



**FIRST ANNUAL HIGH-SPEED RESEARCH WORKSHOP
WILLIAMSBURG, VIRGINIA**

HSCT NOISE REDUCTION TECHNOLOGY DEVELOPMENT AT GE AIRCRAFT ENGINES

**MUNI MAJJIGI
MAY 15, 1991**

N94- 33466

HSCT EXHAUST NOZZLE DESIGN APPROACHES - GEAE AND P & W

GEAE AND P&W ARE EVALUATING HIGH FLOW EJECTOR-SUPPRESSOR-MIXER NOZZLES

($\frac{W_S}{W_P} = 0.6$ AND 1.2) AS A MEANS OF OBTAINING 16-20 EPNdB SUPPRESSION

RELATIVE A SIMPLE CONIC NOZZLE TO ACHIEVE FAR 36-STAGE 3 NOISE LEVELS.

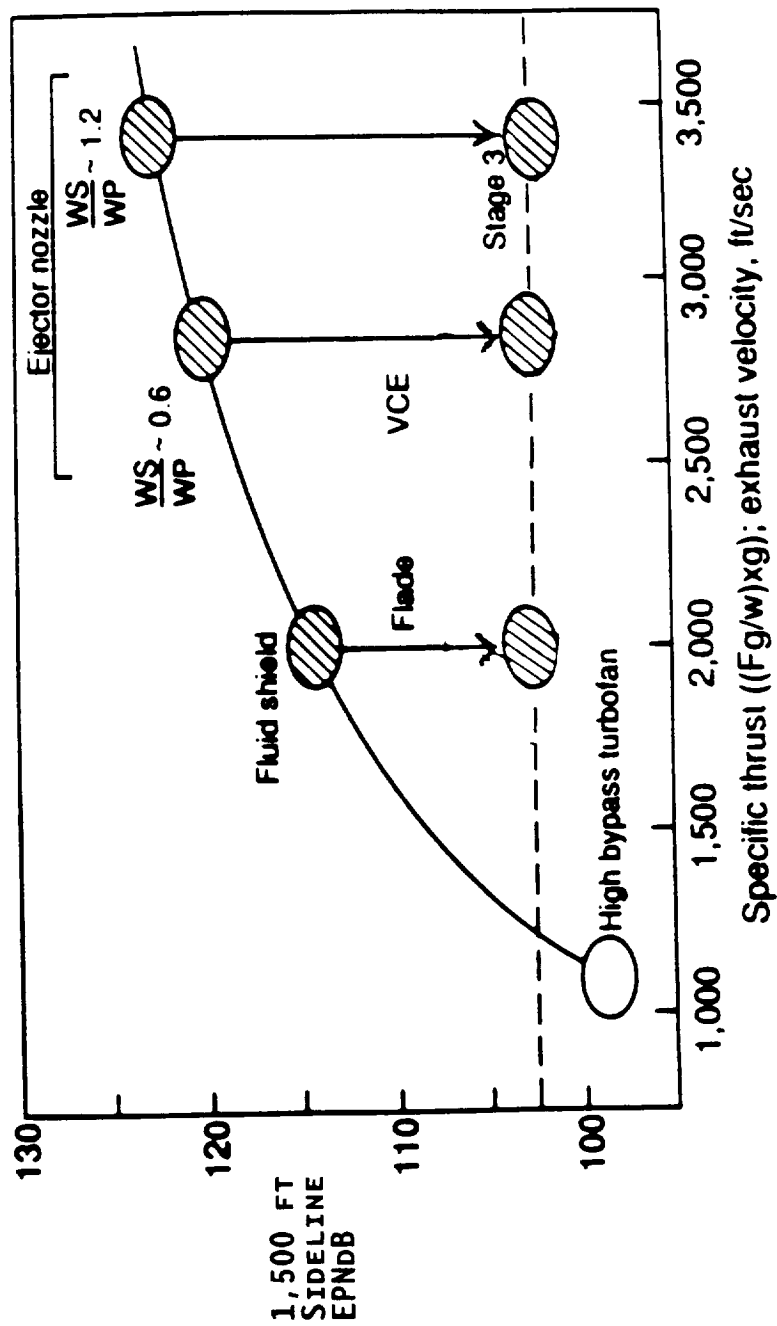
GEAE IS ALSO PURSUING A FLUID SHIELD NOZZLE IN CONJUNCTION WITH FLADE CYCLE, WHICH EMPLOYS A MUCH LOWER MASS-AVERAGED SPECIFIC THRUST (~2000 FPS) COMPARED TO EJECTOR NOZZLE. BY VIRTUE OF THE LOWER MASS-AVERAGED SPECIFIC THRUST,

FLUID SHIELD NOZZLE NEEDS TO ACHIEVE ONLY 12-13 EPNdB SUPPRESSION. ACOUSTIC SUPPRESSION, NOZZLE PERFORMANCE AND PROPULSION SYSTEM WEIGHT NEED TO BE

CONSIDERED IN MAKING A FINAL SELECTION AS ALL THE ABOVE HAVE A SIGNIFICANT IMPACT ON HSCT TOGW AND ECONOMIC VIABILITY.

HSCT EXHAUST NOZZLE DESIGN APPROACHES - GEAE AND P&W

- HIGH FLOW ENGINE + MODEST NOISE REDUCTION
- HIGH IMPULSE ENGINE + AGGRESSIVE NOISE REDUCTION



GEAE HSCT ACOUSTICS RESEARCH IS COMPOSED OF TEST, ANALYSES & SYSTEM TRADE STUDIES

THE CHART ENUMERATES THE MAJOR PROJECTS (NASA FUNDED AS WELL AS GEAE'S IR&D) CURRENTLY UNDER PROGRESS AND THEIR PRIMARY FOCUS. THE PROJECTS OFFER A SYNERGISTIC BLEND OF TEST PROGRAMS, ANALYTICAL ACTIVITIES AND HSCT SYSTEM TRADE STUDIES.

GEAE HSCT ACOUSTICS RESEARCH IS COMPOSED OF TEST, ANALYSES & SYSTEM TRADE STUDIES

PROGRAM

FOCUS

- o 2D-CD NOZZLE PROGRAM (NASA)
 - o DEMONSTRATE ~ 16-17 EPNdB SUPPRESSION REL. TO A CONIC NOZZLE @ VJ~2800 FPS
 - o ASSESS IMPACT ON A/C TOGW.
- o FLUID SHIELD PROGRAM (NASA)
 - o DEMONSTRATE FEASIBILITY OF A FLUID SHIELD NOZZLE SYSTEM (~ 12-13 EPNdB @ VMIX ~ 2000 FPS)
 - o ASSESS IMPACT ON A/C TOGW
- o IR&D PROGRAM (GEAE)
 - o GE/BOEING JOINT TEST OF HIGH AREA RATIO NOZZLE SUPPRESSOR/EJECTOR
 - o SYSTEM STUDIES SUPPORT (ANOPP, CYCLES)
 - o M*G*8 JET NOISE MODEL UPGRADING
- o UNIQUE PROPULSION SYSTEM ANALYSIS (NASA)
 - o CYCLE/NOZZLE SYSTEM TRADE STUDIES

CONTRACT NAS 3-25415 - 2D-CD NOZZLE PROGRAM

BASE PROGRAM AIMED AT EVOLVING A 'PRELIMINARY DESIGN' OF AN INNOVATIVE 2D-CD SUPPRESSOR-EJECTOR NOZZLE COMBINING THE ACOUSTIC REQUIREMENTS FOR HIGH LEVELS OF AMBIENT AIR ENTRAINMENT ($\frac{W_S}{W_P} = 0.6$), SUPERSONIC CRUISE PERFORMANCE ($C_{FG} \sim 0.98$) AND ACCEPTABLE NOZZLE WEIGHT (~ 5000 LBS.).

ADVANCED CFD AND ACOUSTIC CODES WERE UTILIZED IN EVOLVING THE PRELIMINARY DESIGN. CURRENT ACTIVITIES ARE AIMED AT PERFORMING SCALE MODEL ACOUSTIC TESTS IN GEAE'S CELL-41, AERO PERFORMANCE TESTS AT TAKEOFF IN A WIND TUNNEL AND AERO-MIXING EXPERIMENTS IN GEAE'S AERO RESEARCH LAB'S FREEJET WIND TUNNEL.

Contact NAS3-25415 - 2D-CD Nozzle Program Program Scope and Schedule

Task	Title	1989	1990	1991	1992
1	<u>Base program</u>				
2	Preliminary design	—	PDR —▲		
	Code utilization	—	—▲		
3	<u>Option A</u>				
	Scale model tests				
	- Cell 41 acoustic tests			C-41 test —▲	
	- Aero performance tests			—▲	
4	Data analysis				Fluidyne test —▲
5	<u>Option B</u>				
	Aero mixing experiments			ARL test —▲	
7	Program management	—			—▲

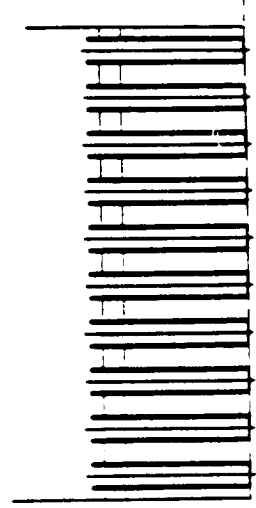
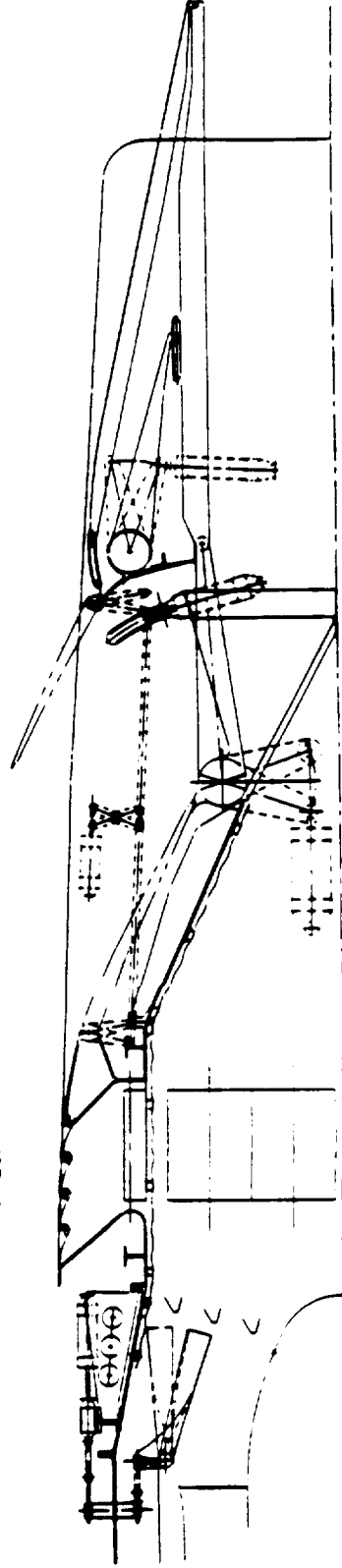
2DCD NON-IVP SUPPRESSOR EJECTOR

THE ACOUSTIC 'PRELIMINARY DESIGN' EVOLVED THRU AN EXTENSIVE REVIEW OF PAST ACOUSTIC DATA, WHICH INDICATED THAT 'INVERTED VELOCITY PROFILE' CONCEPT IN CONJUNCTION WITH SUPPRESSOR DOES NOT YIELD ANY ADDITIONAL ACOUSTIC BENEFIT AND HENCE WAS DELETED. THIS RESULTED IN A SIMPLER WEDGELESS 2D-CD NOZZLE. SIGNIFICANT CARE WAS EXERCISED IN DESIGNING AN EFFICIENT AERODYNAMIC DESIGN FOR THE EJECTOR INLET TO ENSURE THAT AMBIENT AIR ACCELERATED SMOOTHLY WITH MINIMAL INDICATION OF SEPARATION. SINCE IVP IS NOT NEEDED ANYMORE, FAN AND CORE STREAMS OF THE VARIABLE CYCLE ENGINE (VCE) ARE MIXED IN A MIXER. THE AMOUNT OF $\frac{W_8}{W_P} = 0.6$ IS DICTATED BY A_8/A_P , WHICH IN TURN IS LIMITED BY CRUISE NOZZLE AREA RATIO (A_9/A_8), AND BOATTAIL CONSIDERATIONS FOR ACCEPTABLE CRUISE PERFORMANCE AND CHUTE STOWABILITY.

2DCD Non-IVP Suppressor Ejector

September 1990 (PDR)

- Key features
 - IVP feature deleted
 - Wedgeless 2DCD nozzle
 - Efficient aerodynamic design for ejector inlet
 - Independent thrust reverser
 - Fan-core stream mixer



KEY SENSITIVITIES FROM REFERENCE AIRCRAFT ARE ESTABLISHED

IMPACT OF NOISE, AERODYNAMIC PERFORMANCE OF NOZZLE AT TAKEOFF AND CRUISE, NOZZLE WEIGHT, TAKEOFF OPERATIONAL PROCEDURES AND LOW SPEED AIRCRAFT PERFORMANCE (SUBSONIC L/D) ON HSCT TOGW ARE ENUMERATED FOR A VCE WITH 2D-CD SUPPRESSOR EJECTOR NOZZLE. CRUISE PERFORMANCE HAS THE LARGEST IMPACT ON HSCT TOGW AND WILL UNDOUBTEDLY IMPACT THE ECONOMIC VIABILITY OF HSCT. THE PAYLOAD FRACTION FOR HSCT IS ~8%.

Key Sensitivities From Reference Aircraft are Established

<u>Parameter varied</u>	<u>% change in TOGW</u>
• Sideline noise higher by 1 EPNdB	+2.4%
• Cruise performance reduced by 0.01	+4.75%
• Takeoff performance reduced by 0.01	+0.8%
• Nozzle weight increased by 2% (100 lb)	+0.35%
• PLR vs. single cutback	-5.1%
• PLR vs. single cutback and increase takeoff (L/D) of aircraft by 10%	-8.3%

Notes:

Reference TOGW, 743,810 lb

Mission, payload are constant

FAR36 Stage III noise rules satisfied

Individual linear sensitivities only

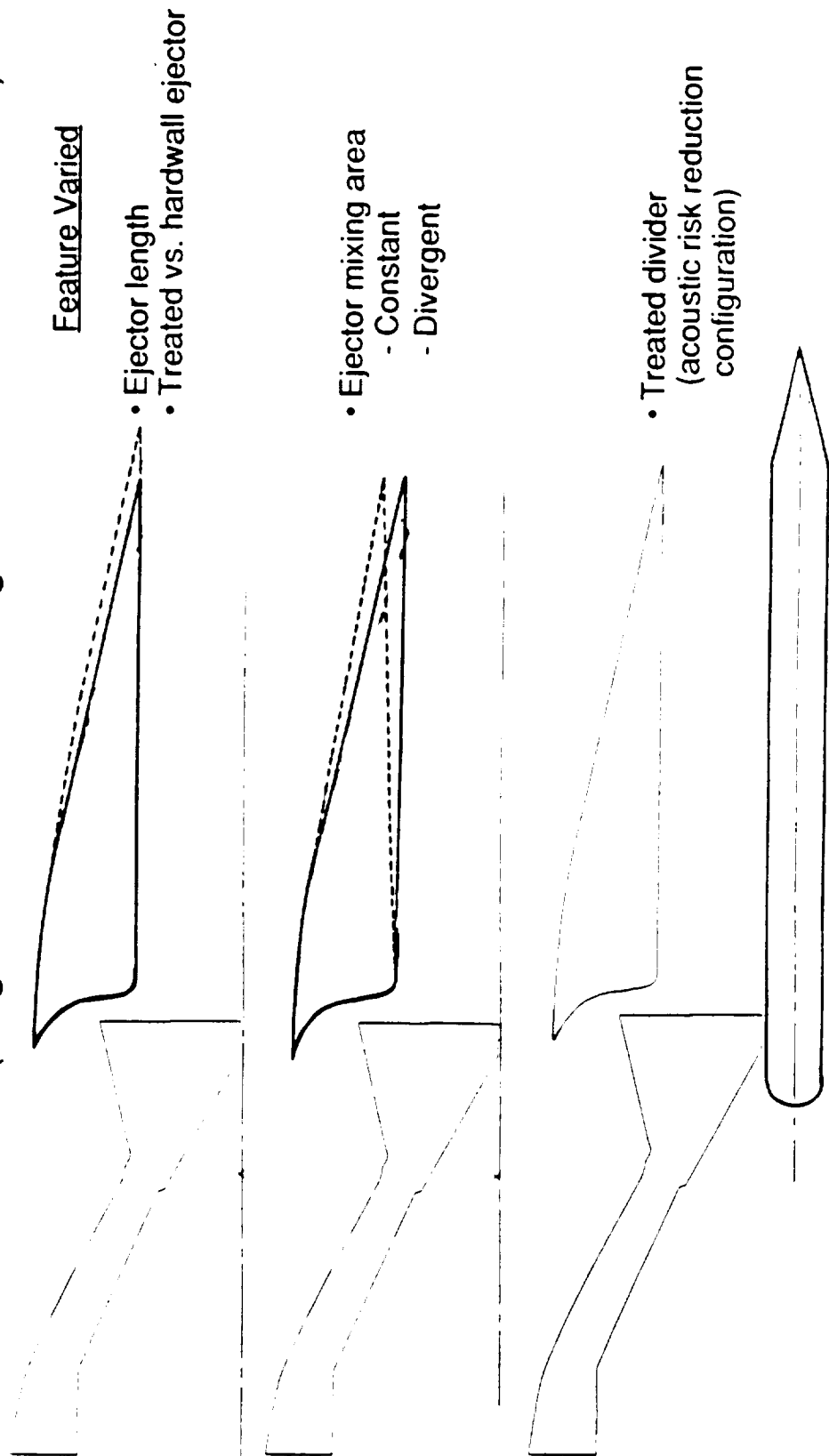
Coupled sensitivities are not necessarily additive

ACOUSTIC EXPERIMENTS

TYPICAL CONFIGURATIONAL VARIATIONS OF THE BASELINE 2D-CD SUPPRESSOR-EJECTOR NOZZLE TO BE EXPLORED IN 1/7TH SCALE ACOUSTIC MODELS IN GEAE'S CELL-41 ANECHOIC FREEJET FACILITY IN LATTER HALF OF 1991 ARE SHOWN. TREATED DIVIDER INCREASES THE ACOUSTICALLY TREATED AREA FOR THE SAME LENGTH OF THE EJECTOR FLAP. IT IS ANTICIPATED THAT THE TREATED DIVIDER WILL INCREASE FRICTIONAL LOSS AND HENCE DEGRADE CRUISE PERFORMANCE. NOISE SUPPRESSION AND CRUISE PERFORMANCE NEED TO BE TRADED.

Acoustic Experiments

Effect of ejector geometry on noise (length, treatment, mixing area and treated divider)

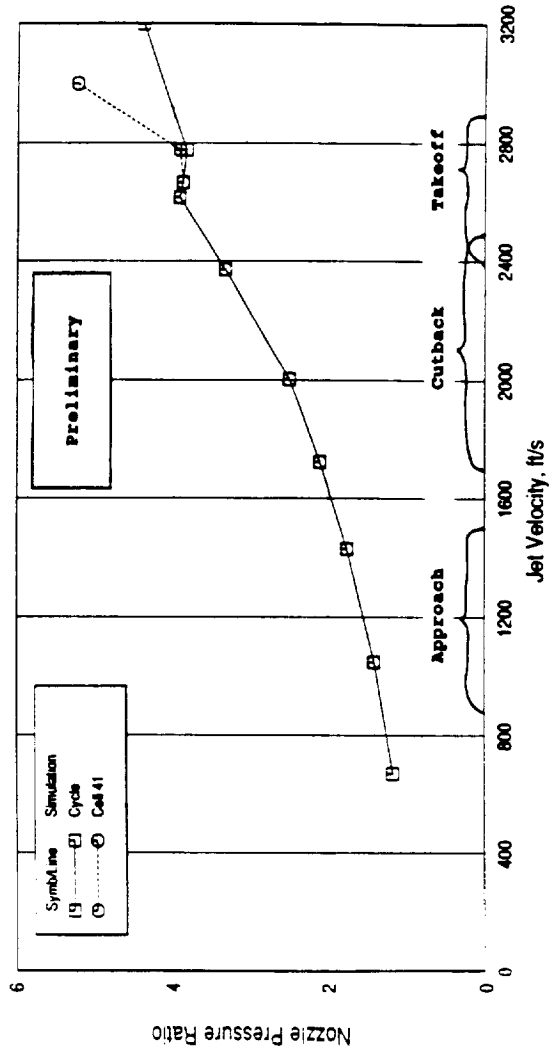


ACOUSTIC EXPERIMENTS

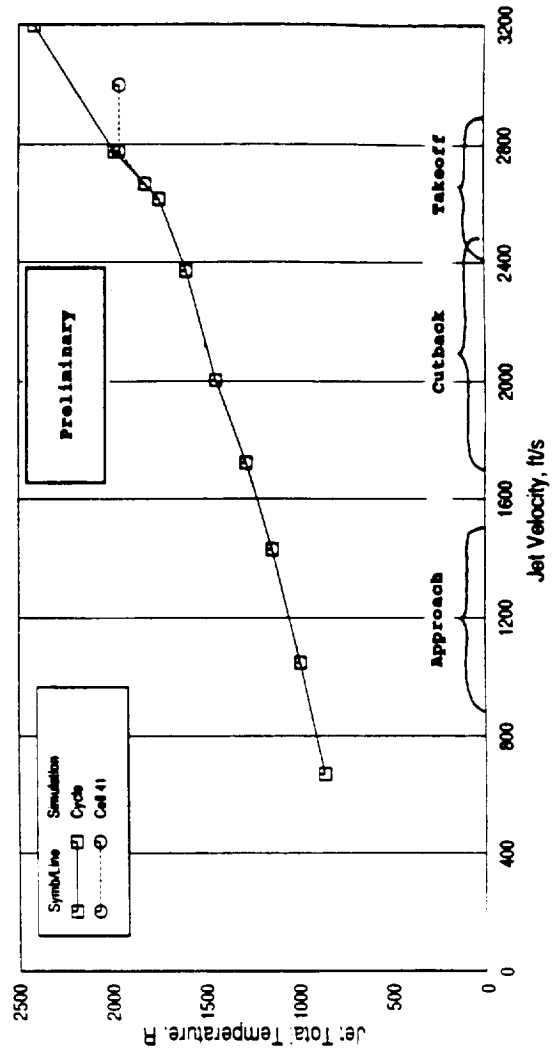
THE CHART SHOWS THE CAPABILITIES OF CELL-41 FACILITY TO SIMULATE THE GE21/F14 LIM VARIABLE CYCLE ENGINE'S EXHAUST NOZZLE AERO THERMODYNAMIC CONDITIONS. FOR $V_{MIX} \leq 2800$ FPS. THE SIMULATION OF TOTAL TEMPERATURE (T_T) AND NOZZLE PRESSURE RATIO (NPR) IS IDENTICAL. VELOCITIES GREATER THAN 2800 FPS ARE OBTAINED IN CELL-41 BY INCREASING NPR WHILE KEEPING $T_T \sim 1960$ R.

ACOUSTIC EXPERIMENTS

GE21/F14 L1M Cycle Simulation in Cell 41 - NPR



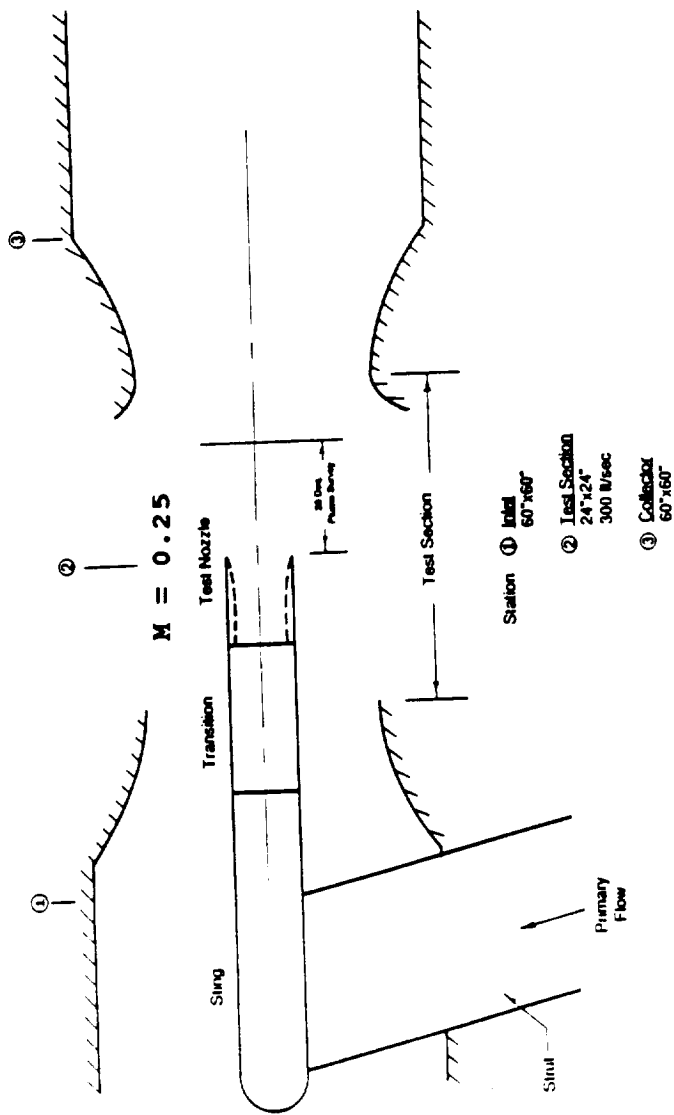
GE21/F14 L1M Cycle Simulation in Cell 41 - Tt



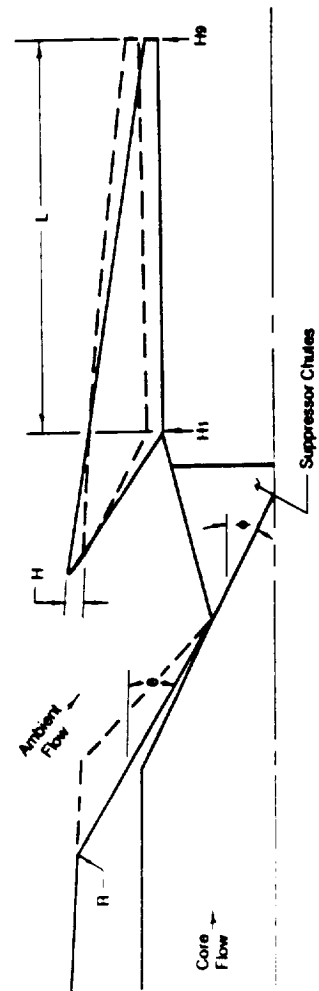
AERO-MIXING EXPERIMENTAL SET-UP AT GEAE'S ARL

THE PRINCIPAL OBJECTIVE IS TO MEASURE AND UNDERSTAND AERODYNAMIC MIXING PHENOMENA BETWEEN AMBIENT AIR AND CORE FLOW IN A FREEJET ENVIRONMENT FOR VARIOUS CHUTE SUPPRESSOR, EJECTOR INLET CONFIGURATIONS. ALSO, THE TESTS WILL BE UTILIZED TO DEVELOP AERO DESIGN DATA BASE AND SCREEN PREFERRED CONCEPTS FOR FUTURE ACOUSTIC TESTING. THE AERODYNAMIC DATA WILL BE UTILIZED FOR THE VALIDATION OF CFD CODES. TYPICAL MODEL CONFIGURATIONAL VARIANTS BEING CONSIDERED AND MEASUREMENT PLANNED ARE ALSO ILLUSTRATED.

AERO-MIXING EXPERIMENTAL SET-UP AT GEAE'S ARL



NOZZLE GEOMETRIC VARIABLES

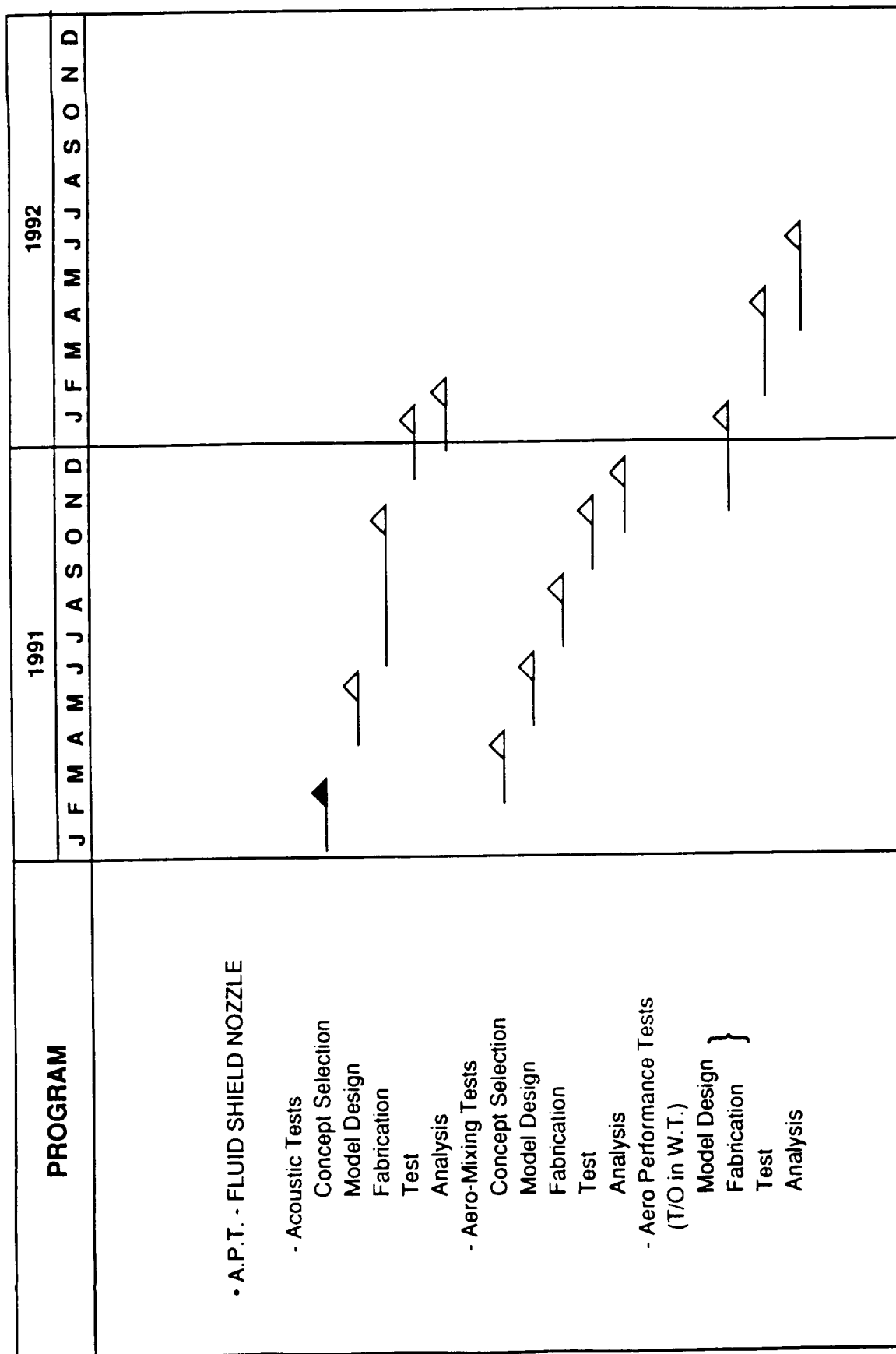


Measurements

- LV
- Kiel Probe
- Wall Static Pressure
- Pt Rakes

A.P.T. - FLUID SHIELD NOZZLE

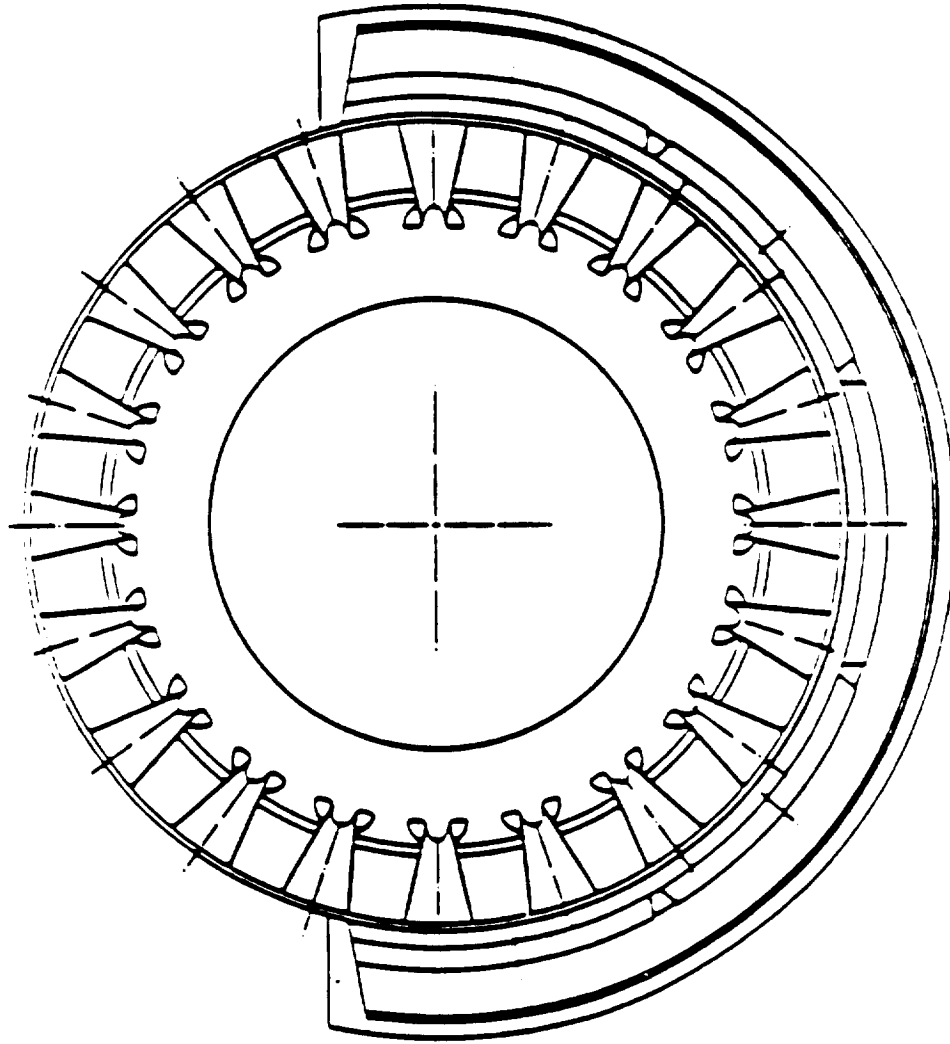
THE FLUID SHIELD NOZZLE PROGRAM CONSISTS OF ACOUS' RO-MIXING
AND AERO PERFORMANCE TESTS, PER ATTACHED SCHEDULE.



HSCT MACH 2.4 FLADE NOZZLE

THE CROSS-SECTIONAL VIEW OF M=2.4 FLADE NOZZLE PRELIMINARY DESIGN AT EXIT SHOWS THE CONFIGURATION DURING TAKE-OFF MODE. THE NOZZLE EMPLOYS A MECHANICAL SUPPRESSOR WITH 20 CHUTES AND A FLUID SHIELD SURROUNDING THE LOWER 200 DEGREES SECTOR.

HSCT Mach 2.4 Flade Nozzle



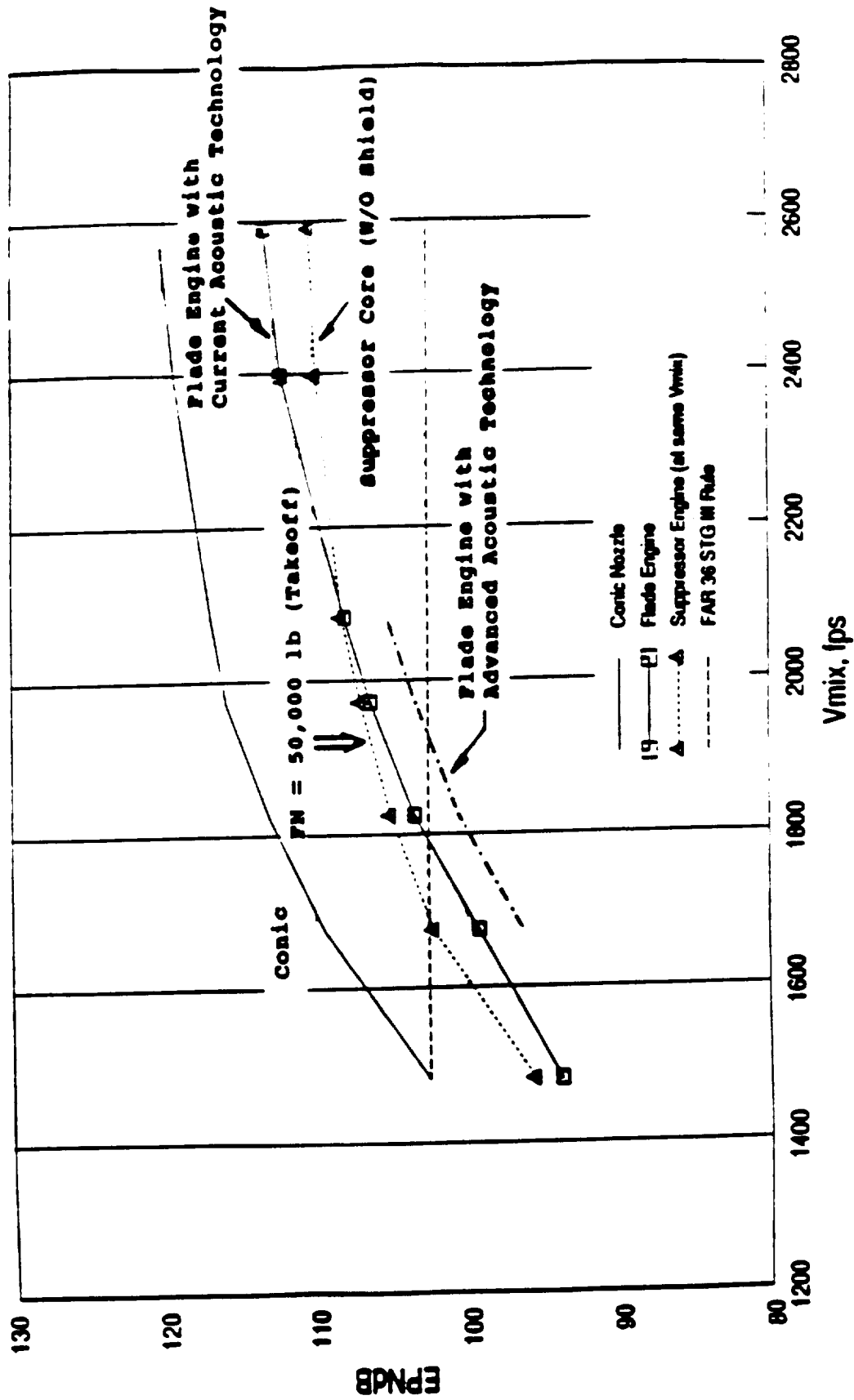
View Alt Looking Forward

SIDELINE NOISE PREDICTION FOR M2.4 FLADE ENGINE

ACOUSTIC PRELIMINARY DESIGN CODES AND DATABASES WERE UTILIZED IN PREDICTING THE SIDELINE EPNL AS A FUNCTION OF MASS-AVERAGED VELOCITY (V_{MIX}) FOR THE M2.4 FLADE ENGINE EMPLOYING THE FLUID SHIELD CONCEPT. FOR AN ENGINE SIZED TO PROVIDE 50,000 LBS OF NET THRUST DURING TAKEOFF, A FLADE ENGINE EMPLOYING ADVANCED ACOUSTIC TECHNOLOGY FEATURES IS ABLE TO MEET FAR-36 STAGE 3 NOISE LEVELS AT A $V_{MIX} \approx 1900-2000$ FPS

Sideline Noise Prediction for M2.4 Flare Engine

Ma/c = 0.32 and Alt = 689 ft (Shock Free, Using Cycles for Ma/c=0.3 and Al =0)

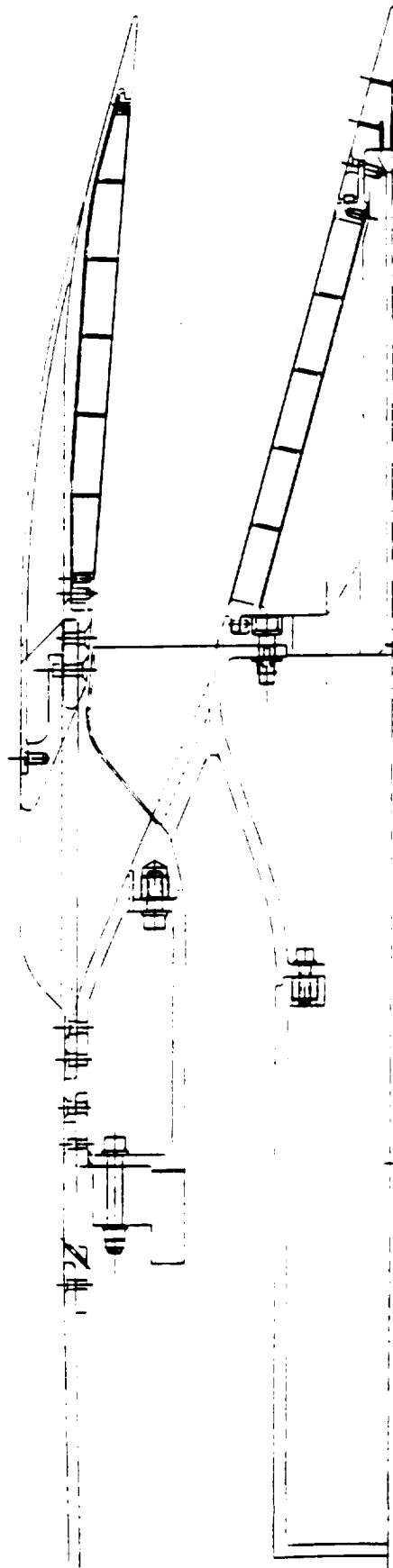


NOZZLE CONCEPT FOR GE/BOEING JOINT TEST

THIS SCALE MODEL OF A HIGH SUPPRESSOR AREA RATIO EJECTOR NOZZLE IS DESIGNED AND FABRICATED BY GEAE FOR A COOPERATIVE TEST IN BOEING'S LOW SPEED AEROACOUSTIC FACILITY (LSAF) DURING THE 3RD QUARTER OF 1991. THE NOZZLE EMPLOYS ACOUSTIC SUPPRESSION FEATURES SUCH AS CONVERGENT-DIVERGENT CHUTES, POROUS PLUG.

NOZZLE CONCEPT FOR GE/BOEING JOINT TEST

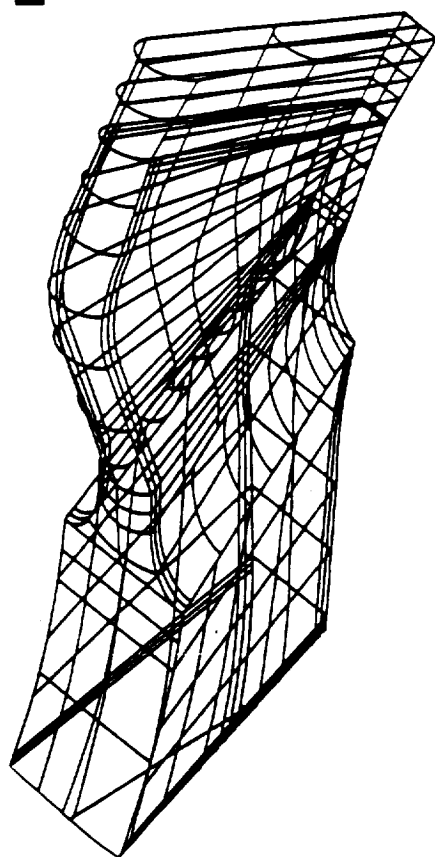
- . $A_8 \approx 13 \text{ in}^2$
- . 24 C-D CHUTES
- . POROUS PLUG
- . $SAR \sim 3$
- . DIVERGENT AREA MIXING



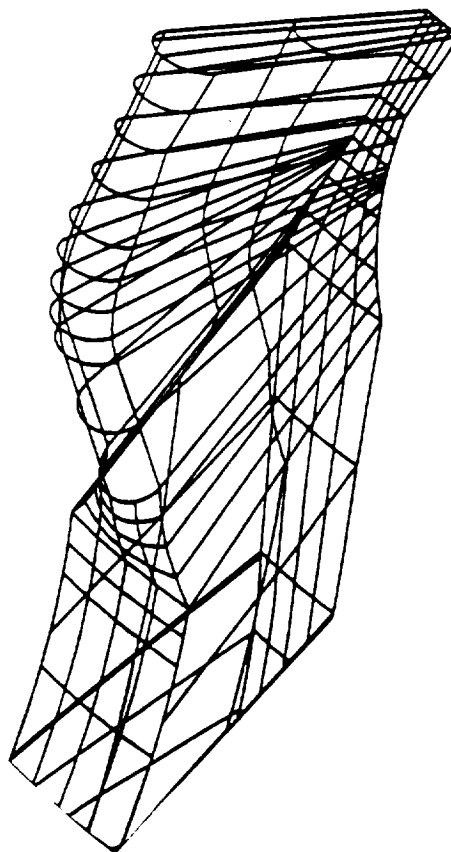
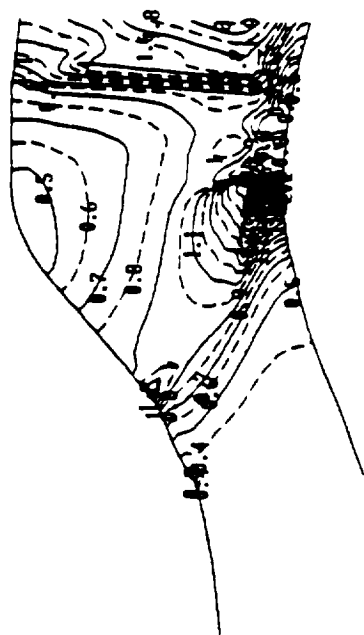
SCALE MODEL HOT CORE FLOW PATH MODIFIED TO PREVENT HUB-CHOKING CFL3D SOLUTION

INVISCID VERSION OF CFL3D CODE WAS UTILIZED IN THE DESIGN OF HOT CORE FLOWPATH. INITIAL DESIGN RESULTED IN A MINIMUM AREA IN THE REGION OF ENTRANCE TO CHUTE DUE TO THE SUPPORT STRUTS. OPENING UP THE HUB AREA PREVENTED HUB-CHOKING AND RESULTED IN A UNIFORM FLOW ACCELERATION TO THE ACTUAL THROAT OF THE C-D CHUTE. CFL3D IS UTILIZED AS A DESIGN TOOL IN THIS ILLUSTRATION.

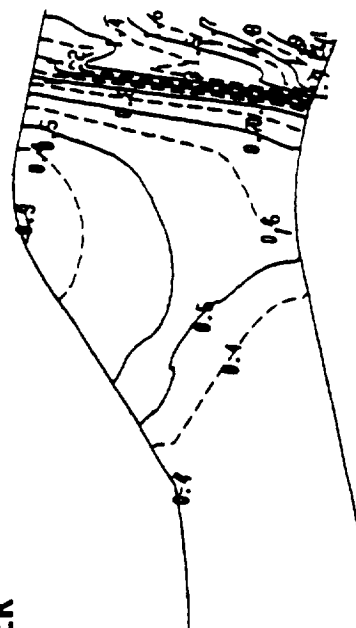
SCALE MODEL HOT CORE FLOW PATH MODIFIED TO PREVENT HUB-CHOKING - CFL3D SOLUTION



BEFORE



AFTER



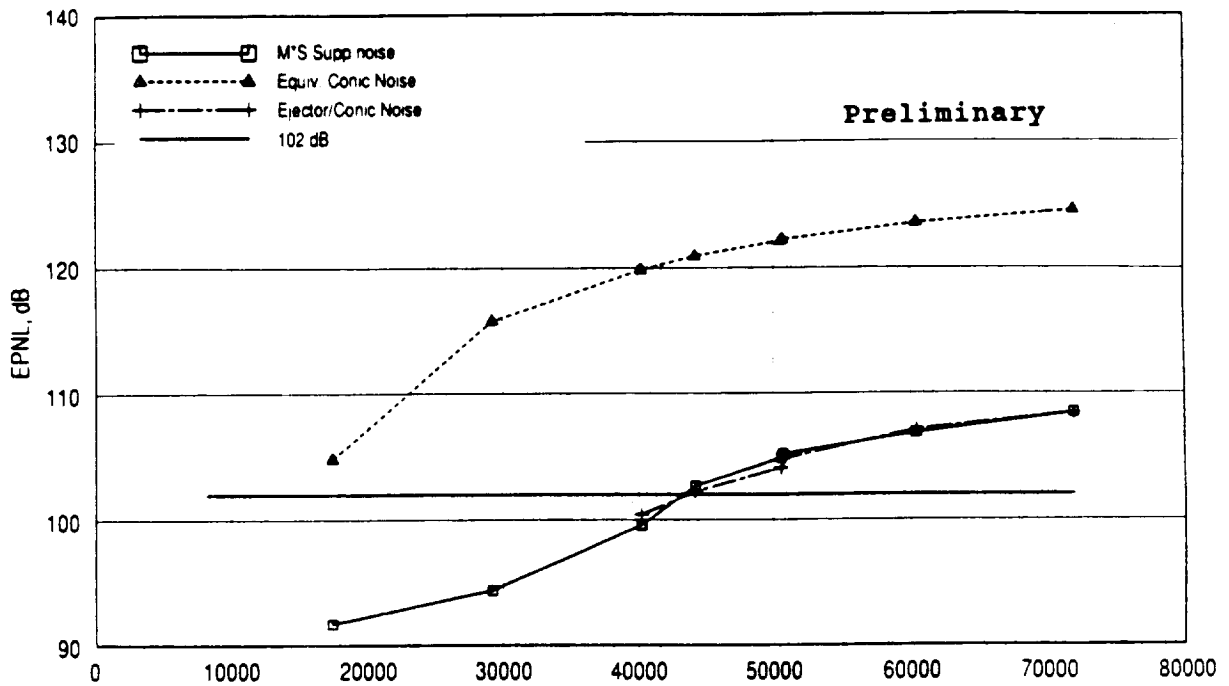
PRE-TEST NOISE PREDICTION

GEAE'S MS EMPIRICAL PREDICTION METHOD WAS UTILIZED TO MAKE THE PRE-TEST PREDICTIONS FOR A TYPICAL VCE CYCLE. FOR A $F_N = 50,000$ LBS. 17-18 EPNdB SUPPRESSION RELATIVE TO CONIC NOZZLE IS BEING PREDICTED FOR SIDELINE (ALT = 689 FT). FOR COMMUNITY NOISE (ALT ~ 1000 FT). SIMILAR LEVELS OF SUPPRESSION ARE PREDICTED AT $F_N = 42000$ LBS.

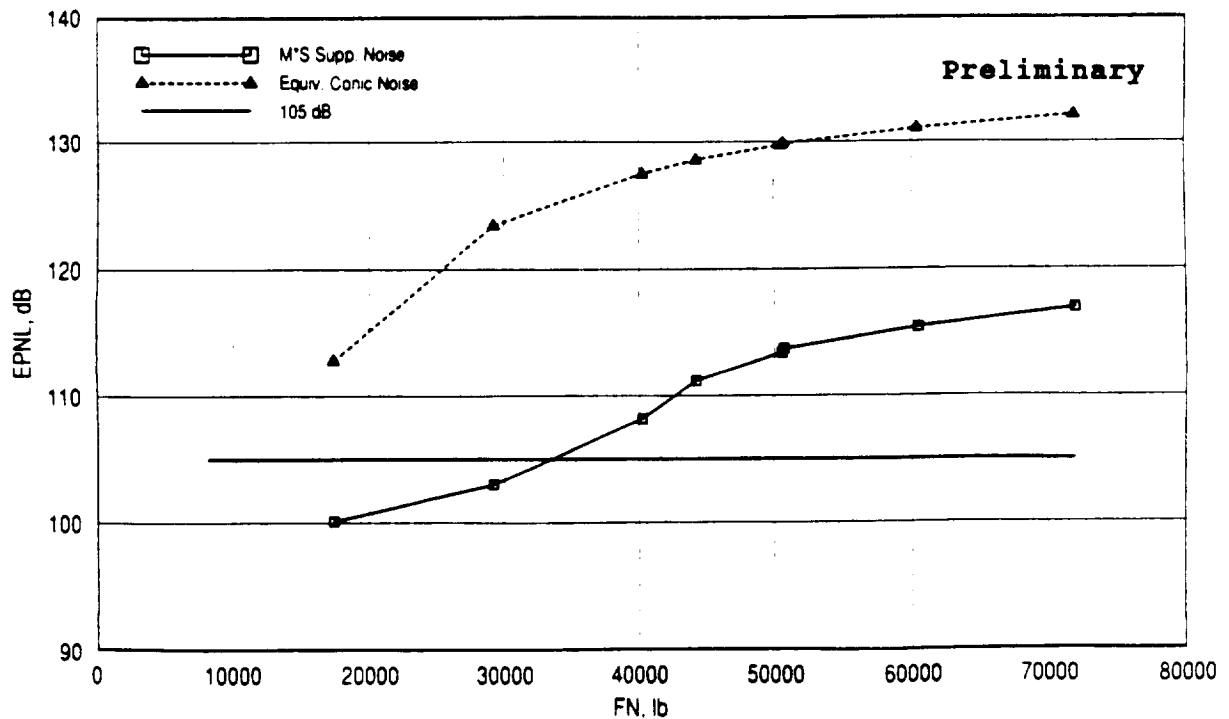
PRE-TEST NOISE PREDICTION

M = 0.23

Sideline Noise. Alt = 689 ft



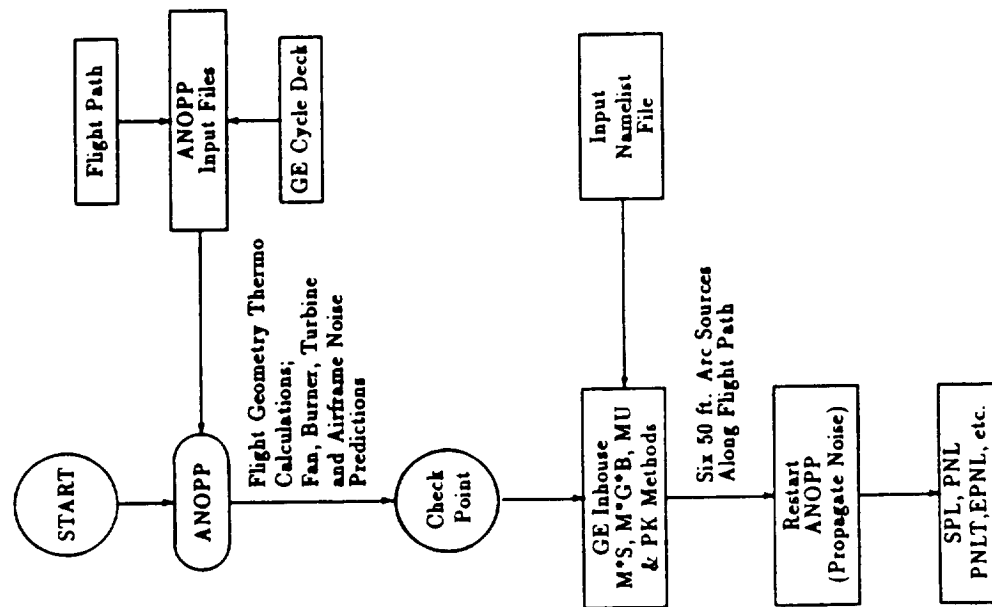
Community Noise. Alt = 1000 ft



FLOW CHART FOR THE GEAE CUSTOMIZED ANOPP

NASA LANGLEY' AIRCRAFT NOISE PREDICTION PROGRAM (ANOPP) HAS BEEN CUSTOMIZED TO UTILIZE GEAE'S CYCLE DECK, TAKEOFF TRAJECTORY AND SOURCE NOISE MODELS (SUCH AS MS, $M*G+B$, ETC.) FOR ASSESSING IMPACT OF TAKEOFF OPERATIONAL PROCEDURES AND LOW SPEED AIRCRAFT PERFORMANCE ON HSCT FAR 36 STAGE 3 RULE COMPLIANCE. HSCT TOGW INFORMATION COULD BE FURTHER UTILIZED FOR ASSESSING ECONOMIC VIABILITY.

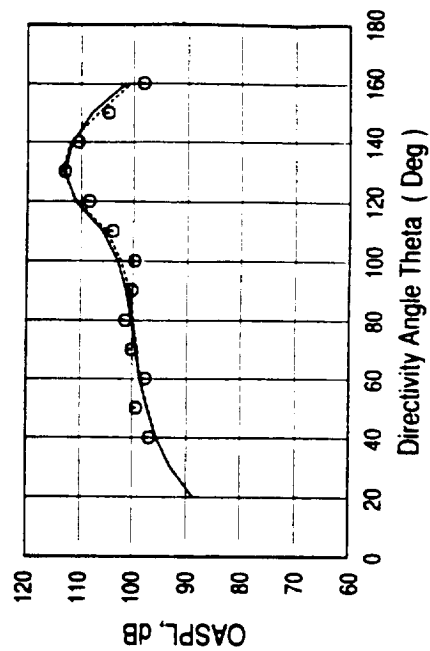
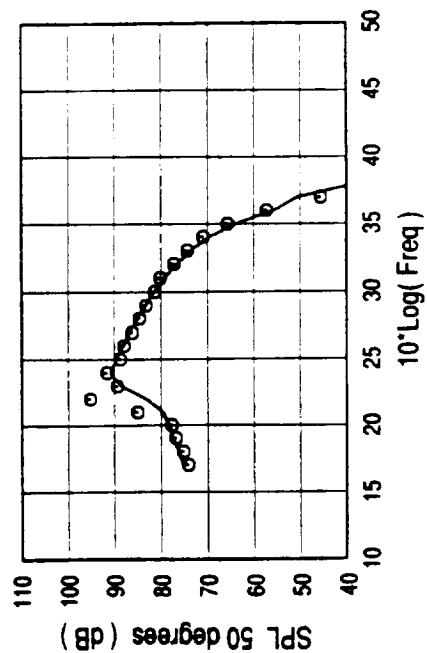
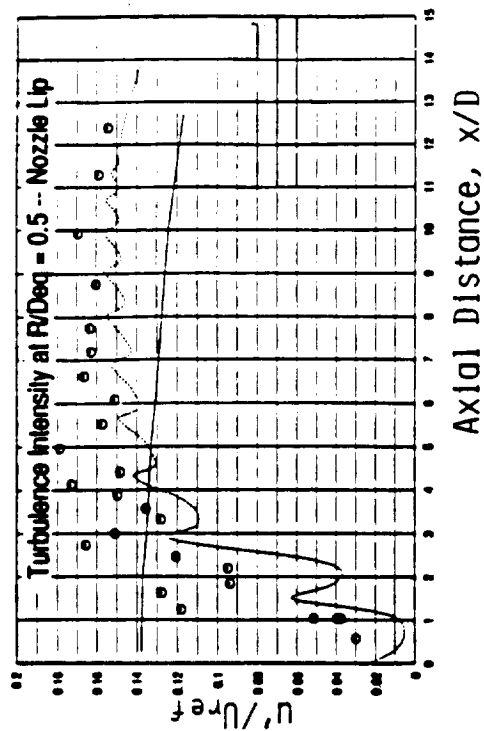
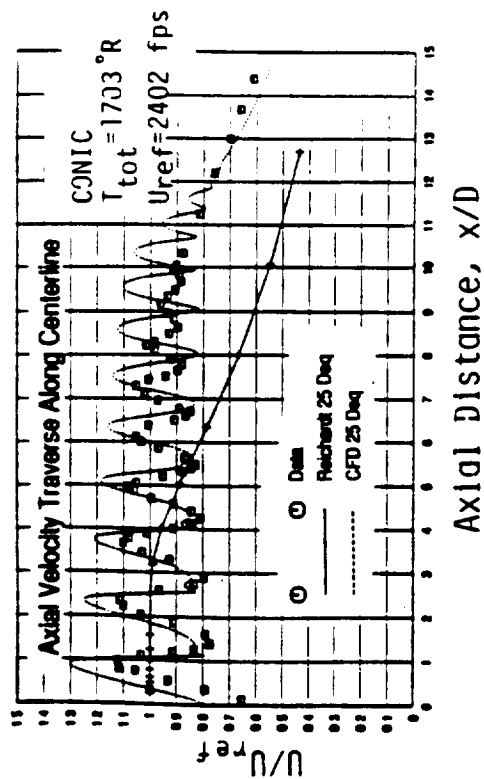
Flow Chart for the GEAE Customized ANOPP



**GEAE'S M*G*B JET NOISE CODE IMPROVEMENTS INCLUDE CFD PLUME FLOW FIELD
AND TAM'S SHOCK NOISE MODEL**

ADVANCED CFD CODES WITH K-E TURBULENCE MODELING PROVIDE MORE ACCURATE
FLOW FIELD INFORMATION FOR NOISE PREDICTIONS UTILIZING GEAE'S M*G*B CODE.
STATE-OF-THE-ART SHOCK NOISE MODEL OF PROF. TAM IS INCLUDED. EXCELLENT
AGREEMENT FOR CONIC NOZZLE (SPECTRAL AND DIRECTIVITY) ARE OBTAINED. MORE
COMPLEX NOZZLE SHAPES ARE PLANNED TO BE ANALYZED.

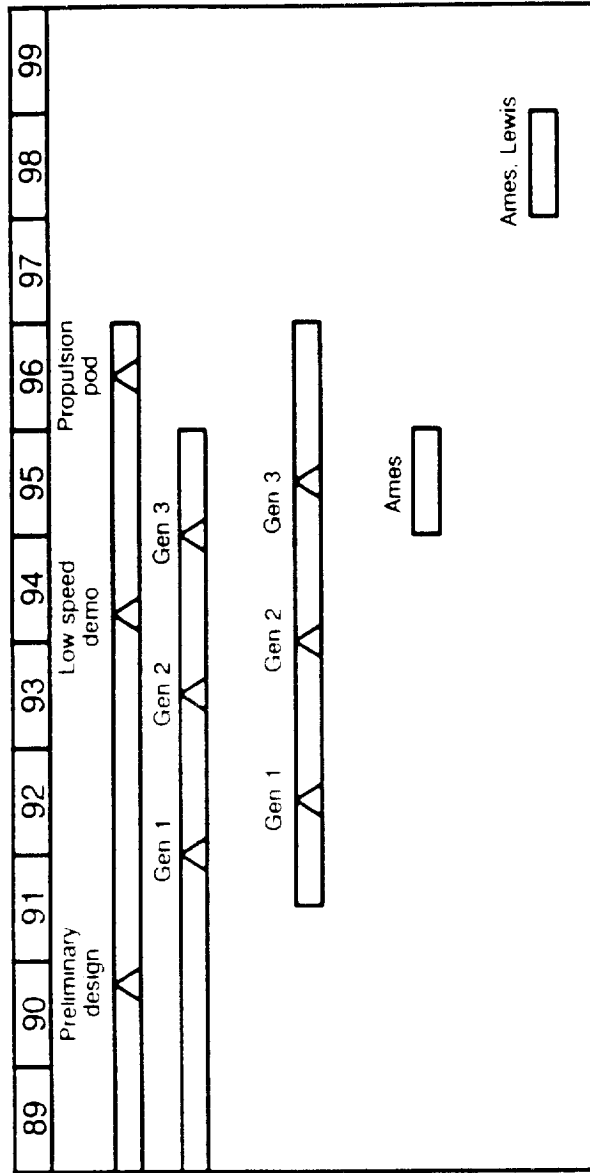
GEAE'S M*G*B JET NOISE CODE IMPROVEMENTS INCLUDE CFD PLUME FLOW FIELD AND TAM'S SHOCK NOISE MODEL



HSCT EXHAUST NOZZLE STATUS

THE HSCT EXHAUST NOZZLE TECHNOLOGY DEVELOPMENT INVOLVES SIGNIFICANT AERODYNAMIC AND ACOUSTIC SCALE MODEL TESTING. INITIAL SCREENING TESTS ARE PLANNED TO BE COMPLETED BY THE END OF 1991 TO EVALUATE THE VARIOUS APPROACHES TO NOISE REDUCTION. ENHANCED COMPUTATIONAL CAPABILITY IS BEING USED IN THE EXHAUST NOZZLE DESIGNS. EXHAUST NOZZLE ACOUSTIC LINING HAS BEEN IDENTIFIED AS A CRITICAL TECHNOLOGY AND PLANS ARE UNDERWAY TO BEGIN TO DEVELOP THIS TECHNOLOGY. THE NEED FOR AN EARLY LARGE SCALE EXHAUST NOZZLE TEST TO VERIFY THE SCALE MODEL RESULTS HAS BEEN IDENTIFIED. TESTING IS PLANNED TO BE CONDUCTED IN THE AMES 40 X 80 WIND TUNNEL. A SECOND LARGE SCALE TEST INCORPORATING A SECOND OR THIRD GENERATION EXHAUST NOZZLE IS PLANNED FOR 1998. THIS NOZZLE WILL BE TESTED IN THE LEWIS 10 X 10 SUPERSONIC TUNNEL, IN ADDITION TO THE AMES FACILITY.

HSCT Exhaust Nozzle Status



Accomplishments

- Preliminary designs of 3 exhaust nozzle systems
- Tested 2 high entrainment ejector concepts
- Initiated 3 additional generation 1 model test programs for 1991
- Assessed/developed analytical tools for nozzle design (aero and acoustics)
- Identified acoustic lining as critical technology
- Utilized ANOPP to evaluate aircraft takeoff noise and impact of operational procedures and aircraft low speed performance

KEY ACOUSTIC TECHNOLOGY ISSUES FOR HSCT

GEAE'S PERSPECTIVE

THIS WORD CHART IS SELF-EXPLANATORY.

KEY ACOUSTIC TECHNOLOGY ISSUES FOR HSC1

GEAE'S PERSPECTIVE

- o **ADVANCED LOW NOISE NOZZLE CONCEPTS MUST BE MECHANICALLY VIABLE WITH DUE CONSIDERATION GIVEN TO MISSION REQUIREMENTS (CRUISE PERFORMANCE, WEIGHT, STOWABILITY, INSTALLATION, ETC.)**
- o **ALTERNATE CYCLES (HIGH FLOW) WHICH SIMPLIFY EXHAUST NOZZLE CONSIDERABLY SHOULD CONTINUE TO BE STUDIED.**
- o **FOR EJECTOR NOZZLE CONCEPT TO SUCCEED, CRITICAL ELEMENTS OF ACOUSTIC LINER TECHNOLOGY (SUPPRESSION POTENTIAL, SCALING, DESIGN CONCEPTS, HIGH MACH AND TEMPERATURE EFFECTS, ETC.) NEED TO BE DEVELOPED AGGRESSIVELY.**
- o **CONTROLLED EXPERIMENTS TO ASSESS BASELINE NOZZLE NOISE LEVELS IN FLIGHT ARE NECESSARY TO QUANTIFY SUPPRESSION NEEDED.**
- o **OTHER NOISE SOURCES (FAN, CORE, TURBINE) MAY NEED TO BE CONSIDERED FOR APPROACH NOISE ASSESSMENT.**

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