facilities and acoustics measurement capability. Figure 5-2 shows a comparison of the two sound fields at Peebles and Edwards. The typical far-field microphone array (as used in the Early Acoustic Test) for the VCE engine utilizes microphones on a 30.48m (100 ft) arc in the forward quadrant and on a 21.34m (70 ft) sideline in the aft quadrant. As Figure 5-2 shows, both test sites adequately meet these requirements.

Figure 5-3 is an aerial photograph of the Edwards test site taken during the recent VCE Early Acoustic Test and Figure 5-4 shows the EATD vehicle on the stand at the Edwards facility. Since the Early Acoustic Test was conducted at Edwards, this will in all probability be the prime test site for the VCE testbed engine acoustic test, however detailed.

Planning, including final choice of acoustic site for the Testbed Program test phase, will be conducted at a later date making full use of the experience gained and the lessons learned on the Early Acoustic Test.

5.5.1 Test Program

5.5.1.1 Core Engine Test

The objective of this test is to evaluate the core-driven third stage on the YJ101 core engine for aerodynamic performance (clean and distorted inlet), stall line determination of fan and core, and aeromechanical characteristics. This test precedes the addition of the current fan front block and acoustic exhaust nozzle for evaluation at Peebles or Edwards, and, therefore, will be conducted with heated inlet to simulate the fan discharge conditions. The total test will consist of approximately 100 hours of running time comprised of the following:

- Mechanical Checkout - 10 hours
- VG/Bypass/Schedule Eval./Optim. - 30 hours
- Fan rear block mapping
- Fan/HP Compressor Perf. Mapping - 25 hours

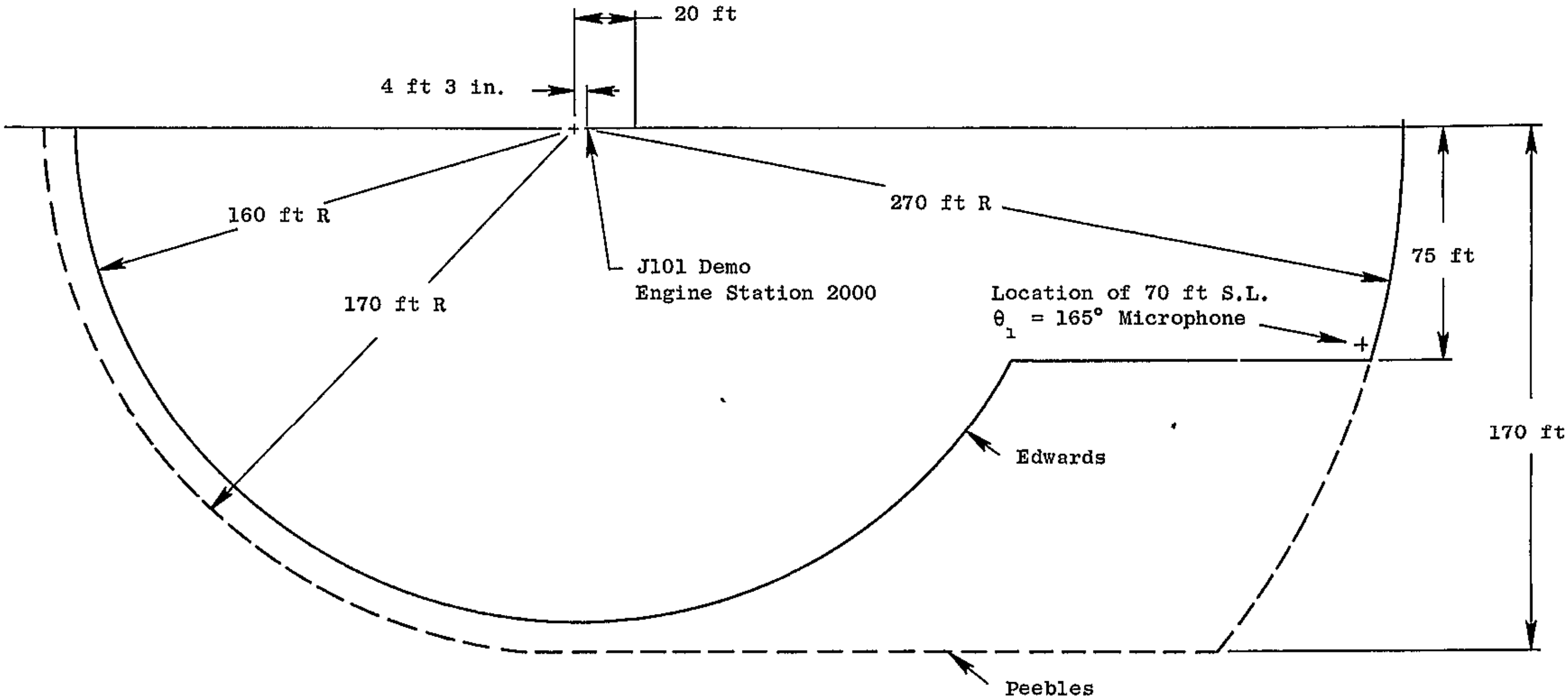

Figure 5-2. Comparison of Peebles/Edwards Sound Fields.

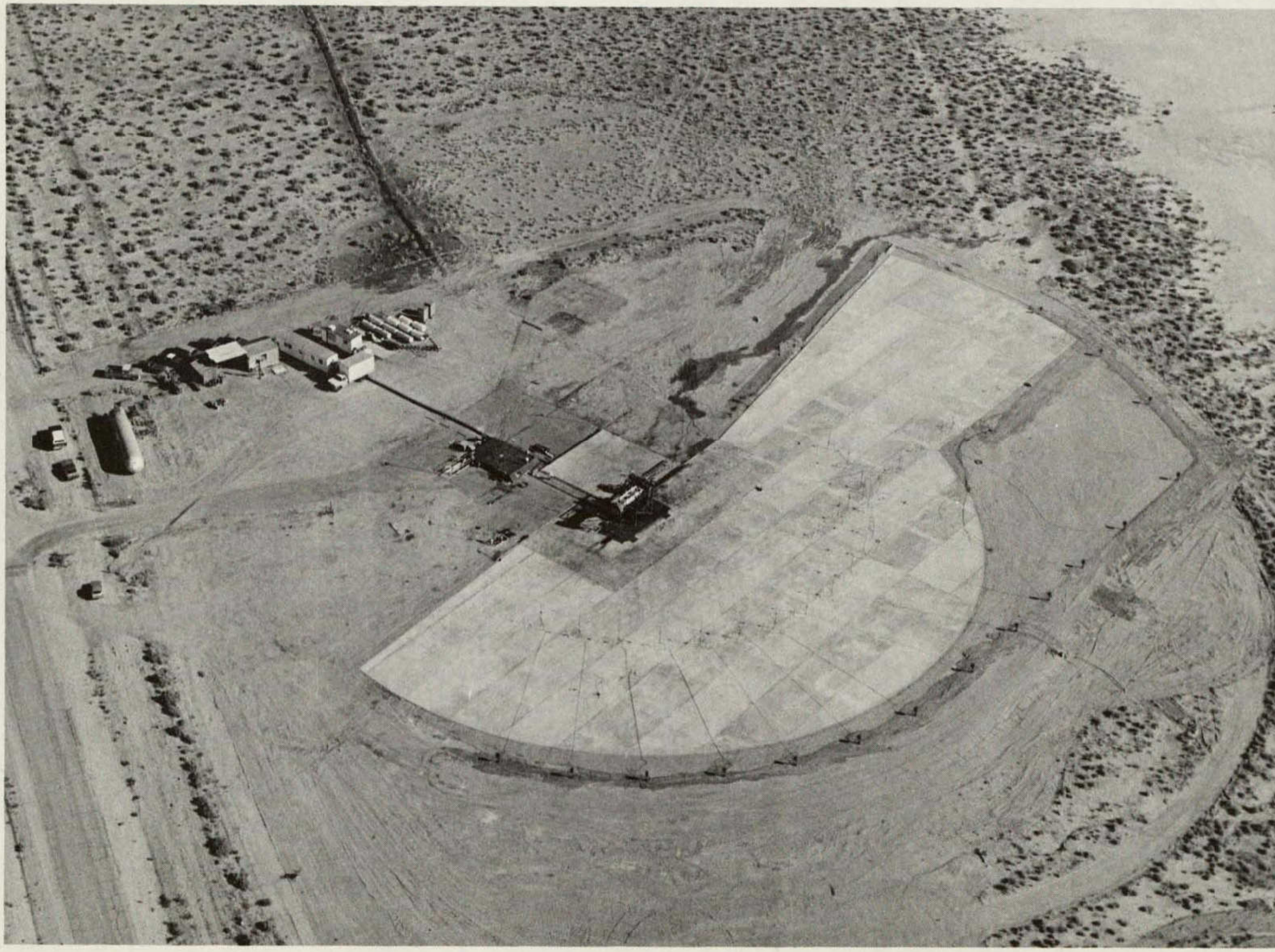

Figure 5-3. Edwards Acoustic Test Site.

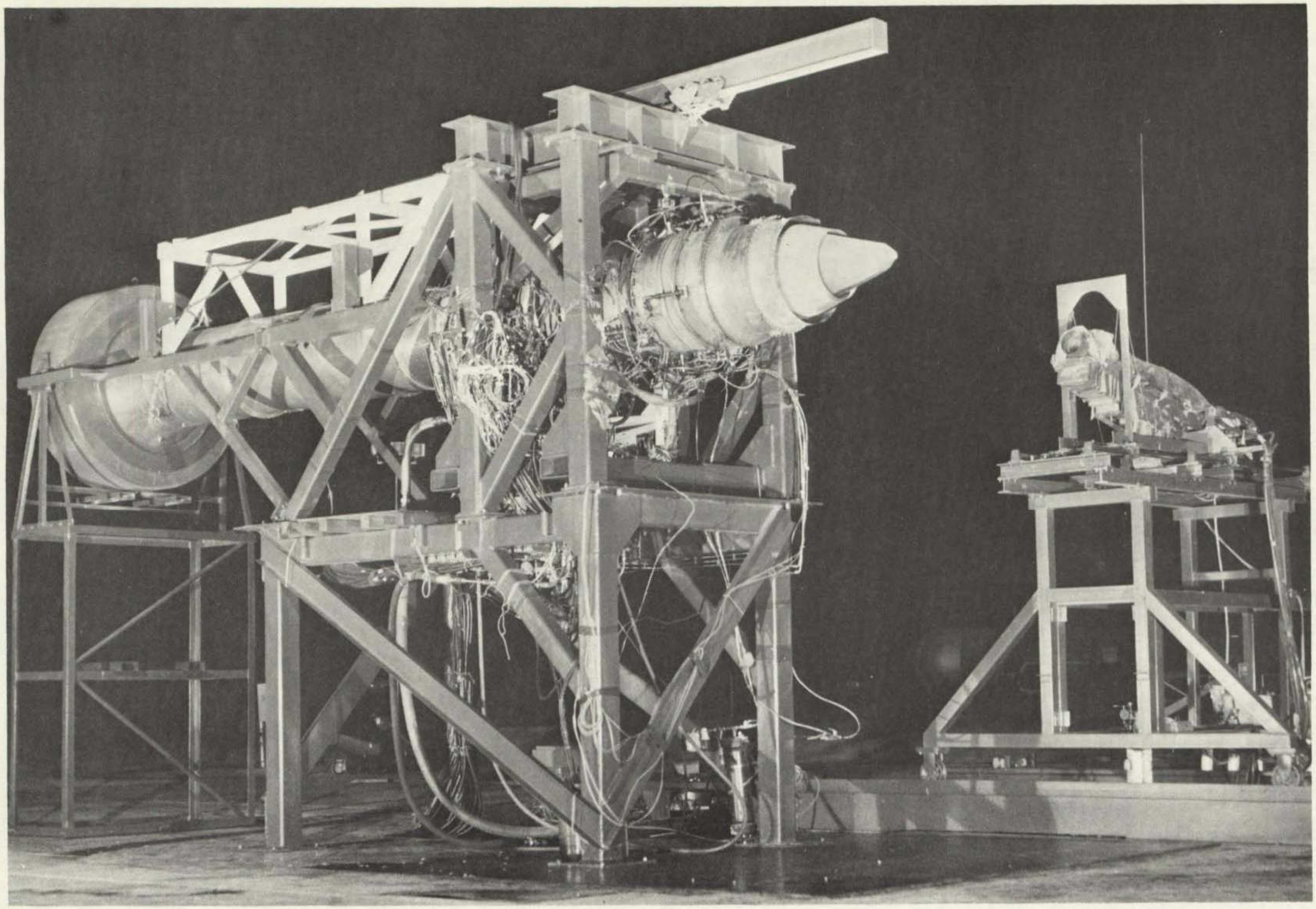

Figure 5-4. Early Acoustic Test Vehicle.

- Distortion - 25 hours

- Distortion testing (2 inlet patterns). Patterns will be the same as tested on FWD VABI in 1978 in Lynn, under NASA Contract NAS3-20582.

- Performance Demo with Selected Fan/HPC VG Schedule - 10 hours

5.5.1.2 Engine System Test

5.5.1.2.1 Performance Test

- 30 hours - all steady-state

- Single and double bypass performance - IRP and part power SFC optimization and airflow extension (A8/Fwd, and rear VABI variation)

- One engine setup/configuration

- One coannular plug nozzle configuration (with variable A8 provisions through various plus crown/outer shroud combinations)

- Breadboard/knob box control on variable features; IGV_3, Fwd VABI, and selector valve, rear VABI, VATN, A8 and A18.

- Standard bellmouth

5.5.1.2.2 Acoustic Test

- 15 hours

- 4 configurations (versus seven in August 1978 test)

- Four configurations are:

    - Conic baseline nozzle - standard bellmouth

    - Conic baseline nozzle - treated bellmouth*
      *J79 acoustic bellmouth - 1978 setup

    - Coannular nozzle (radius ratio to be determined)

    - 36 chute suppressor added to coannular nozzle (this will be mounted on a replaceable outer shroud of nozzle) - one A8, variable A18

    - Require laser velocimeter setup (like addendum to Edwards 1978 test) to measure exhaust plume velocity profile.

5.5.2 Facilities and Equipment

5.5.2.1 Test Facility Requirements

The scope of the SCAR/VCE testbed engine evaluation program, insofar as test facility requirements are concerned, is expected to be similar to the work being done for the 1978 acoustic nozzle evaluations of the 2X1 Fwd VABI engine configuration. The testbed is a double bypass YJ101 VCE demonstrator with essentially a different method of driving the aft fan block. The core drive engine configuration is 0.178 m (7 inches) longer (axially) between mounts than the 2X1 August 1978 configuration. It is also smaller in diameter at the front mount by approximately 0.305 m (12 inches) than the August 1978 configuration. This mount difference will have to be accommodated in the Lynn core test (which precedes the Peebles test) - therefore, whatever new provisions are made for the forward and aft mounts should be the same for both tests.

5.5.2.2 Test Equipment Requirements

The following primary test equipment has been identified for the testbed engine evaluation. Revisions will be made as required during detailed test planning.

Type Equipment	Comments
Bellmouth	J85-21 type
Adapter, Bellmouth to Engine	
Bulletnose	
Exhaust System	J85 water cooled type
Distortion Screens (3)	
Distortion Screen Rig	
VG Actuation System	5 individually variable stages
Slip Ring	Fan/HPC rotor strain gages
Core Engine Mounts	
Electronic Fuel Control	
Assembly Tools	As required
Expendable Crib Material	As required
Inlet Modifications	For rotating distortion

5.5.3 Instrumentation Requirements

5.5.3.1 Operational Instrumentation

Engine operational instrumentation will be similar to that utilized during the Fwd VABI Test (NASA Contract NAS3-20582, ref.: Test Plan dated 30 March 1978). Revisions as necessary will be made during detailed test planning.

5.5.3.2 Core Engine Instrumentation

The following instrumentation is planned for the SCAR/VCE testbed core test. Refinements will be made during detailed planning utilizing information gained on the Early Acoustic Test.

5.5.3.2.1 Aerodynamic Instrumentation

Location	Type Instrumentation	Comments
a) Trailing edge of FWD VABI	PS - 4 statics	Same as FWD VABI test
b) Cooling slot inner casing	PT - 2 single element bent impact proves	Same as FWD VABI test
c) Outer duct	P_T T_T, P_S - 4 each rakes/taps	Same as FWD VABI test
d) Inlet bellmouth	P_T/PS 4-6 element pilot statics	J101 for engine
Inlet screen	T_T 24 elements	J85-21 for core
e) Stage 3 inlet	P_T T_T 4-5 element comb. rakes P_S 4 O.D. wall static P_S 4 I.D. wall static	New
f) Stage 3 inlet	P_T 5-element O.D. boundary layer rake (one)	Use J101 1X2 VCE
h) Exit IGV_3	PS3 - O.D. wall static	Locate similar to stator 2 exit on 1X2 VCE
i) Discharge S3 rotor	P_{S3} O.D. wall static	Same as J101 1X2 VCE engine
j) HPC inlet	P_T/T_T 4-5 element PS 4 O.D. wall statics PS 4 I.D. wall statics	Vane Mounted (not rakes)

Location	Type Instrumentation	Comments
k) Inner Bypass	P_T/T_T 4-3 element Comb. rakes (sta. 14B) P_S 4 O.D. wall static P_S 4 I.D. wall static	Similar to FWD VABI test
l) H.P. compressor IGV exit	P_S 3 O.D. wall static P_S 3 I.D. wall static	5 taps each Manifolded together
m) H.P. compressor R1 exit	P_S 3 O.D. wall static	5 taps each Manifolded together
R2	P_S 3 O.D. wall static	
R3	P_S 3 O.D. wall static	
n) H.P. compressor Stator 1 leading edge Stator 2 leading edge Stator 3 leading edge	T_T 9 elements total	3 per vane, 3 vanes, 3 stages

5.5.3.2.2 Aeromechanical Instrumentation

The aeromechanical instrumentation will consist of approximately 30 rotor strain gages and 20 stator strain gages. Exact placement of these gages will be established after the completion of detailed mechanical design studies.

5.5.3.3 Engine System Instrumentation

The engine system will, in general, incorporate the instrumentation from the core drive test (i.e., aft bypass duct and core engine). Additionally, the exhaust nozzle will include the same type of instrumentation as the 1978 acoustic test and provision for acoustics measurements and a laser velocimeter will be made. The following is the list of instrumentation currently contemplated. This list will be reviewed during the detail test planning.

Location	Type Instrumentation	Comments
Sta. 259.0	P_T - 1-element	67.5°
Sta. 260.0	P_T - 3-element	67.5°
Sta. 264.5	P_T - 3-element	67.5°
Sta. 265.5	2-P_T - 8-element	0°, 320°
Sta. 269/274	2-P_T - 3-element	67.5°
Sta. 276.0	P_T - 1-element	67.5°

Location	Type Instrumentation	Comments
Sta. 283	8-P_T/T_T - 8-element	-
Sta. 289.5	3-P_T/T_T - 5 element	-
Sta. 290/295	2-Kulite	180°
Sta. 308.0	Sound separation probe	180°
Sta. 313.5	Accelerometer	0°
Conical nozzle	P_T/T_T - 30-element	0°
Various	42-P_S wall static	Various
269/301	2 skin T/C	22.5°

6.0 SUMMARY OF RESULTS AND CONCLUSIONS/RECOMMENDATIONS

The objectives of this program were to integrate the results of the individual NASA-funded General Electric SCAR and VCE technology program, update the definition of the most promising Product/Study engine cycle and mission, and define a similar but smaller testbed engine configuration and test program. This test program would determine the acoustic, performance and compatibility characteristics of the unique critical components operating in a real engine environment.

6.1 SUMMARY OF RESULTS

- Update of the Product/Study GE21 engines resulted in all supersonic Mach 2.4 mission range improvements of 370 to 740 km (200 to 400 nautical miles) for both the 10% and 20% high flow engines, when annalytically flown in the NASA-specified airplane.

- The preliminary design for a testbed engine employing the same critical technology concepts as the Product engine was accomplished.

- Detailed preliminary program plans to design, build, and test a close coupled core-driven testbed engine were established. The recommended program can be accomplished in 27 months for an estimated cost of $6,500,000 at selling price.

6.2 CONCLUSIONS AND RECOMMENDATIONS

- The updated product/study engines show significant mission range improvements over the previous SCAR Phase III designs. Difference in range between the 10% and 20% high-flow VCE engines are small at FAR 36 (1969) with a 3780 m (12,400 ft.) BFL takeoff, but if the field length is reduced to 3200 m (10,500 ft.) then the 20% high flow engine has clearly superior range.

- The testbed engine design recommended is based on the current YJ101/VCE engine being used in the VCE Early Acoustic Test. The engine should be reconfigured with the third stage fan driven by the core spool instead of the LP spool to more closely simulate the product/study engine designs. The flowpath similarity will also be increased by a close coupling of the aft block fan stage and compressor. Interblock fan losses will be reduced by a closer spacing between the two fan blocks of the recommended configuration.

- Program and test plans indicate that the detailed engine design can be accomplished in some 15 months from program go-ahead, leading to a core engine test to evaluate the third stage fan performance in early 1980 and a full engine system test, including acoustic evaluation of a simple coannular acoustic nozzle outer stream suppressor, in late 1980.

APPENDIX

Nomenclature

AMS	American Material Standard
A8	Core Nozzle Area
A18	Fan Nozzle Area
AST	Advanced Supersonic Technology
C/C	Close Coupled
CDFS	Core Driven Fan Stage
EATD	Early Acoustic Test Demonstrator
EGV	Exhaust Guide Vanes
FDFS	Fan Driven Fan Stage
HP	High Pressure
HPC	High Pressure Compressor
ID	Inner Diameter
IGV	Inlet Guide Vanes
IRP	Intermediate Rated Power
LP	Low Pressure
M/C	Manufacturing Cost
N1	Low Pressure Rotor Speed (RPM)
N2	High Pressure Rotor Speed (RPM)
nmi	Nautical Miles
OD	Outer Diameter
OGV	Outlet Guide Vanes
P_S	Static Pressure

P_T	Total Pressure
RPM	Revolutions per Minute
R/R	Radius Ratio
SABBL	GE Boundary Layer Program
SCAR	Supersonic Cruise Airplane Research
sfc	Specific Fuel Consumption
STC	Stream Tube Curvature Program
TBD	SCAR/VCE Test Bed Demonstrator
T_T	Total Temperature
U/C	Uncoupled
USN	United States Navy
VABI	Variable Area Bypass Injector
VATN	Variable Area Turbine Nozzle
VCE	Variable Cycle Engine
VG	Variable Guide Vanes