VCE TEST BED ENGINE FOR SUPERSONIC CRUISE RESEARCH

J. W. Vdoviak and J. A. Ebacher
General Electric Company

General Electric initiated a broad investigative variable cycle demonstrator engine test program in 1976, utilizing the YJ101 engine as the basic vehicle. This program is aimed at evaluating variable cycle concepts applicable to a supersonic, mixed mission propulsion system which would combine the merits of a turbofan at subsonic operating conditions with those of a turbojet for supersonic operating conditions. Over the last four year period five sequential VCE demonstrator tests have been accomplished under combined U.S. Air Force, U.S. Navy, and NASA auspices in a uniquely cooperative and complementary test program. This test program is illustrated in the attached Figure 1. By way of background, the first USAF Single Bypass Test investigated the effects of a variable rear mixer. This was followed by the first split fan/double bypass VCE test which was the USAF 1 X 2. (1 X 2 refers to the number of fan stages in the forward and rear fan blocks respectively, i.e., 1 stage front fan block and 2 stage rear fan block.) A Navy sponsored 2 X 1 double bypass VCE demonstrator test was evaluated next. This combined double bypass with a variable area low pressure turbine nozzle (VATN), a product type rear VABI (Variable Area Bypass Injector) or mixer and an augmentor. All of these test vehicles employed separate bypass ducting for the front and rear fan block flow and considerable exhaust system complexity. The NASA Forward VABI VCE test combined the features of a split fan, variable area LP turbine nozzle, and rear variable area mixer with a concept to substantially simplify the bypass ducting and exhaust system of a double bypass VCE engine. This is referred to as a Front Variable Area Bypass Injector or Front VABI. The Front VABI allows both single and double bypass operation with a common bypass duct and single exit exhaust nozzle. Upon successful demonstration of this concept, a unique co-annular exhaust nozzle was tested with the same basic gas generator in a combined performance and acoustic test at an external test facility. The results of this co-annular nozzle acoustic testing is the subject of another presentation later in this conference. The NASA Acoustic Test VCE engine configuration incorporating all of these features, which was tested successfully in late '78, is illustrated in Figure 2. The top view shows a typical low noise take-off operating mode (double bypass), and the bottom view shows the high specific thrust (single bypass) operating mode. In excess of 300 test hours have been accumulated in this step-wise VCE Test Program to date. The basic YJ101 has proven to be a highly versatile and dependable test vehicle, adaptable to a broad range of test requirements.

Figure 3 summarizes the technical payoffs or advantages that have been demonstrated with the various variable cycle features. Double bypass allows bypass ratio increase for specific fuel consumption (SFC) improvement at part power subsonic cruise operating conditions. Beyond the SFC gain, there is the prospect of providing air flow modulation at constant thrust to potentially simplify and/or improve the performance of inlet and afterbody configurations. For a future supersonic transport application double bypass provides for low noise at take-off by virtue of lower specific thrust/lower exhaust velocity. The Rear VABI (variable mixer) allows fan operating line control for thrust and SFC gain and bypass flow extension. The Rear VABI concept appears applicable to Military requirements such as Advanced F404 and F101 DFE, and is being further pursued under new, recently initiated USN and USAF auspices. The Variable Area Low Pressure Turbine Nozzle (VATN) provides for rotor speed ratio and core stall margin control. It can also provide reducd compressor exit temperature at constant T_4 - important to low level - high density - high flight speed requirements. As previously described, the benefits of the forward or Front VABI are mainly for engine simplification with single and double bypass capability with respect to the bypass ducting and the exhaust nozzle. The acoustic nozzle is a unique subcomponent applicable to low noise requirements. Early next year the same basic engine used in the recent NASA VCE tests will be tested with a Full Authority Digital Electronic Control (FADEC) under U.S. Navy auspices as part of the continued VCE test sequence. Such a control allows full utilization of variable cycle flexibility and operating benefits.

This summary provides a backdrop for the next NASA program referred to as the Test Bed Engine Program. A description of this program is the principal purpose for this presentation. The concept of the Core Driven (aft fan block) Fan Stage is a logical benefit for variable cycle propulsion engines, in fact, it has broad applicability to any low pressure ratio, mixed mission requirement including single bypass (only) engine arrangements. The Core Drive Concept is illustrated in Figure 4. In the simplest terms this puts the second block fan stage of a split fan, double bypass VCE engine on the high pressure core spool. The high pressure compressor is mechanically attached to the aft fan block through a rotor coupling. The prior VCE demonstrators described earlier evaluated several variations of split fans, but all were driven by the low pressure/LP turbine shaft. The core drive arrangement is integrated with a forward VABI to allow high flow/double bypass operation or high specific thrust/single bypass operation. This is accomplished by geometric variation of the Forward VABI valving in conjunction with the Variable Inlet Guide Vane of the core driven fan stage. The variable inlet guide vane modulates the second block fan air flow over a relatively broad range and is nominally open in the single (low bypass) flow condition and substantially closed for the double (high bypass) flow condition. Under double bypass operating conditions, a relatively small portion of the total (increased) bypass flow is handled by the inner rear bypass duct and most of the flow is discharged forward of the core driven fan stage into the outer bypass duct. In the single bypass operating mode the aft fan block flow is matched to the front block by rotor speed ratio and to the high pressure compressor by the inner bypass duct and high pressure inlet guide vane scheduling, respectively.

The unique technical benefits or payoffs of the core driven concept are summarized in Figure 5. It allows a redistribution of compression system work so that an oversized front block fan can be driven with a single stage low pressure turbine. This has been adopted for future SCR/VCE configurations for reduced take-off noise, but it also provides further reductions in subsonic SFC. A 20% increase in front block fan flow is planned for future NASA VCE test engines and has also been incorporated into the SCR product engine studies. The corresponding increase in compression work with the rear block fan stage on the high pressure spool provides a higher energy extraction in the high pressure turbine. This has two benefits: It reduces the high pressure turbine bucket metal temperature, hence reduces chargeable cooling air requirements and it also reduces the inlet temperature to the low pressure turbine, thereby also reducing the LPT cooling requirements as well. In essence, this turbine work re-arrangement allows a better utilization of increased turbine temperature technology with reduced associated cooling penalties.

Additionally, the core driven principle allows split fan flow modulation using rotor speed variation in addition to variable stator manipulation. Higher rear block compression efficiencies are projected by using the speed ratio flexibility.

Typical part power (subsonic) SFC expected improvements are shown in Figure 6. This graph displays SFC as a function of air flow. Both benefits of double bypass operation are depicted, SFC reduction and air flow extension. With reference to the single bypass SFC characteristic, an improvement in air flow of 25% at the same SFC, or a reduction in SFC of 5.3% at a flow increase of 9.6% is expected. The core drive SFC characteristic is better than the LP turbine driven fan characteristic by virtue of the improved aft fan block aerodynamic performance and turbine loading characteristics.

The core driven fan aerodynamic characteristics are relatively conservative and are defined in Figure 7. The selected design has a stage pressure ratio of 1.37 at a tip speed of 381 m/s (1251 fps) at relatively modest levels of flow per unit of annulus area. The unique aspect of this compression stage lies in the broad swing in inlet guide vane variation for the rear block flow modulation which accompanies transition from single to double bypass operation. This is further illustrated in Figure 8 where several of the key and widely divergent operating modes are described. It is noted that the transition in operating mode essentially halves the inner bypass ratio. The inlet guide vane closure with double bypass operation brings about a very large swing in fan rotor outlet air angle; in excess of 40 degrees for that portion of the flow which exits through the inner bypass duct. The corresponding flow angle in the high pressure compressor inlet guide vane varies to a smaller degree because of the designed acceleration of the air flow in that path along with the high pressure matching. Furthermore, the high pressure compressor incorporates a variable inlet guide vane to handle the inlet swirl variation.

To accommodate this exit swirl problem, a unique configuration of blading has been devised. This is shown in Figure 9, which is a flow path illustration of the Core Driven Fan Stage.

The current two stage fan front block exit transitions through a structural frame into both the outer bypass and core driven stage inlet. A selector valve, made up of individual flaps positioned between the struts, is actuated closed as shown for single bypass operation and is opened for double bypass operation. The core driven stage has a flap type IGV with a fixed forward portion and movable aft portion for broad variation capability. Downstream of the low aspect ratio rotor a part span delta vane is positioned to straighten the flow into the inner bypass duct. A delta shaped part span airfoil has been selected based on relatively broad aircraft wing experience which shows that delta wings have higher angle of attack capability than conventional wings. The fixed exit guide vanes in the inner bypass duct complete the flow straightening upstream of the

VABI modulating valve. It is planned to test the beneficial effects of the delta exit guide vane in the initial core test on a comparative basis - i.e., with the vanes installed and removed.

The planned NASA Test Bed Engine Program will be conducted in two steps. First, the core driven stage will be coupled with the core engine to evaluate the aerodynamic performance of this stage and the matching with the high pressure compressor. Performance mapping including individual variability of the two inlet guide vane systems as well as the high pressure compressor stators is available to optimize the performance and compressor variable stator schedules. This initial test setup is shown in Figure 10. The core test vehicle will be tested in the Lynn engine ram test facility which allows simulation of the front block fan exit pressure and temperature. The front VABI selector and modulating valves are integrated with the core testing to provide initial evaluation of those Test Bed features as well. For this testing the modulating valve serves as the fan stage throttle valve. This testing is planned to be accomplished in the first half of 1980. In this phase the additive effects of the delta exit guide vanes will be tested. The core test phase will result in the selected compressor geometry for complete engine testing.

The addition of the low pressure rotor system, including the front block fan, and low pressure turbine with VATN (Variable Area Turbine Nozzle) to the afore-defined core vehicle will provide the complete Test Bed Engine shown in Figure 11. The co-annular nozzle exhaust system planned for the Test Bed Engine is a modification of the design tested earlier, with the addition of a radial chute type of noise suppressor to further reduce the take-off noise levels. A more detailed description of the suppressor is available by reference to Figure 12, which is a perspective drawing of the radial chute suppressor integrated with the co-annular nozzle. The suppressor will be tested in a fixed geometry arrangement, however, the chutes would be retractable into the plug in a product implementation.

In summary, the NASA Test Bed Engine Program is a logical extension of the VCE technology previously demonstrated on the YJ101 test vehicle. Some attractive test options beyond the described and currently planned Test Bed Engine tests are available as potential additive test phases and may be implemented later.

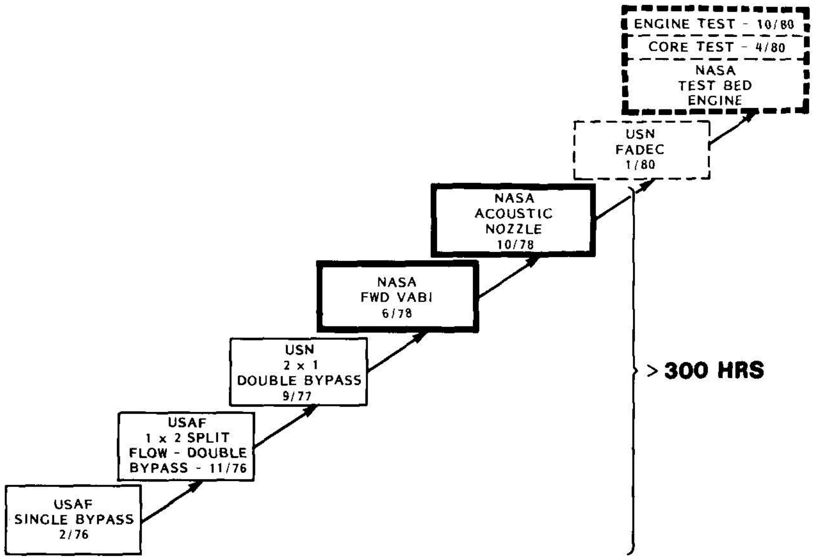

Figure 1.- YJ101 VCE concept demonstrators - test summary.

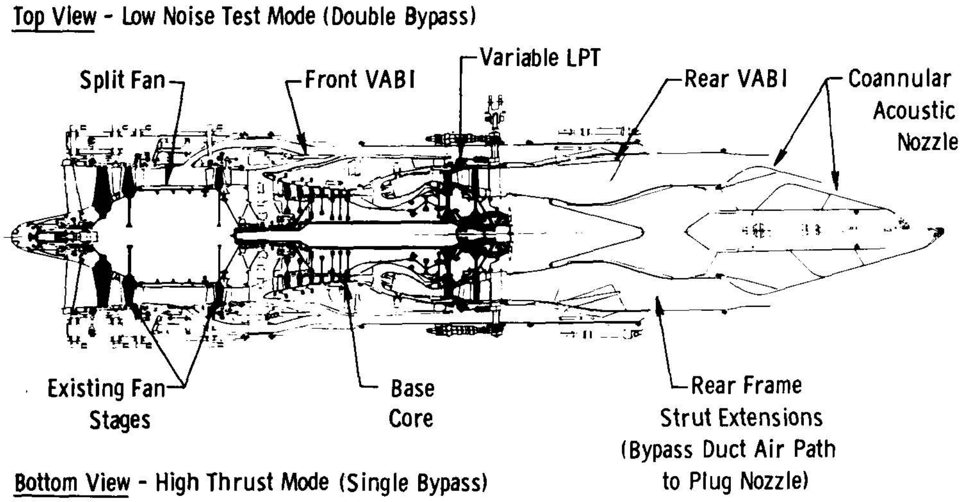

Figure 2.- NASA AST acoustic test VCE - initial double bypass VCE noise test configuration.

DOUBLE BYPASS	• PART POWER SFC GAIN (5%) • AIR FLOW EXTENSION AT CONSTANT F_N • LOW NOISE/AST
REAR VABI (VARIABLE MIXER)	• FAN OPERATING LINE CONTROL (THRUST AND SFC GAIN) • BYPASS FLOW EXTENSION
LPT VATN (VARIABLE AREA TURBINE NOZZLE)	• CONTROL OF ROTOR SPEED RATIOS • T_3 CONTROL AT CONSTANT T_4 • CORE STALL MARGIN
FORWARD VABI	• SINGLE EXIT EXHAUST NOZZLE FOR DOUBLE BYPASS • SIMPLIFIED BYPASS DUCTING
ACOUSTIC NOZZLE	• REDUCED SIDELINE NOISE (~ 5 PndB)

Figure 3.- Demonstrated VCE technical payoffs.

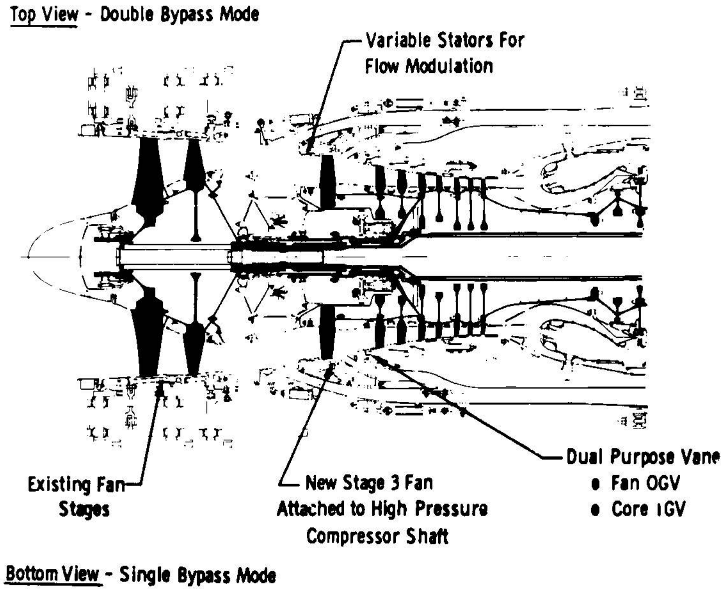

Figure 4.- NASA core driven fan stage.

- ALLOWS OVERSIZE FRONT BLOCK FAN WITH SINGLE STAGE LP TURBINE.
- HIGHER HPT ENERGY EXTRACTION.
  - LOWER BUCKET METAL TEMPERATURE WITH INCREASED T_4.
- LOWER LPT INLET TEMPERATURE.
  - REDUCED COOLING REQUIREMENTS.
- ROTOR SPEED FLEXIBILITY.
  - FLOW MODULATION

BROAD APPLICABILITY FOR MIXED MISSION/LOW CORE PRESSURE RATIO SYSTEMS.

Figure 5.- Core driven third stage technical payoffs.

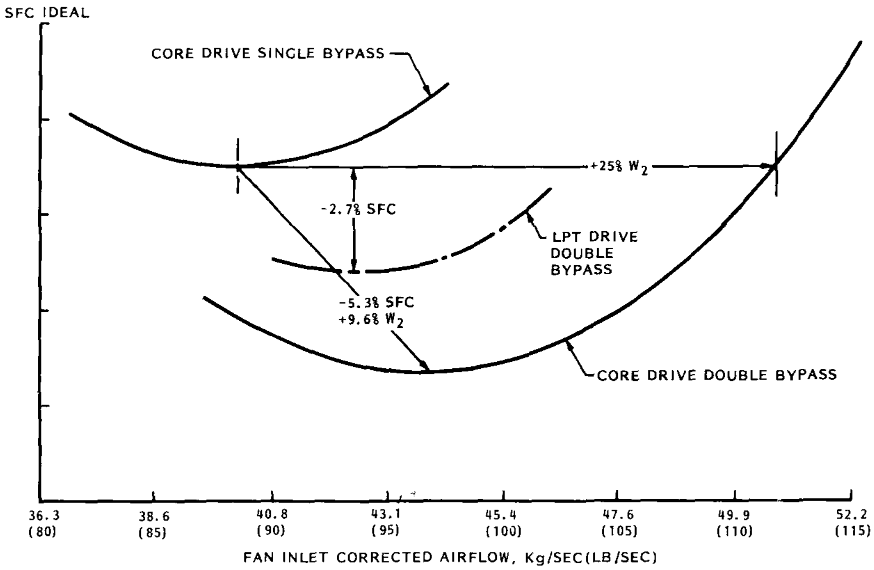

Figure 6.- Typical VCE SFC/airflow characteristics (Part Power ~50% F_N).

STAGE PRESSURE RATIO -	1.37
CORRECTED TIP SPEED M/SEC (FT/SEC) -	381 (1251)
INLET RADIUS RATIO -	.69
CORRECTED FLOW/ANNULUS AREA -	36
ROTOR ASPECT RATIO -	1.4
IGV VARIATION -	SINGLE BYPASS - NOM./OPEN DOUBLE BYPASS - 40° CLOSED

Figure 7.- Core driven fan stage - aerodynamic description.

SIMULATED FLIGHT CONDITION	HIGH SPECIFIC THRUST	TAKEOFF/ LOW NOISE	SS CRUISE
OPERATING MODE (BYPASS)	SINGLE	DOUBLE	SINGLE
CDFS % $N\sqrt{\Theta}$	100	96.8	94.3
INNER BYPASS RATIO	.45	.23	.66
FLOW ANGLE INTO BYPASS OGV	37	69	27
		(Δ42°)	
FLOW ANGLE INTO CORE IGV	41	50	46

Figure 8.- Core driven fan stage - operating conditions.

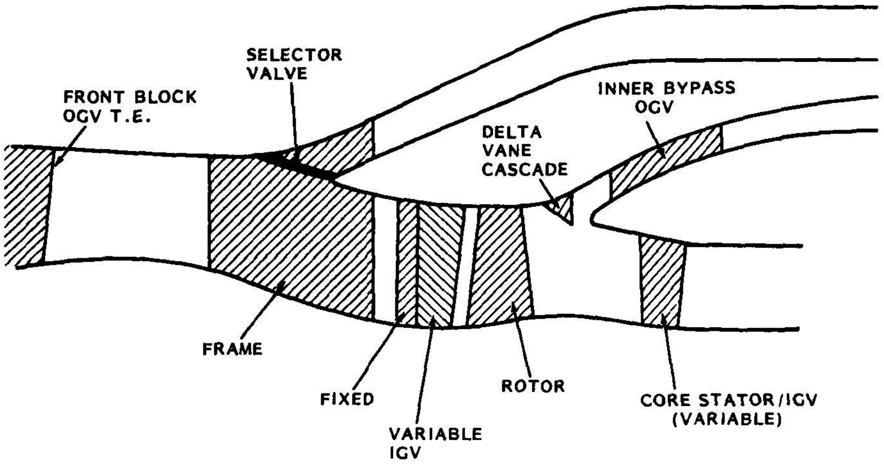

Figure 9.- Core driven fan stage flowpath - test bed engine.

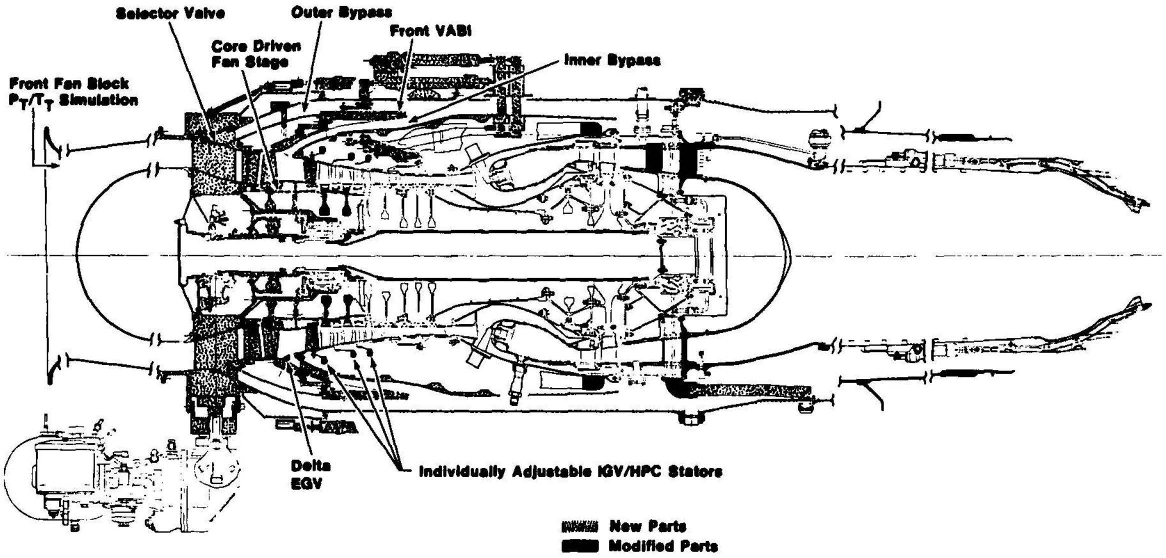

Figure 10.- Core test configuration - VCE test bed engine.

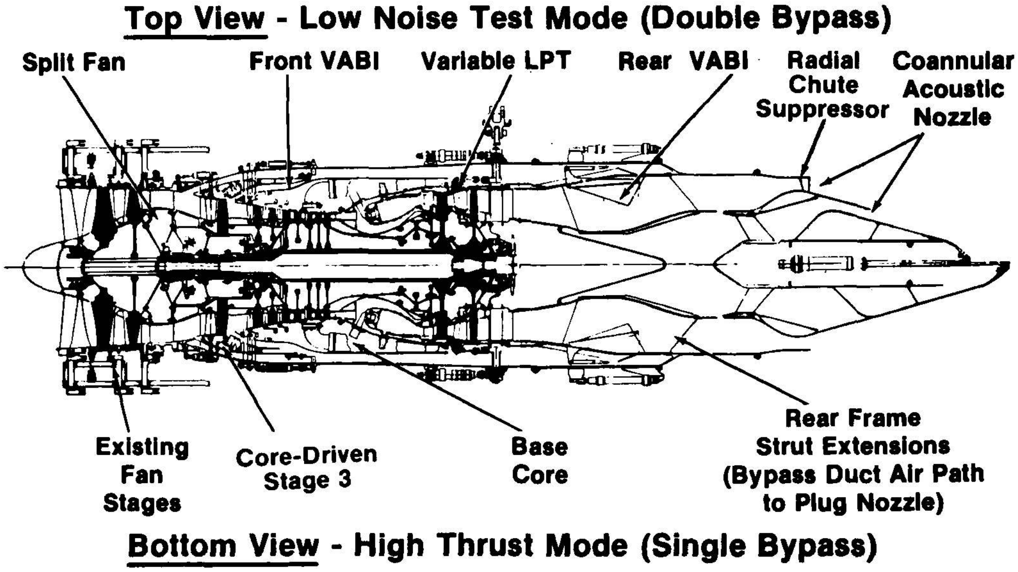

Figure 11.- NASA AST test bed VCE - core-driven 3rd stage configuration.

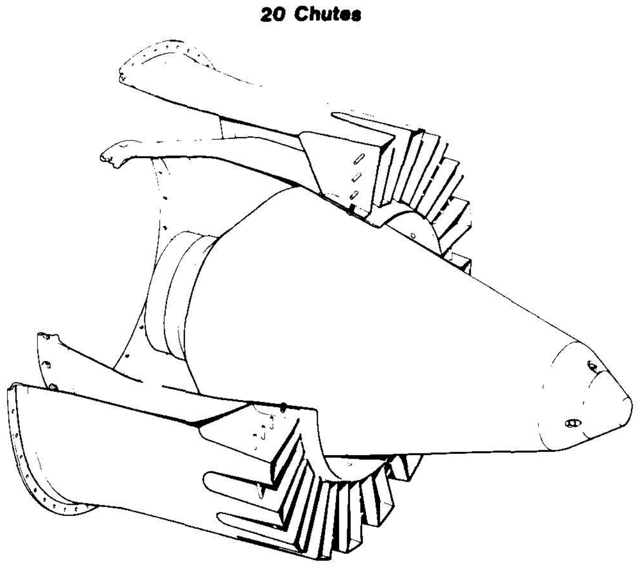

Figure 12.- Coannular nozzle suppressor - test bed engine.