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# DEFINITION STUDY OF A VARIABLE CYCLE EXPERIMENTAL ENGINE (VCEE) AND ASSOCIATED TEST PROGRAM AND TEST PLAN

## FINAL REPORT

by

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GENERAL ELECTRIC COMPANY

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**16. Abstract**

The Definition Study of a Variable Cycle Experimental Engine (VCEE) and Associated Test Program and Test Plan, Contract NAS3-20810, was initiated to identify the most cost effective program for a follow-on to the AST Test Bed Program. The VCEE Study defined various subscale (smaller than full scale product size) VCE's based on different available core engine components, and a full scale VCEE utilizing current technology. The cycles were selected, preliminary design accomplished and program plans and engineering costs developed for several program options. In addition to the VCEE program plans and options, NASA requested that a limited effort be applied to identifying programs that could logically be accomplished on the AST Test Bed Program VCE to extend the usefulness of this test hardware. Component programs were provided that could be accomplished prior to the start of a VCEE program.

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# 1.0 SUMMARY

The National Aeronautics and Space Administration (NASA) is engaged in a study of the application of advanced technology to long-range, supersonic, commercial transport aircraft under the Supersonic Cruise Aircraft Research (SCAR) program.

In conjunction with this effort, the NASA VCE Component Test Program was begun. Its purpose was to experimentally verify,in a real-engine environment, promising unique variable-cycle features and the predicted reduction in co-annular jet noise. Under this program, the General Electric Company in the fall of 1978 will ground-test a double-bypass, double-VABI VCE, based on YJ101 hardware.

A second test configuration, having greater flowpath and aeromechanical similarity to projected production-line engines, will be tested in 1979 and 1980. The present study, done under Contract NAS3-20810, was initiated to identify the most cost-effective program for a follow-on to the VCE Component Test Program. Various subscale VCEE's based on different available core engine components were considered, along with a full-scale VCEE utilizing current technology. The cycles were selected, preliminary designs were drawn up, and program plans and engineering costs were developed for several program options. A subscale double-bypass configuration based on F404 core hardware was recommended. Program options range from a $52 million alternate base program to a $164 million P-PFRT assurance program for the subscale VCE.

In addition to the VCEE program plans and options, a limited effort was applied to identifying the programs that could logically follow the Component Test Program to extend the usefulness of that VCE test hardware. Totaling about $6.5 million, these programs include (1) altitude performance evaluation in a tank test at NASA-Lewis and (2) low-speed flight-noise tests in the Ames 40x80 wind tunnel. Additional component programs were also noted that could be accomplished prior to the start of a VCEE program.

## VCEE Configuration Design

Define the mechanical configuration of both the subscale and full-scale VCEE in sufficient depth for program plan definition and costing.

## VCEE Program Plans and Options

1. Provide program plans and engineering cost estimates for the subscale VCEE program options, from Sea Level Static tests (Base Program) to flight test support.

2. Provide a program plan and an engineering cost estimate for the full-scale VCEE base program (Sea Level Static tests).

## Augmented VCE Component Test Programs

1. Provide engineering cost estimates for follow-on engine tests performed on the Component Test VCE (YJ101) after the currently planned tests are complete.

2. Provide other component development effort that could be accomplished prior to the start of a full VCEE program.

## 2.0 INTRODUCTION

As part of the NASA SCAR program, the General Electric Company has been conducting advanced supersonic propulsion studies aimed at identifying the most promising advanced engine concepts and related-technology programs necessary to provide a sound basis for the design and possible future development of an advanced supersonic propulsion system. Phases I, II, III, and IV of this effort were reported in NASA CR-143634, NASA CR-134913, and NASA CR-135236, respectively.

The Phase I studies included the design and analysis of several conventional supersonic engines and several supersonic engines having variable-cycle features. Phase II was a follow-on study in which specific variable-cycle features or arrangements (both dual-cycle and double-bypass) were incorporated in a mixed-flow turbofan cycle. The engines were modified to incorporate annular nozzles so as to take advantage of their simplicity, lightweight, and inherent acoustic suppression. The Phase II studies found that the most attractive of these engines was a double-bypass variable-cycle engine having a high-flowed fan and an annular nozzle. Its attractiveness lay in its range, performance, and low noise. Phase III and IV studies refined the double-bypass variable-cycle engine (VCE) and introduced major performance improvements, many of which resulted from engine/airframe integration studies conducted in cooperation with the NASA SCAR airframe contractors. These refinements greatly increased the range of each airplane considered.

In addition to studies, demonstrator programs have been continuing that will confirm the operation of the variable-cycle concepts in the double-bypass VCE. These tests, being performed under contract with the USAF, USN and NASA, are utilizing YJ101 hardware, with minimum modifications, and are intended for sea level static testing.

The current contract effort fulfills a NASA requirement for engine definition, test plans, and costs for a broader program with various options, among them being flight test. The contract work effort was divided into the following tasks:

### VCEE Cycle Definition Studies

1. Define the most cost effective subscale Variable Cycle Experimental Engine utilizing the following existing core engine hardware:
   - F404
   - F101/ATEGG
   - Energy Efficient Engine ($E^3$)
2. Define a full-scale VCEE based on product engine cycle (M2.4) and current component and material technology similar to the subscale VCEE.

## 3.0 SYMBOLS AND NOMENCLATURE

Measurement values used in this report are stated in SI units followed by English units in parenthesis. The study was conducted using customary Engligh units for the principal measurements and calculations, see Table I.

Table I. Symbols and Nomenclature.

| Symbol | Definition | SI Unit | English Unit |
|---|---|---|---|
| ALT, alt | Altitude | m | ft |
| Aux | Auxiliary | - | - |
| Avg | Average | - | - |
| $A_8$ | Exhaust Nozzle Throat Area | $m^2$ | $ft^2$ |
| $A_9$ | Exhaust Nozzle Exit Area | $m^2$ | $ft^2$ |
| BPR | Bypass Ratio | - | - |
| Cfg | Nozzle Thrust Coefficient | - | - |
| ECU | Electrical Control Unit | - | - |
| EPNL<br>EPNdB | Effective Perceived Noise Level | dB | dB |
| FAR 36 | Federal Air Regulation Part-36 Noise Level | dB | dB |
| FADEC | Full Authority Digital Engine Control | - | - |
| $F_n$ | Net Thrust | N | lb-ft |
| g | Acceleration of Gravity | $m/sec^2$ | $ft/sec^2$ |
| GE | General Electric Company | - | - |
| HMU | Hydromechanical Unit | - | - |
| HP | High Pressure | - | - |
| HPT | High-Pressure Turbine | - | - |
| IGV | Inlet Guide Vane | - | - |
| ISA | Temperature of the International Standard Atmosphere | - | - |
| JENOTS | General Electric Jet Noise Test Facility | - | - |

Table I. Symbols and Nomenclature. (Continued)

| Symbol | Definition | SI Unit | English Unit |
|---|---|---|---|
| LP | Low Pressure | - | - |
| LPT | Low-Pressure Turbine | - | - |
| M | Mach Number | - | - |
| $M_o$ | Free-Stream Mach Number | - | - |
| N | Shaft Speed | Rev/min | Rev/min |
| PNL<br>PNdB | Perceived Noise Level | dB | dB |
| PR | Pressure Ratio | - | - |
| $PR_F$,<br>$PR_{FAN}$ | Fan Pressure Ratio | - | - |
| $PR_{OA}$ | Overall Engine Pressure Ratio | - | - |
| $P_{T2}, P_2$ | Total Pressure at Fan Face | $N/m^2$ | $lb/ft^2$ |
| $P_{To}, P_o$ | Total Pressure, Free-Stream | $N/m^2$ | $lb/ft^2$ |
| $P_{T3}, P_3$ | Total Pressure at Compressor Exit | $N/m^2$ | $lb/ft^2$ |
| $(P_{T2}/P_o)$ | Inlet Ram Recovery (Ratio) | - | - |
| SCAR | Supersonic Cruise Airplane Research | - | - |
| sfc | Specified Fuel Consumption | kg/hr/N | lb/hr/lb-ft |
| SL | Sea Level | - | - |
| SLS | Sea Level Static | - | - |
| SST | Supersonic Transport | - | - |
| $T_t$ | Total Temperature | °C | °F |

Table I. Symbols and Nomenclature. (Concluded)

| Symbol | Definition | SI Unit | English Unit |
|---|---|---|---|
| $t_o$ | Ambient Temperature | ° C | ° F |
| $T_3$ | Compressor Exit Temperature | ° C | ° F |
| $T_{41}$ | Turbine Rotor Inlet Temperature | ° C | ° F |
| VABI | Variable-Area Bypass Injector | - | - |
| VCE | Variable Cycle Engine | - | - |
| $V_j$ | Exhaust Jet Velocity (fully expanded) | m/sec | ft/sec |
| $V_j$ max. | Maximum Exhaust-Jet Velocity | m/sec | ft/sec |
| $w_a$ | Engine Airflow | kg/sec | lb/sec |
| W25 | HP Compressor Inlet Airflow | kg/sec | lb/sec |
| $WAT_2$ | Total Fan Airflow | kg/sec | lb/sec |
| $W_{36}$<br>$W_{cool}$ | Cooling Airflow | kg/sec | lb/sec |
| W1R,W2R | Total Fan Airflow (corrected) | kg/sec | lb/sec |
| $\delta$ | Ratio of Total Pressure to Sea Level Standard Ambient Pressure | - | - |
| $\Delta T_{am}$ | Difference Between Ambient Temperature and ISA Temperature | ° C | ° F |
| $\eta$ | Efficiency | - | - |
| $\theta$ | Ratio of Total Temperature to Sea Level Standard Ambient Temperature | - | - |

# 4.0 RESULTS AND DISCUSSION

The following sections describe the task actively accomplished in the Definition Study of a Variable Cycle Experimental Engine (VCEE) and Associated Test Program and Test Plan, under Contract NAS3-20810.

## 4.1 VARIABLE CYCLE ENGINE (VCE) DESCRIPTION

The variable cycle engine (VCE) recommended for the SCAR application is a variable-bypass-ratio (0.25 to 0.60), dual-rotor turbofan with a low-temperature augmentor; it is designed for dry power supersonic cruise, using the afterburned for transonic climb and acceleration only (see Figure 1). The cruise Mach number range of 2.2 to 2.4 allows selection of a high cycle-pressure ratio. The higher turbine inlet temperatures and component efficiencies predicted for the 1980's allow use of a bypass cycle with low specific weight and improved subsonic and supersonic specific fuel consumption, compared to first-generation SST engine designs.

The basic difference between a VCE and a conventional turbofan engine is the VCE's separation of the fan into two blocks with a double bypass: an outer bypass duct between the fan blocks, plus the normal bypass duct after the second fan block. The airflow size of the front block is larger than would be possible with a conventional turbofan using the same core size.

Oversizing the front block is accomplished by using the same core size but increasing the physical size (diameter) of the fan. High flowing is accomplished by increasing the front block spool speed and closing down variable inlet guide vanes of the rear block. When the front block fan is operated in the high-flow mode, the excess airflow (the air in excess of what the rear block fan will accept) passes through the outer bypass duct.

For the low-noise takeoff mode, the front block fan is set for high flow. The second fan block is operated in such a way as to tailor the velocity and flow of the jet exhaust to the desired thrust/noise relationship for takeoff.

The VCE exploits the concept of coannular suppression by allowing adjustment of the velocities and flows of of the inner and outer streams to meet takeoff thrust and noise requirements.

During subsonic cruise operation the front fan block is set to provide the best match between inlet spillage and internal performance. In this mode the second fan block is set to provide the proper cruise thrust. A high inlet airflow can be maintained down to the required subsonic cruise thrust, reducing the afterbody drag and practically eliminating inlet spillage drag.

In the climb/acceleration and supersonic cruise modes, the front block fan is set to satisfy the aircraft inlet flow supply, the rear block fan is set to pass all of the front block fan flow, and the engine operates in the same way as a conventional low-bypass-ratio turbofan engine.

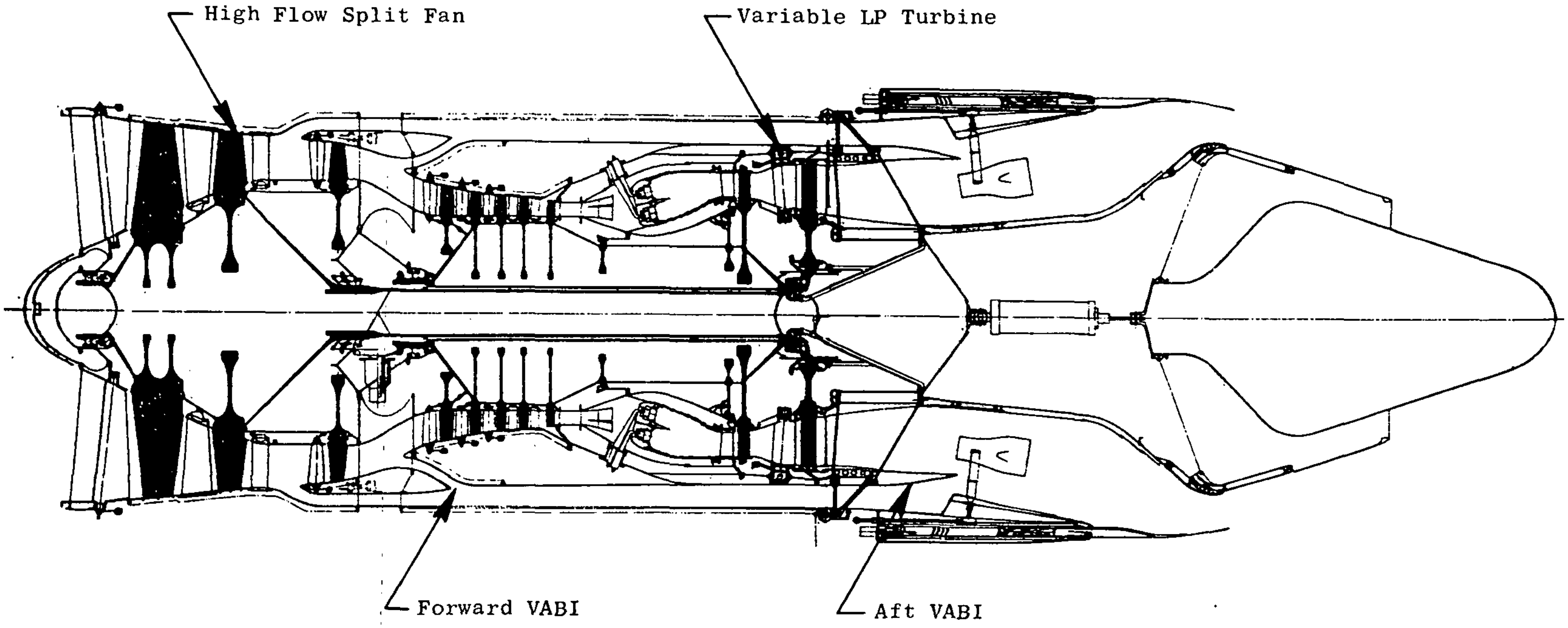


Figure 1. GE21 VCE Schematic.

Another advantage of the split-fan configuration is that for high takeoff airflow sizing, only the front block fan and low-pressure turbine are affected. Thus, a large weight savings is realized over the weight of a conventional turbofan or turbojet engine sized for the same takeoff airflow and noise level.

The five variable-cycle features that give the double-bypass VCE (Figure 1) its flexibility edge over mixed-flow turbofans are:

- Split fan (outer) bypass duct between the higher-flow front block and rear block with its variable inlet guide vanes
- Fan variable-area bypass injector (forward VABI)
- Exhaust variable-area bypass injector (rear VABI)
- Variable-area low-pressure turbine
- Variable-area coannular exhaust system

The first four VCE features allow the independent control of the high- and low-pressure rotor speeds to provide at subsonic part-throttle conditions and at transonic/supersonic high thrust conditions airflow levels that are higher than would be possible with mixed-flow turbofans, thus resulting in a variable-bypass-ratio engine. The last item, the variable-area coannular exhaust, accommodates the passage of the additional takeoff fan flow at reduced specific thrust with an inverted jet velocity profile for low noise.

The high-flow front fan block provides the high-takeoff and subsonic-transonic airflow capability of the VCE without having the weight penalty incurred by oversizing the complete engine. The maximum dry-power airflow can be maintained down to the subsonic cruise thrust requirement, eliminating the spillage drag that is present when a mixed-flow turbofan is throttled back. As the VCE subsonic cruise thrust is obtained at constant inlet airflow, the variable inlet guide vanes on the rear fan block are modulated to reduce the flow going into the HP compressor, bypassing the excess air. Cycle performance is improved by the VCE's higher bypass ratio, and therefore higher propulsive efficiency. This improvement, together with the reduction in installation losses made possible by eliminating inlet spillage drag and reducing afterbody drag, lowers installed subsonic sfc by about 15% over a conventional mixed-flow turbofan.

With a correctly sized VCE fan that provides the required supersonic cruise airflow, the inlet supply curve can be met. This results in minimum spillage drag and also an increased acceleration thrust from the higher engine airflow compared to a nonoversized fan engine.

The exhaust variable-area bypass injector (rear VABI) allows independent control of high and low rotor speeds by eliminating the mixed-flow turbofan dependence on matching static pressures of the primary and bypass streams in the tailpipe. The rear VABI varies the Mach number in the bypass stream to the correct value for the flow and total pressure to obtain the static pressure balance for mixing the flows. This same concept is also used in the front VABI and eliminates the need for separate full-length bypass ducts for the two bypass streams.

The variable-area low-pressure turbine stator adds flexibility by allowing a match of the low-pressure turbine entrance flow requirement with the high-pressure turbine discharge corrected flow over a wide range of operating conditions.

## 4.2 VCEE CYCLE DEFINITION STUDIES

Cycle studies were conducted in sufficient detail to help define component sizes and operational requirements needed for determining program costs and development schedules for both a subscale and a full-scale version of a Variable Cycle Experimental Engine (VCEE). Various existing core compressors, both as-is and modified, were evaluated for the subscale engine; an all-new core was evaluated for the full-size machine.

### 4.2.1 Fan Pressure Ratio/Turbine Temperature Selection

A single common fan pressure ratio was assumed for all the VCEE versions studied. Fan size was varied with core size. This split-fan system, described in Table II, has been evaluated in the engines under study for the various airframe companies involved in current SCAR-contracted work with NASA-Langley. These evaluations have found it to be a good low-pressure system for the double-bypass, core-driven, third-stage type of variable cycle engine.

Product levels of turbine rotor inlet temperature were selected for all the VCEE cycles evaluated with 1538° C (2800° F) being used during climb and 1482° C (2700° F) being selected for sustained supersonic cruise.

### 4.2.2 Product Cycle Descriptions

Table III contains the present cycle definitions for the current round of NASA-sponsored SCAR/VCE cycles. Overall pressure ratio has been varied with design Mach number. Bypass ratio has also been adjusted somewhat for the various engines shown. A criterion to be used in the selection of the VCEE will be to relate how closely the final VCEE cycle compares with these product engine definitions.

## Table II. VCEE Definition Study Fan Selection

- Product Level of Fan Pressure Ratio Used
  - Nominal Fan PR & Low Noise Operating PR = 3.7
  - Fan PR Split From Product Studies

    Front Block PR = 3.17 Design

    = 2.70 Nominal

    Rear Block PR = 1.37 Nominal

- Fan Size = f (Core Size & Core Match Point)

Table III. Current SCAR Product Cycles for the Aircraft Companies.

| Max Mach Number | 2.0 | 2.4 | 2.55 |
|---|---|---|---|
| Fan Airflow Sizes kg/sec (lb/sec) | 349 -- 381<br>(770 -- 840) | | |
| PR, Fan, Nominal | 3.7 | 3.7 | 3.7 |
| PR, Core | 5.2 | 4.4 | 4.1 |
| PR, Overall | 19.0 | 16.2 | 15.1 |
| BPR, Nominal | 0.35 | 0.25 | 0.25 |
| T41 Class - °C (°F) | 1538 (2800) | 1538 (2800) | 1538 (2800) |

### 4.2.3 Selection of Subscale VCEE Core

Table IV lists the major figures of merit that were used for selecting the subscale VCEE core. Reference back to Table III indicates the desire for a core pressure ratio in the 4-6 range. Since most of the candidate cores had ratios higher than this, stage removal was required.

Two of the figures of merit (Items 3 and 4) relate to the supercruise potential of the resulting engines. The dry specific thrust parameter is an indicator of the potential of the system for being able to cruise at dry thrust (no afterburning) during supersonic cruise. The level of dry sfc relates to range potential. While the size of the VCEE subscale engine is not necessarily critical to demonstrating a high level of technilogical readiness, its overall size will affect cost and does relate to the size of some future aircraft that might be designed around the VCEE.

The cores that were considered are listed in Table V. Various stage configurations of the F404, F101, and $E^3$ compressors were used for the subscale VCEE definition, while the product cycle core parameters were used for the near-term full-size core definition.

Use of existing cores requires that close attention be paid to physical hardware limits, All core compressors have two speed parameters that govern their use. One is their design corrected speed ($N/\sqrt{\theta}$); the other, their design physical speed. In simple terms, the corrected speed relates to the aerodynamic design of the blading; the physical or mechanical speed, to stresses in the blading and disks. The mathematical difference in these two speeds dictates the level of supercharging temperature (produced either by fan pressure ratio, flight ram compression, or a combination of the two) that the core can withstand while still being operated at its airflow design level. Once maximum core physical speed is achieved the core must slow down aerodynamically and thus lose airflow-swallowing capability. Since a fan pressure ratio of around 3.7 is desired for the SCAR product cycles, any core that has been designed for a fan pressure ratio lower than this will operate at reduced corrected speed when at full mechanical speed. This will result in a reduced core corrected flow, as shown in Figure 2, and the core will not be able to fully exploit its flow potential.

Table VI indicates the corrected speed and airflow matches for the core systems being studied. Since the F404 core has been designed to run to Mach 2 behind a 4+ fan pressure ratio, core corrected speed and flow may be fully used. The F101 and ATEGG cores that retain Stage 1 (full aero size) must be operated at reduced flow potential due to physical speed limitations. (The basic F101 core was designed to run behind a 2+ fan pressure ratio.) Removal of Stage 1 from either the F101 core or ATEGG core would result in an aerodynamic/mechanical speed match with a higher fan pressure ratio; but the resulting cores (with rear stages also removed) would not be unique. They are basically just scaled-up versions of the various F404 cores studied.

## Table IV. Core Selection Study.

- <u>Figures of Merit For Core Selection</u>

  1. Reasonable Simulation of Mach 2.0 - 2.4 Product Compressor
  2. Minimum Hardware Changes to Existing Core
  3. Dry Supersonic Thrust Per Pound of SLS Airflow Size
  4. Dry Supersonic sfc
  5. Reasonable Resultant Engine Size Suitable for 2- or 4-Engine Subscale Experimental Aircraft

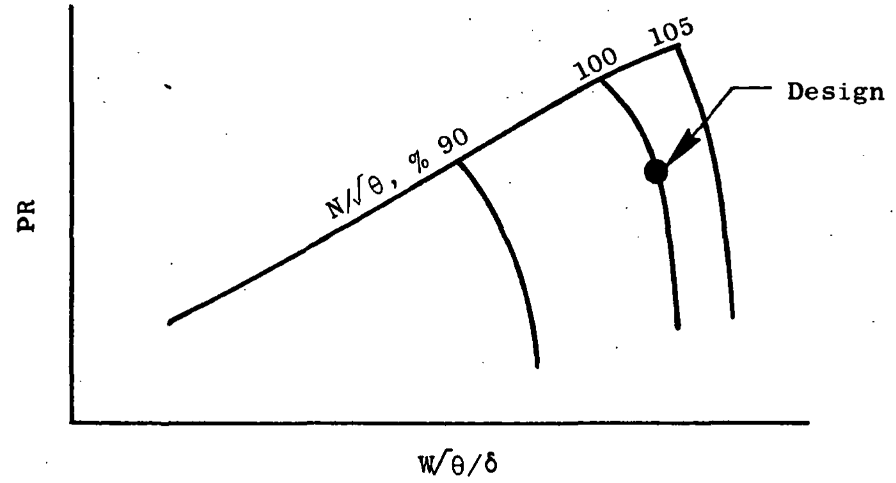
## Table V. VCEE Definition Study, Core Compressor Selection.

- Candidate Parent-Core Compressors

  1. F404 - (5-7) Stage Versions
  2. F101 (ATEGG) - (5-9) Stage Versions
  3. NASA $E^3$ - (6-Stage "Center Block" Version Only)

- Near-Term Full-Size Core

  - Select Same Parameters as Product Cycles



RPM Considerations:

- Core rpm's (Aero design and maximum mechanical)
- If VCEE fan discharge temperature is higher than original core design level, physical rpm must be increased or full core flow size

Figure 2. Core Selection - Match Point Analysis.

Table VI. Core Selection Study, Match Point Analysis.

| Parent Core | Stage Configuration | $N/\sqrt{\theta}$,% | Relative $W\sqrt{\theta}/\delta$ | PR |
|---|---|---|---|---|
| F404 | 1 - 7 | 100 | 1.0 | 6.2 |
| F404 | 1 - 6 | 100 | 1.0 | 4.9 |
| F404 | 1 - 5 | 100 | 1.0 | 4.0 |
| F101 | 1 - 9 | 90.9 | 1.34 | 7.6 |
| or | 1 - 8 | 93.9 | 1.56 | 8.0 |
| ATEGG | 1 - 6 | 93.9 | 1.56 | 5.5 |
|  | 2 - 8 | 100* | 1.25 | 6.2 |
|  | 2 - 7 | 100* | 1.25 | 4.9 |
| $E^3$ (Proposal Size) | 4 - 9 | 100* | 1.14 | 5.2 |

The basic $E^3$ core has only been designed to operate behind a 1.6+ fan pressure ratio in a strictly subsonic flight environment. In order to establish a viable candidate core out of this compressor, both front and rear stages had to be removed. The resulting core, while being of reasonable size, would require such major changes that it has not been seriously considered a viable candidate. Also, it would at best only be a larger version of the VCEE derived from the F404 core.

Table VII contains the nominal cycle descriptions, fan sizes, and supersonic cruise operating parameters for all the subscale VCEE cycles evaluated. Fan size is seen to vary with the parent core and design bypass ratio selected. (Product bypass ratios vary from 0.25 to 0.35.) The Sea Level Static overall pressure ratio (a key to supersonic performance because of the operating constraints imposed by compressor discharge temperature limits) varies with the particular core and stage configuration used. The overall pressure ratio ranges from a low of 15 for the 1 to 5 stage version of the F404 to greater than 29 for some of the F101/ATEGG versions. From the product engine studies, it has been determined that the overall pressure ratio must be in the 15-19 region (Table III). Only the F404 versions with rear stages removed meet this requirement (The $E^3$ "center block" also fits, but the extreme modifications required make it an unsatisfactory selection.) Since the resulting F101 versions are basically just scaled-up versions of the F404, they were dropped from consideration. Removing the ATEGG core's front stages, and especially its rear ones, would rule out keeping the high-temperature combustor and turbine being developed for ATEGG; as a result, new high-temperature hardware would be required for the VCEE program.

Selection of the exact stage configuration and bypass level, based on using the F404 core, can be made by inspecting supersonic performance, fan size, and the product cycles discussed previously.

The 1-5 stage configuration results in a loss in supersonic sfc relative to the 1-6 stage version while showing only a slight increase in dry thrust potential. The bypass ratio should be between 0.25 and 0.35 is not a critical parameter, so a 0.30 level was picked. A reasonable turbine flowpath also results from this selection. The resultant fan size is 70.3 kg/sec (155 lb/sec) for the high-flow mode. The elimination of the last HP compressor stage results in a small increase in HP compressor discharge Mach number, but the increase is not large enough to have a major impact on burner pressure loss.

Based on this analysis, the F404 core with the 1-6 stage configuration was chosen for determining VCEE costs and development schedules.

Table VII. Resultant Engine Cycle Descriptions and Supersonic Potentials.

| Parent Core | Stage Config. | Nominal SLS Cycle | | | Relative Fan Aero Size | M2.32 - Max Dry | |
|---|---|---|---|---|---|---|---|
| | | $PR_F$ | $PR_{OA}$ | BPR | | Thrust<br>SLS $\sqrt{\theta}/\delta$ | sfc |
| F404 | 1 - 7 | 3.7 | 22.8 | 0.30 | 1.0 | Base | Base |
| F404 | 1 - 6 | 3.7 | 18.2 | 0.30 | 1.0 | +26% | Base |
| F404 | 1 - 5 | 3.7 | 14.6 | 0.30 | 1.0 | +35% | +2.3% |
| F404 | 1 - 6 | 3.7 | 18.2 | 0.25 | 0.96 | +29% | +0.2% |
| F404 | 1 - 6 | 3.7 | 18.2 | 0.35 | 1.04 | +21% | +0.2% |
| F101 | 1 - 9 | 3.7 | 27.9 | 0.30 | 1.34 | -22% | +5.0% |
| or | 1 - 8 | 3.7 | 29.3 | 0.30 | 1.56 | -28% | +7.0% |
| ATEGG | 1 - 6 | 3.7 | 20.3 | 0.30 | 1.56 | +13% | Base |
| | 2 - 8 | 3.7 | 22.8 | 0.30 | 1.25 | Base | Base |
| | 2 - 7 | 3.7 | 18.2 | 0.30 | 1.25 | +26% | Base |
| $E^3$ (Proposal Size) | 4 - 9 | 3.7 | 19.2 | 0.30 | 1.14 | +20% | Base |

### 4.2.4 Cycle Comparisons

Table VIII contains the product and VCEE cycle descriptions and sizes. The full-size VCEE is an exact copy of the Mach 2.4 product cycle, while the subscale cycle fits between the Mach 2.0 and 2.4 product cycle overall pressure ratios.

Table IX indicates the noise test potential and resultant takeoff thrusts of the VCEE engines and the product engines. Either VCEE system could be run over a wide range of exhaust velocities to meet various noise criteria caused by airplane-dependent sideline and flyover altitude and Mach number.

Table X compares the supersonic performance potentials of the near-term VCEE cycles with the cycles expected on product engines of 1990. Both the full-scale and subscale VCEE cycles closely match the airflow-swallowing and dry-thrust potentials of the Mach 2 product engines. Supersonic sfc's are somewhat higher due to the higher cooling-air levels and lower component efficiencies of the near-term engines.

The subscale VCEE cannot match the dry specific thrust levels of the product engines due to the core limitations (T3) resulting from the overall pressure ratio being around 18 instead of the more desirable value of 16 as used in the product engine. Some slight augmentation would be needed to match the relative thrust output of the product cycle, but a further sfc increase would occur.

Figure 3 contains a preliminary attempt at defining the dry sfc increase of the subscale VCEE relative to the production cycle. Both supersonic (M2.32) and subsonic (M 0.9) cruise analyses were conducted with their results presented in bar chart form. The supersonic losses can be almost completely explained by examining component efficiency differences. These component inefficiencies have a similar impact at subsonic cruise, but account for only about 70% of the sfc change. The remaining 30% can be traced to a non-optimum geometry schedule for producing part-power performance. More work in ensuing programs could reduce this loss.

Table VIII. Cycle Comparisons, Current Product Vs. VCEE Candidates.

| | Product Studies | | VCEE Studies | |
|---|---|---|---|---|
| | | | Full Size | Subscale* |
| Max Mach Number | 2.0 | 2.4 | 2.4 | 2.4 |
| Fan Airflow, Nom./High Flow | Base/+ 10% &<br>Base/+ 20% | Base/+ 10% &<br>Base/+ 20% | Base/+ 20% | 0.19 Base/+ 20% |
| PR, Fan, Nominal | 3.7 | 3.7 | 3.7 | 3.7 |
| PR, Core | 4.8 | 4.4 | 4.4 | 4.9 * |
| PR, Overall | 18.0 | 16.0 | 16.0 | 18.2 |
| BPR | 0.35 | 0.25 | 0.25 | 0.30 |
| $T_{4.0}$ Class - °C | 1538 | 1538 | 1538 | 1538 |
| (°F) | (2800) | (2800) | (2800) | (2800) |

* Selected core - F404, 1-6 stage version.

Table IX. Comparison of VCEE Cycles with Product Cycles, Rotation.

Operating at M 0.3/SL - Hot Day (Rotation)

|  |  |  | VCEE Cycles |  |
|---|---|---|---|---|
|  |  | Product Engine Current Cycles | New Full-Size Core | Modified F404 Core |
| ● Fan Airflow Nom/Rotation |  | Base/+ 20% | Base/+ 20% | 0.19 Base/+20% |
| ● V Jet Mass Avg, | M/sec | 610 - 732 | 610 - 732 | 610 - 732 |
|  | (ft/sec) | (2000 - 2400) | (2000 - 2400) | (2000 - 2400) |
| ● Thrust at Rotation, | N | 186,800-226,000 | 186,800-226,800 | 35,600-42,700 |
|  | (1b) | (42,000-51,000) | (42,000-51,000) | (8000 - 9600) |
| ● Sideline Noise (Approx), db |  | 108 - 110 | - | - |
| ● Traded FAR (Approx) |  | (-2-3) - ~0 | - | - |

Table X. Comparison of VCEE Cycles with 1990 - Production Cycles.

- Operation During Supersonic Cruise
  (All Cycles at 1482° C (2700° F) Turbine Temperature)

| | Product Cycles | VCEE Cycles | | |
|---|---|---|---|---|
| | Mach 2-2.4 Designs | New Core | | F404 Core |
| **Mach 2.0 - Hot Day** | | | | |
| - M2 $W\sqrt{\theta}/\delta$ /SLS $W\sqrt{\theta}/\delta$ | Base | Base | | -0.7% |
| - M2 Dry FN/SLS $W\sqrt{\theta}/\delta$ | Base | -1.5% | | -2.0% |
| - M2 Dry sfc | Base | +4.5% | | +4.8% |
| **Mach 2.32 - Hot Day** | | | | |
| - M2.32 $W\sqrt{\theta}/\delta$ /SLS $W\sqrt{\theta}/\delta$ | Base | Base | Base | -12% |
| - M2.32 Dry FN/SLS $W\sqrt{\theta}/\delta$ | Base | -4.0% | -18% | -17% * |
| - M2.32 Dry sfc | Base | +4.3% | + 5% | +4.9% |

* Would require ~ $93^{\circ}$ C ($200^{\circ}$ F) augmentation during M2.32 cruise

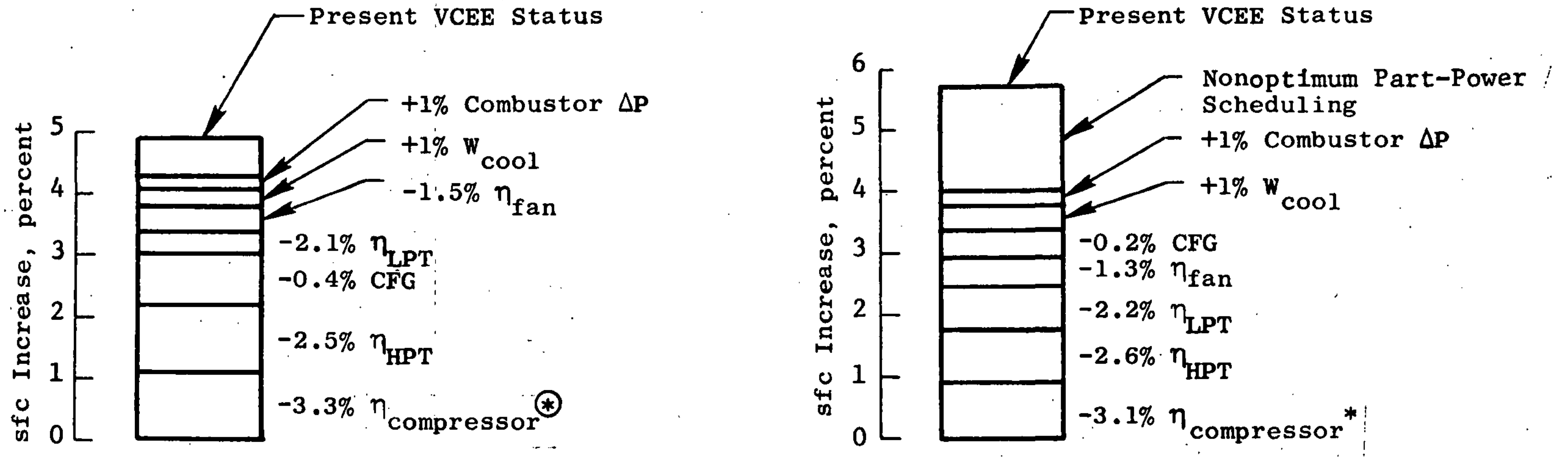
Supersonic Cruise (M 2.32, Hot Day)

- Dry thrust loss due to lower $T_8$ that results from lower efficiencies, higher cooling air, and higher operating bypass-ratio.

Subsonic Cruise (M 0.9, Hot Day)

- 4% of 5.7% sfc$\Delta$ results from lower component efficiencies.
- +1% of $\Delta$ is due to nonoptimum part-power scheduling. More work needed.

- **Dry sfc Increases due to:**



⊛ • 1-1 1/2%$\Delta\eta_{compressor}$ due to smaller size core.

- Other component efficiency $\Delta$'s reflect estimated 1980 performance potentials for experimental engine components.
- First engines to test in a flight program would be quoted with temperature margin.

Figure 3. Comparison of F404 VCEE with Production Cycle.

Table XI Illustrates the suitability of the F404 VCEE for use in a subscale aircraft. A simple approach to defining the aircraft weight was taken by selecting a representative takeoff-thrust to gross-weight ratio of 0.30 - 0.35 and back-calculating the TOGW using the subscale VCEE low-noise takeoff thrust. Two VCE engines could similate the power loading of a full size SST if the TOGW were in the 23-27,000 kg (50-60,000 lb) class. Four VCEE's would result in a TOGW of 45-54,000 kg (100-120,000 lb).

Table XII illustrates the flow in developing future SCAR technology readiness that can result from the implementation of the VCEE program. Table XII describes the characteristics of the Early Acoustic Test VCE Configuration and the planned follow-on Test Bed Configuration. For progressing from these two concept demonstrators to the full-size production engine, the Variable Cycle Experimental Engine is a necessary bridge.

## 4.3 VCEE CONFIGURATION DESIGN

The mechanical design of the selected cycle defined in Section 4.2 emphasizes maximum commonality with F404 hardware (Figure 4). When a part would be made from a different material, the use of available tooling was emphasized. The mechanical design was thorough enough to verify the design feasibility without necessarily solving all mechanical questions. The design effort was aimed at providing a solid base for estimation of the program costs and schedule.

Each major section or component in the F404 subscale demonstrator is shown schematically in Figures 4 through 14. The major aero and mechanical design data are also given. These data include the number of parts, the materials, and the maximum stress design points.

## 4.4 VCEE PROGRAM PLANS AND OPTIONS

### 4.4.1 Introduction and Summary

The subscale VCEE program Plan was defined in options ranging from SLS testing alone to Preliminary Pre-Flight Rating Test (P-PFRT) assurance. These options can provide the design and test essential for successful P-PFRT and Flight Test Programs. This program was modeled after the Contractor's YJ101 P-PFRT Program.

The overall program was broken down into various options which are technically additive and which would allow incremental funding while providing a cohesive effort. These options also allow important and realistic endpoints in themselves should the decision be made to limit the VCEE program scope. The following are the options available:

Table XI. F404 VCEE Suitability for Subscale Aircraft Usage.

At M 0.3/SL + 10° C (18° F)

$W\sqrt{\theta}/\delta$ Fan = 0.19 Scale

V Jet Mass Avg = 668 m/sec (2190 fps) ($V_J$ Range = 610 - 762 m/sec (2000 - 2500 fps)

$V_J$ Cold/$V_J$ Hot = 0.65

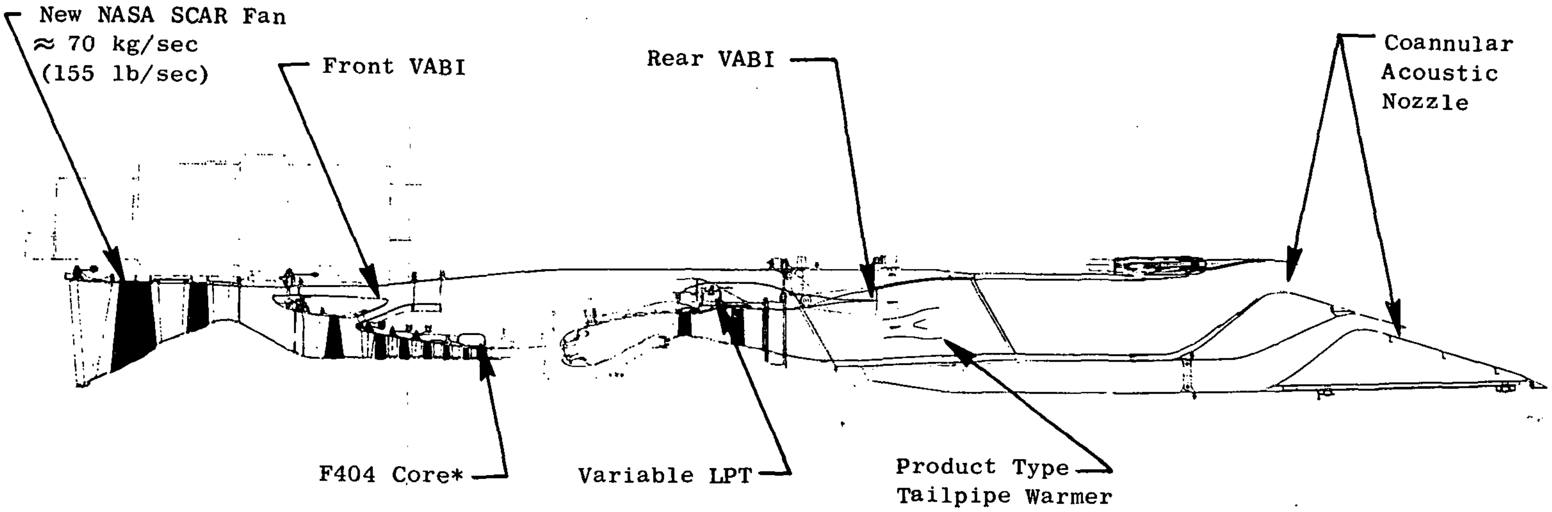
W Cold/W Hot = 0.42

Thrust = 39,600 N (8900 lb)

- Subscale Aircraft Usage - For TO-Thrust TOGW Ratio = 0.30 - 0.35
    - 2 VCEE Engines - TOGW = 23-27,000 kg (50-60,000 lb)
    - 4 VCEE Engines - TOGW = 45-54,000 kg (100-120,000 lb)

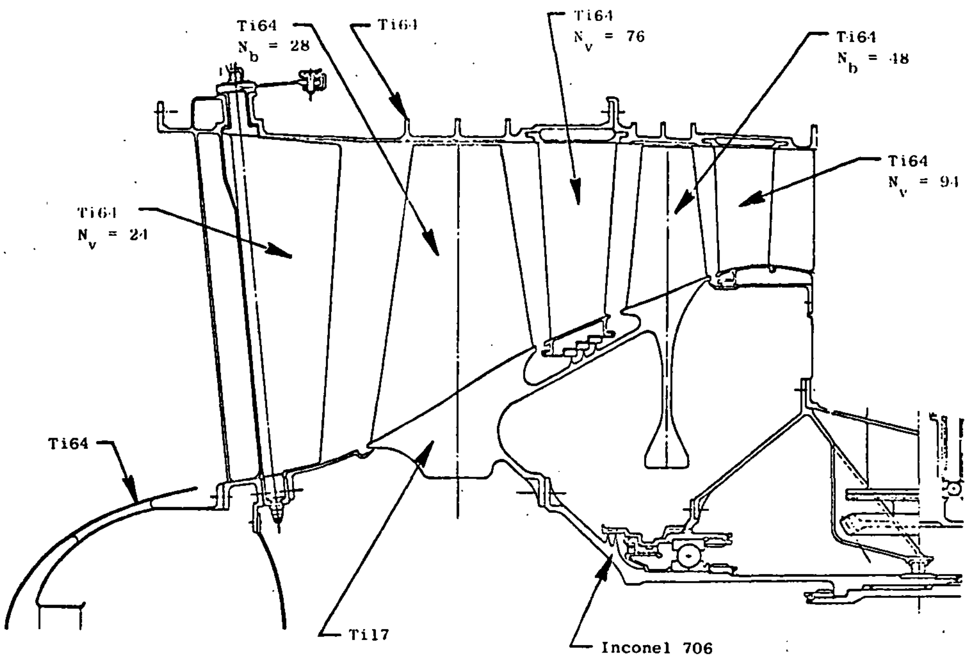
Table XII. SCAR Variable Cycle Engine Development.

| | NASA Acoustic Test Engines | | VCEE Candidate | Full-Size Product |
|---|---|---|---|---|
| | Early Acoustic Demo | Test Bed Demo | Preliminary Definition | Present Study Status |
| Technology Level | • YJ101 | • YJ101 | • F404 Aero<br>• Increased T41<br>• Oversize Front Block Fan | 1985 Technology |
| Nominal Cycle Description | | | | |
| Airflow (Nominal/TO), kg/sec (lb/sec) | 44/56 (98/123) | 46/56 (102/123) | 60/70 (132/155) | 318/349 - 318/381 (700/770 - 700/840) |
| Fan PR/Overall PR | 3.1/17.5 | 3.1/15.5 | 3.7/18 | 3.7/15-18 |
| Bypass Ratio | 0.22 | 0.45 | 0.30 | 0.25-0.35 |
| Turbine Temperature Class, Rotor Inlet, ° C (° F) | 1316 (2400) | 1316 (2400) | 1538 (2800) | 1538 (2800) |
| Low Noise Takeoff Operation | Test Range of: | Test Range of: | To be Selected | Study Range of: |
| Bypass Ratio | 0.22-0.66 | 0.35-0.80 | • Flexibility of Mode Changes to Minimize Noise During Flight Testing | 0.30-0.80 |
| $V_{Jet}$ Mass Average, m/sec (ft/sec) | 750-610 (2460-2000) | 732-597 (2400-1960) | | 759-637 (2490-2090) |
| Coannular Nozzle Parameters | | | | |
| Velocity Ratio (Cold/Hot) | 0.64-0.56 | 0.64-0.57 | | 0.71-0.62 |
| Mass Flow Ratio (Cold/Hot) | 0.15-0.60 | 0.15-0.60 | | 0.15-0.60 |
| Vehicle Usage | | | | |
| (Basic VCE & Turbine Temperature Technology Also Needed for Advanced Military Systems<br>• V/STOL "B"<br>• ATS<br>• Advanced Reconn.) | 1. Initial Noise Testing<br>2. New VCE Component Testing | 1. Further Noise Testing<br>2. New VCE Configuration Testing with Greater Aero/Mechanical Similarity to Product Engine | 1. Refined Component Matching<br>2. Possible In-Flight Noise/Pollution Testing<br>3. Flight Testing of VCE Concept | • Future SST Application |



* Low Emissions Combustor Optional

Figure 4. Variable Cycle Experimental Engine Schematic.



### Aerodesign Data

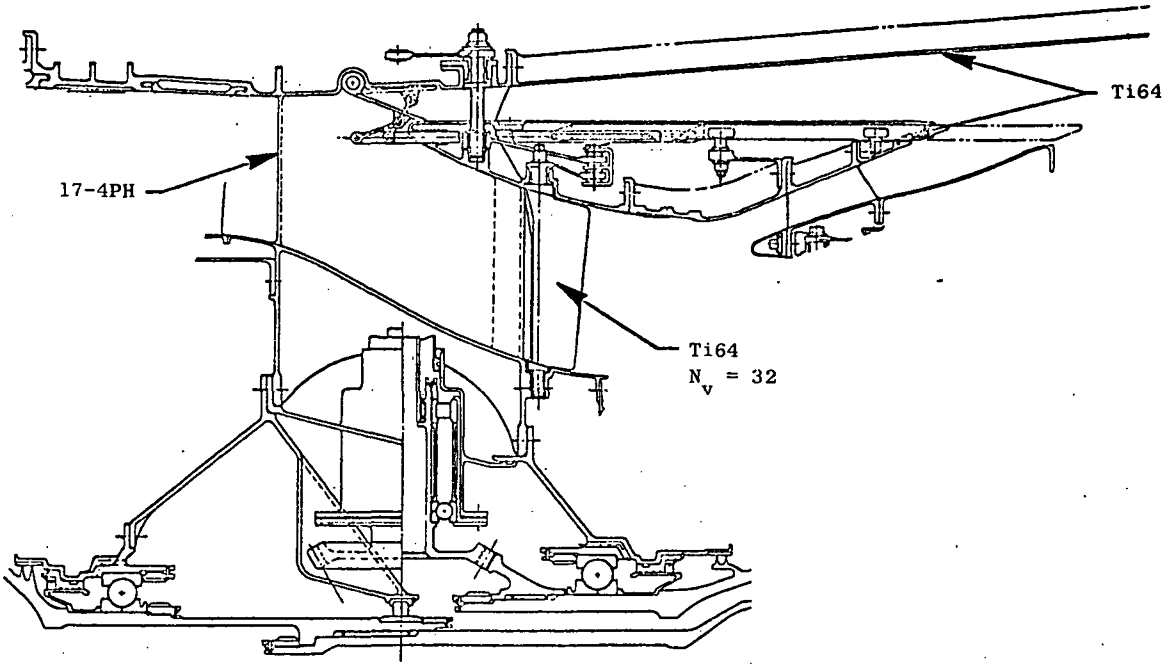
| | |
|---|---|
| • Corrected Inlet Flow | 70.3 kg/sec (155 lb/sec) |
| • Inlet Specific Flow | 20.5 kg/sec-$m^2$ (42 lb/sec $ft^2$) |
| • Inlet Radius Ratio | 0.40 |
| • Corrected Inlet Tip Speed | 467 m/sec (1531 ft/sec) |
| • Design Pressure Ratio | 3.172 |
| • Average Exit Mach | 0.48 |
| • Exit Radius Ratio | 0.736 |
| • IGV Type | Articulated |

### Mechanical Design Data

- Front Frame Antiicing
- Spring Constants - N/A
- 360° Casing Extended Aft to Stage 1 Vane
- Aft 360° Casing Part of Midframe
- Rotor Construction BLISK Type
- Cantilevered Shaft System
- Fan Blade Data:

| Stage | 1 | 2 |
|---|---|---|
| Solidity | 1.8 | 1.6 |
| Aspect Ratio | 1.6 | 1.6 |
| Maximum Stress | 482.6<br>(70 ksi) | 344.7 x $10^6$ N/$m^2$<br>(50 ksi) |
| N/Rev Margin % | 2/15 | 3/8 |
| Flex. Reduced Vel. | 2.7 | 3.5 |
| Tors. Reduced Vel. | 1.0 | 1.4 |

Figure 5. Front Frame and Block 1 Fan.



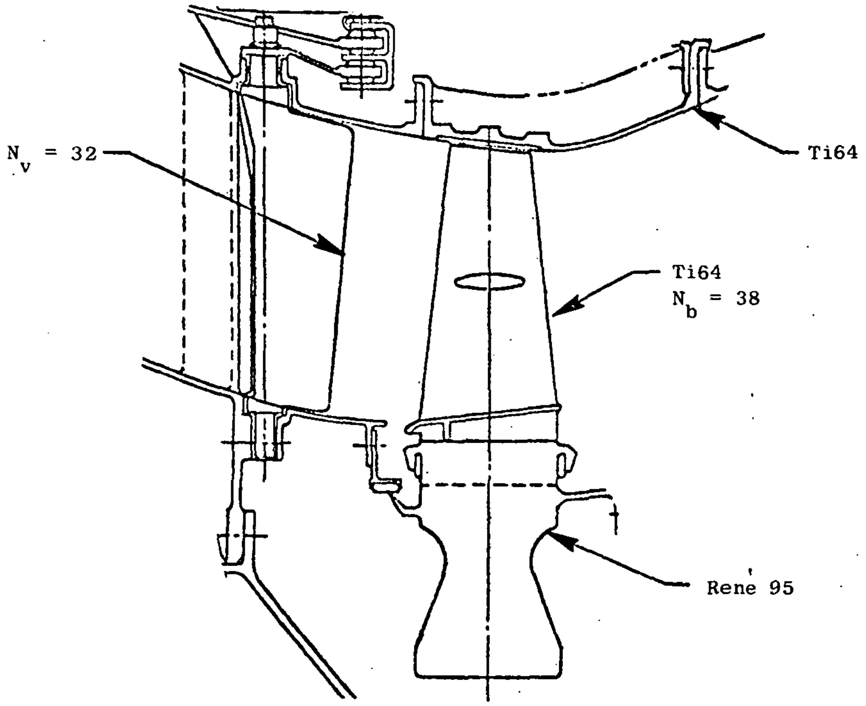
Aerodesign Data

- Inner Duct Inlet Maximum Mach = 0.50 at Supersonic Cruise
- Inner Duct Passage Approximately Constant Area
- Forward VABI to Close Aft End of Inner Duct, to Hold Operating Line on Rear Block in Double Bypass Mode
- Outer Duct Inlet Maximum Mach = 0.55 at Rotation
- Outer Duct Downstream Area Equal to Sum of Inner and Outer Bypass Duct Exit Areas

Mechanical Design Data

- Frame Spring Constants:
  - Radial = $192.6 \times 10^6$ N/m ($1.1 \times 10^6$ lb/in.)
  - Moment = $14.2 \times 10^6$ N/radian ($125 \times 10^6$ in.-lb/radian)
- Number of Struts = 8
- Block II Fan IGV Type - Articulated
- Outer Blocker Door Positive Actuation
- VABI is Simple Sliding Cylinder
- Both HP and LP Thrust Bearings Supported
- One Strut is Larger for PTO
- Supports Main Engine Mount and Accessory Gearbox

Figure 6. Midframe and Forward VABI.



Aerodesign Data

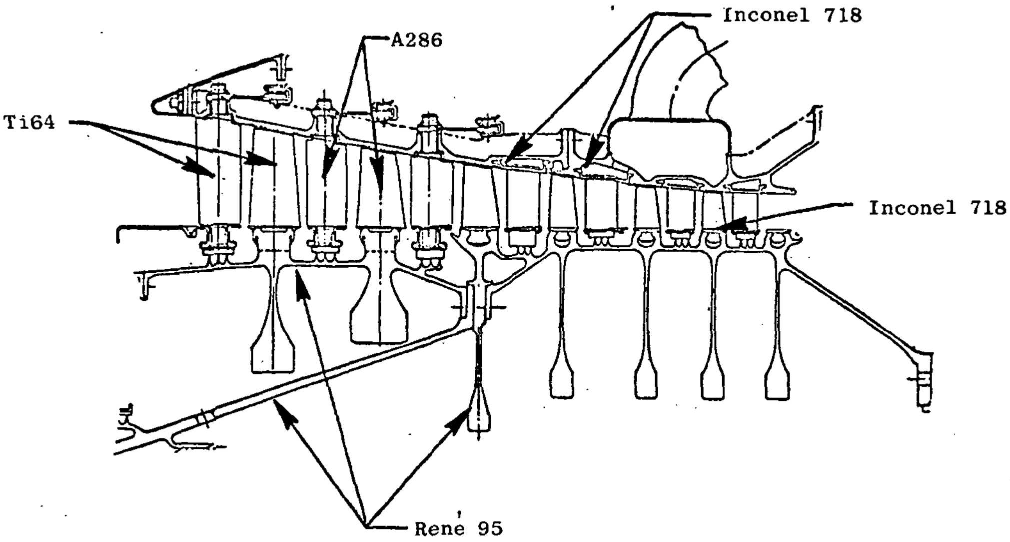
| | |
|---|---|
| Corrected Inlet Flow | 26.3 kg/sec (58 lb/sec) |
| Inlet Specific Flow | 188.0 kg/sec-m$^2$ (38.5 lb/sec-ft$^2$) |
| Inlet Radius Ratio | 0.68 |
| Corrected Inlet Tip Speed | 424.6 m/sec (1393 ft/sec) |
| Design Pressure Ratio | 1.362 |
| Average Exit Mach | 0.43 |
| Exit Radius Ratio | 0.70 |
| IGV Type | Articulated |

Mechanical Design Data

| | |
|---|---|
| Physical Tip Speed | 505.7 m/sec (1659 ft/sec) |
| Solidity | 1.56 |
| Aspect Ratio | 1.35 |
| Maximum Stress | 462.0 x $10^6$ N/m$^2$ (63 ksi) |
| N/Rev Margin, percent | 3/15.7* |
| Flex Reduced Velocity | 2.6* |
| Torsional Reduced Velocity | 1.3* |
| Axial Type Dovetails | |
| Steel Disk Dovetail Stress/Yield | 70/76 |

* Without Midspan Shroud

Figure 7. Block 2 Fan.



| Stage | $N_b$ | $N_v$ |
|---|---|---|
| IGV | -- | 56 |
| 1 | 52 | 84 |
| 2 | 52 | 72 |
| 3 | 64 | 84 |
| 4 | 73 | 96 |
| 5 | 82 | 108 |
| 6 | 82 | 120 |
| 7 | 0 | 0 |

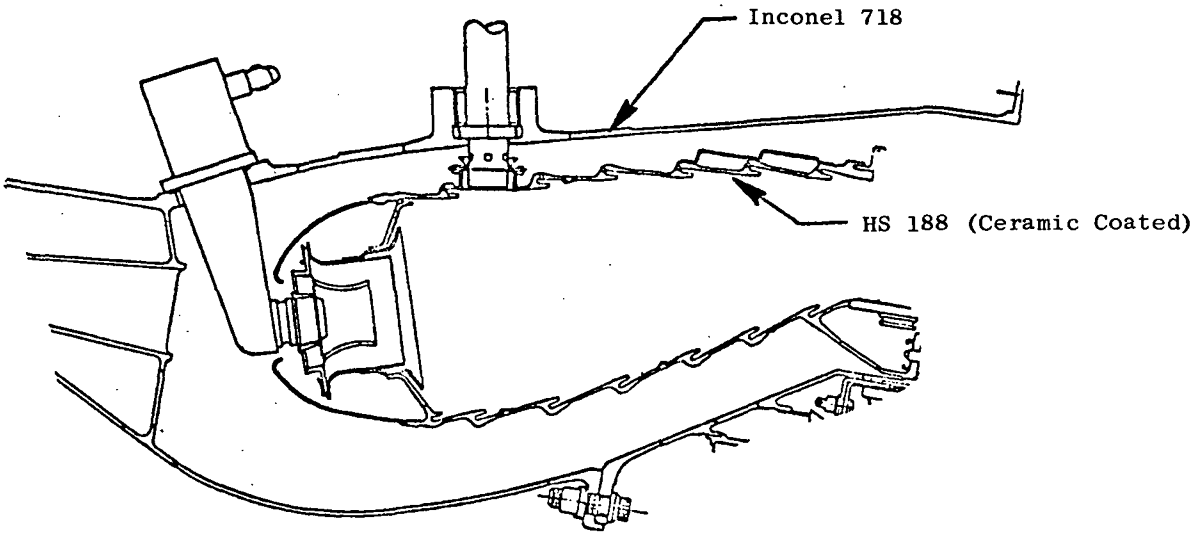
Aerodesign Data

| | |
|---|---|
| Corrected Inlet Flow | 15.5 kg/sec (34.2 kg/sec) |
| Inlet Specific Flow | 181 kg/sec-m$^2$ (37.1 lb/sec-ft$^2$) |
| Inlet Radius Ratio | 0.764 |
| Corrected Inlet Tip Speed | 360 m/sec (1180 ft/sec) |
| Design Pressure Ratio | 5.09 |
| Average Exit Mach | 0.35 |
| Exit Radius Ratio | 0.90 |
| IGV Type | Variable |
| Number of Stages | 6 |

Mechanical Design Data

- Stage 1 Physical Tip Speed - 450 m/sec (1478 ft/sec)
- Stages 1 and 2 Redesigned for Higher Temperatures
- Stages 3-6 Drum is F404 Design
- Blade Materials Changed
- Forward Case Material Changed
- Aft Stator is F404
- Solidities and Aspect Ratios - F404
- Forward Stub Shaft New Design

Figure 8. High-Pressure Compressor.



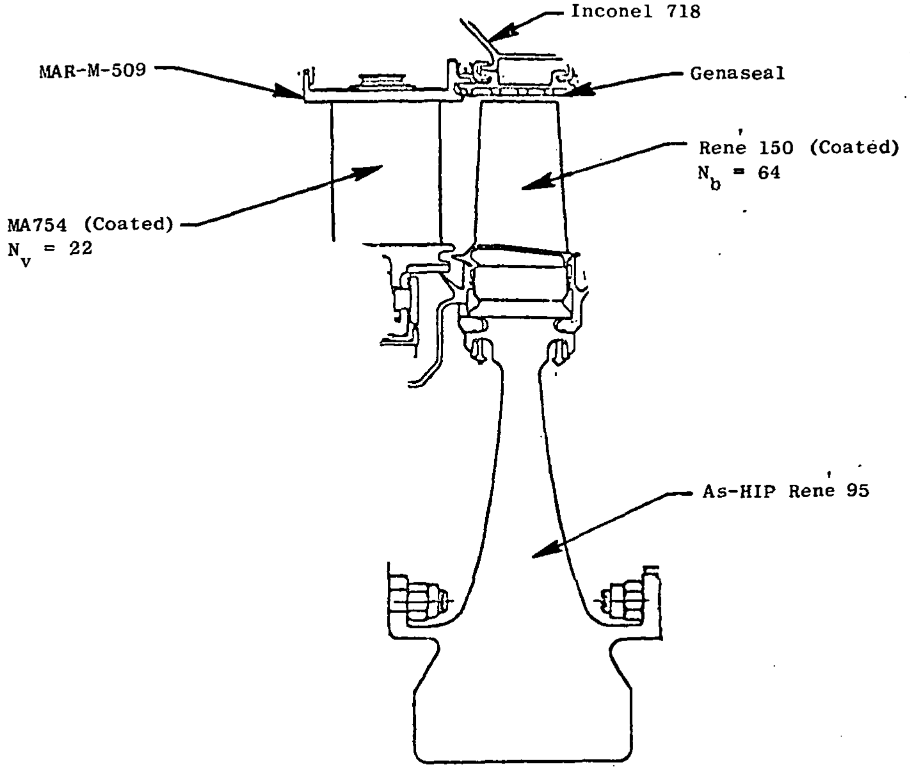
### Aerodesign Data

| | |
|---|---|
| • Space Rate | $32.8 \times 10^{16}$ J/m$^3$-atm-hr (8.8 Btu/ft$^3$-atm-hr) |
| • Reference Velocity | 24.7 m/sec |
| • Pattern Factor | 0.32 |
| • Profile Factor | 0.12 |
| • Maximum ΔT | 994° C (1790° F) |
| • ΔP/P | 6% |
| • Liner Cooling Flow | 26% W36 |

### Mechanical Design Data

- F404 Combustor Design
- Outer Diameter Increased Slightly to Match Turbine Flowpath
- Number of Fuel Nozzles - 14
- Number of Ignitors - 2

Figure 9. Combustor.



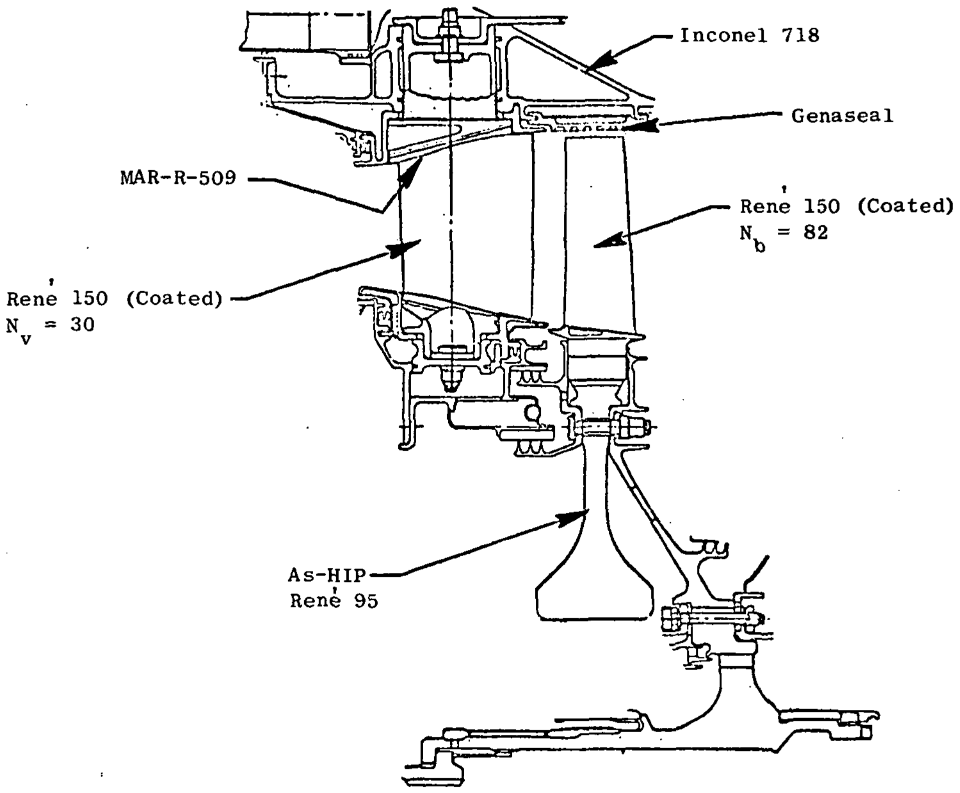
### Aerodesign Data

| | |
|---|---|
| • Design Point | Mp 2.32, 16,459 m (54,000 ft) |
| • Design Pitch Loading | 0.84 |
| Hub Loading | 1.03 |
| • Energy Extraction | $4.18 \times 10^5$ J/kg (180 Btu/lbm |
| • Solidity Stator/Rotor | 0.49/1.22 |
| • Aspect Ratio Stator/Rotor | 1.33/1.63 |
| • Outer Band Angle | 0° |
| • Exit Mach | 0.46 |
| • Exit Flow | 19.6 kg/sec (43.1 lb/sec) |
| • Exit Temperature | 1407 K (2533° R) |
| • Inlet Temperature | 1756 K (3161° R) |

### Mechanical Design Data

- Hub Flowpath Identical to F404
- Blade Height Slightly Higher than F404
- Design Point Tip Speed - 549 m/sec (1800 ft/sec)
- Design Point $AN^2 \times 10^{-9}$ 43.3
- Conventional Dovetail Blade Retention
- Disk Slightly Heavier than F404 - Should be within Forging Envelope

Figure 10. High-Pressure Turbine.



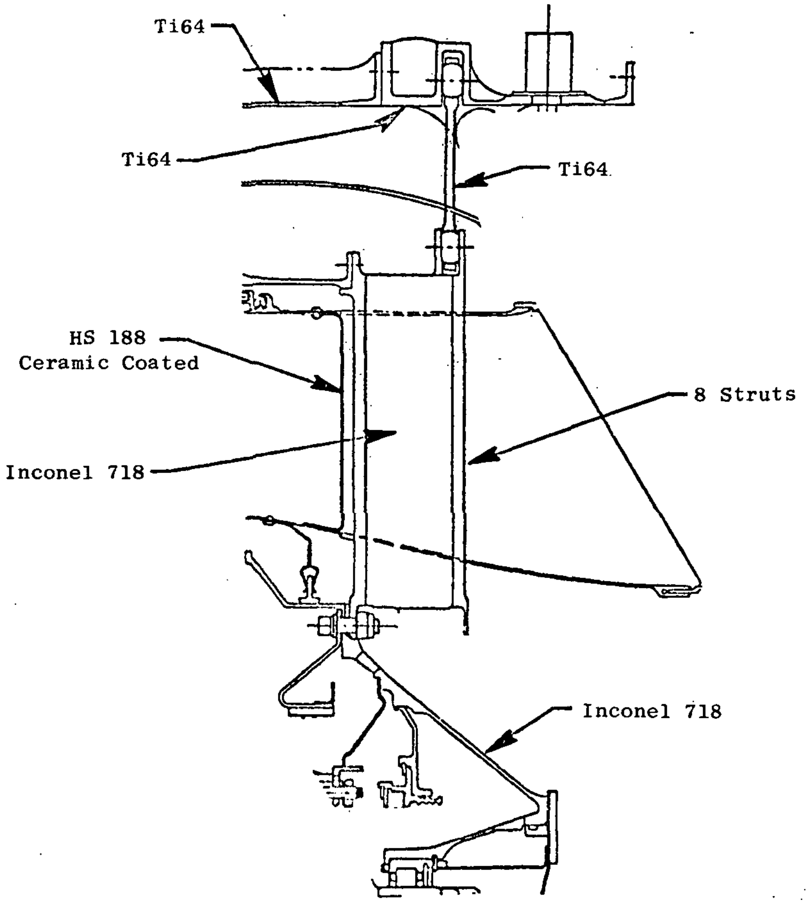
## Aerodesign Data

| | |
|---|---|
| • Design Point = M 0.3, Sea Level (Rotation) (Modified to use F404 Exit Area) | |
| • Design Pitch Loading | 0.79 |
| Hub Loading | 1.14 |
| • Energy Extraction | $2.37 \times 10^5$ J/kg (102 Btu/lbm) |
| • Solidity Stator/Rotor | 0.70/1.34 |
| • Aspect Ratio Stator/Rotor | 1.5/3.3 |
| • Vane Design | JTDE-Type Variable |
| • Outer Band Angle | 18° |
| • Exit Mach (Design) | 0.60 |
| • Exit Flow | 48.1 kg/sec (106 lb/sec) |
| • Exit Temperature (Design) | 1111 K (2000° R) |
| (Cruise) | 1261 K (2270° R) |

## Mechanical Design Data

| | |
|---|---|
| • Flowpath Identical to F404 | |
| • Design Point Tip Speed | 454.2 m/sec (1490 ft/sec) |
| • Design Point $AN^2 \times 10^{-9}$ | 45.2 |
| • Conventional Dovetail Blade Retention | |
| • Rotor Components (Disk, Shaft, etc.) F404 | |

Figure 11. Low-Pressure Turbine.



<u>Aerodesign Data</u>

- Maximum Mach Number - 0.65 at Rotation
- Exit Swirl Low (~10-15°)
- OGV's not Required
- Outer Duct Sized for Maximum $M_o$ - 0.35

<u>Mechanical Design Data</u>

- Frame Spring Constants:
  - Radial $147 \times 10^6$ N/m ($0.84 \times 10^6$ lb/in.)
  - Moment $16 \times 10^6$ N/radian ($3.6 \times 10^6$ lb/radian)
- Number of Struts 8
- Linkage to Rear Mount Transmits Radial Load Only
- Supports Aft Roller Bearings
  (Bearing and Sump System Identical to F404)

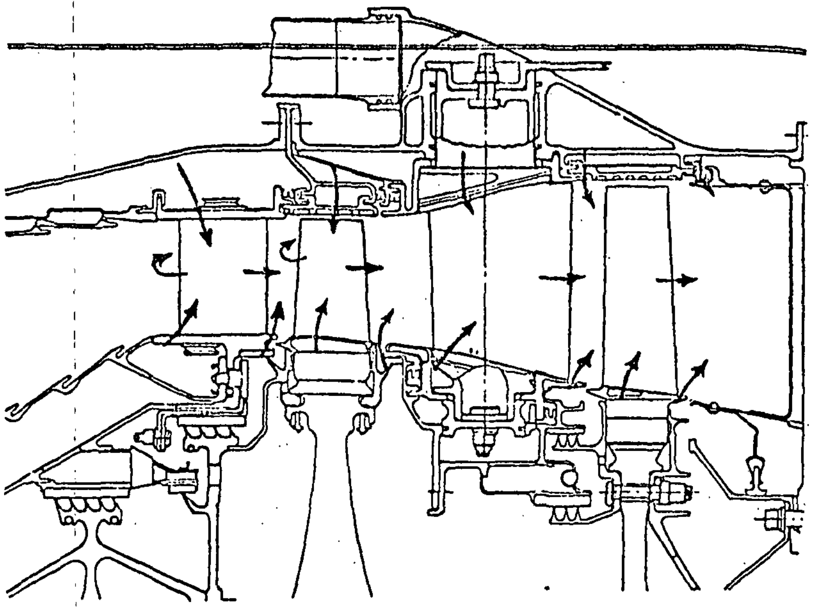
Figure 12. Rear Frame and Outer Duct.

HP Diaphragm:

Outer Band
Inner Band
Airfoil
5.10

HP Rotor:

Shroud
Pf Leakage
Airfoil
Seal Leakage
6.51



LP Diaphragm:

Outer Band and Trunnion
Inner Band and Trunnion
Forward Cavity Leakage
Airfoil
2.82

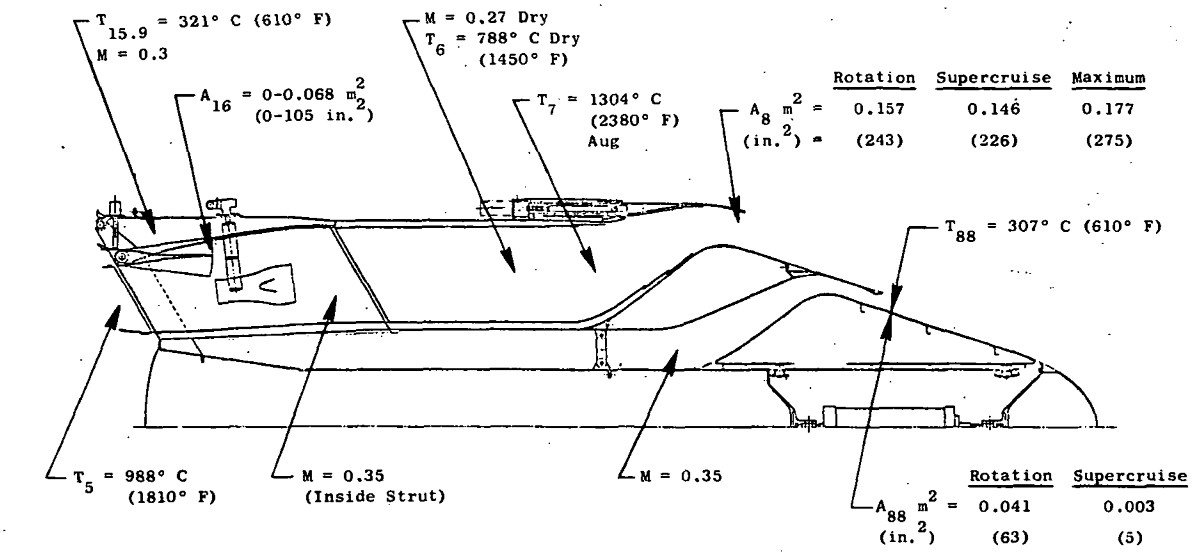
LP Rotor:

Shroud
Aft Shroud Leakage
Pf Leakage
Airfoil
Seal Leakage
Cover Plate Leakage
3.08

Cooling Flows

- Equivalent Life at M 2.32, 16,307 m (53,500 ft): 100 hr
- Single Insert Cooling Technology (HP)
- GE23 Technology - Cold Bridge Multiple Serpentine (LP)
- Blade Material - Rene 150 HP and LP
- Low Solidity Vanes HP and LP
- Low Solidity Radiation Adder (1/2%) HPT
- Thermal Barrier Coatings on Vanes, Bands and Blades
- Total Cooling Flows (% W25)
  Nonchargeable 5.1%
  Chargeable 12.4%

Figure 13. Cooling Flow Distribution.



Materials

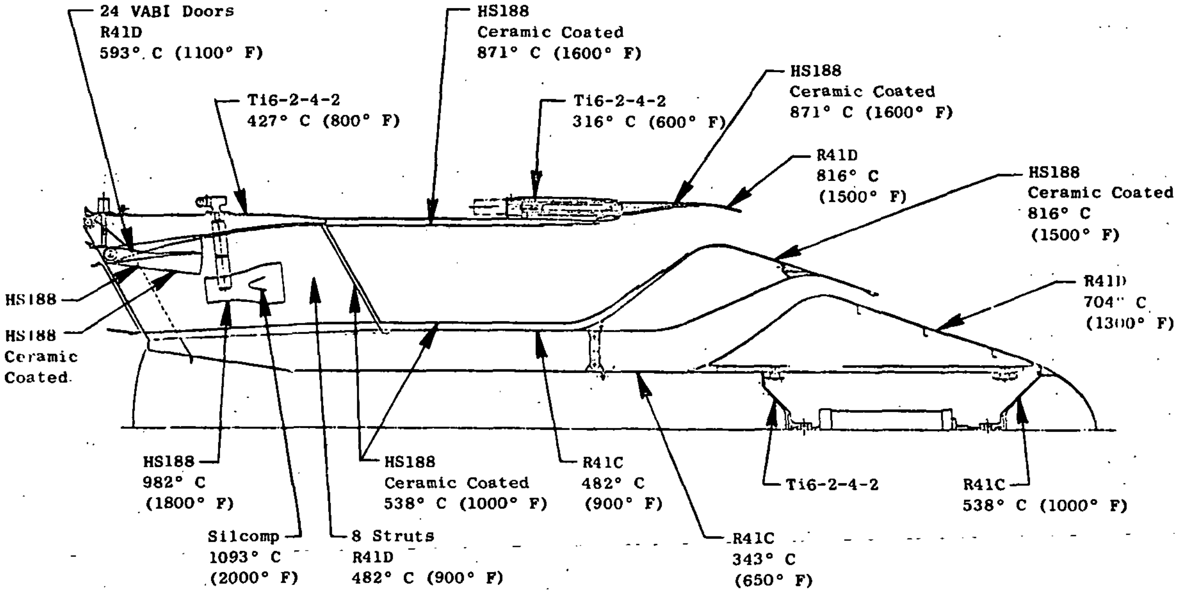


Figure 14. VCEE Exhaust System Aero Data.

- Base Program - Essential to Options 1 through 4 (both subscale and full scale VCEE)
- Alternate Base Program - Sea Level Demo only (lower cost/extended schedule)
- Altitude Performance - Option 1
- In-flight Noise - Option 2
- P-PFRT - Option 3 (includes Options 1 & 2)
- Flight Test Support - Option 4

These subscale programs are described further in Table XIII; the corresponding schedules are shown in Figure 15. Table XIV lists the important planning assumptions. The Total Program Costs and Selling Price are shown in Tables XV and XVI. Both Manufacturing Cost (MC) and Selling Price (SP) are shown. Selling Price is MC plus general and administrative expense and fee. For this study MC plus 30% has been used. Figure 16 shows the cost in relation to the schedule.

### 4.4.2 Base Program

The base program is the principal building block for the VCEE program and is devoted to Sea Level rating only. It is designed to provide the first step toward an engine that is flight capable. This base program is similar in scope and content to the prior YJ101/VCE test programs under current NASA contract.

Component tests are planned to the extent they are required to provide basic design information or first engine aeroperformance and mechanical design assurance. Those component tests that are aimed at performance verification or improvement are included in the P-PFRT option.

Table XIII. Preliminary Subscale VCEE Program Plans/Options.

| | |
|---|---|
| (A) Base Program | • Scope Limited to SLS Testing<br>• About 305 Hours of Testing<br>• Core and Full Engine Tests<br>• Minimum Required Component Testing<br>• Two Base Programs Defined:<br>1. As Part of Continuing P-PFRT Effort<br>2. Lower Cost/Longer Schedule Alternative (Assuming Program does not Extend Beyond Base) |
| (B) Altitude Performance Evaluation (Option 1) | • Altitude Performance Testing in NASA-Lewis Facility - 75 Test Hours<br>• Includes FADEC Control |
| (C) NASA-AMES In-Flight Noise Evaluation (Option 2) | • Flight Acoustic Simulation - 75 Test Hours<br>• Scale Model/Full-Scale Correlation of In-Flight Effects<br>• "Representative" Aircraft Inlet/Nacelle Design<br>• Static Tests at Peebles (Inlet/Nacelle/Engine)<br>• NASA Windtunnel Tests at Takeoff and Approach Conditions |

Table XIII. Preliminary Subscale VCEE Program Plans/Options. (Concluded)

| | | |
|---|---|---|
| (D) | <u>P-PFRT (Demo Flight Test Qualification)</u> (Option 3) | ● Patterned After YJ101 P-PFRT Program<br>● - 745 Hours Additional Testing Beyond Base Program and Options 1 and 2<br>- 1200 Hours Total Testing<br>● Additional Component Testing to Achieve VCEE Performance Objectives |
| (E) | <u>Flight Test Support</u> (Option 4) | ● Engineering Support for 1 Year; 1 Subscale Aircraft Flight Test Program |

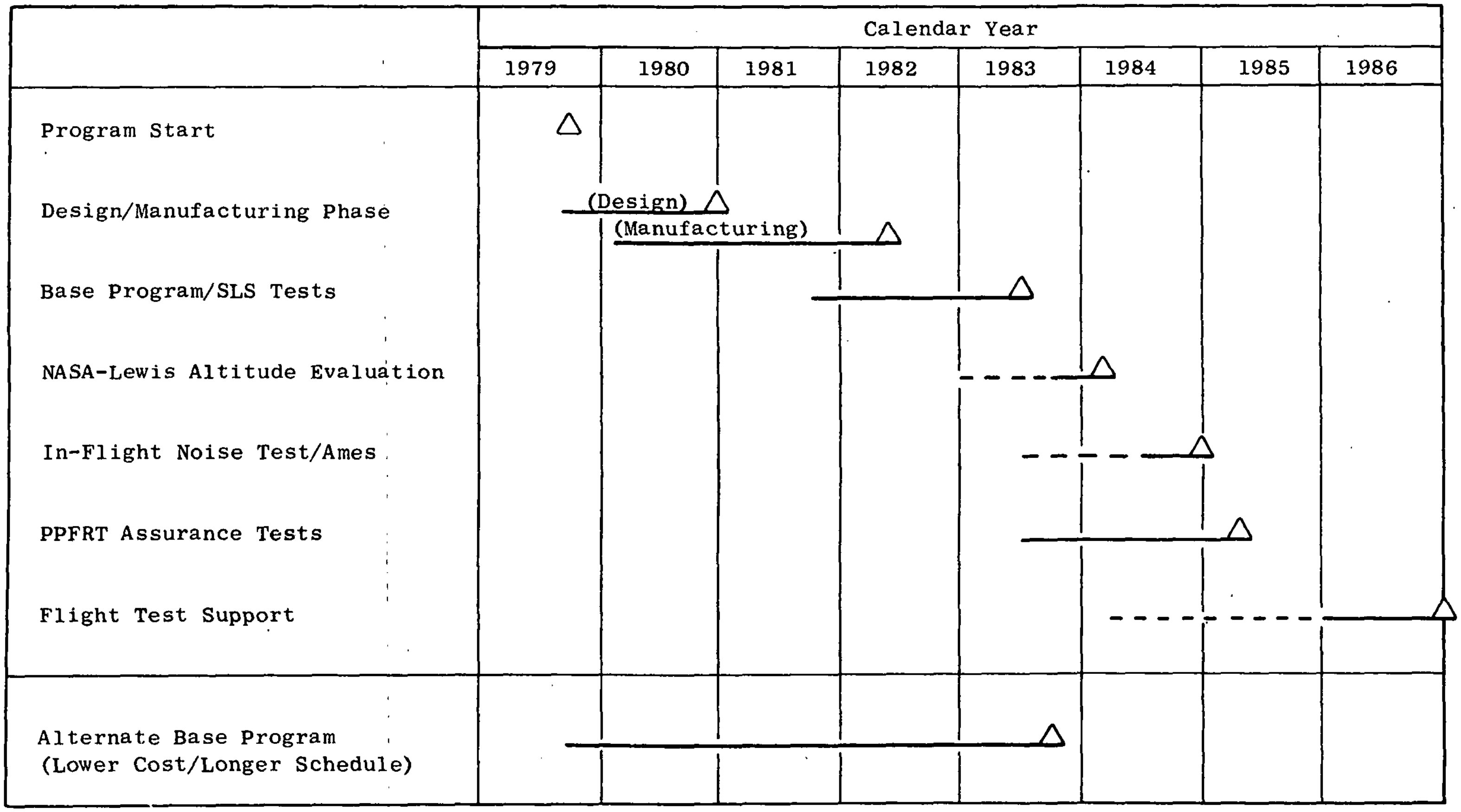


Figure 15. Preliminary Subscale VCEE Program Schedule.

Table XIV. Preliminary Subscale VCEE Program Planning Assumptions.

- The program is planned for October 1979.
- Preliminary estimated costs are in then-year dollars at Manufacturing Cost (MC).
- The cost of F404 hardware acquisition is included.
- The program elements are independent of potential YJ101 augmented component test program options (prepared separately).
- Test facility and test costs at Lewis (Option 1) and Ames (Option 2) are to be covered by NASA.
- The Government will furnish the fuel and oil.
- Reverser program is limited to model tests/design only.
- The only GE engineering reporting required will be internal reports for program management. This reporting is included in the program costs. The costs of external report preparation or publishing are not included.

Table XV. Subscale VCEE Program Cost Summary - Manufacturing Cost.

(Then-Year $)

| | | Manufacturing Cost ($K) |
|---|---|---|
| Base Program | | 56,251 |
| Alternate Base Program<br>(Without FADEC) | 40,216<br>(36,000) | |
| Altitude Performance Evaluation | | 2,627 |
| In-Flight Noise Evaluation | | 5,742 |
| P-PFRT Δ | | 61,650 |
| | Subtotal P-PFRT | $ 126,270 |
| Flight Test Support Program | | $ 23,060 |

Table XVI. Subscale VCEE Program Cost Summary-Selling Price.

(Then-Year $)

| | | Selling Price ($ million) |
|---|---|---|
| Base Program | | 73.1 |
| Alternate Base Program<br>(Without FADEC) | 52.3<br>(46.8) | |
| Altitude Performance Evaluation | | 3.4 |
| In-Flight Noise Evaluation | | 7.5 |
| P-PFRT | | 80.1 |
| | Subtotal P-PFRT | $164.1 million |
| Flight Test Support Program | | $ 30.0 million |

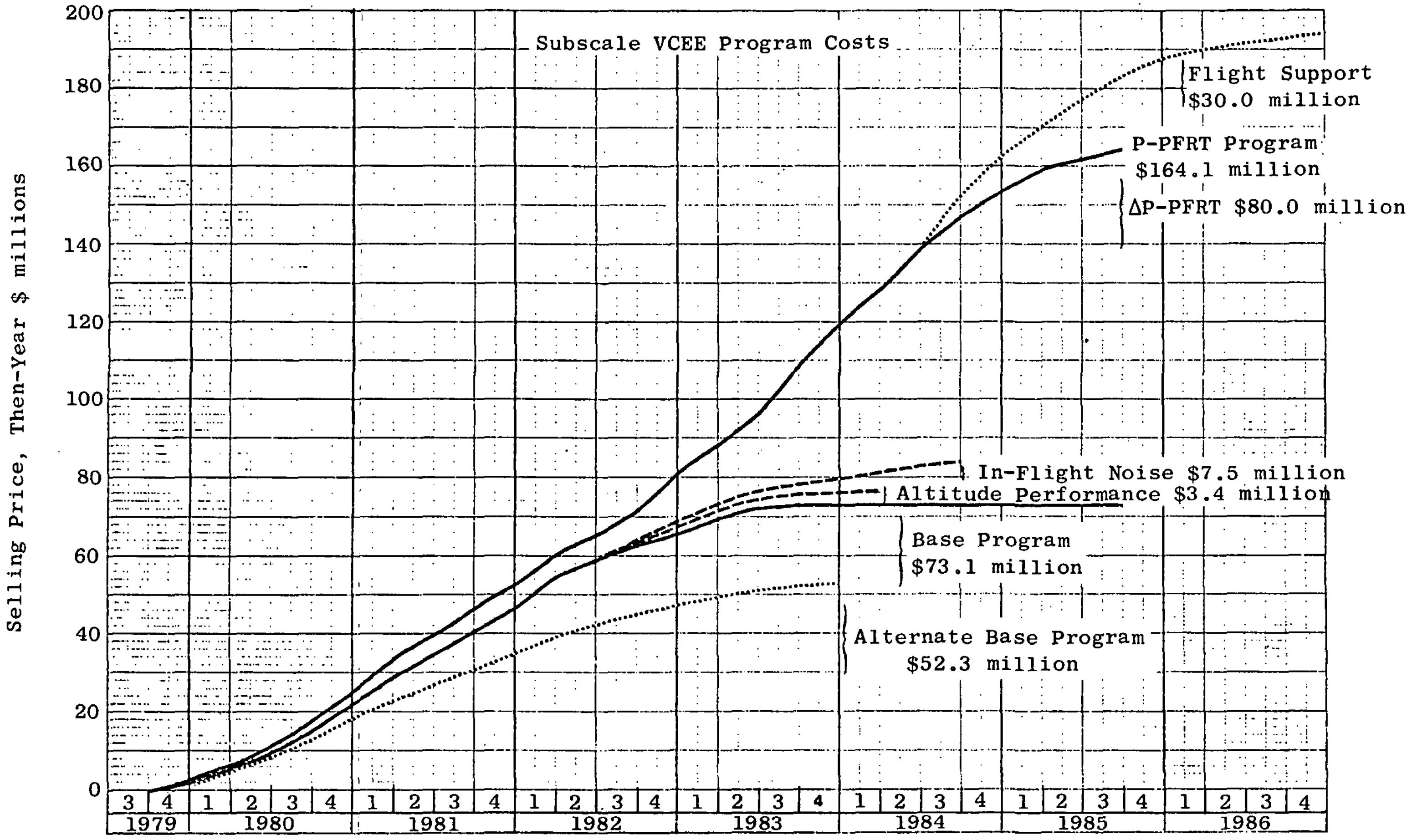


Figure 16. Selling Price Versus Schedule, Subscale VCEE Program.

Table XVII compares the subscale VCEE Base Program tests with the YJ101 and Alternate Base Program. Figure 17 shows the detailed Program Schedule and test content for the base program. The full-scale VCEE base program is very similar to the subscale base program. The costs of both of these base programs are detailed in Table XVIII and Figure 18.

The hardware requirements included in each program are:

Base Program - Two core engines, one LP spool and one exhaust system, plus spares.

Alternate Base Program - One core engine, one LP spool and one exhaust system, plus spares.

P-PFRT Program - Base program and four complete engines, plus spares.

### 4.4.3 Alternate Subscale VCEE Base Program

In light of the proposed base program's cost requirement ($56 million for MC), it was deemed desirable to present an alternative, lower-cost base program in case effort beyond SLS testing would not be authorized.

This program was presented as a reduced-cost, extended-schedule alternative. It results in a demo engine with Sea Level capability only. If this program is selected, P-PFRT can be achieved but only with an overall cost and timing penalty. Table XIX shows the major assumptions made to reduce the program costs. Figure 19 shows the program schedule and test content. Table XX compares the costs of the subscale Base Program with those of the subscale Alternate Base Program.

Despite the fact that the cost reductions in the Alternate Base Program limit operation to SLS testing, the 2800° F design temperature of the HP turbine would in all likelihood still be attainable. This would be accomplished by using increased cooling airflows, applying coatings, limiting the bucket high-T4 running time, and using other such techniques, as required, to offset the substitution of lower capability bucket material.

Table XVII. SLS Test Program Comparison.

| Test Hours | Base<br>Hrs./Tests | Alternate Base<br>Hrs./Tests | NASA YJ101 VCE (Ref.)<br>Hrs./Tests |
|---|---|---|---|
| Core Tests | 170 (2) | 100 (1) | 100 (1) (A) |
| **Full Engine Tests** | | | |
| SLS Lynn | 105 (2) | 105 (2) | 55 (1) (B) |
| Peebles | 30 (1) | 30 (1) | 115 (2) (C) |
| Total Test Hours | 305 | 235 | 270 |

| | | |
|---|---|---|
| (A) | Test Bed Core | |
| (B) | Forward VABI | 55 |
| (C) | Acoustic Nozzle | 65 |
| | Test Bed | 50 |

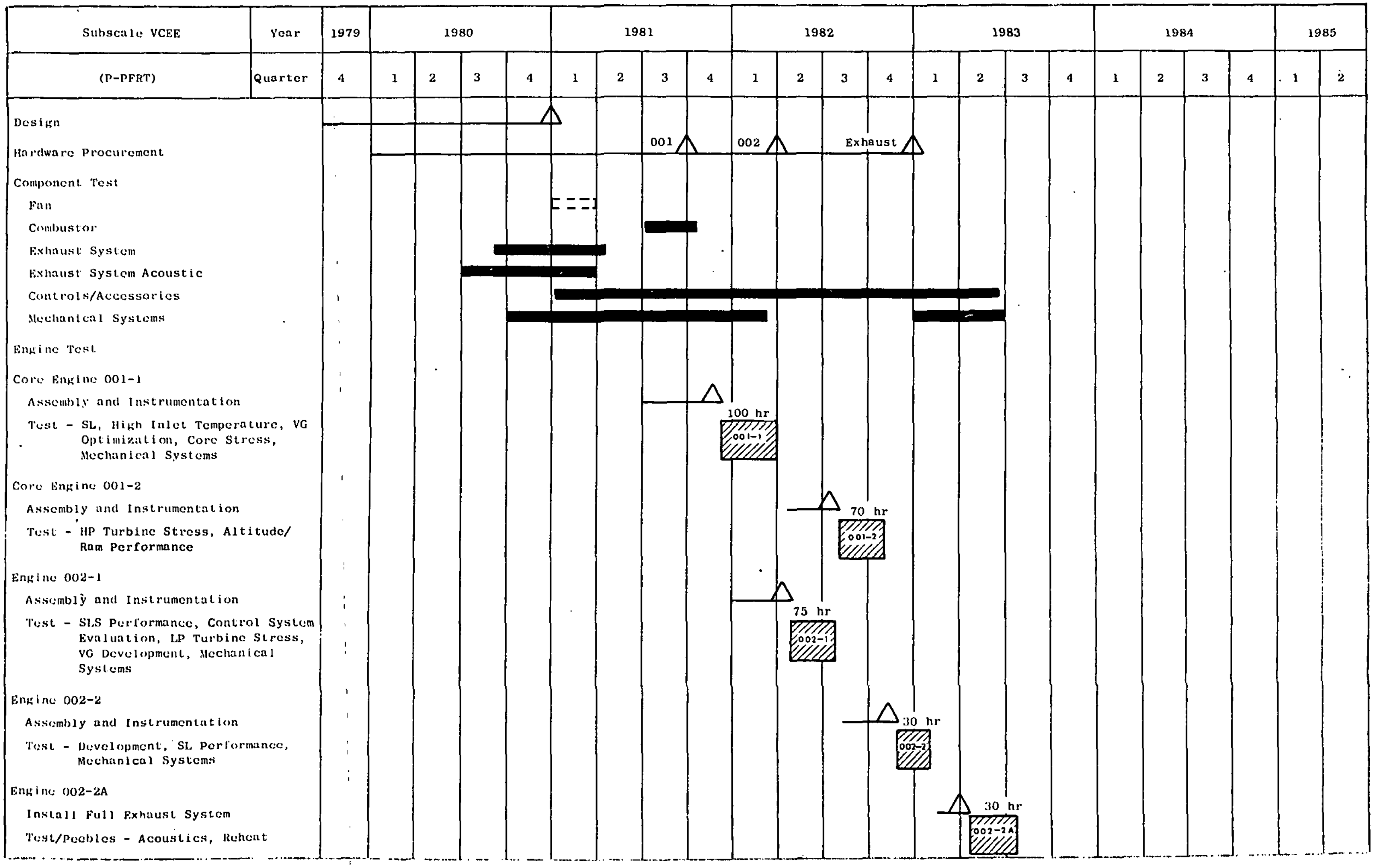


Figure 17. P-PFRT Program Base Schedule.

Table XVIII. Subscale/Full-Scale VCEE, - Program Costs.

| | Subscale Base Program | Full-Scale Base Program |
|---|---|---|
| | $ K | $ K |
| Fan/Compressor | | |
| Aerodynamic Design | 650 | 2,100 |
| Mechanical Design | 2,444 | 7,300 |
| Component Test | | 4,550 |
| HP/LP Turbine | | |
| Aerodynamic Design | 1,192 | 3,200 |
| Mechanical Design | 2,874 | 5,700 |
| Component Test | | 2,750 |
| Combustion System | | |
| Aerodynamic Design | 71 | 1,450 |
| Mechanical Design | 366 | 3,700 |
| Component Test | 222 | 2,600 |
| Controls & Accessories | | |
| Mechanical Design | 9,802 | 10,650 |
| Component Test | 1,684 | 3,300 |
| Frames/Lube System/Config. | | |
| Mechanical Design | 2,935 | 3,480 |
| Component Test/Mock-Up | 460 | 2,550 |
| Bearings/Seals Design/Test | 355 | 2,330 |
| RR VABI/Exhaust System | | |
| Aerodynamic Design | 1,820 | 1,820 |
| Acoustics Design | 995 | 995 |
| Mechanical Design | 1,510 | 1,510 |
| Component Test | 2,599 | 2,599 |
| Engineering Design Support | | |
| Mechanics/Dynamics | 694 | 845 |
| Materials/Weight/Config. Mgmt. | 744 | 935 |
| Drafting | 2,903 | 3,700 |
| Cycle & Systems Analysis | 1,891 | 1,891 |
| Plans & Programs | 437 | 437 |
| Hardware/Tools | 15,084 | 30,880 |
| Engine Assembly & Test | 4,621 | 6,650 |
| Total (Then-Yr. MC $) | $56,251 K | $107,992 K |
| Total Selling Price | 73,126 K | 140,390 K |

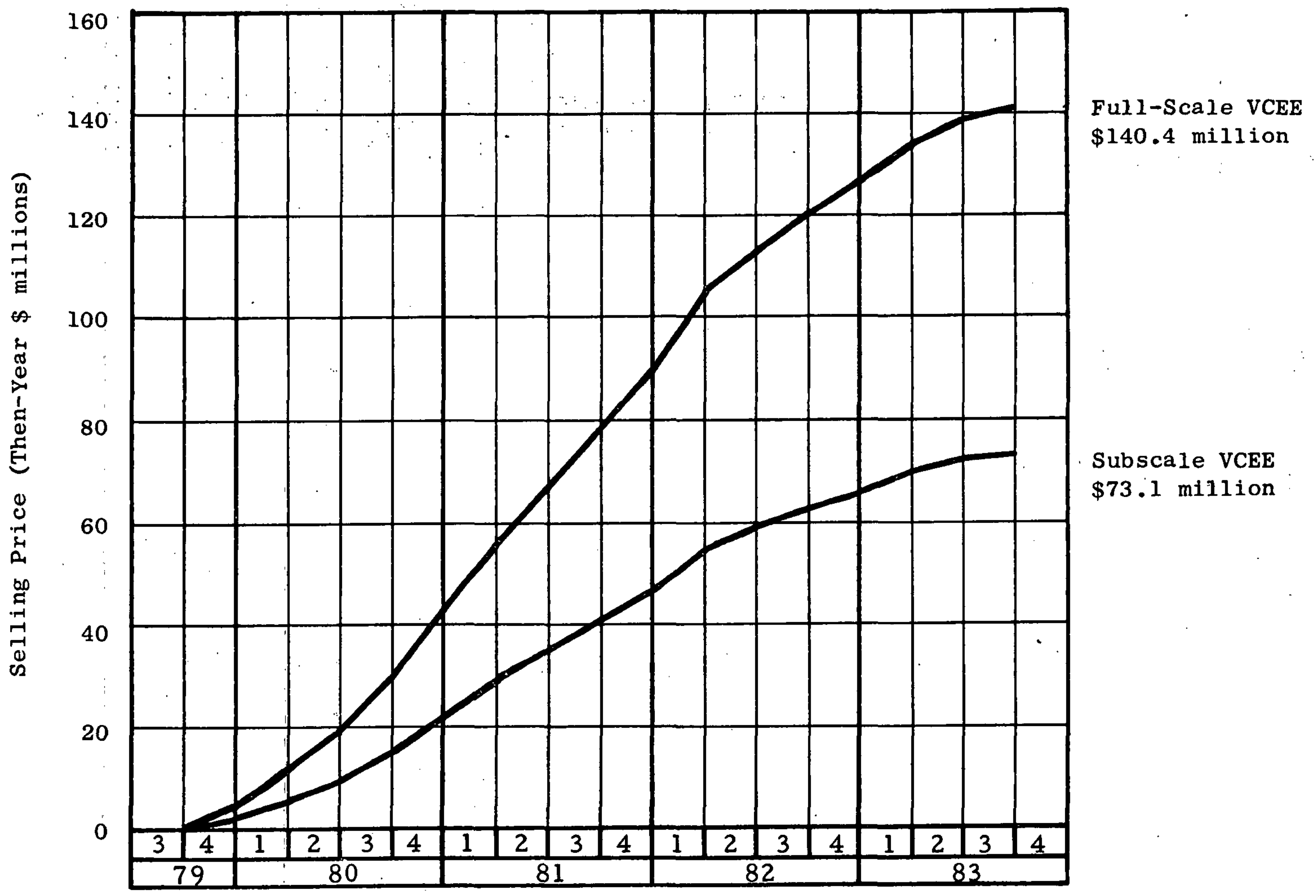


Figure 18. Demonstrator Base Program Selling Price Comparison.

Table XIX. Major Assumptions for Subscale Alternate Base Program (Reduced Cost/Extended Schedule).

Engine Hardware/Tooling Changes

- No change in compressor disk and shaft materials (that is, the use of F404 materials/capability)
- R125 (F404) material for blades of HP turbine and LP turbine - elimination of R150 material
- A simplified Full Authority Digital Electronic Control (FADEC)
    - using test-cell hydraulic system
    - using test-cell electrical power
    - doing without backup control functions

Engine Hardware Requirements

- One core engine instead of two

Component Tests

- Reduced-scope component test program

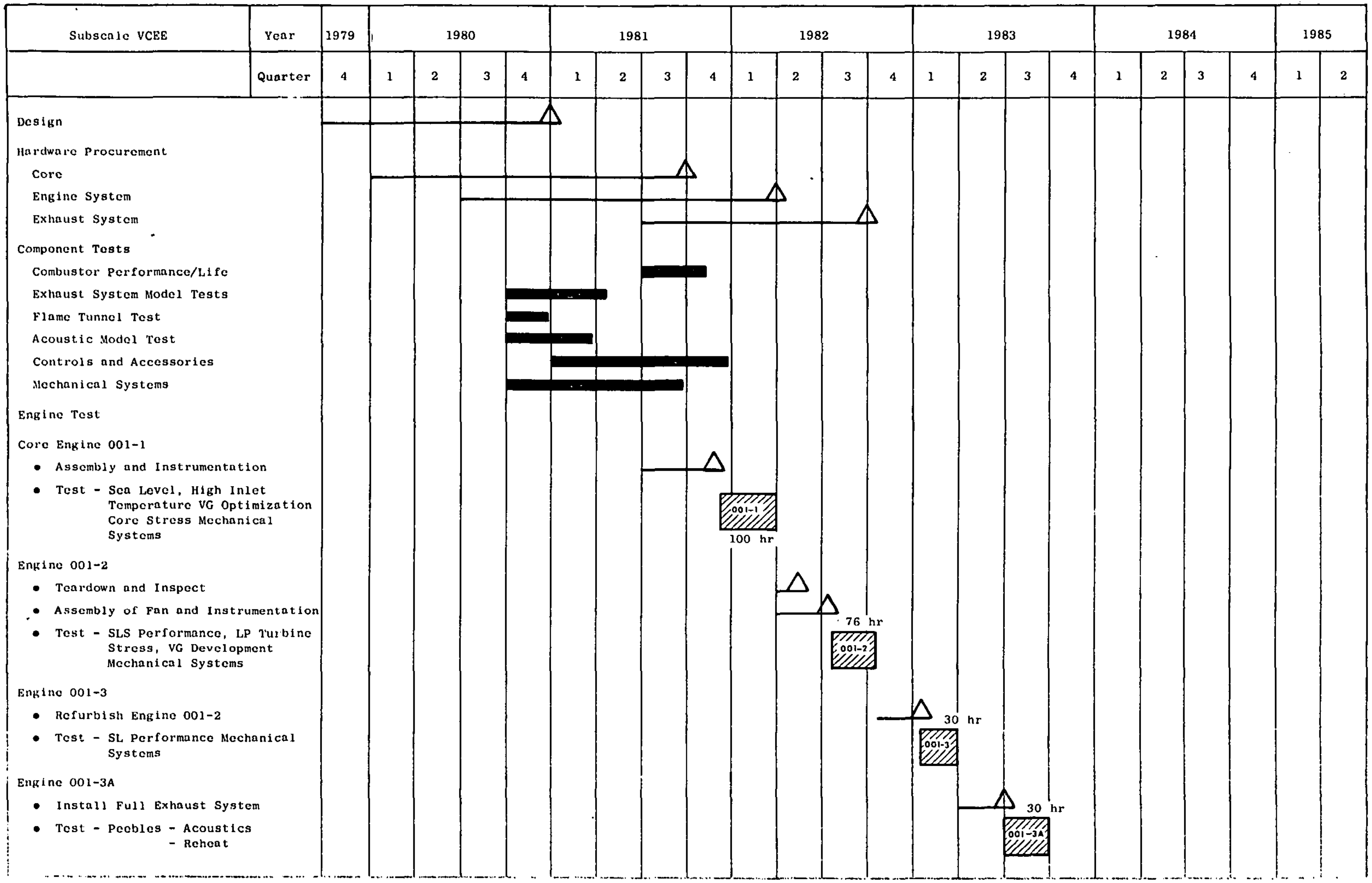


Figure 19. Subscale Alternate Base Program (Reduced Cost/Extended Schedule).

Table XX. Subscale VCEE - Program Costs Comparison.

| | Base Program | Alternate Base Program |
|---|---|---|
| **Fan Compressor** | $ K | $ K |
| Aerodynamic Design | 650 | 500 |
| Mechanical Design | 2,444 | 1,540 |
| **HP/LP Turbine** | | |
| Aerodynamic Design | 1,192 | 1,192 |
| Mechanical Design | 2,874 | 1,961 |
| Component Test | | |
| **Combustion System** | | |
| Aerodynamic Design | 71 | 71 |
| Mechanical Design | 366 | 366 |
| Component Test | 222 | 222 |
| **Controls & Accessories** | | |
| Mechanical Design | 9,802 | 4,000 |
| Component Test | 1,684 | 760 |
| **Frames/Lube System/Config.** | | |
| Mechanical Design | 2,935 | 2,769 |
| Component Test/Mock-Up | 460 | 200 |
| Bearings/Seals Design/Test | 355 | 355 |
| **RR VABI/Exhaust System** | | |
| Aerodynamic Design | 1,820 | 1,820 |
| Acoustics Design | 995 | 915 |
| Mechanical Design | 1,510 | 1,303 |
| Component Test | 2,599 | 2,139 |
| **Engineering Design Support** | | |
| Mechanics/Dynamics | 694 | 625 |
| Materials/Weight/Config. Mgmt. | 744 | 744 |
| Drafting | 2,903 | 2,903 |
| **Cycle & Systems Analysis** | 1,891 | 1,891 |
| **Plans & Programs** | 437 | 249 |
| **Hardware/Tools** | 15,084 | 9,691 |
| **Engine Assembly & Test** | 4,621 | 4,000 |
| Total (Then-Yr. MC) | $56,251 K | $40,216 K<br>(36,000 K)* |
| Total Selling Price | $73,126 K | $52,280 K<br>($46,800 K)* |

* With breadboard control instead of FADEC

The component tests planned for the Alternate Base Program include:

1. Combustor Full-scale Component Tests - These tests are to verify SLS performance at the increased $M_3$ and $T_4$ levels at the VCEE combustor. They include tests for efficiency and pressure drop; the determination of turbine inlet temperature profile; and pattern factor development. Since turbine inlet temperature objectives for both the Base and Alternate Base programs at SLS conditions are the same, it is planned that the required combustor component testing would be the same.

2. HP and LP Turbine - It is planned that component testing would not be included for either the Base or Alternate Base programs, but would be conducted if the P-PFRT system is selected. This is due to the conclusion that component testing would be required for reaching the performance goals of the P-PFRT program; but that for a program limited to SLS demonstrator running only, absolute HPT and LPT performance levels would be of secondary importance. For a program option limited to SLS testing, the HPT and LPT design would rely on applicable related technology from ATEGG/JTDE, F404 Growth, or similar demo programs.

3. Exhaust System (as defined in Table XVI) - Since exhaust system design/aerodynamic performance is fundamental to the unique requirements of the AST application, it is planned that all component tests identified for the Base Program would also be accomplished for the Alternate Base Program. These include:

   - Scale-Model Rear VABI Test (Augmentor Integration)
   - Scale-Model Nozzle Internal Aero Performance Tests
   - Scale-Model Thrust Reverser Tests (to define reverser integration design requirements)
   - Augmentor sector flametunnel tests

   The proposed AST exhaust system is unquestionably unique, with its rear VABI that is integrated with a coannular exhaust nozzle; its low-temperature-rise augmentor; and its reverser integration. Because of this uniqueness, there are no forecasts for applicable component development programs from other advanced technology programs that could provide the required design data and component performance verification.

4. Exhaust Nozzle Scale-Model Acoustic Tests - Because its testing is limited to sea level conditions the Alternate Base Program could get by with a less inclusive component program than the flight-capable configuration, for the program would essentially represent a second phase to the YJ101/VCE demonstrator program conducted in 1978.

5. Controls and Accessory Tests - Controls designed for SLS capability differ greatly from those meant for flight capability. Two ways that sea level testing allows simpler controls are: (1) the backup functions can be eliminated and (2) off-engine electrical and hydraulic power supplies can be used. Table XIX explains the difference between the Alternate Base Program (Sea Level Test only) and the Base Program (flight-capable). The Alternate Base Program is expected to be able to make considerable use of the results of the JTDE/USN programs (which are also SLS-testing-oriented).

6. Mechanical Systems - For a program limited to SLS testing, not as much testing would be needed to assure sound structure and bearings/accessory drives. The differential bearing, recognized as a key technical problem area, would have the same level of component development in either program.

### 4.4.4 Subscale VCEE Altitude Performance Evaluation (Option 1)

During the conduct of the Base Program, an option to conduct an altitude performance evaluation can be chosen. The Base Program, as defined, includes the engine capability for altitude operation. Engine 002-2A would be refurbished and checked out. Altitude testing would be conducted in the NASA-Lewis PSL facility with technical support from General Electric. The program schedule is shown in Figure 20; the program cost in Table XXI. The engineering cost covers all engineering functions, including those for manufacturing and test activities.

### 4.4.5 Subscale VCEE In-Flight Noise Evaluation (Option 2)

An option to conduct an In-Flight Noise Simulation Test is available during the course of the Base Program. The program would be aimed at conducting wind tunnel tests at the NASA-Ames 40 x 80-ft facility, utilizing a representative inlet and nacelle for which the design would be conducted by an aircraft company with GE integration. The wind tunnel test would be conducted following an SLS calibration and checkout test at the GE Peebles facility.

The program schedule is shown in Figure 21; the costs are given in Table XXII. The P-PFRT option also contains this type of testing.

### 4.4.6 Subscale VCEE P-PFRT Program (Option 3)

The Base Program presented earlier is predicated on the requirement for a flight-capable engine. It, therefore, includes this requirement in the basic design effort. Should the P-PFRT option be elected after the Base Program is underway, there would be no delay in the overall timing. There are, however, certain elements of the P-PFRT program which, due to the lead time involved, should be initiated within nine months after Base Program go-ahead.

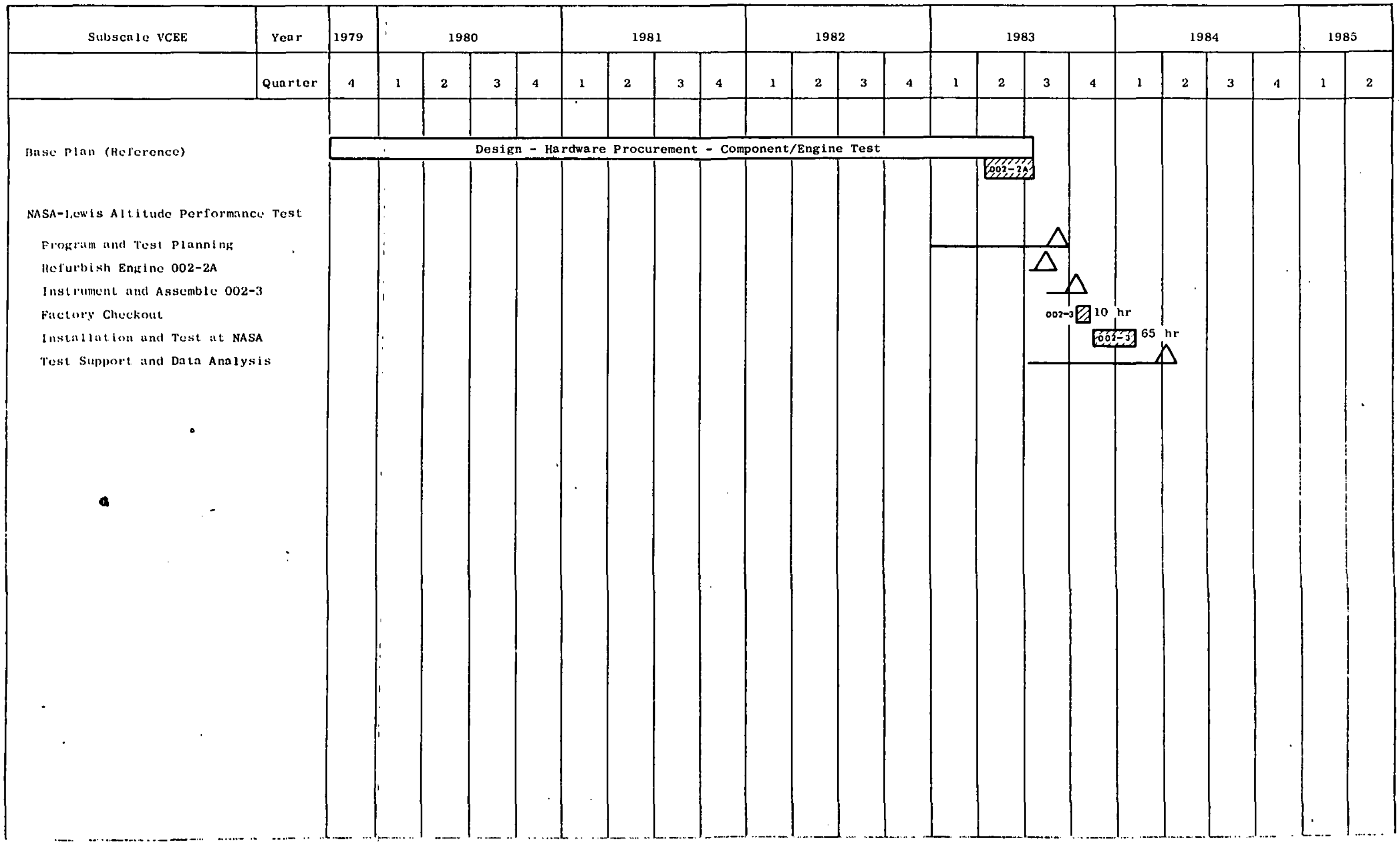


Figure 20. Altitude Performance Evaluation Schedule.

Table XXI. Subscale VCEE Program Costs, Altitude Performance Test Option.

Then-Year Mfg. Cost, $K

| | Altitude Performance (NASA-Lewis) |
|---|---|
| Fan/Compressor | |
| Aerodynamic Design | 144 |
| Mechanical Design | 100 |
| HP/LP Turbine | |
| Aerodynamic Design | 85 |
| Mechanical Design | 100 |
| Combustion System | |
| Aerodynamic Design | 12 |
| Controls & Accessories | |
| Mechanical Design | 230 |
| Frames/Lube System/Configuration | |
| Mechanical Design | 136 |
| Rear VABI/Exhaust System | |
| Aerodynamic Design | 345 |
| Mechanical Design | 202 |
| Engineering Design Support | |
| Aeromechanics | 57 |
| Cycle & Systems Analysis | 379 |
| Engine Assembly & Test | 837 |
| Total | $ 2,627 K |
| Total Selling Price | $ 3,415 K |

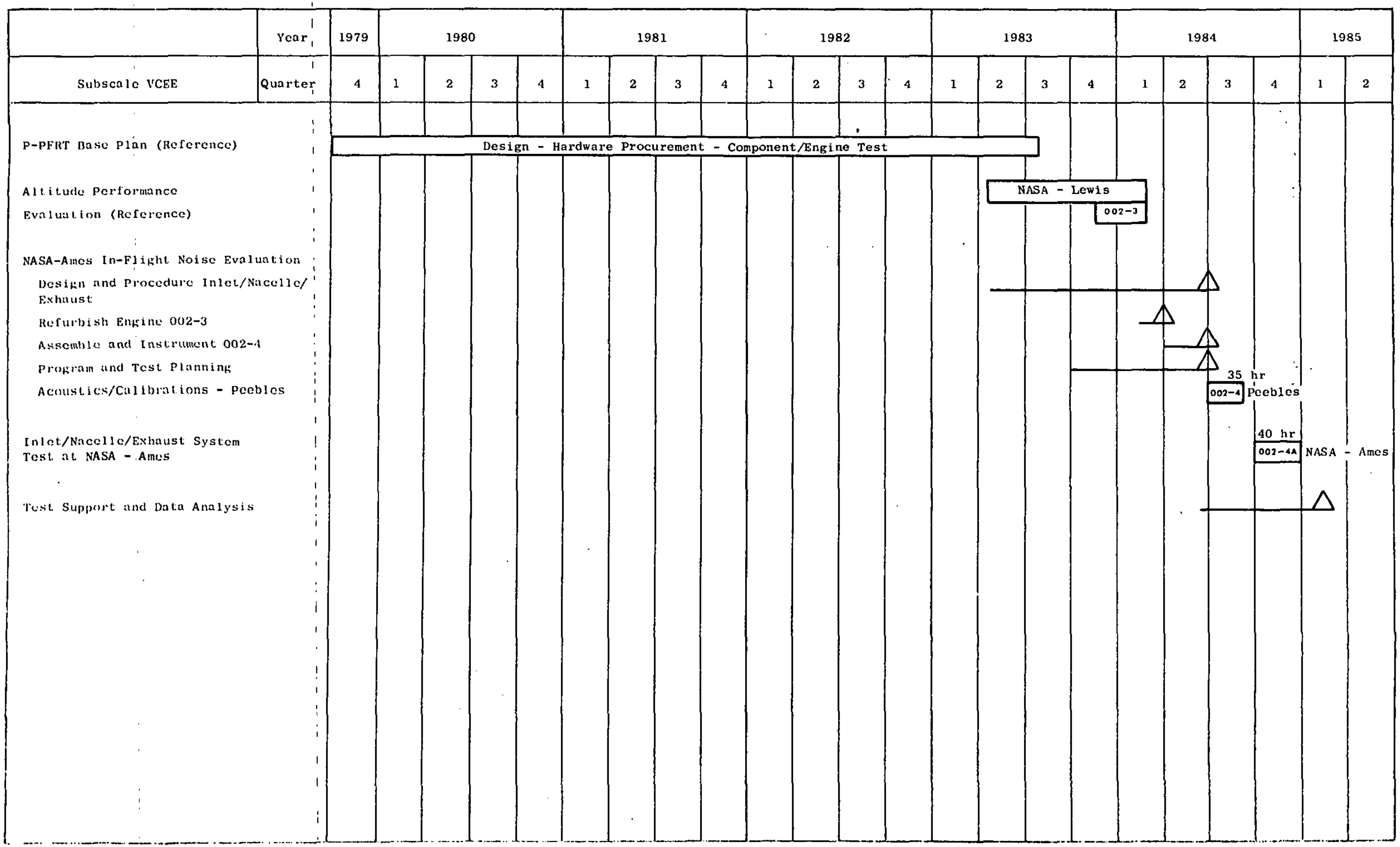


Figure 21. In-Flight Noise Evaluation Schedule.

## Table XXII. Subscale VCEE Program Costs - In-Flight Noise Evaluation.

Then-Year Mfg. Cost, $K

| | In-Flight Noise (Peebles/NASA-Ames) |
|---|---|
| **Fan/Compressor** | |
| Aerodynamic Design | 60 |
| Mechanical Design | 85 |
| **HP/LP Turbine** | |
| Aerodynamic Design | 93 |
| Mechanical Design | 85 |
| **Combustion System** | |
| Aerodynamic Design | 13 |
| **Controls & Accessories** | |
| Mechanical Design | 328 |
| **Frames/Lube System/Configuration** | |
| Mechanical Design | 105 |
| **Rear VABI/Exhaust System** | |
| Aerodynamic Design | 345 |
| Mechanical Design | 201 |
| Acoustics Design | 1,614 |
| **Inlet & Nacelle** | 1,510 |
| **Cycle & Systems Analysis** | 409 |
| **Engine Assembly & Test** | 894 |
| Total | $ 5,742 K |
| Total Selling Price | $ 7,465 K |

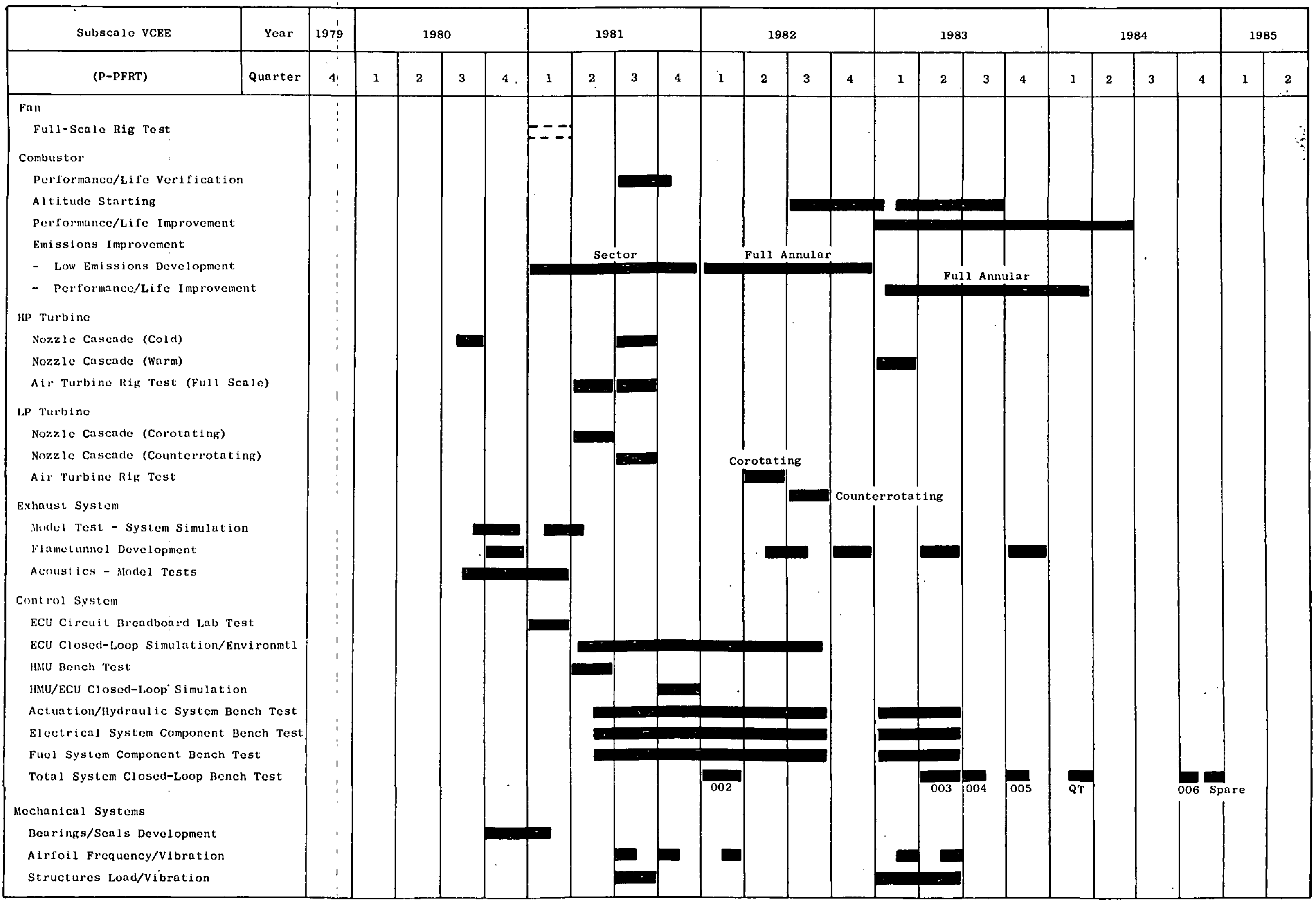


Figure 22. P-PFRT Component Test Plan.

The P-PFRT program scope includes significant component development effort to provide confidence in the component performance and durability prior to engine testing. The schedule for these tests is shown in Figure 22. The scope of the component tests is described in Tables XXIII through XXVIII.

The combustor will have some shell modifications and reorientation to accommodate the increased T4 and outer-diameter change in the HP turbine. Efficiency, $\Delta P$, and pattern factor effects will be checked. Altitude capability will also be evaluated. An emissions-reduction program is included as an option. Features of the combustor tests are presented in Table XXIII.

The HP turbine component tests are shown in Table XXIV and are primarily designed to evaluate two parameters: the aero performance of a reduced-solidity nozzle, and the heat transfer effectiveness of the airfoil cooling system. The reduced-solidity turbine vanes provide two improvements: they reduce the vane cooling-air introduced into the HP turbine rotor inlet, and they improve the turbine efficiency.

The LP Turbine Tests (Table XXV) are aimed at evaluating the performance advantage of counterrotation, as well as the effects of having a nozzle of reduced solidity. Counterrotation can improve the LP turbine efficiency by reducing the turning losses as the flow moves from the HP to the LP turbines. This advantage, however, must be evaluated against the increased differential bearing speed and the increased relative seal speed.

The Exhaust System tests (Table XXVI) include scale-model tests to evaluate internal aeroperformance to aid definition of the final detail design. Augmentor sector flametunnel tests are included to evaluate proposed augmentor/flameholder configurations.

Table XXIII. Combustor Component Tests - Subscale VCEE.

Scope - Full-Size (F404) Annular Tests

| | |
|---|---|
| 1. • Base Program<br>• Alternate Base Program | • SLS Performance<br>• High $M_3$<br>• Increased $T_4$<br>• Efficiency/$\Delta P$<br>• Pattern Factor/Profile |
| 2. P-PFRT | • Altitude Performance<br>• Altitude Ignition/Stability<br>• Endurance/Reliability |
| 3. Low Emissions (Special Option) | • Idle Emissions (HC and CO)<br>• Sector Burning<br>• Impingement-Cooled Primary Zone<br>• Sector & Annular Tests |

Table XXIV. HP Turbine Component Tests - Subscale VCEE.

Scope

- Nozzle Cascade - Aeroperformance/Cold
  (Reduced Solidity)

- Nozzle Cascade - Heat Trans./Warm
  (Evaluate Cooling-Air Effects)

- Full-Size/Uncooled and Cooled-Air Turbine Tests

| | | |
|---|---|---|
| 1. | Base Program<br>Alternate Base Program | Not Included.<br>Design/Technology<br>Derived From<br>ATEGG/JTDE. |
| 2. | P-PFRT | • Cold Cascade and Full-Size Air Turbine Tests<br>• Aeroperformance Evaluation |

Table XXV. LP Turbine Component Tests - Subscale VCEE.

<u>Scope</u>

- Nozzle Cascade - Aeroperformance
  - Counterrotating Nozzle
  - Corotating Nozzle
  - Reduced Solidity

- Full-Size (F404) Uncooled - Air Turbine Tests
  - Counterrotating } Same Rotor
  - Corotating }

| | | |
|---|---|---|
| 1. | Base Program<br>Alternate Base Program | Not Included.<br>Design/Technology Derived From F404/JTDE |
| 2. | P-PFRT | • Cascade and Full-Size Air Turbine Tests<br>• Aeroperformance Development |

Table XXVI. Exhaust System Component Tests - Subscale VCEE.

### Scope

- Scale-Model Rear VABI Aero Tests (Augmentor Integration)
- Scale-Model Exhaust Nozzle Internal Aeroperformance (Continued Counterpart Installed Performance Test Program at Langley Assumed)
- Limited Scale-Model Thrust Reverser Aero Tests (To Define Reverser Integration Requirements)
- Augmentor Sector Flametunnel Tests

| | | |
|---|---|---|
| 1. | Base Program<br>Alternate Base Program | All Component Aeroperformance Programs |
| 2. | P-PFRT | Extended Augmentor Tests For Altitude Performance/ Nozzle Cooling Interaction And Endurance Development. |

Scale-Model Exhaust Nozzle Acoustic Tests (Table XXVII) will be conducted to evaluate wind-on/flight conditions and will incorporate improvements indicated from ongoing programs. Mechanical Suppressor alternatives will also be investigated.

Table XXVIII shows a comprehensive Control System development program, the major portion of which is the development and evaluation of a FADEC and its associated control system components. Each engine control system will also undergo a closed-loop bench test prior to installation.

The other component tests will include: (1) the development of a differential bearing for the counterrotating LP turbine, and (2) standard mechanical development tests such as airfoil frequency and fatigue, structural loading and vibration, and flow checks. It is assumed that a front block AST fan component test will be conducted as part of the ongoing NASA programs and will be authorized and funded separately.

Figure 23 shows the overall P-PFRT program schedule and shows the items included in the Base Program. Table XXIX shows the breakdown of engine test hours for the Base Program and the options leading to P-PFRT. This program was patterned after the successful YJ101 P-PFRT effort. Table XXX compares the two P-PFRT programs - YJ101 and subscale VCEE.

The engine test program is designed to use one core engine plus one complete engine if the program does not progress to P-PFRT, five complete engines if it does.

The program can be accomplished with one factory test facility, use of the Peebles site, and use of the NASA-Lewis and NASA-Ames facilities.

The core engine and Engine 002 are devoted to performance verification, engine systems investigations, and mechanical checkouts. Engine 003's mission is to evaluate altitude performance and acoustics with the aircraft inlet/nacelle and exhaust system configuration. Engines 004 and 005 will provide durability assurance and checkout of design modifications. Engine 006 is the Preliminary Pre-Flight Rating Test engine.

### 4.4.7 Flight Test Support Program

Figure 24 shows the Flight Test Support schedule. It assumes a one-year flight test effort conducted on one twin-engine aircraft. In accord with the NASA instructions, three new engines are provided (two flight and one spare) to the P-PFRT design. Nevertheless, a lower-cost alternative, utilizing refurbishment of factory test engines, should be evaluated. Provision is made for limited factory engine test support and for field engineering support.

Table XXXI breaks down the cost of the subscale VCEE effort into its two parts, the Base/P-PFRT program and the Flight Test Support option.

Table XXVII. Exhaust Nozzle Scale-Model Acoustic Tests.

Scope

- Extension of Current/Proposed Scale Model Follow-on Programs
- Wind-On/Flight Simulation Emphasis
- Aero/Acoustic Improvements to Basic Coannular Plug Nozzle
- Evaluation of Mechanical Suppressor Alternatives

| | | |
|---|---|---|
| 1. | Alternate Base Program | Reduced Scope<br>( ≈ 4 Models) |
| 2. | - Base Program<br>- P-PFRT | Normal Scope<br>(6 - 8 Models) |

Table XXVIII. Control System Component Tests - Subscale VCEE.

Scope

- FADEC/Hydromechanical Unit
  1. FADEC Circuit Laboratory Development
  2. Closed-Loop Simulation Bench Tests
  3. Environmental Tests
- Electrical System<br>Fuel System<br>Actuation/Hydraulic System } Design Assurance Development Tests
- Total System Closed-Loop Bench Tests
  1. Alternate Base Program
     - Modified JTDE/USN VCE Design
     - No FADEC Backup Control Functions Included
     - Use Remote (Test Cell) Electrical and Hydraulic Power
  2. Base Program
     - FADEC Altitude Capability
  3. P-PFRT Program
     - Includes Flight-Type Alternator and Self-Contained Hydraulic System Development
     - Includes FADEC Backup Function

All Phases - Utilize F404/Other Flight Design Actuation Where Applicable

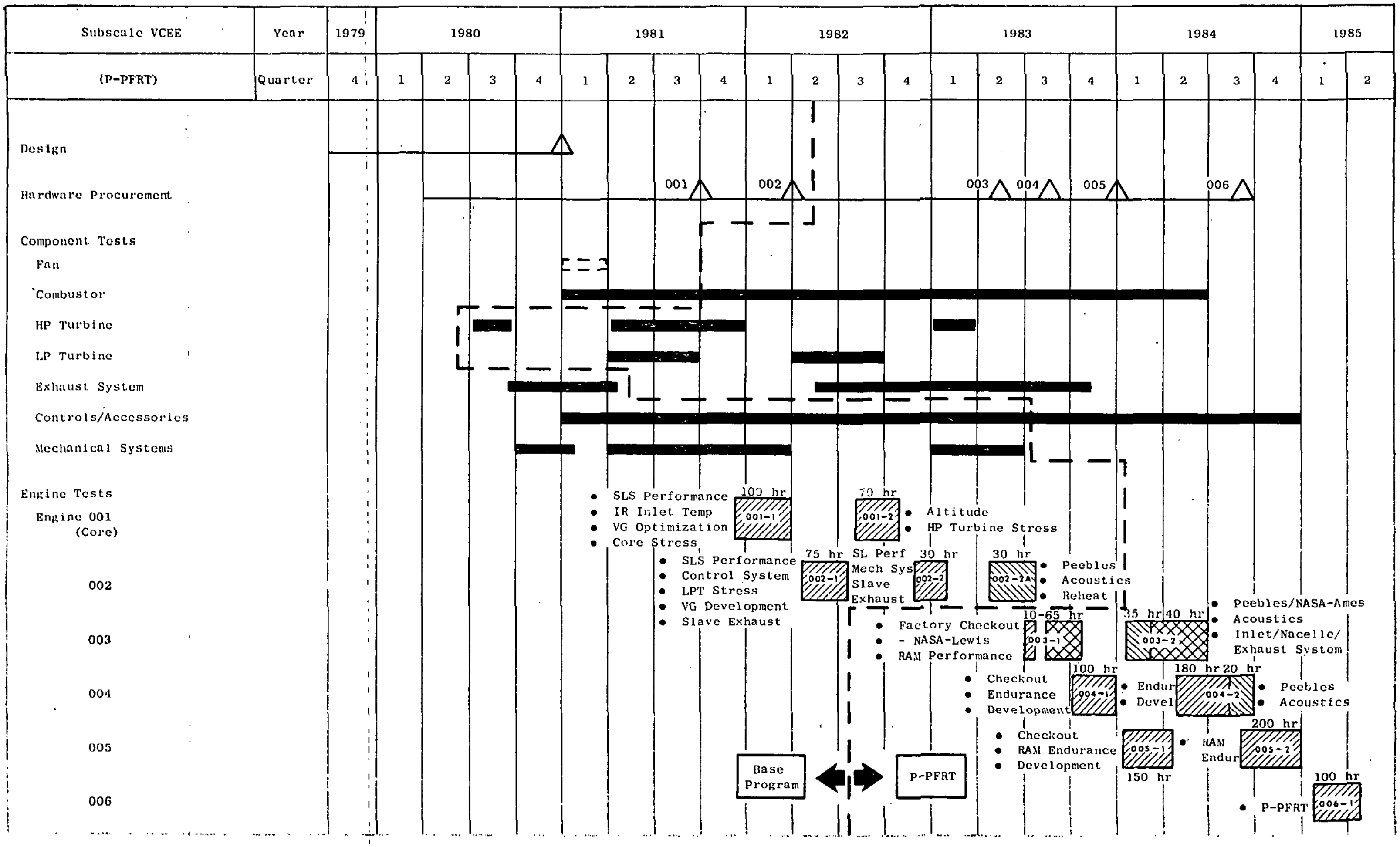


Figure 23. VCEE Program Schedule through P-PFRT Option.

Table XXIX. Subscale VCEE Test Program Through P-PFRT - Test Hour Summary.

| | Core | Engine | External Facility Tests |
|---|---|---|---|
| **Base Program** | | | |
| • Core Tests | 170 | | |
| • Engine | | | |
| - Lynn | | 105 | |
| - Peebles | | 30 | |
| **Option 1** | | | |
| Altitude Tests (Lewis) | | 10 | 65 |
| **Option 2** | | | |
| In-Flight Noise Tests | | | |
| - Peebles | | 35 | |
| - Ames | | | 40 |
| **Option 3** | | | |
| P-PFRT | | | |
| - Lynn | | 730 | |
| - Peebles | | 20 | |
| | 170 | 930 | 105 |

$$\underbrace{170 \quad 930 \quad 105}_{\text{1205 Hours}}$$

Table XXX. P-PFRT Program Comparison.

| | YJ101 | Subscale VCEE |
|---|---|---|
| **Test Hours** | | |
| Core Tests | 310 (4) | 170 (2) |
| Engine Tests | | |
| ● SLS Lynn | 834 | 845 |
| ● Peebles/Ames | 0 | 125 |
| ● Altitude | 116 | 65 |
| Total | 950 | 1035 |
| Total Program | 1260 | 1205 |
| **Engine Hardware Requirements** | | |
| Core | 1 | 1 |
| Engine | 5 | 5 |
| **Major Component Test Programs** | | |
| Fan | X | X |
| Combustor | X | X |
| HP Turbine | | X |
| LP Turbine | | X |
| Nozzle/Rev. Aero | | X |
| Acoustic Scale Model | | X |
| A/B | X | X |
| C & A | X | X |
| Bearing/Lube System | X | X |

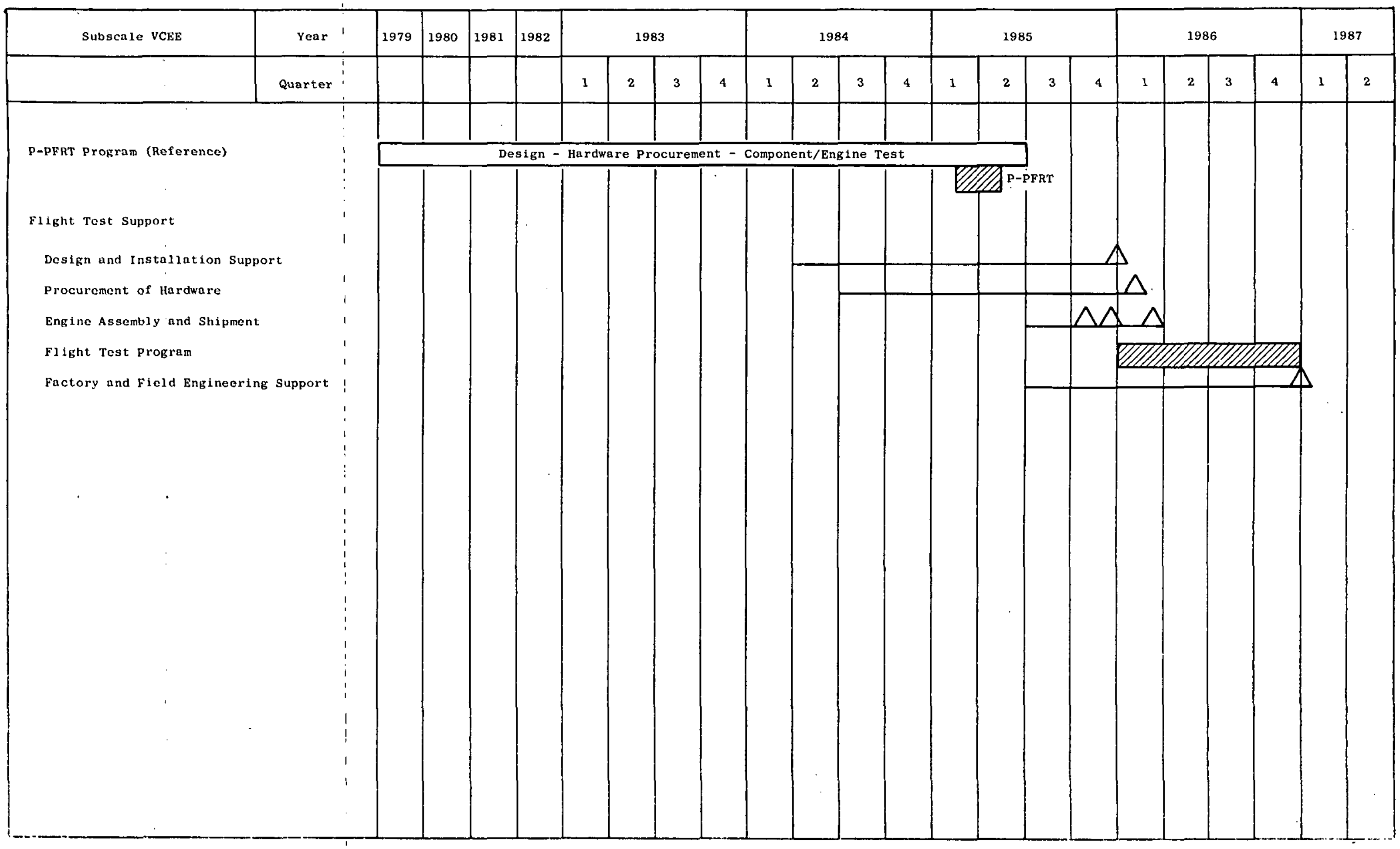


Figure 24. Flight Test Support Program.

Table XXXI. Subscale VCEE - Program Costs of Base/P-PFRT and Flight Test Support.

| | P-PFRT Program | Flight Test Support Program |
|---|---|---|
| | (Including Base) | (Option) |
| Fan Compressor | | |
| Aerodynamic Design | $K 1,104 | |
| Mechanical Design | 5,018 | |
| HP/LP Turbine | | |
| Aerodynamic Design | 2,876 | |
| Mechanical Design | 5,689 | |
| Component Test | 1,696 | |
| Combustion System | | |
| Aerodynamic Design | 108 | |
| Mechanical Design | 826 | |
| Component Test | 1,699 | |
| Controls & Accessories | | |
| Mechanical Design | 18,164 | |
| Component Test | 6,169 | 840 |
| Frames/Lube System/Configuration | | |
| Mechanical Design | 4,949 | |
| Component Test/Mock-Up | 620 | 200 |
| Bearings & Seals Design/Test | 541 | |
| RR VABI/Exhaust System | | |
| Aerodynamic Design | 3,655 | |
| Mechanical Design | 3,319 | |
| Acoustics Design | 2,609 | |
| Component Test | 3,028 | |
| Engineering Design Support | | 3,720 |
| Mechanics/Dynamics | 1,008 | |
| Life/R&M/Materials/Configuration Management | 3,024 | |
| Drafting/Drafting Supervision | 3,874 | |
| Cycle & Systems Analysis | 6,172 | |
| Plans & Programs | 768 | |
| Engine Assembly & Test | 10,160 | 2,550 |
| Inlet/Nacelle Design/Fabrication | 1,510 | |
| Hardware/Tools | 36,786 | 15,750 |
| Total MC | $126,270 K | $23,060 K |
| Total Selling Price | $164,150 K | $30,000 K |

## 4.5 AUGMENTED VCE TEST BED PROGRAMS

### 4.5.1 Introduction and Summary

The ongoing NASA YJ101 Component Test Program is aimed at providing and evaluating the basic design concepts for a variable cycle engine with an acoustic nozzle. Expanded engine test programs using the same basic hardware could permit an early evaluation of altitude performance and flight noise, and could identify areas needing improvement in advance of a subscale VCEE program. Similarly, initiation of additional component tests in key areas would enhance achievement of subscale VCEE technical objectives.

Table XXXII summarizes the proposed augmented Component Test Program options.

### 4.5.2 Augmented VCE Component Test Program Engine Usage Options

Figure 25 shows the schedule for two engine-test program options proposed to be initiated under the VCE Component Test Program at the end of the current contract program. These programs could be performed about two years before the VCEE plan. The proposed options include: (1) an Altitude Performance Test at NASA-Lewis, and (2) an Inlet/Exhaust Noise Test at NASA-Ames. The Altitude Test objectives are shown in Table XXXIII. Among these objectives is the modification of a FADEC control to permit altitude operation. Table XXXIV shows the estimated cost for this option.

Table XXXII. Augmented YJ101 VCE Component Test Program.

I. <u>Purpose</u>

1. To identify key problem areas and evaluate technical objectives well in advance of counterpart subscale VCEE program options

2. To verify the soundness of the subscale VCEE's design and to improve its performance

II. <u>Proposed Component Test Program Engine Test Options</u>

1. Altitude performance evaluation at NASA-Lewis, including modified FADEC control

2. Inlet and exhaust noise evaluation for VCE engine flight noise simulation

   - Using existing YJ101 inlet with modifications
   - Two-step test program
     - Static tests at Peebles
     - Low speed tests at Ames

III. <u>Proposed Component Rig/Model Test Programs</u>

1. Programs in process or currently proposed
   - 155-pps fan front block (this program is initiated under current contract auspices)
   - Scale-model acoustic nozzle follow-on (Fiscal '79 and '80)

2. Additional Component Development Test Programs
   - HP turbine cascade and air turbine tests
   - LP turbine cascade and air turbine tests, corotating and counterrotating
   - Combustor component tests for emission reduction (idle power CO and HC)
   - Augmentor flametunnel test to define VCEE configuration
   - Scale-model exhaust-nozzle/reverser aeroperformance tests
   - Bearing component tests for counterrotating shafts

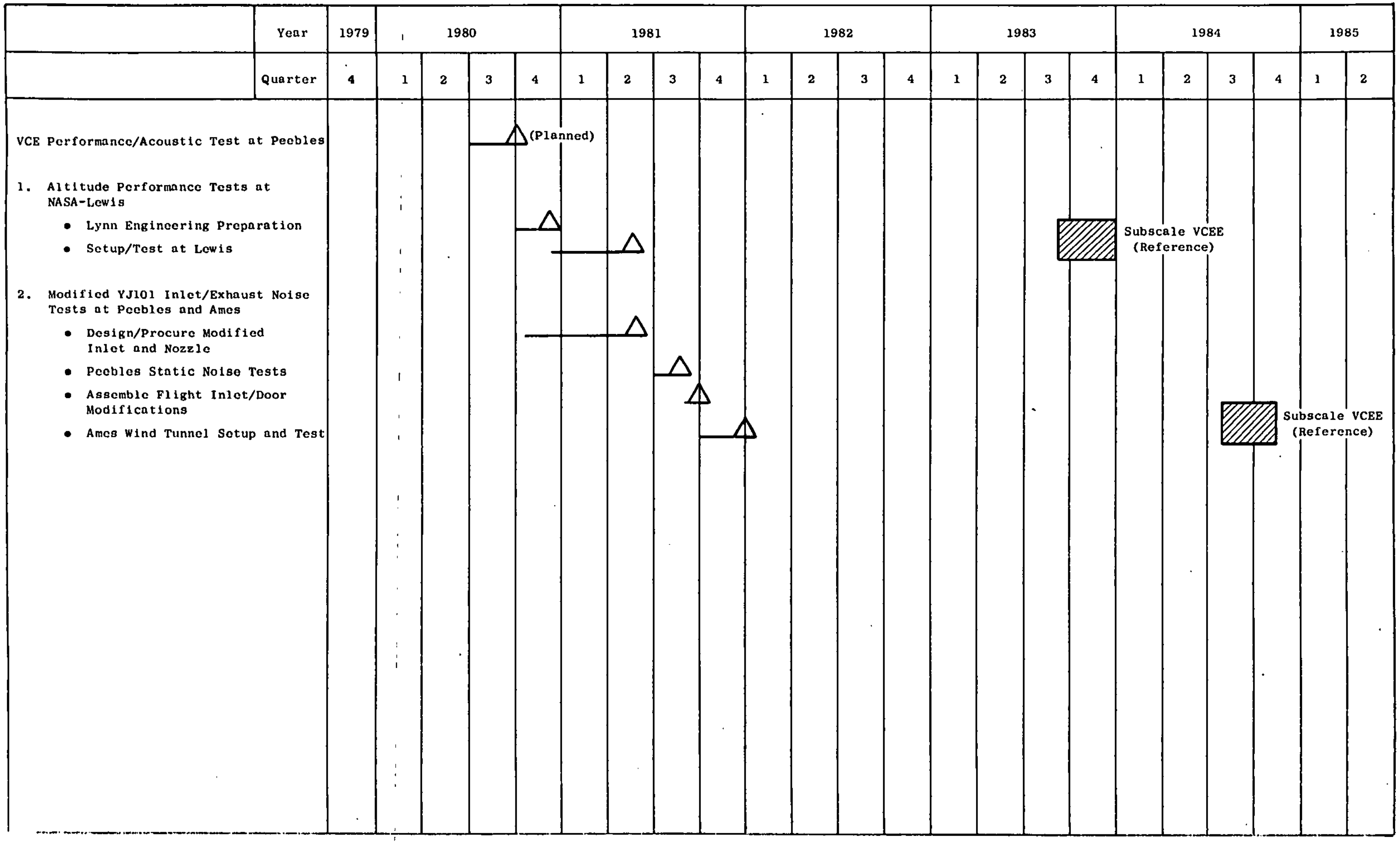


Figure 25. VCE Component Test Program Options.

## Table XXXIII. Augmented Component Test Program Engine - Tests in NASA Altutude Facility.

Principal Objectives

- Demonstrate VCE Engine Altitude Performance Characteristics at Subsonic Cruise
  - Demonstrate sfc at Part Power
  - Demonstrate Airflow Extension (Part-Power Airflow Holding)
  - Compare Altitude Results with SLS Results
- VCE Engine Performance at Typical Supersonic Accel Conditions
- - FADEC Control
  - Altitude Transient Performance
- Distortion Testing
  - Stall Limit Determination

Table XXXIV. Augmented Component Test Program Options, Altitude Performance Evaluation.

| | | | Then-Year Mfg. Cost, $K |
|---|---|---|---|
| Engineering Support | | | |
| Aeromechanics | | | 45 |
| Mechanical Design | | | 95 |
| Aerodynamic Design (Turbomachinery) | | | 50 |
| VABI/Exhaust | - | Aero | 120 |
| | - | Mechanical | 50 |
| | - | Rework/Fabrication | 130 |
| Cycle & Systems Analysis | | | 200 |
| Controls Design & Fabrication | | | 1,500 |
| Engine Hardware Refurbishment | | | 250 |
| Engine Assembly & Test | | | 310 |
| Program Management | | | 30 |
| | | Total MC | $2,780 K |
| | | Total Selling Price | $3,614 K |

Table XXXV describes the objectives for an Inlet/Exhaust Noise evaluation at the NASA-Ames facility. The Ames evaluation would follow a checkout and calibration at GE's Peebles facility. Table XXXVI presents the estimated cost for this option.

The primary benefits of conducting the Augmented Component Test Program options at NASA-Lewis and NASA-Ames are those of cost and time. The VCEE options can be elected only after the completion of a $76 million, four-year design and development program. Conducting these programs on the VCE Component Test Program engine will provide early in-flight simulated evaluations: (1) of present acoustic concepts and (2) of altitude engine performance characteristics. These evaluations will in turn help in two ways: in determining the direction for the ensuing program, and in implementing future design improvements.

The VCEE In-Flight noise evaluation is more costly than the VCE Component Test Program engine option mainly because it provides for a new inlet, a new nacelle, and the assembly and instrumentation of new engine components. Another reason it is more costly is that its engineering design test coverage and data analysis are associated with new rather than proven engine components. These include a new exhaust system and acoustic design. For the YJ101 VCE Component Test Program, it is proposed that an existing inlet be used, with modifications.

The Augmented Component Test Program engine requires significant effort on the engine control system for altitude operation, while the altitude capable control is already provided in the Base Program for the VCEE.

For both tests, the VCEE engines/hardware are available from the Base Program. But the Augmented VCE Component Test engine will require hardware refurbishment; these costs are included in the program, as shown in Table XXXVI.

### 4.5.3 Subscale VCEE Component Development Programs

During the course of the subscale VCEE design and development program, various components of the selected configuration will undergo component testing.

Should initiation of the subscale VCEE program be delayed, activity could begin meanwhile in some of the major technology areas, running design and performance tests on key components. Such tests would shorten the development cycle by letting any problems be identified, and perhaps solved, beforehand.

The recommended component programs, described in Figures 26 through 31, are comprised by the following:

Table XXXV. VCE Component Test Engine, Inlet/Exhaust Noise Evaluation.

Prime Concerns

I. Inlet Noise

1. Static Tests - Peebles
2. In-Flight Simulation - Ames
3. Test Variables at Simulated Flight Speeds and Power Settings
    - Effects of Throat Mach No.
    - Effects of Auxiliary/Blow-In Doors
    - Treatment
    - Angle of Attack

II. Exhaust Noise

1. Static Tests at Peebles
2. In-Flight Simulation at Ames
3. Test Variables
    - Coannular Nozzle/Selected Configuration
    - Effects of Mechanical Suppressor Addition
    - Correlation with Scale Model Wind-On Test Results
    - Test Results Will Confirm/Refine Full-Scale Predictions

Table XXXVI. Proposed Component Test Program Options, Inlet and Exhaust Noise Evaluation Cost Summary.

(Then-Year Mfg. Cost, $K)

| | | |
|---|---|---|
| <u>Engineering Support</u> | | |
| Mechanical Design | | 100 |
| Aerodynamic Design (Turbomachinery) | | 30 |
| VABI/Exhaust | - Aero | 180 |
| | - Mechanical | 40 |
| | - Acoustics | 540 |
| <u>Cycle & Systems Analysis</u> | | 125 |
| <u>Controls</u> | | 150 |
| <u>Engine Assembly and Test</u> | | 525 |
| <u>Program Management</u> | | 25 |
| <u>Inlet Design & Hardware</u> | | |
| Aero Design | | 155 |
| Mechanical Design | | 185 |
| Inlet Hardware/Modification | | 215 |
| | Total MC | $2,270 K |
| | Total Selling Price | $2,951 K |

#### 4.5.3.1 High-Pressure Turbine (Figure 26)

Cascade tests would be conducted to evaluate reduced vane solidity in combination with cooling effects. The air turbine test rig would be run uncooled to establish the aerodynamic performance followed by a fully cooled test to establish the cooling effects. This program will benefit by utilization of existing F404 air turbine test hardware.

#### 4.5.3.2 Low-Pressure Turbine (Figure 27)

Tests similar to these run on the HP turbine would be conducted to evaluate configuration effects. Additionally, the variable-area turbine nozzle and counterrotating effects will be evaluated.

#### 4.5.3.3 Combustor (Figure 28)

Sector and full-annular rig tests would be conducted to evaluate idle emission reduction design approaches such as sector burning at idle.

#### 4.5.3.4 Exhaust System (Figure 29)

Scale-model tests would be conducted on the rear VABI (for augmentor integration), the exhaust nozzle (for internal aero performance) and a thrust reverser (to define reverser aero integration requirements). Augmentor flametunnel teste would be run to evaluate flameholder design concepts that would be integrated with the rear VABI/coannular nozzle flowpath.

#### 4.5.3.5 Exhaust Nozzle (Figure 30)

Scale-model acoustic tests would be conducted to evaluate simulated flight conditions, aero/acoustic improvements, and different mechanical suppressor configurations.

#### 4.5.3.6 Bearings and Seals (Figure 31)

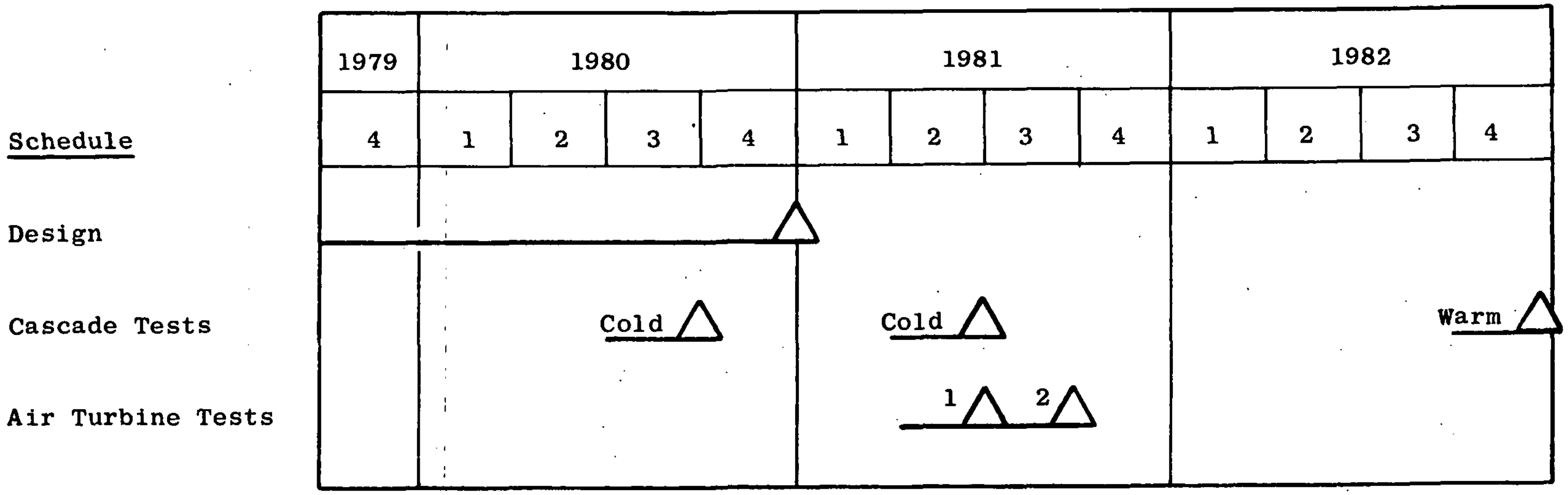
The counterrotating LP turbine requires a new bearing/seal design beyond the current state-of-the-art. Before the counterrotating LP turbine can be adopted, development tests must be conducted early in the overall program to ensure that a satisfactory bearing/seal design can be achieved.

### 4.5.4 Combined Augmented Component Test Program Option

Table XXXVII cost summarizes the Augmented Component Test Program Options that have been treated individually in previous sections. The program would provide a low-cost beginning to the VCEE Program, and could provide important and timely answers to some of the technology questions that the VCEE program would raise.

## High Pressure Turbine

- Low-Solidity Stators
- Advanced Aerodesign



**Cost**

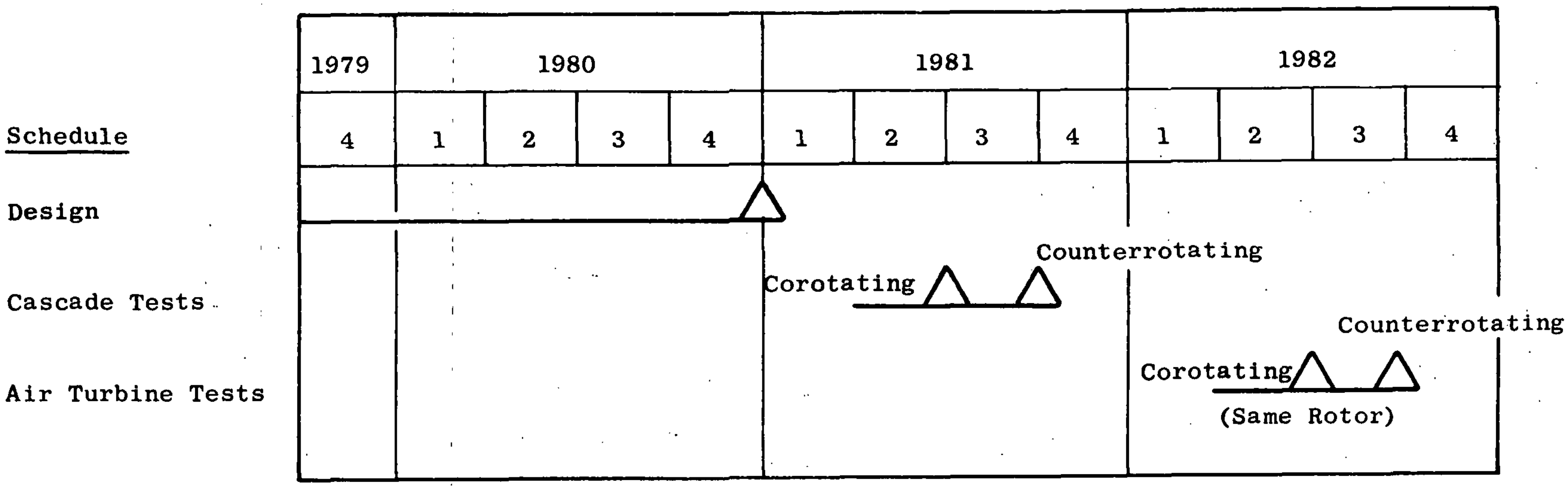
| | |
|---|---|
| Engineering | $830,000 |
| Material | 525,000* |
| Test | 180,000 |
| Total | $1,535,000 |
| Total Selling Price | 1,995,000 |

* Use Existing F404 Air Turbine Wheels/Rig

Figure 26. Component Technology Programs - HP Turbine.

**Low Pressure Turbine**

- Counterrotating Versus Corotating
- Advanced Aerodesign
- Low-Solidity Stator



**Cost**

| | |
|---|---|
| Engineering | $860,000 |
| Material | 385,000* |
| Test | 180,000 |
| Total | $1,425,000 |
| Total Selling Price | 1,855,000 |

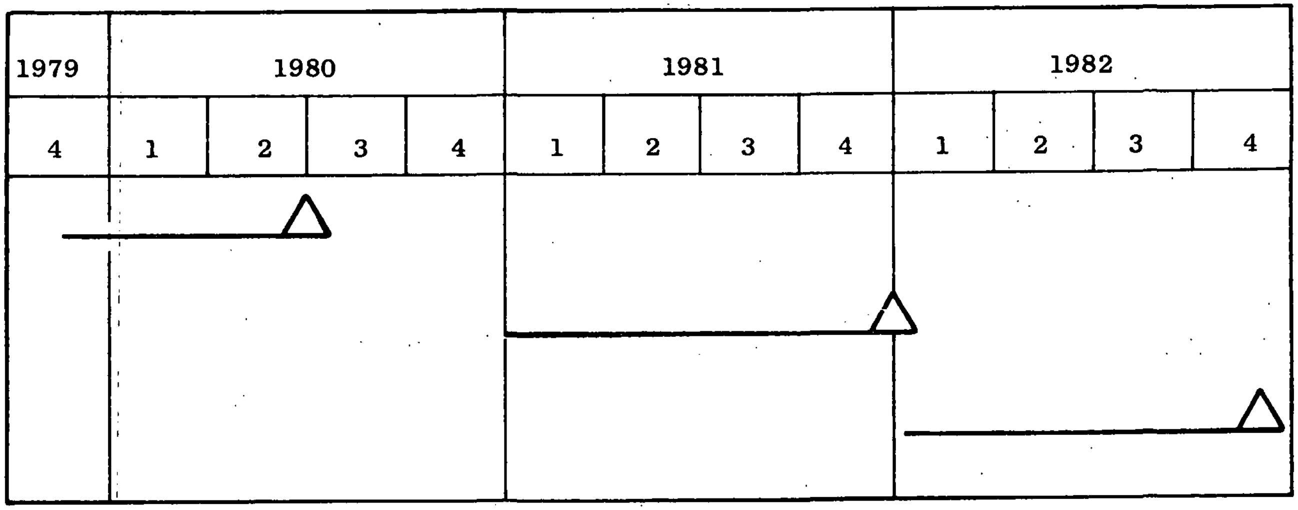
* Use Existing F404 Air Turbine Wheels/Rig

Figure 27. Component Technology Programs - LP Turbine.

**Combustor**

- Reduced Idle Emissions
- Improved Performance/Life

**Schedule**



**Cost**

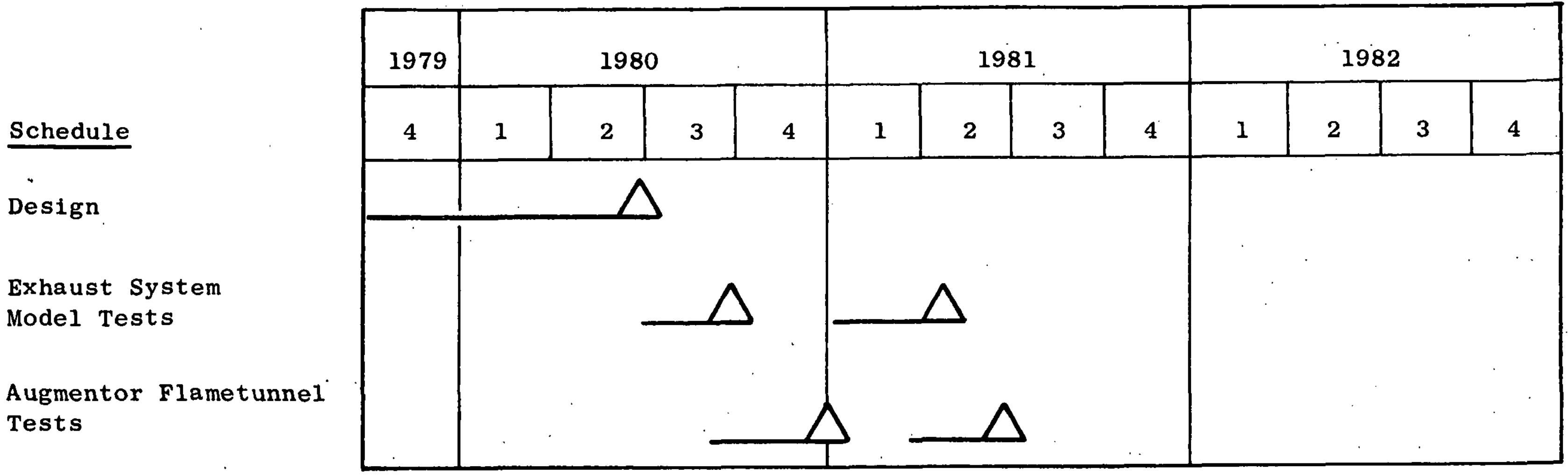
| | |
|---|---|
| Engineering | $400,000 |
| Material | 160,000 |
| Test | 400,000 |
| Total | $960,000 |
| Total Selling Price | $1,250,000 |

Figure 28. Component Technology Programs - Combustor.

Exhaust System

- Rear VABI/Augmentor Integration
- Exhaust Nozzle Aeroperformance
- Thrust Reverser Aeroperformance
- Augmentor Sector Flametunnel

} Scale-Model Tests

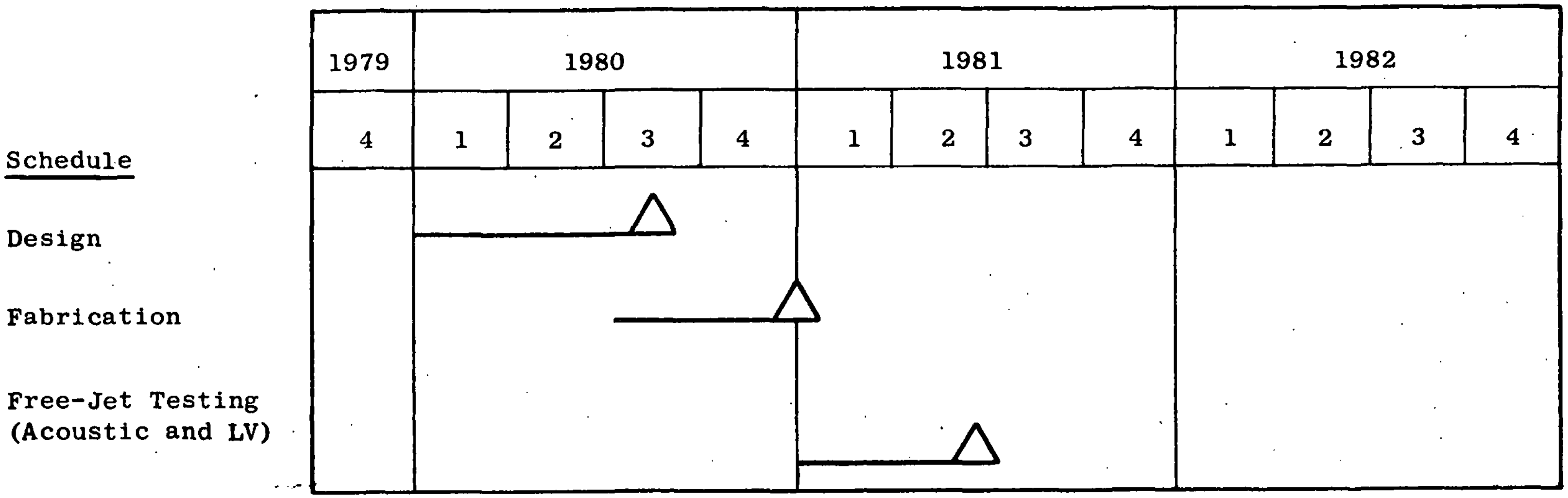


| Costs | Exhaust System | Flametunnel |
|---|---|---|
| Engineering | $1,140,000 | $220,000 |
| Material/OV Test | 555,000 | 120,000 |
| Test | - | 130,000 |
| Total | $1,695,000 | $470,000 |
| Total Selling Price | $2,200,000 | $610,000 |

Figure 29. Component Technology Programs - Exhaust Nozzle.

Exhaust Nozzle Acoustics (Scale Model)

- Wind-on/Flight Simulation
- Aero/Acoustic Improvement
- Suppressor Alternatives



Cost

| | | |
|---|---|---|
| Engineering | | $500,000 |
| Material | | 200,000 |
| Test | | 200,000 |
| | Total | $900,000 |
| Total Selling Price | | $1,170,000 |

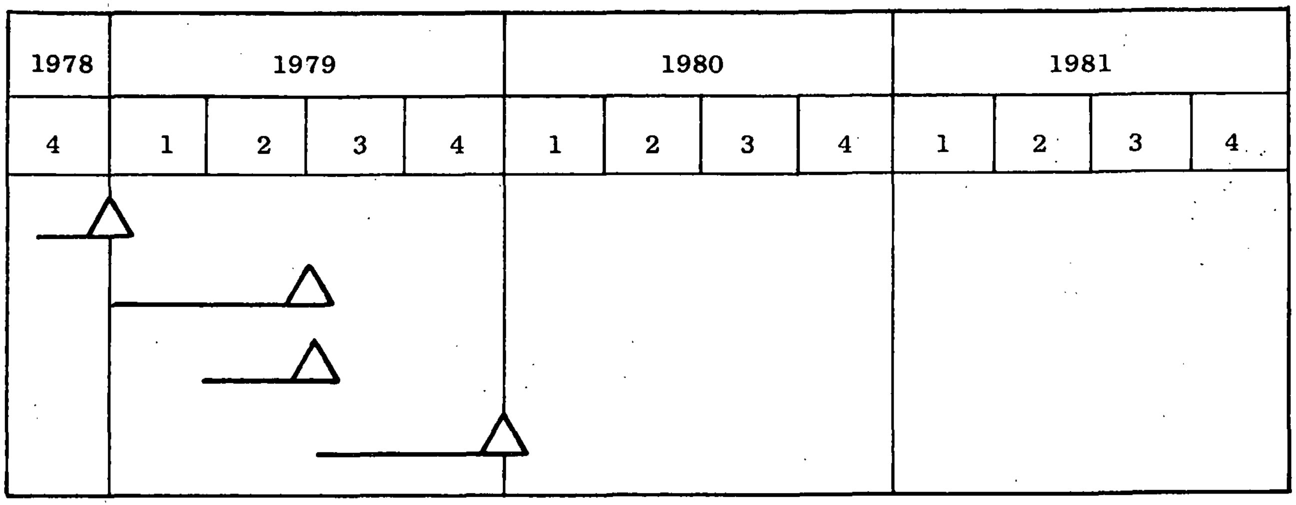
Note: This program is dependent on the acceptance of a shorter range (fiscal year 1979-80) follow-on scale model program currently proposed.

Figure 30. Component Technology Programs - Exhaust Nozzle Acoustics.

**Bearings and Seals**

- Counterrotating Tests
  - Bearings
  - Seals

**Schedule**



**Cost**

| | |
|---|---|
| Engineering | $30,000 |
| Hardware/Material | 100,000 |
| Test | 55,000 |
| Total | $185,000 |
| Total Selling Price | $240,000 |

Note: This program should start in fiscal year 1979-80 to provide data for VCEE design selection by 1/1980.

Figure 31. Component Technology Programs - Bearings and Seals.

Table XXXVII. Cost Summary of Augmented Component Test Programs and VCEE Component Technology Programs.

| | Then-Year Mfg. Cost $K |
|---|---|
| Engineering Design & Support | |
| • Aeromechanics (Basic Engine) | 135 |
| • Mechanical Design (Basic Engine) | 350 |
| • Aerodynamic Design (Basic Engine) | 1855 |
| • Controls Design & Fabrication | 1650 |
| • Inlet/VABI/Exhaust System | |
| - Aerodynamic Design | 1350 |
| - Mechanical Design | 740 |
| - Acoustics Design | 1040 |
| • Cycle & Systems Analysis | 425 |
| Component Rig Hardware | 2045 |
| Engine Test Hardware | 595 |
| Component Rig Assembly & Testing | 1145 |
| Engine Assembly & Testing | 835 |
| Program Management | 100 |
| Total | $12,265 K |
| Total Selling Price | $15,945 K |

## 5.0 CONCLUSIONS

An F404 core engine design with one aft compressor stage removed for improved supersonic cruise performance was selected as the basic building block for a Variable Cycle Experimental Engine Program.

The F404 subscale VCE demonstrator is a logical, cost-effective follow-on to the NASA Supersonic Cruise Component Test Program. It would integrate an oversize front block fan, planned for rig-testing under the Component Test Program, with a high-temperature core engine modified to simulate, at reduced size, the projected double-bypass product VCE. All features except for high-temperature materials technology would be similar to those found in the product line VCE. Other VCE hardware (second-block fan stage, VABI's, and coannular acoustic plug nozzle) would be similar to that used in earlier NASA VCE tests which used a YJ101 core engine.

The VCEE program would provide technological readiness for a full-scale engine development program that matches the projected schedules for an advanced-technology SST.

The F404 subscale VCE demonstrator core engine can also serve as a building block for flight demonstration, in a small flight research aircraft, of both military and commercial supersonic cruise vehicles. This aircraft would also help provide technology readiness in aerodynamics, structures, propulsion integration, stability and control, and other related disciplines.

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