Select Aeroacoustic Problems Associated with High Performance Aerospace Vehicles

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Colloquium for Geneviève Comte-Bellot
Fifty Years of Research on Turbulence and Acoustics
October 29 & 30, 2009

NCPA Current Research Areas

•Basic Research

-Atmospheric Acoustics (Battlefield Acoustics)

–Thermoacoustics

–Infrasound / Infrasound Sensors

•Applied Research

-Aero-Acoustics

-Wind Turbines

–Insect Acoustics

–Instrumentation for Aquaculture

•Acoustics of Porous Media

- Soil Acoustics

– Mine Detection

•Energy & Bio-Acoustics / Medical

- Fusion Research

-High Intensity Focused Ultrasound (HIFU)

-Materials Characterization (RUS)

-Hydrogen Storage

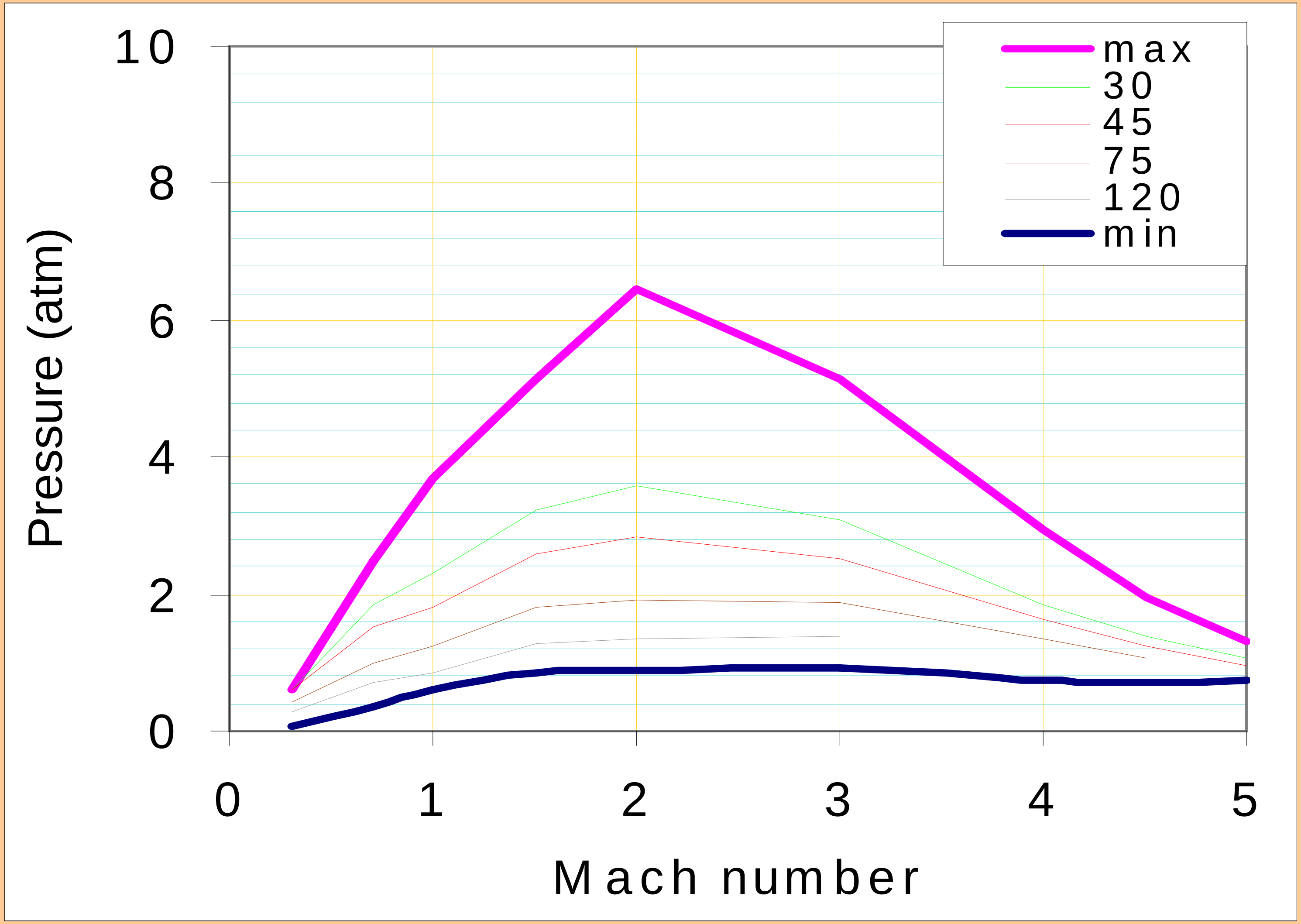
-Flexible Composite Transducers

NCPA Mach 5 Trisonic Tunnel
0.3 X 0.3 Meter Test Section

Performance Envelope

Maximum Reynolds No./Ft. : 70 X 10^6

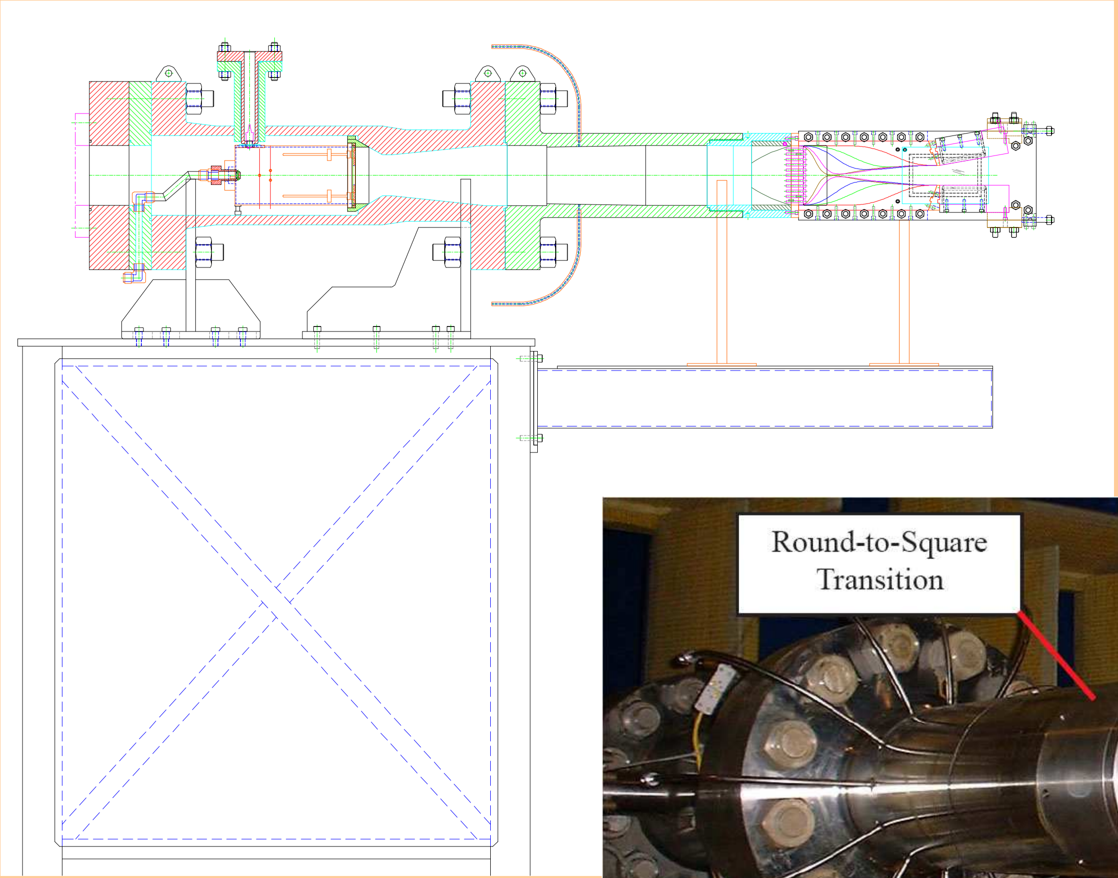
600 PSIA, 6000 Ft^3 Storage With 30 Minute Recharge Time



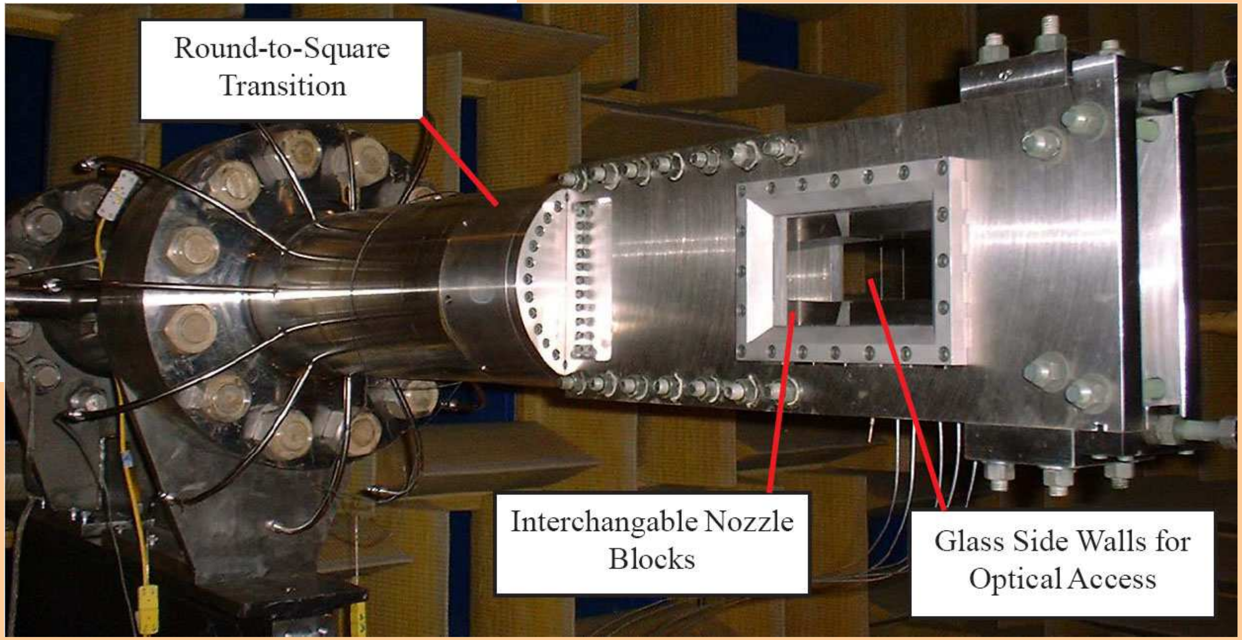
Maximum Testing Altitudes

M_∞	P_S / P_O	P_O, Min (PSIA)	P_S, Min (PSIA)	Altitude KM	Comment
1.5	0.27240	30.3	8.26	4.6	Transonic Cart
2.0	0.12780	36.4	4.65	8.7	Available
3.0	0.02722	81.8	2.23	13.4	Not Designed
3.5	0.01311	115.2	1.51	15.9	Available

Mach 5 NCPA 2 x 2 Wind Tunnel Installed on Burner in Test Cell



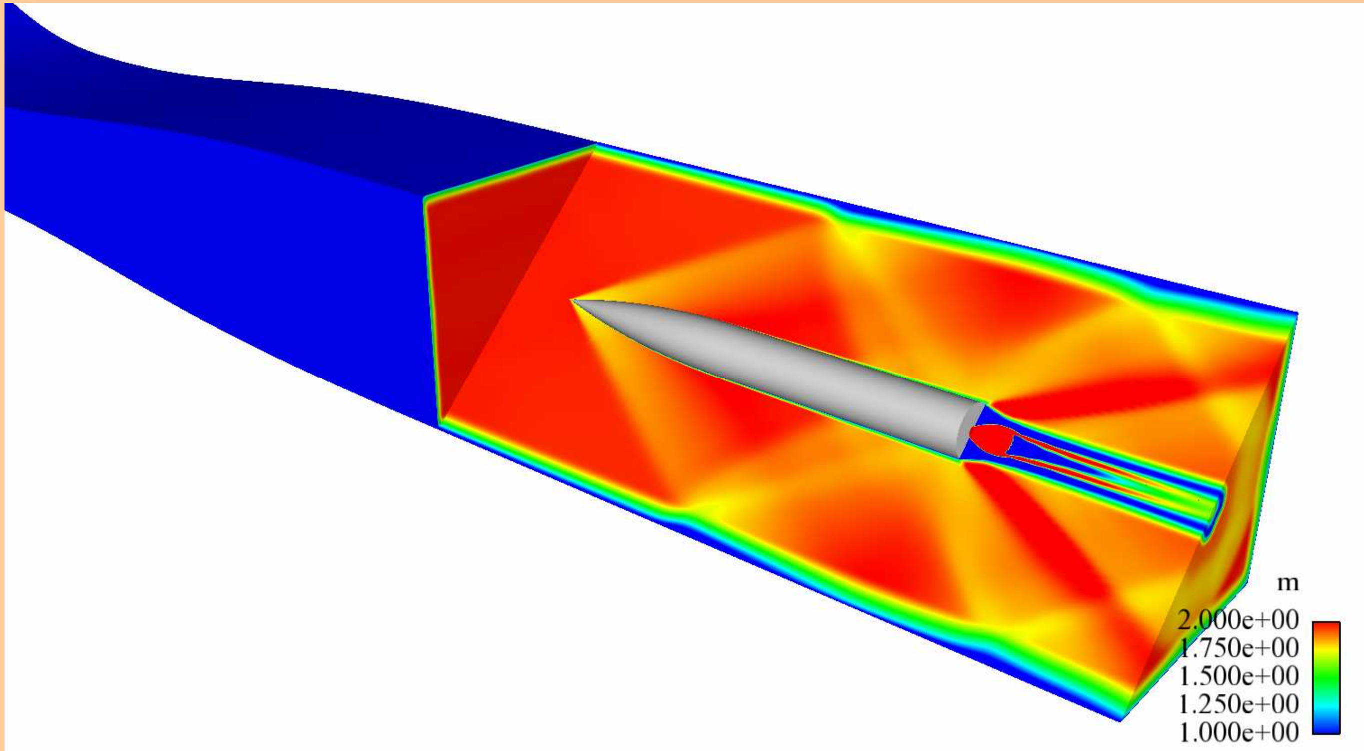
Can Operate to 2000^0R

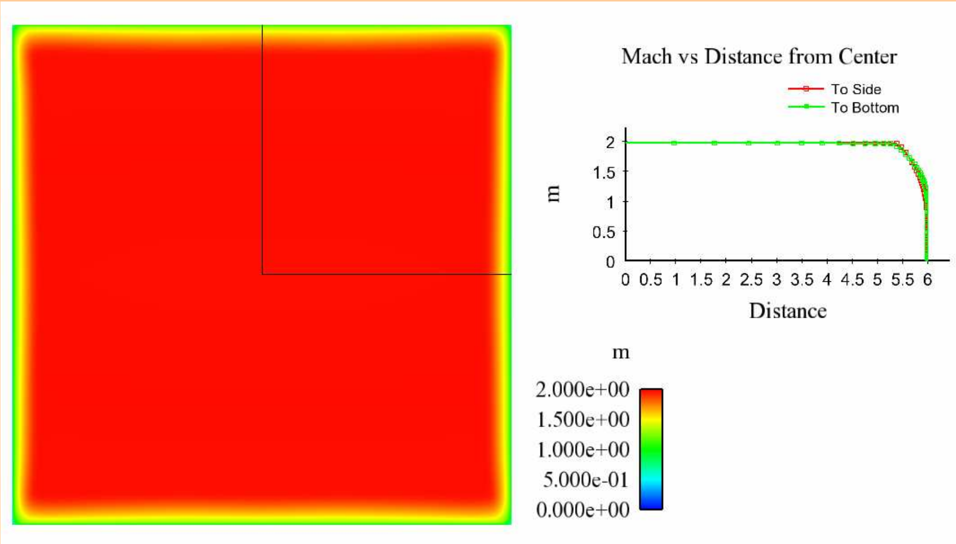


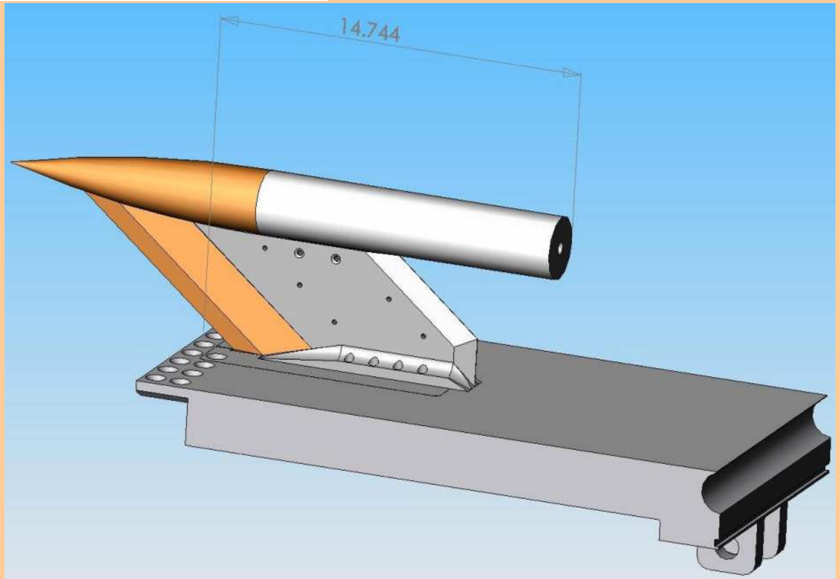
Aeroacoustics Research Topics

- **Rocket Base Flow Pressure Recovery for NASA.**
- **BWS Improvement by Flow Control.**
- **Improved Scramjet Combustion Efficiency for Army.**
- **Weapons Bay Dynamic Loads and Store Release for AFWL.**
- **High Performance Military Aircraft Noise Reduction for NAVAIR.**

Rocket Model Mach 2, Phi=1, Craft Code Simulation



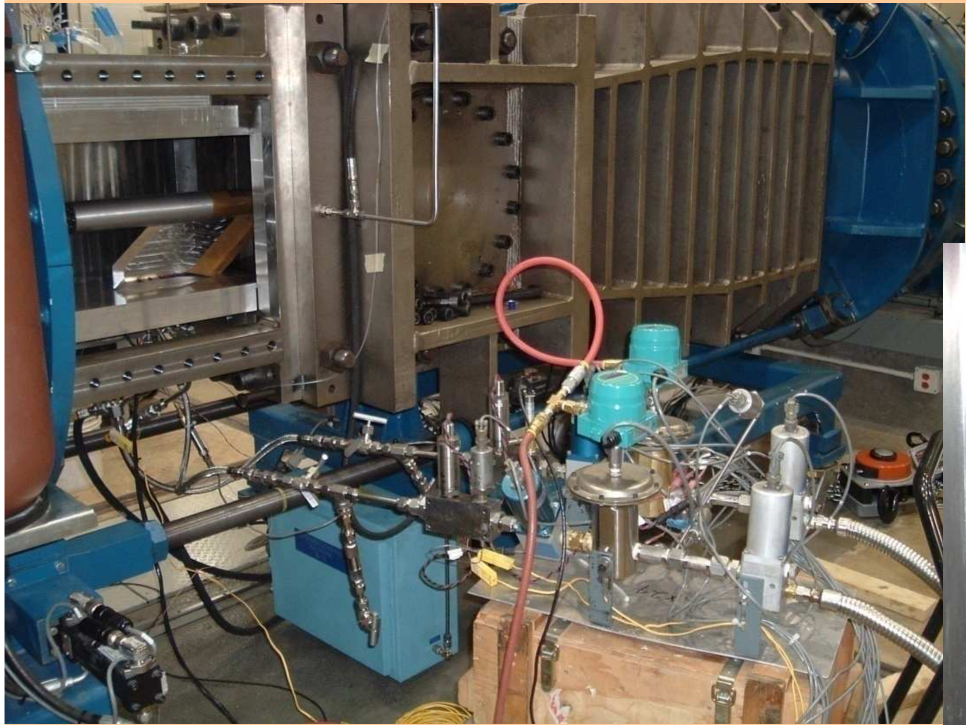




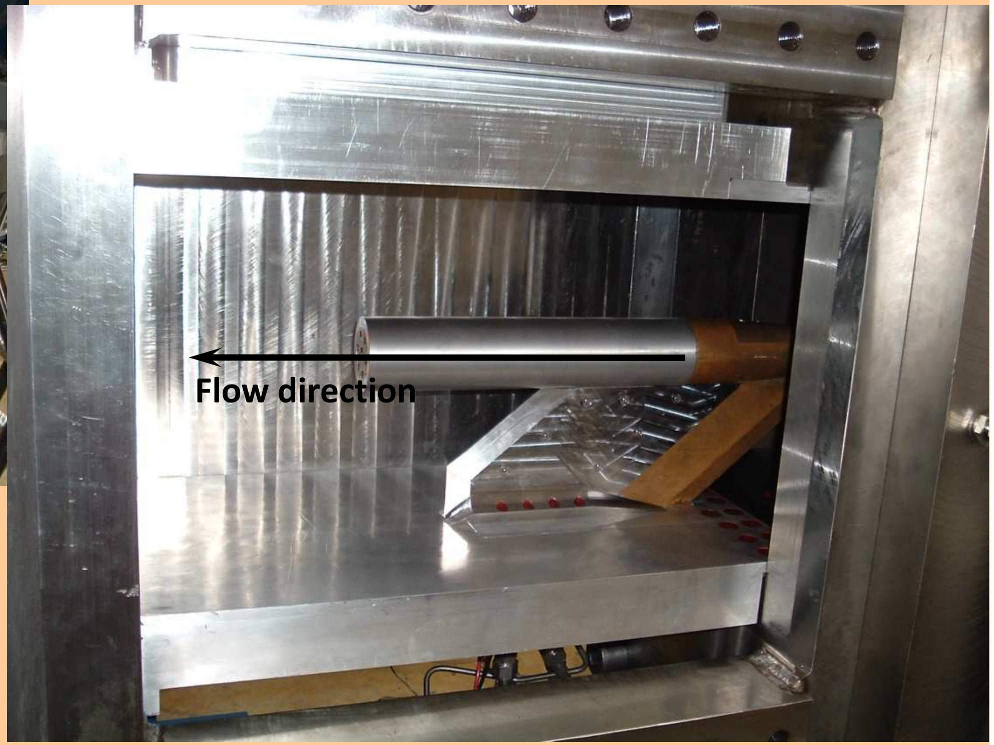
Model Features

- Jet Exit Diameter 7/16 Inch
- NPR = 50
- NSPR = 2.15
- $A_E/A^* = 3.189$
- $M_T = 1.50$
- 12 Base Pressure Ports (Cold Model)
- 11 Nacelle Pressure Ports (Cold Model)
- PIV Seeding Ports
- Charging Station

Experimental Setup



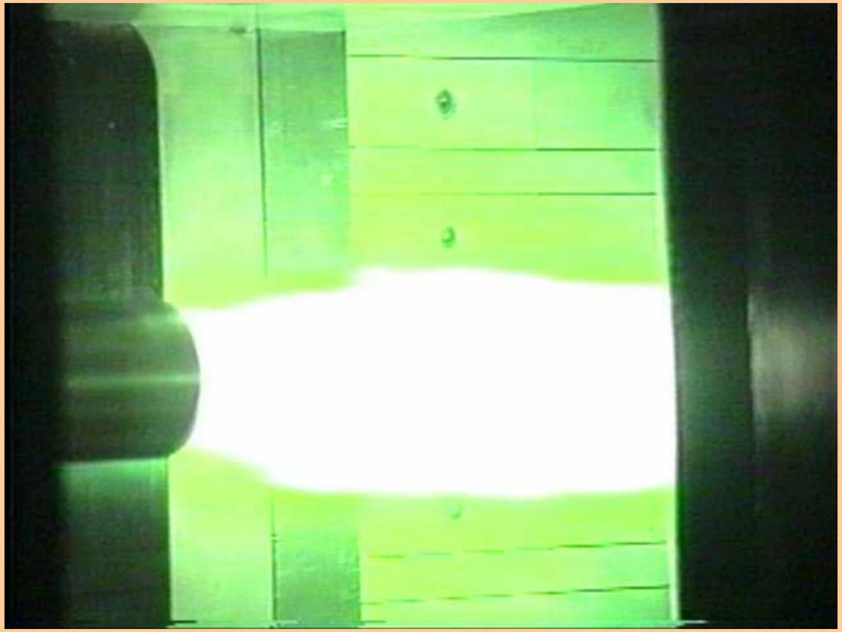
View of the model in the test section and the Hydrogen and Oxygen mass flow controllers

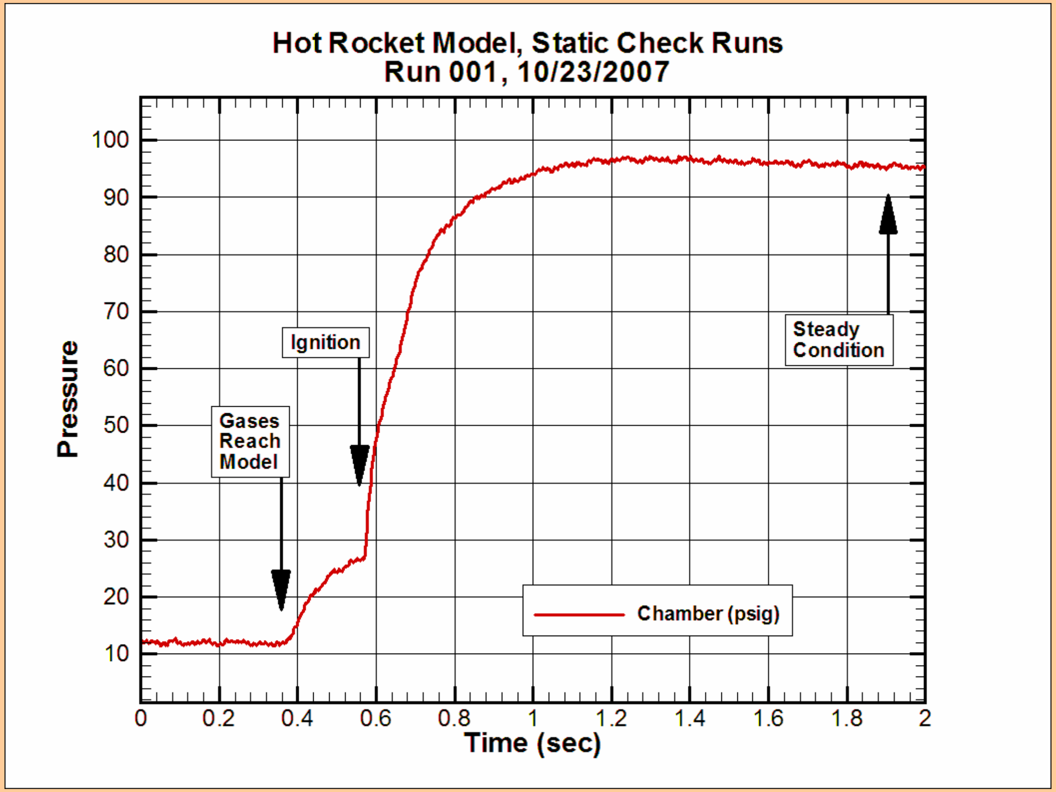


Close-up view of the model in the test section showing the modified support strut

Hydrogen Powered Nacelle Sting Model for NCPA 12 X 12 Inch Tunnel

Rocket Model Ignition With Gaseous Hydrogen And Oxygen



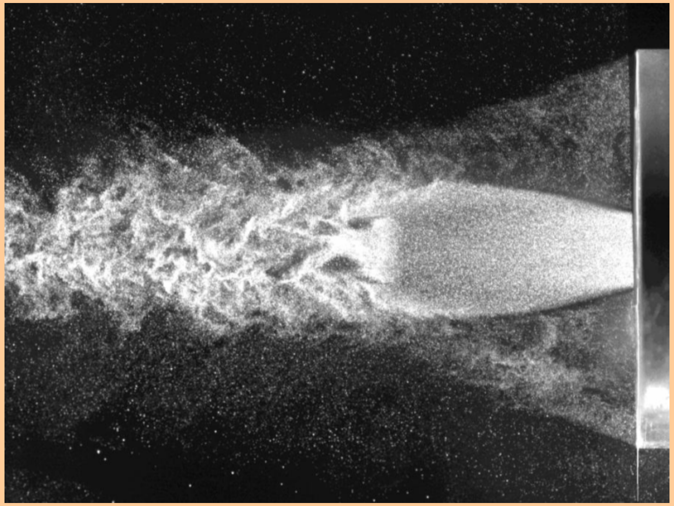


Summary of Test Runs Analyzed

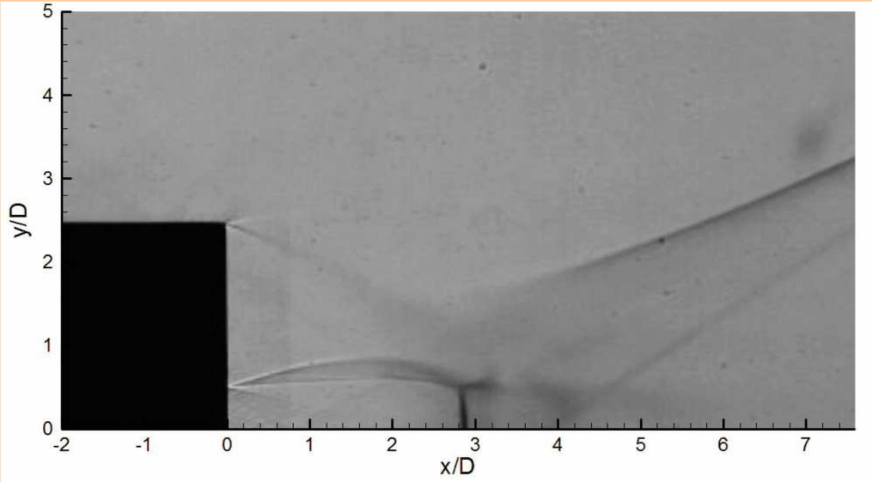
Mixture Type	Chamber Pressure P_C (psia)	Tunnel Static Pressure P_s (psia)	q (psi)	Equivalent Altitude (feet)	AFR	$mdot_{TOTAL}$ (lb_m/s)	$mdot_{Hydrogen}$ (lb_m/s)	$mdot_{Oxygen}$ (lb_m/s)	Command $P_{1(Hydrogen)}$ (psia)	Command $P_{1(Oxygen)}$ (psia)
Fuel Rich	210.82	5.99	16.77	22822	3.79	0.04437	0.00926	0.03511	455.29	362.12
Stoichiometric	216.67	5.97	16.72	22899	7.96	0.05217	0.00582	0.04635	285.75	473.04
Fuel Lean	210.24	5.98	16.74	22860	9.01	0.05452	0.00545	0.04907	266.48	499.31
Fuel Rich	220.64	7.45	20.86	17628	3.81	0.04489	0.00933	0.03556	456.36	365.22
Stoichiometric	215.53	7.45	20.86	17628	7.89	0.05227	0.00588	0.04639	287.93	474.34
Fuel Lean	208.80	7.45	20.86	17628	9.01	0.05430	0.00542	0.04888	265.88	499.40

Rocket Plume PIV Measurements & Schlieren

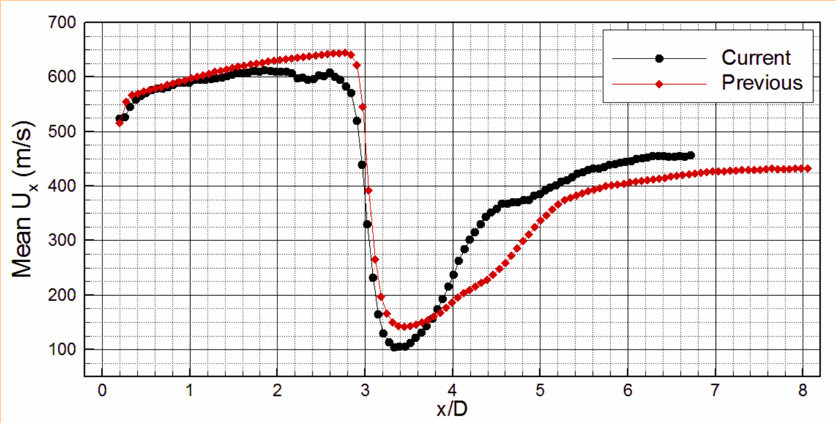
Heavily Laden Rocket



Correct Seeding Level



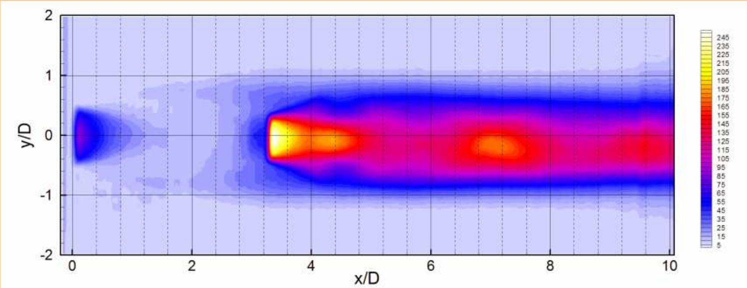
a. Avg of 2000 schlieren images



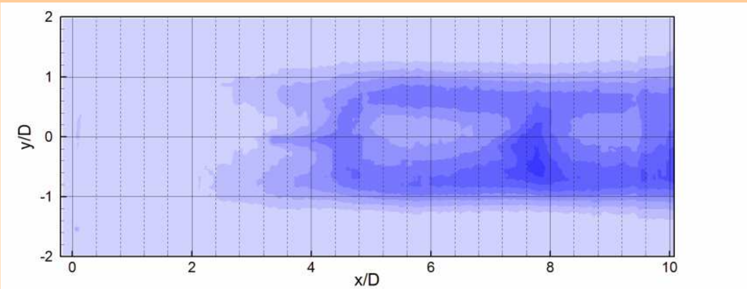
Centerline Velocity Profile

Preliminary Results

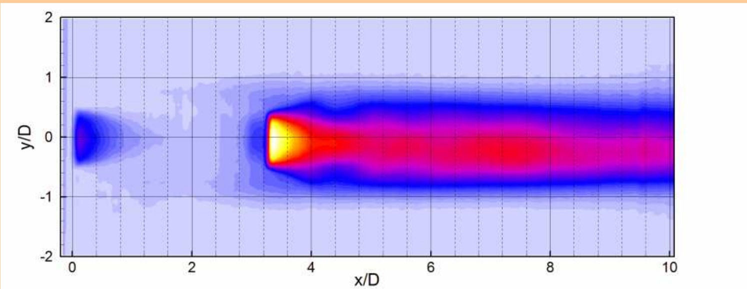
Ps = 6 psi



Stoichiometric

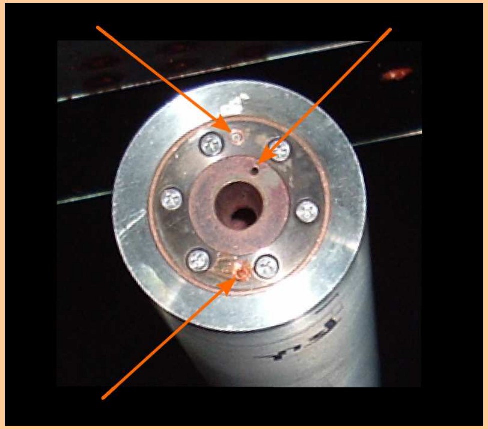


Fuel Rich



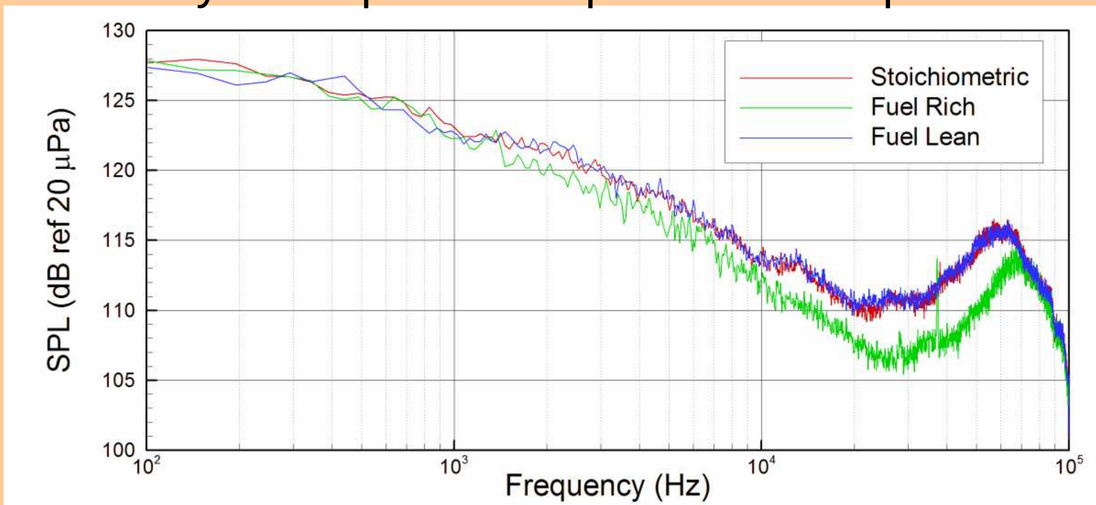
Fuel Lean

Dynamic Pressure **PIV Seed Port**



Temperature

Dynamic pressure spectra Ps = 6 psi



BWS Improvement by Flow Control

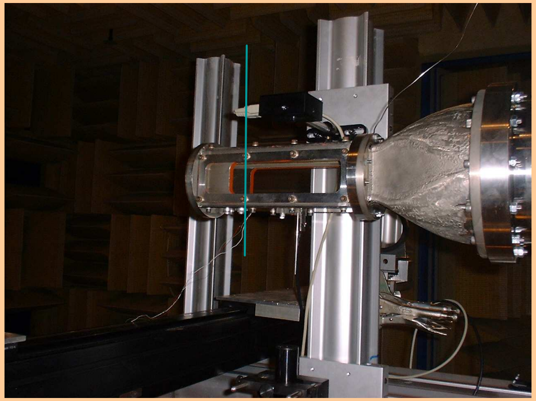
Flow Over a Cavity & a Bubble

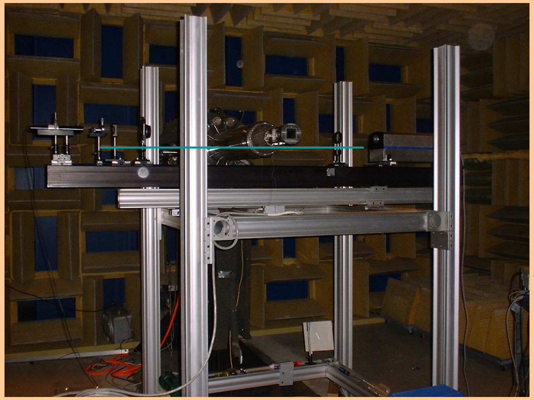
Program
Funded by AFOSR and AFRL/VA

Objective:

Evaluate Ability of Flow Control to Facilitate Capability of Beam to Reach Target Intact

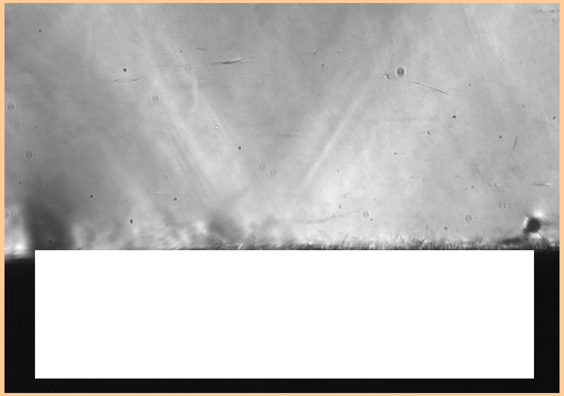
- **Experiments In NCPA Anechoic Jet Lab:**
  - **Flow characteristics evaluated by flow visualization and Particle Image Velocimetry**
  - **Beam quality evaluated by beam wander and wave front distortion measurements**
- **Initial investigation with impinging jet flows and resonating cavities.**



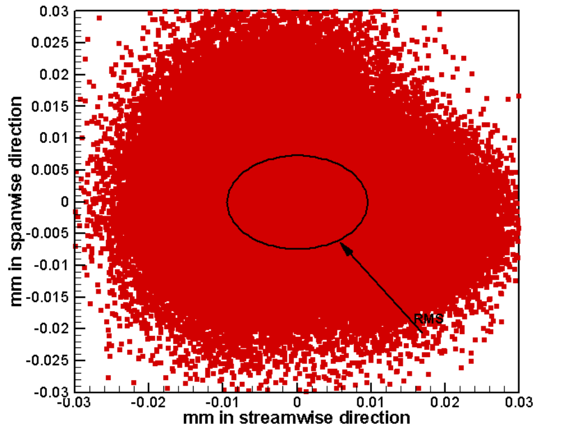


BWS Program

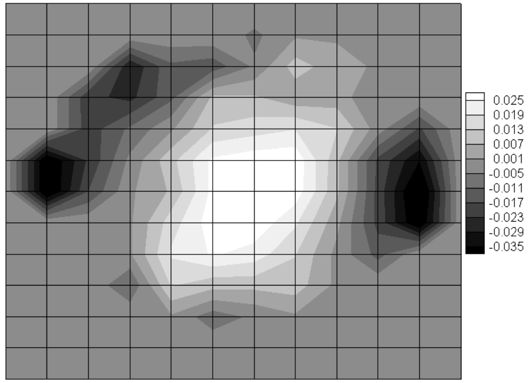
Schlieren



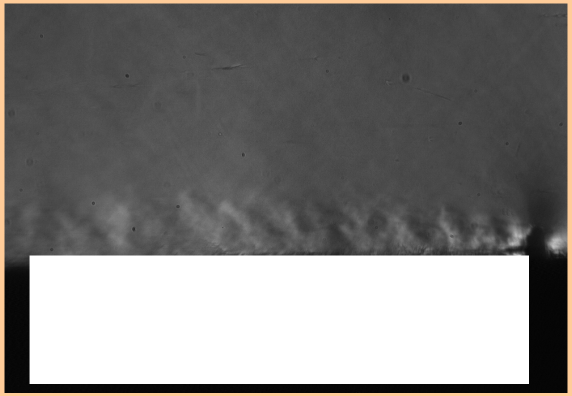
Wander

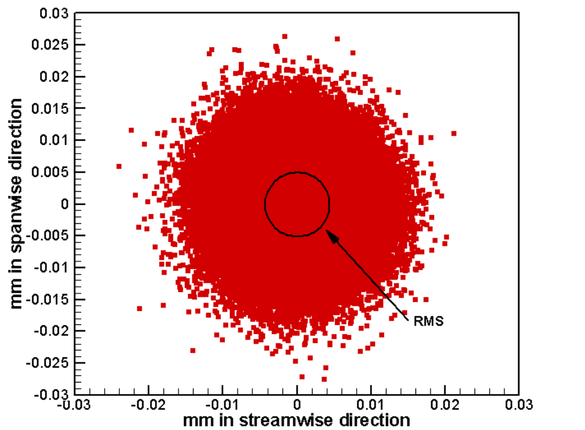


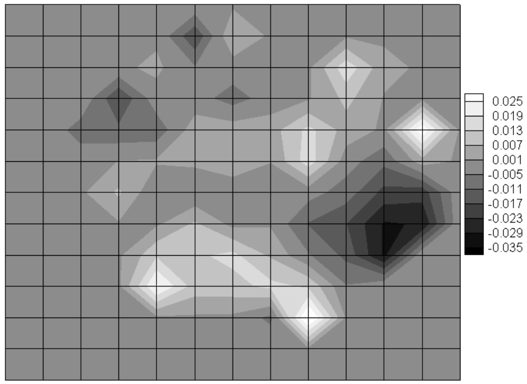
OPD



Without flow control

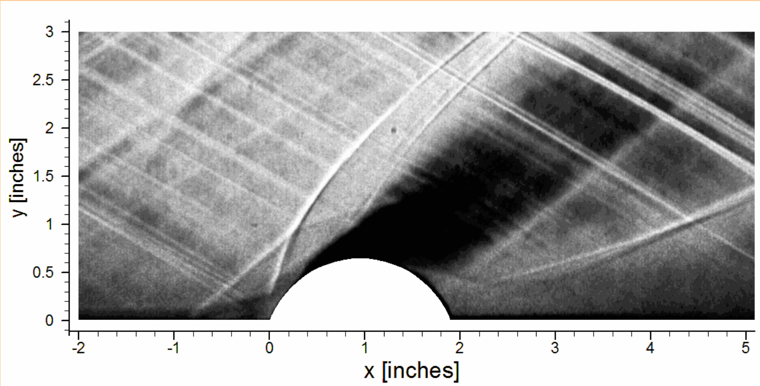




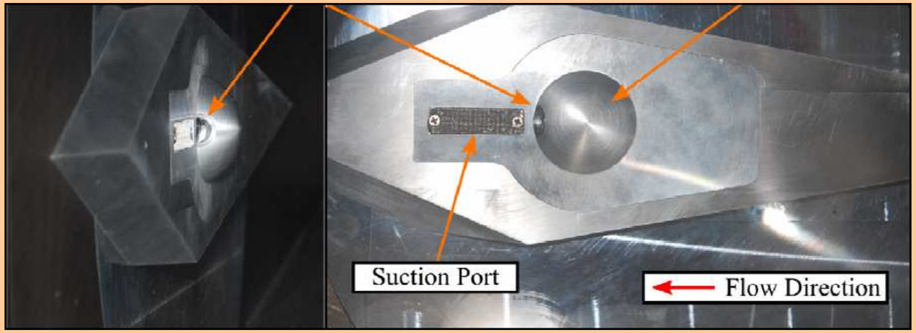


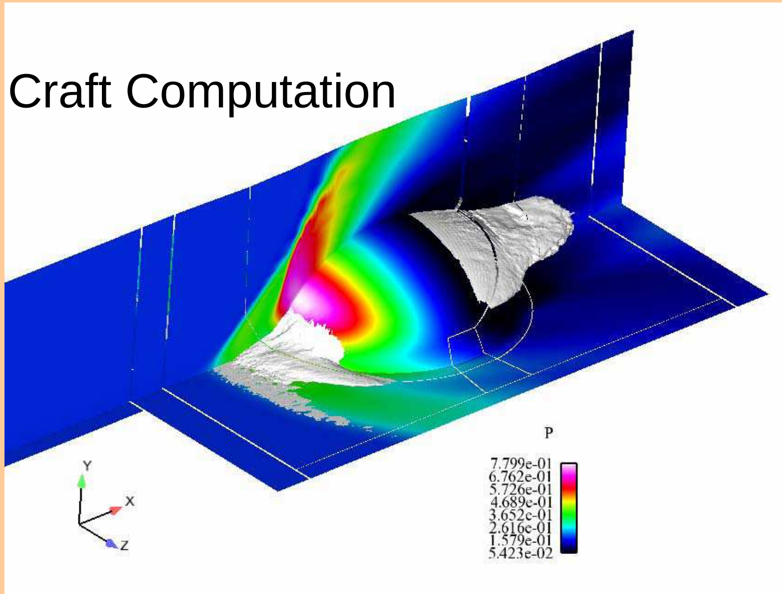
With flow control

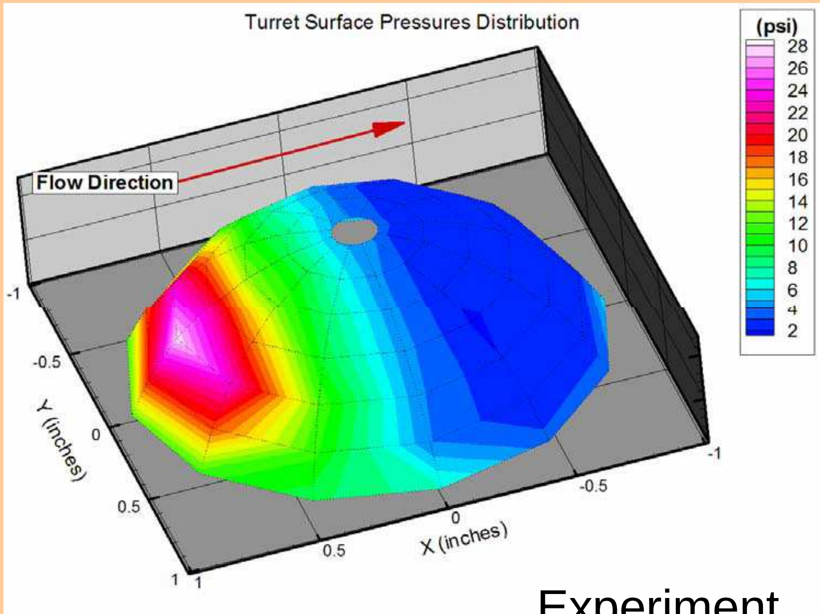
BWS Experiment at Mach 2 & 6.7 km



Flow Direction

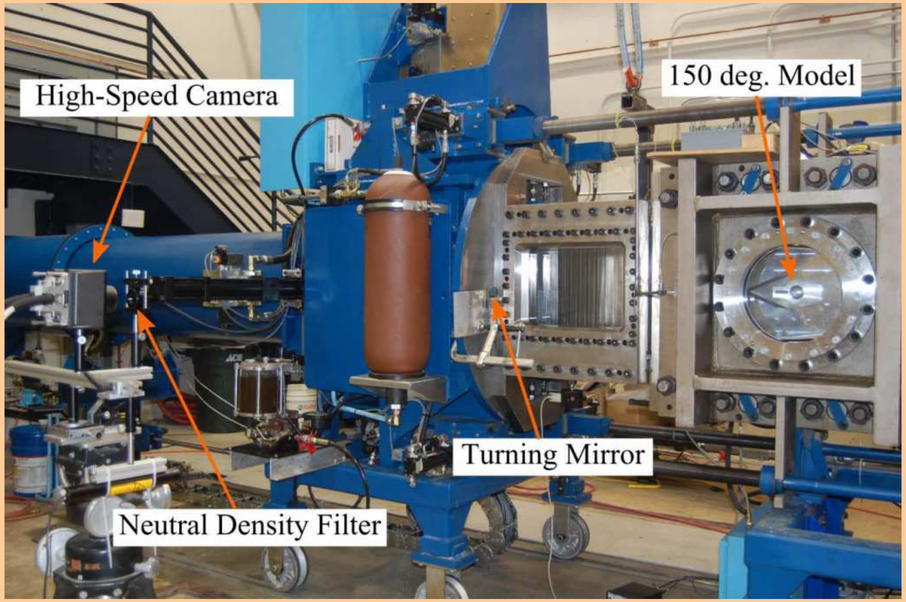


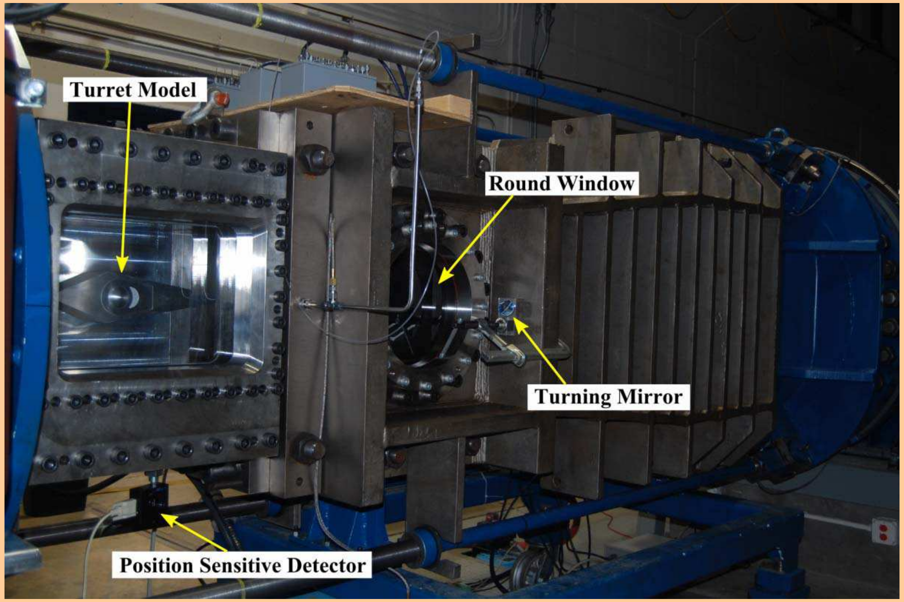


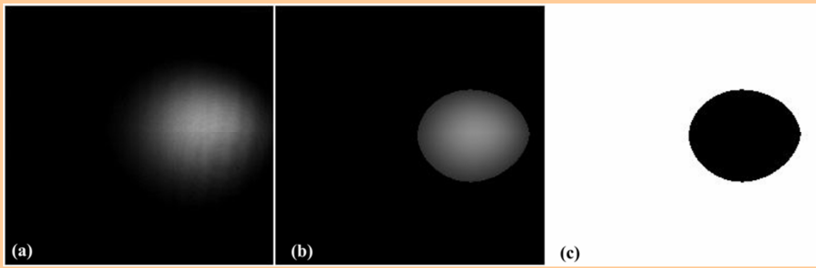


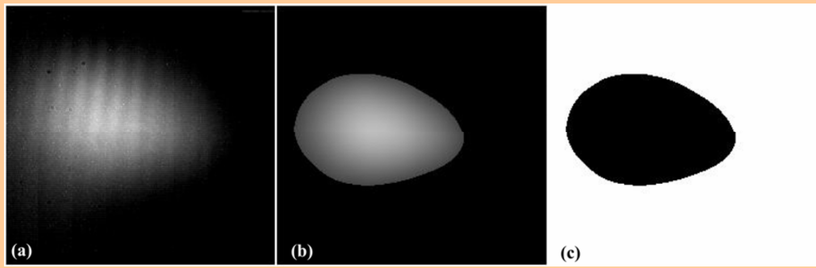
Experiment

Beam Wander & Spread Over a Bubble at Mach 2









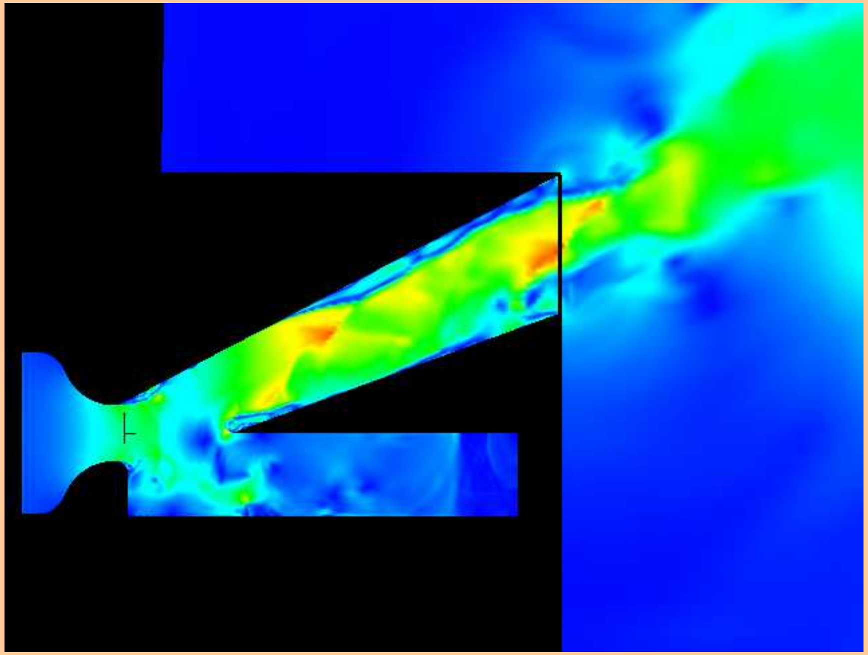
Wind-OFF **Wind-On**

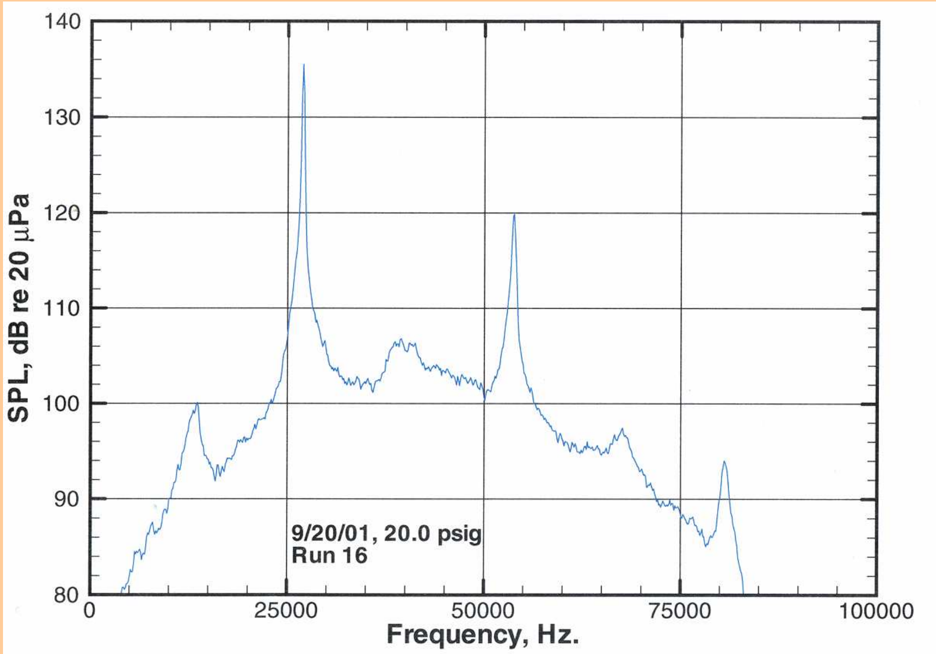
ImageJ processing steps: (a) the raw 256x256 image, (b) Gaussian blur and threshold applied to image, (c) image converted to binary

Improved Scramjet Combustion Efficiency

Scramjet Combustion – Powered Resonance Tubes

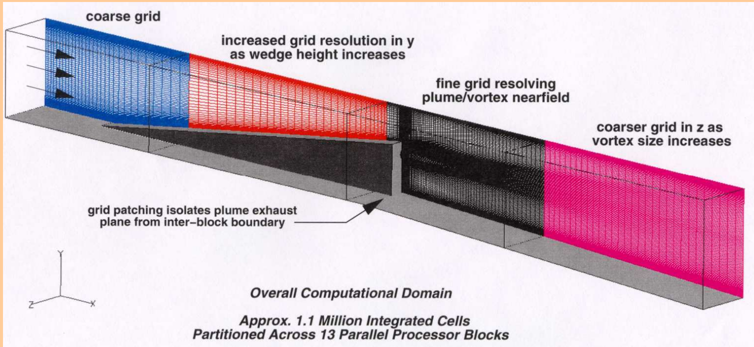
High Frequency Actuator



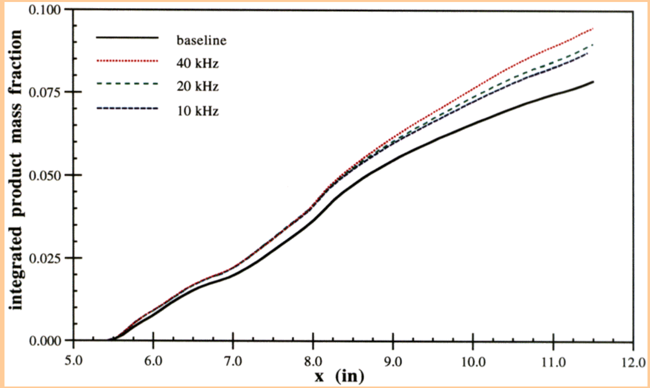


Scramjet Oscillating And Pulsatile Hydrogen Fuel Injectors

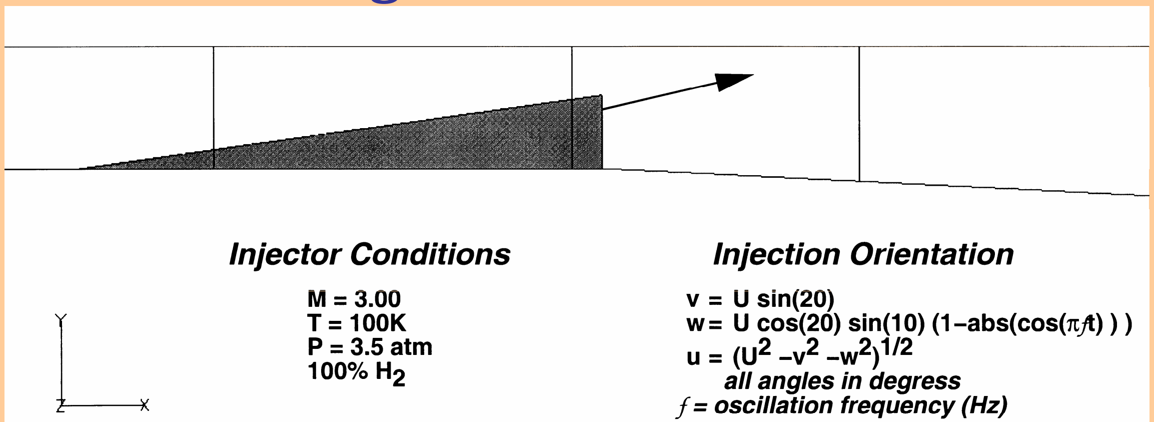
Computational Grid Volume



Improved Combustion Efficiency



Ignition Details



Injector Conditions

M = 3.00
T = 100K
P = 3.5 atm
100% H_2

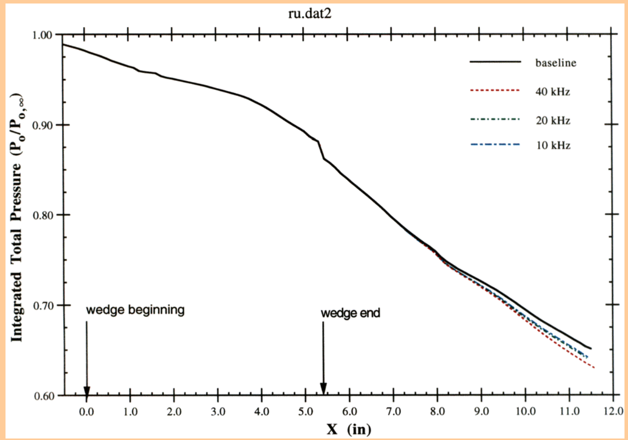
Injection Orientation

$v = U \sin(20)$
$w = U \cos(20) \sin(10) (1 - abs(\cos(\pi f t)))$
$u = (U^2 - v^2 - w^2)^{1/2}$
all angles in degrees
f = oscillation frequency (Hz)

Complete (Infinite Rate) Combustion Modeling

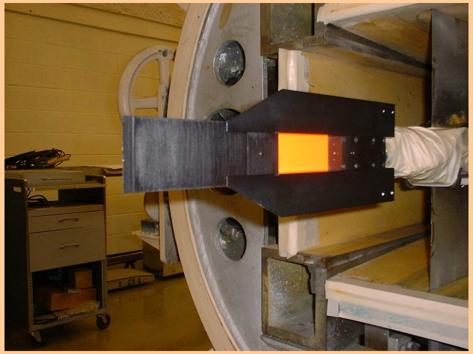
Fuel + Oxidizer –> Product
$H_2 + 2.381 (0.79N_2 + 0.21O_2) \rightarrow H_2O + 1.881N_2$

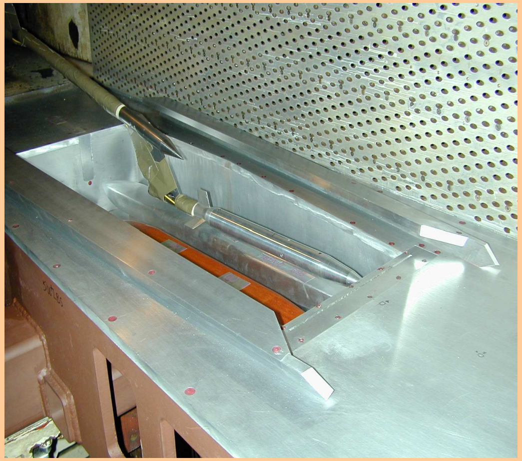
Aero Performance



Off- Site Weapons Bay Research

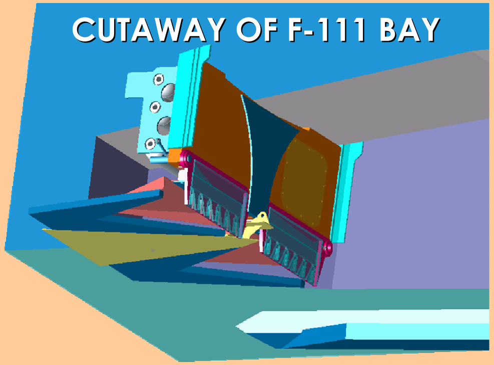
- Air Force Academy Aug.-Oct. 2001
- DERA, Bedford, England, March 2002
- AEDC, Tullahoma, TN, June 2002.
- Lockheed Georgia, Atlanta, Aug. 2002
- F111 Aircraft Flight Test, Australia, June 2004.





Weapons Bay Cavity Research
Australia Flight Test Program

- Flight test minimize pressure loads in weapons by cavity will be conducted in conjunction with AFRL/VA and AFRL/MN using an RAAF F-111 in the spring of 2004.
- Actuator concept (jointly designed by NCPA and CRAFT Researchers) has been verified through a series of experimental tests at U.S Air Force Academy, DERA (U.K.), AEDC and Lockheed Marietta.
- NCPA personnel responsible for all acoustic/pressure data analysis.



Predicting the Velocity Field

PROPER ORTHOGONAL DECOMPOSITION - POD

$$R_{ij}(\vec{x}, \vec{x}') = \langle u_i(\vec{x}, t) u_j(\vec{x}', t) \rangle$$

$$\int_\Omega R_{ij}(\vec{x}, \vec{x}') \phi_j^{(s)}(\vec{x}') d\vec{x}' = \lambda^{(s)} \phi_i^{(s)}(\vec{x})$$

$$u_i(\vec{x}, t) = \sum_s \alpha^{(s)}(t) \phi_i^{(s)}(\vec{x})$$

QUADRATIC STOCHASTIC ESTIMATION - QSE

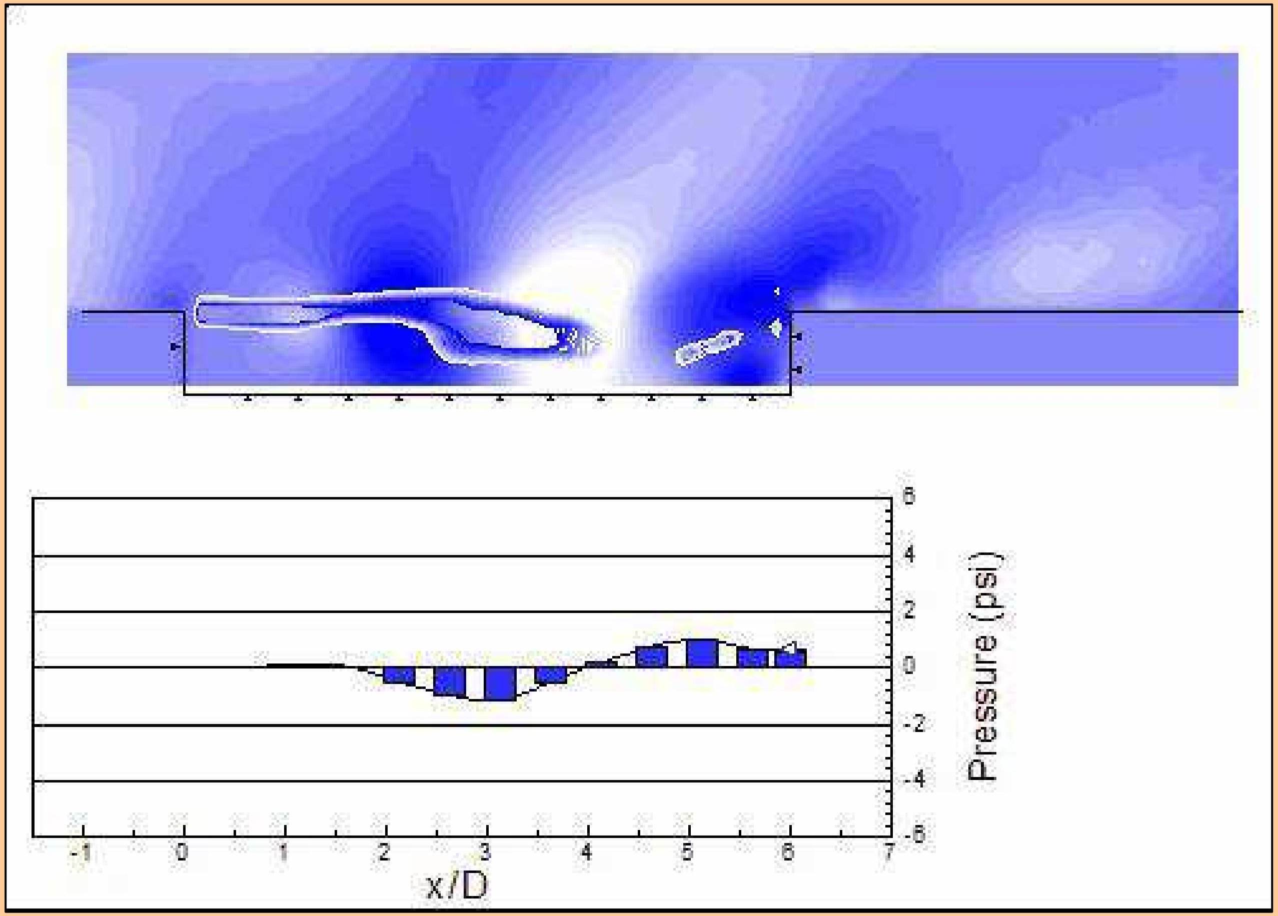
$$\tilde{\alpha}^{(s)}(t) = A_k^{(s)} P_k(t) + B_{qr}^{(s)} P_q(t) P_r(t)$$

MODIFIED QSE - ESTIMATING THE VELOCITY DYNAMICS

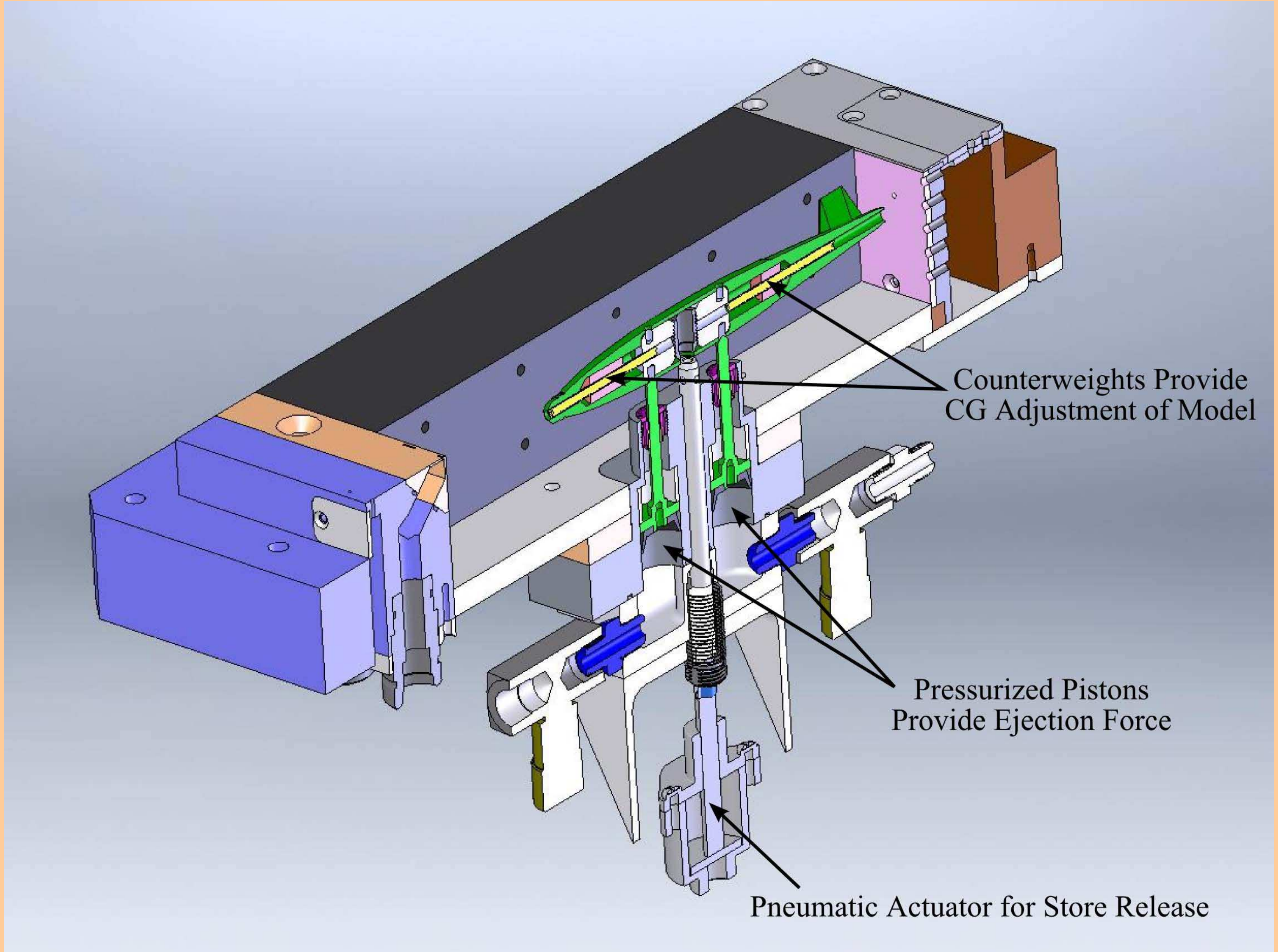
Combining POD and QSE allows estimation of the time-dependent velocity field from surface pressure measurements using a database of 2-point statistics.

Predicting the Velocity Field

EXAMPLE OF mQSE OF CAVITY FLOW



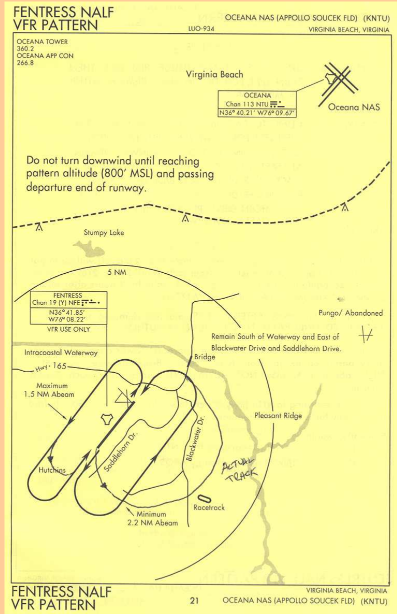
Store Release Mechanism



Store Release With Loads Suppression

Store Release With Suppression

Noise Impact on US Naval Missions

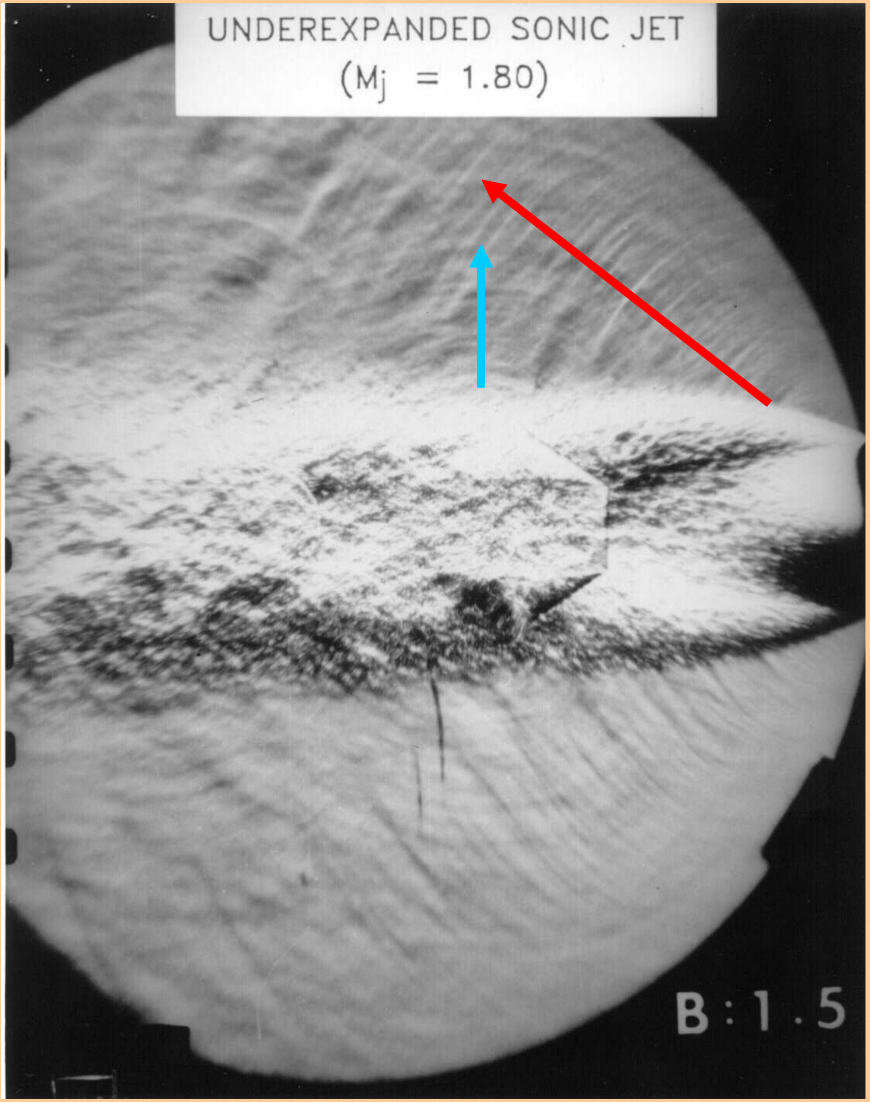


- **Community Noise Impact During The Field Carrier Landing Practice (FCLP) Mission**
- **Naval Crew Hearing Loss Associated With Carrier Deck Launch and Retrieval of Aircraft.**

Carrier Deck Mission Launch With Jet Blast Deflector - JBD

1. Final Checker
2. Final Checker
3. JBD Operator
4. Misc. Cat Crew
5. Arming Crew
6. Arming Crew
7. Arming Crew
8. Holdback Man
9. Topside Petty Officer
10. Aircraft Director
11. Misc. Cat Crew
12. Weight Board Operator
13. Fuels
14. Fuels
15. Chocks, Chains,Tractors

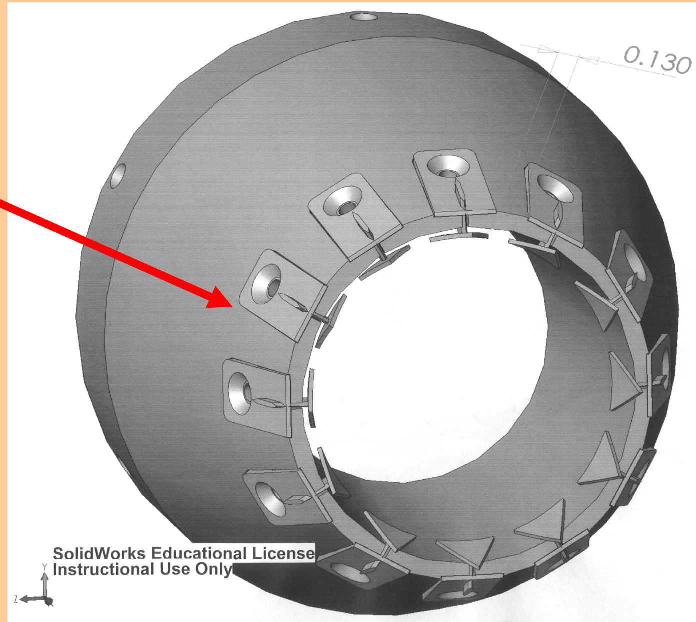
Mach Wave Emission & Shock Generated Noise



Both Mach Wave and Shock Noise Sources are Extremely Efficient Producing Noise Energy That Is Approximately 0.1% of the Total Mechanical Jet Power.

Aero-Performance Efficient Suppression Concepts Investigated

- Outer Flap Chevrons
- Inner Seal Detached Chevrons
- Corrugated Engine Seals
- High Pressure Water Jet Spray
- Beveled Exhaust Nacelle

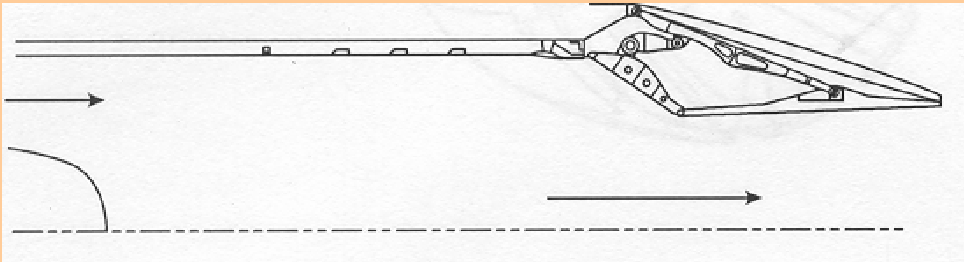


Configurations:

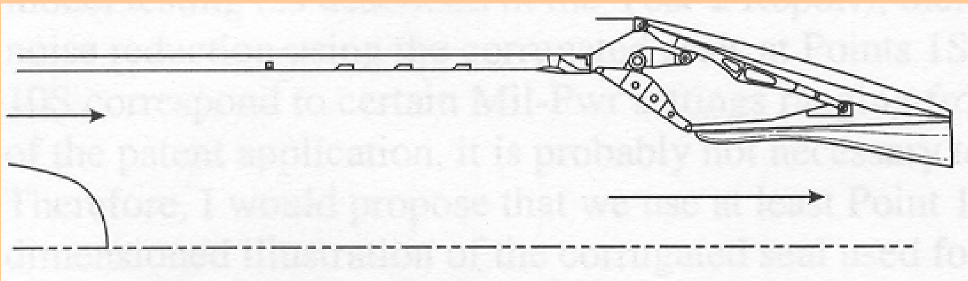
•1/10'th Scale Model Single Jet Nacelle, NCPA
•1/10'th Scale Model Twin Jet Nacelle, NCPA
•1/5'th Scale Model Single Jet Nacelle, Boeing LSAF
•F404-400 GE Engine Thrust Stand at NAWCADLKE

Modified Internal Secondary Seal

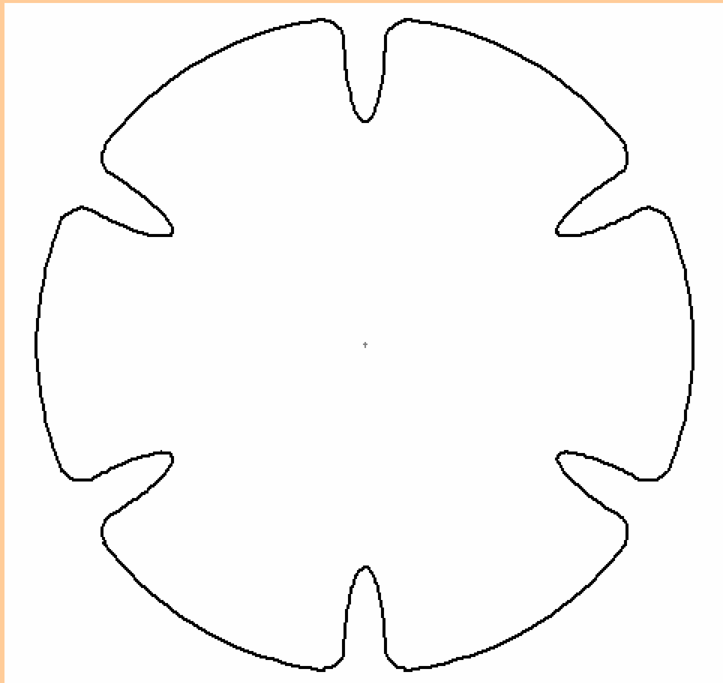
Unmodified GE F404-400 Engine



Modified GE F404-400 Engine



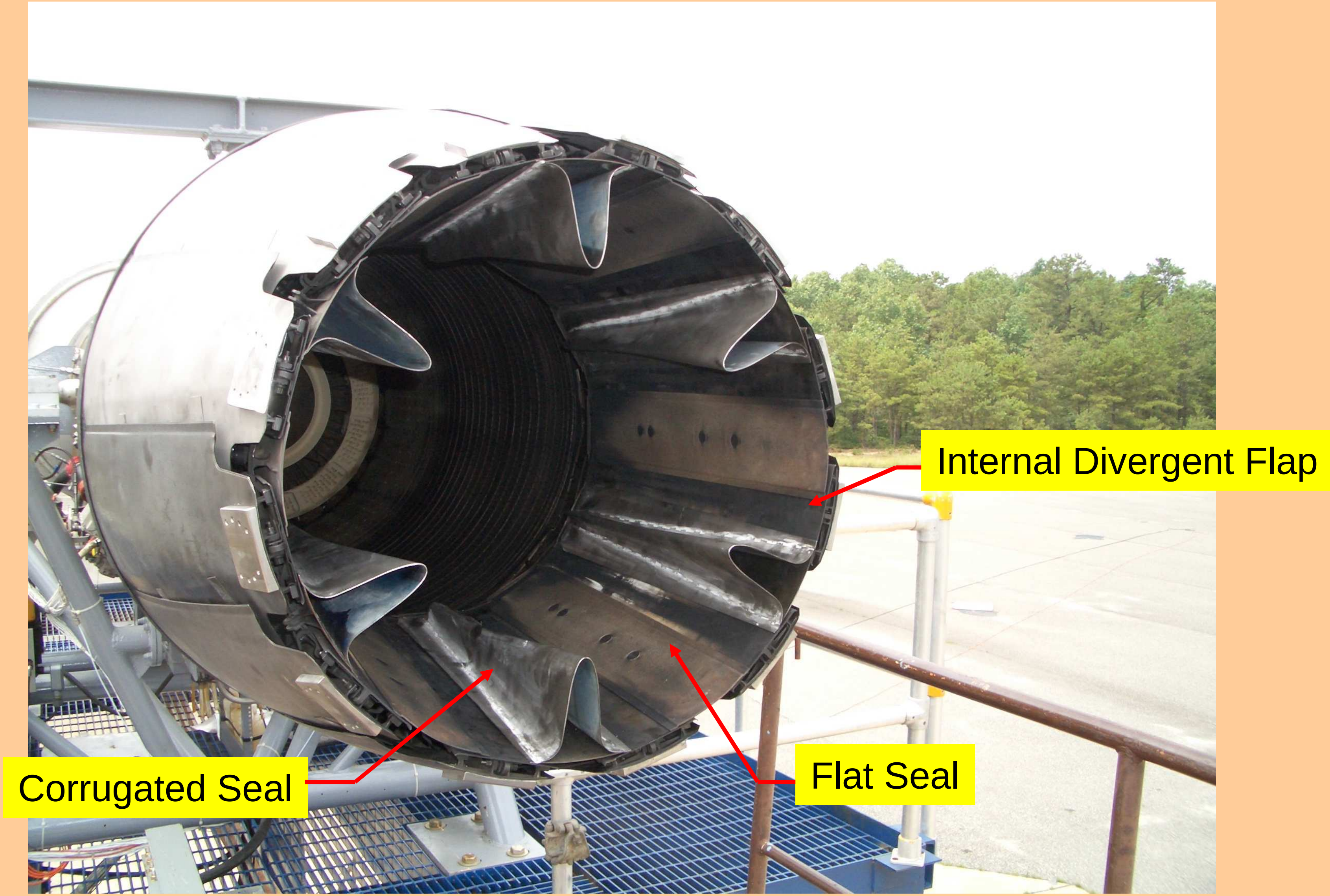
Engine Exit Profile Design For 6



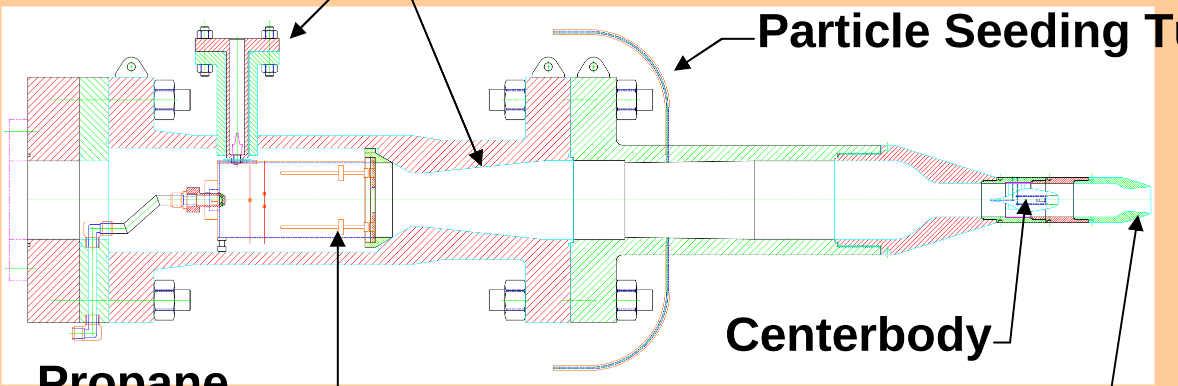
Corrugated Engine Seal Concept

- **MOC Based Design**
- **Shock Noise Elimination**
- **Mixing Noise Reduction Due to Enhanced Mixing With External Stream**
- **Jet Plume Infrared Signature Reduction**
- **Thrust Augmentation**
- **Simple Part to Replace Existing Flat Seals**

GEAE F404-400 Engine at NAWCADLKE With Corrugated Engine Seals



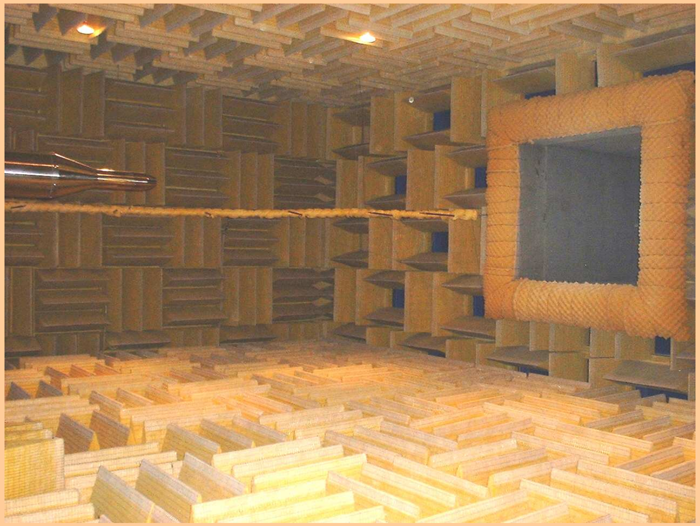
NCPA Jet Noise Laboratory



- •Max. Continuous Flow Rate: 5 Lbm./Sec.
- •Max. Continuous Temp: 2100 Deg. R

<u>**Anechoic Room Properties**</u>

- Low Frequency Cut-Off 200 Hz.
- Microphones mounted at angles
- ψ = 45, 52.5, 60, 75, 90, 105, 120, 127.5, 135, 142.5, 150, and 160 degrees.
- R/D = 55.
- Maximum NPR = 40.
- Maximum Tj = 2100 Deg. R
- Flow Through Wedges

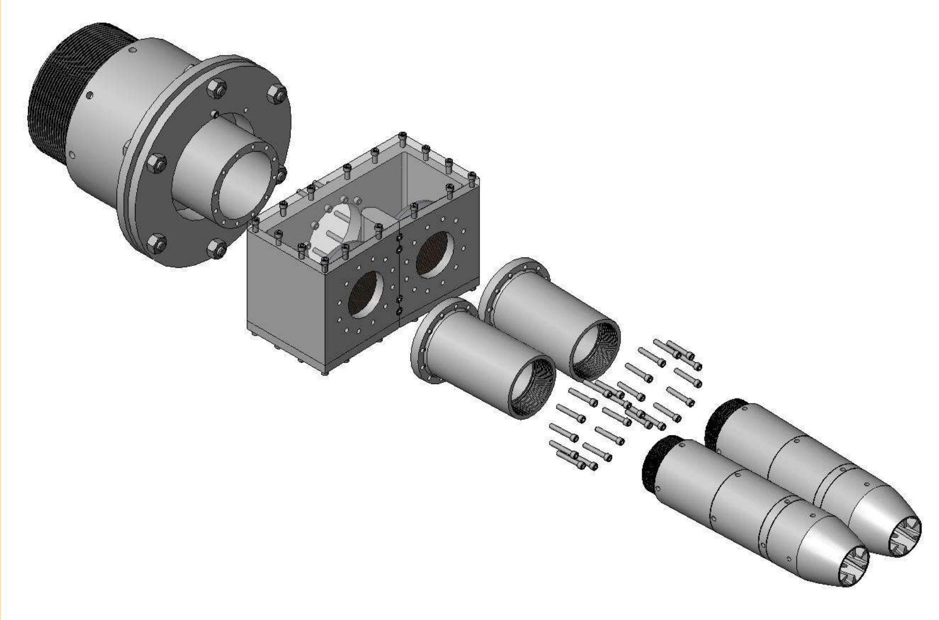


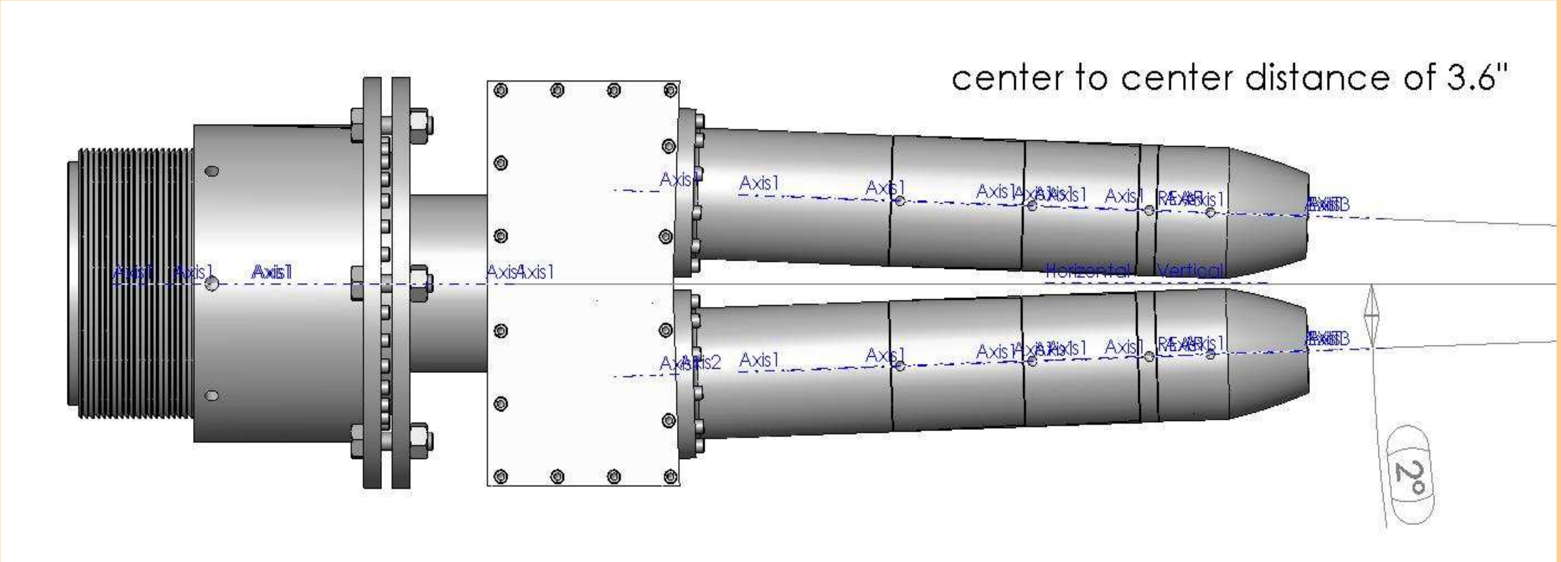
NCPA Fabricated Model Geometry

Corrugated Seal Inserts

Installed Corrugations With Baseline Insert

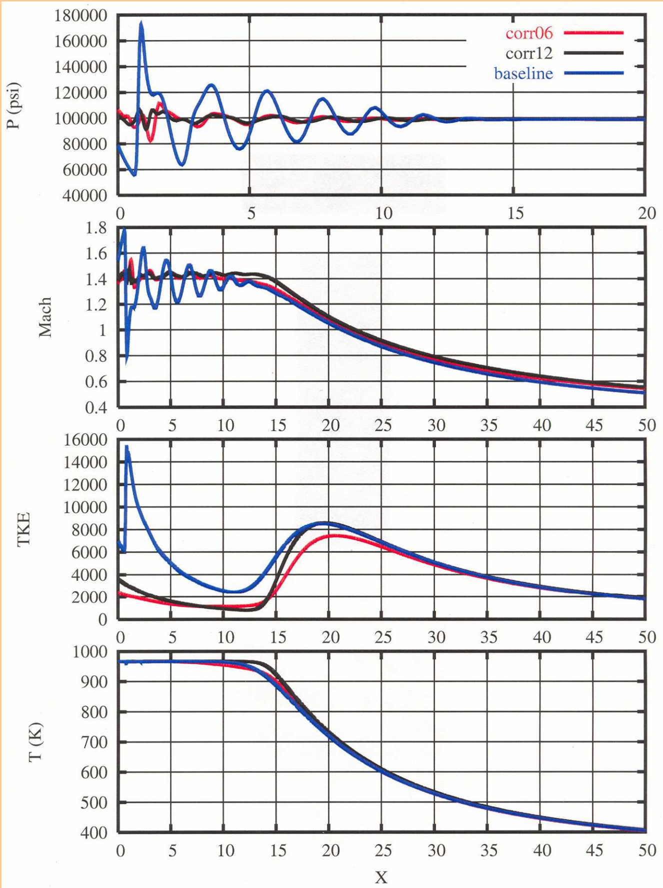
Twin-Jet Setup



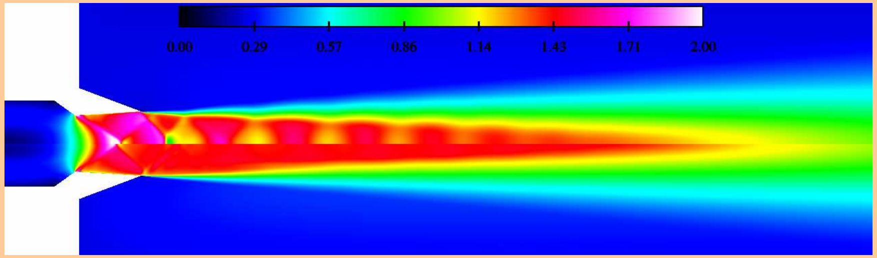


Twin Jet Nacelle In NCPA Jet Noise Lab With Corrugated Seals

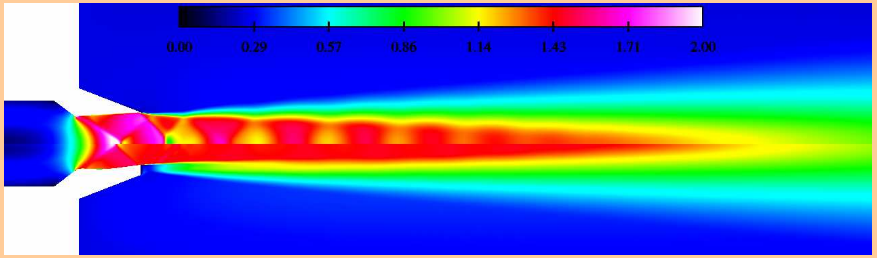
Reduction of Plume Shocks With Corrugated Engine Seals



Mach Number Contours At Military Power

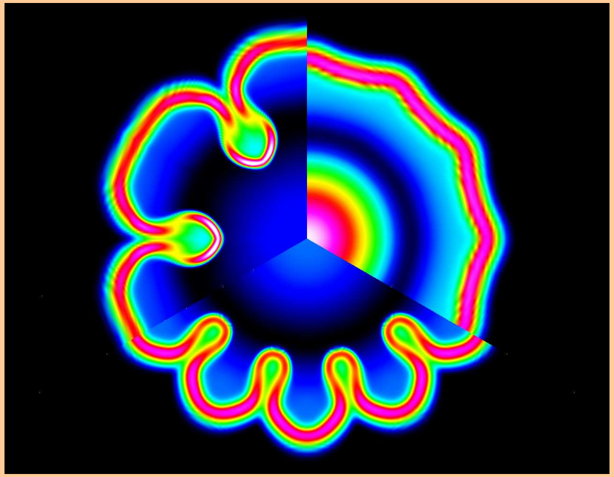


Trough of Corrugation



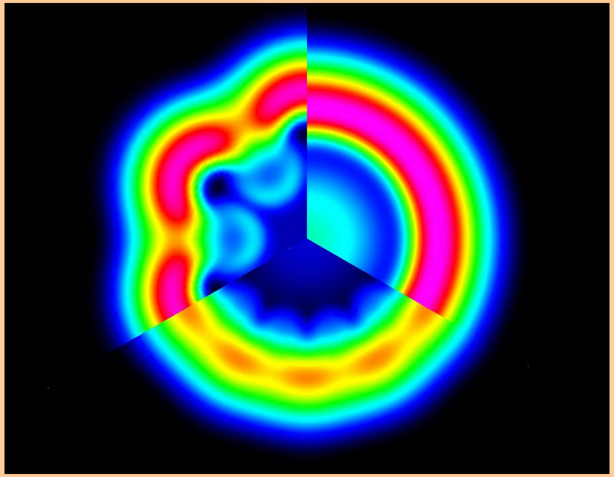
Apex of Corrugation

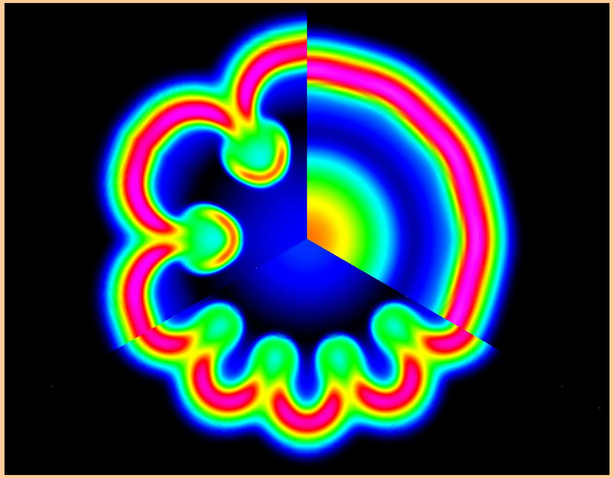
Cross-Plane TKE Predictions



X/D = 1

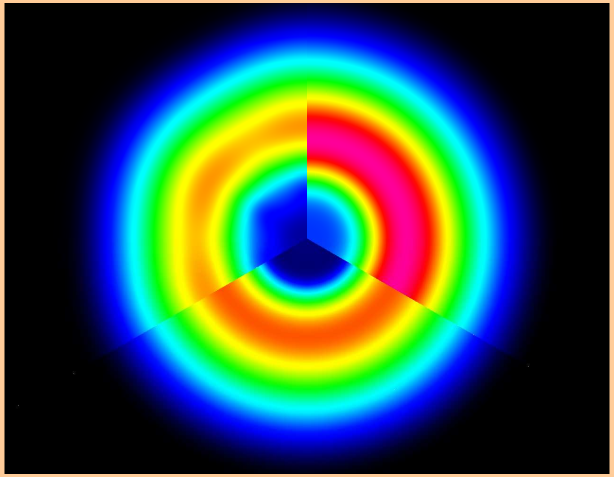
X/D = 5



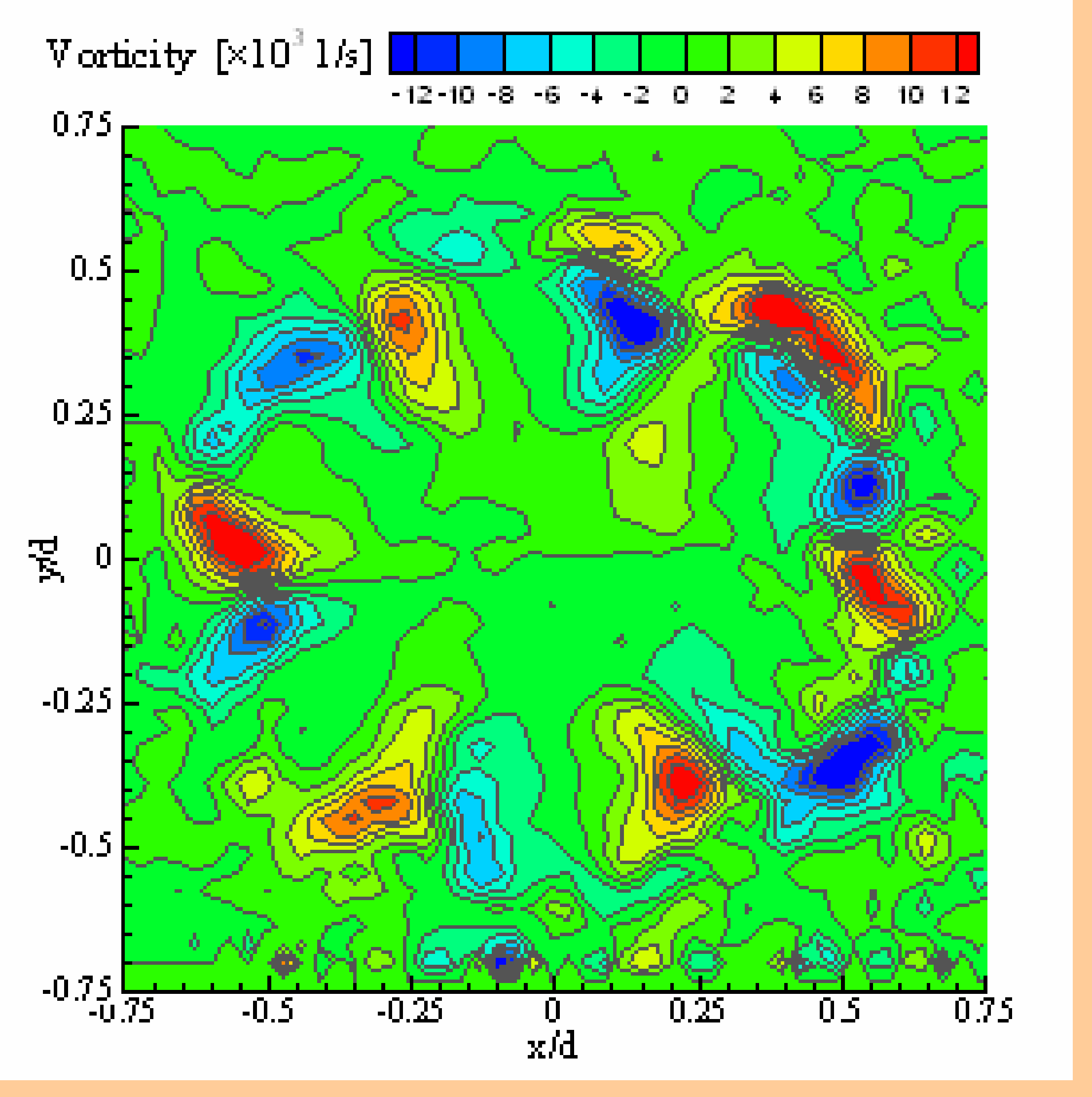


X/D = 2

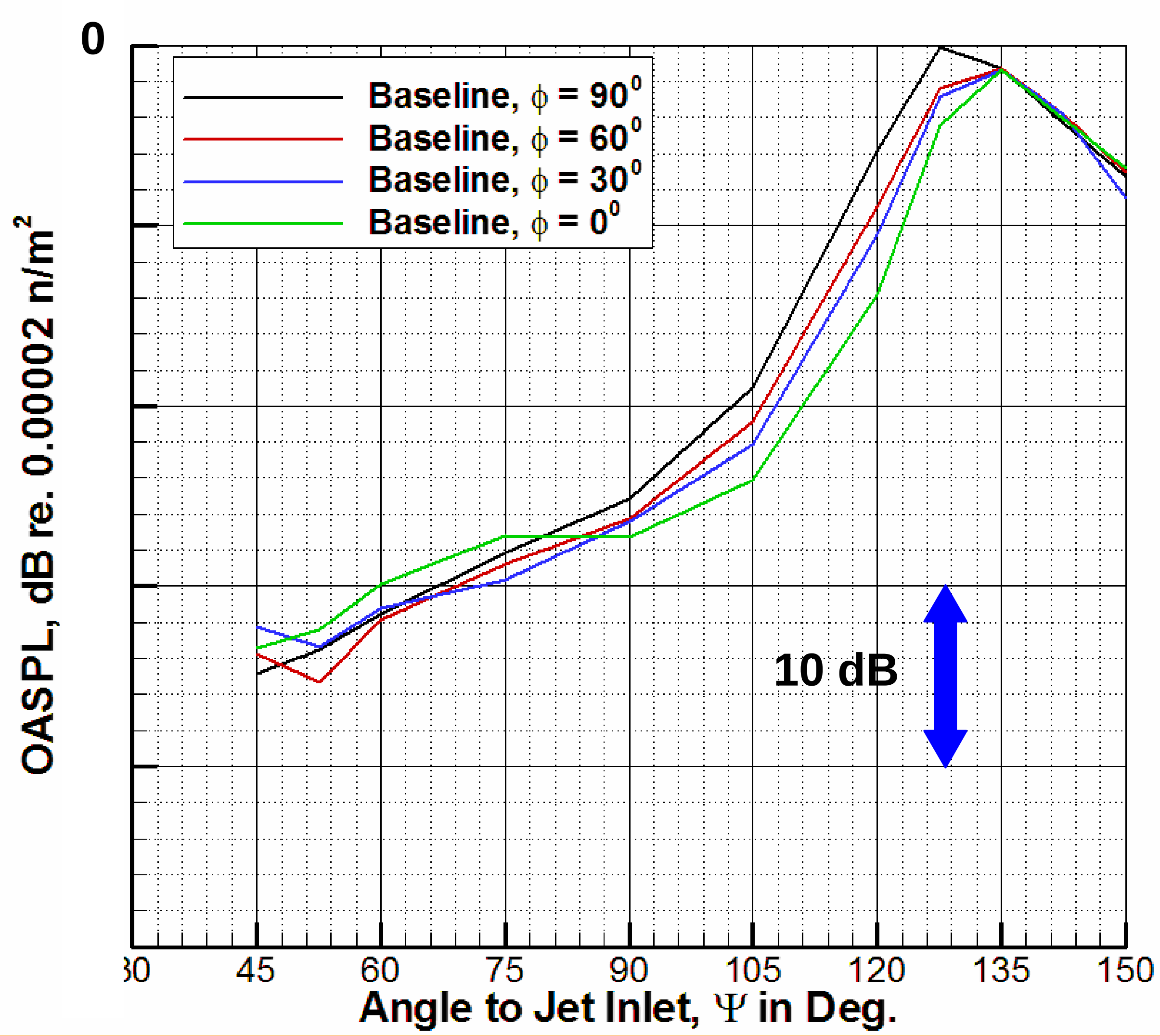
X/D = 10

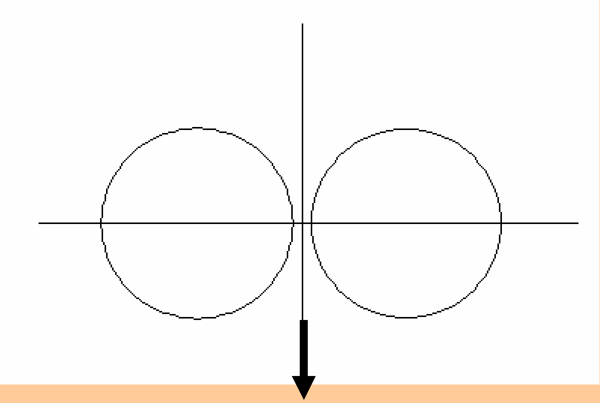


Axial Vorticity at Military Power of Corrugated Nozzle (SPIV)



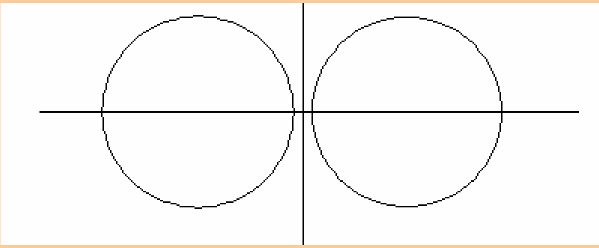
Twin Jet Azimuthal Noise Field
Baseline Faceted Nozzle



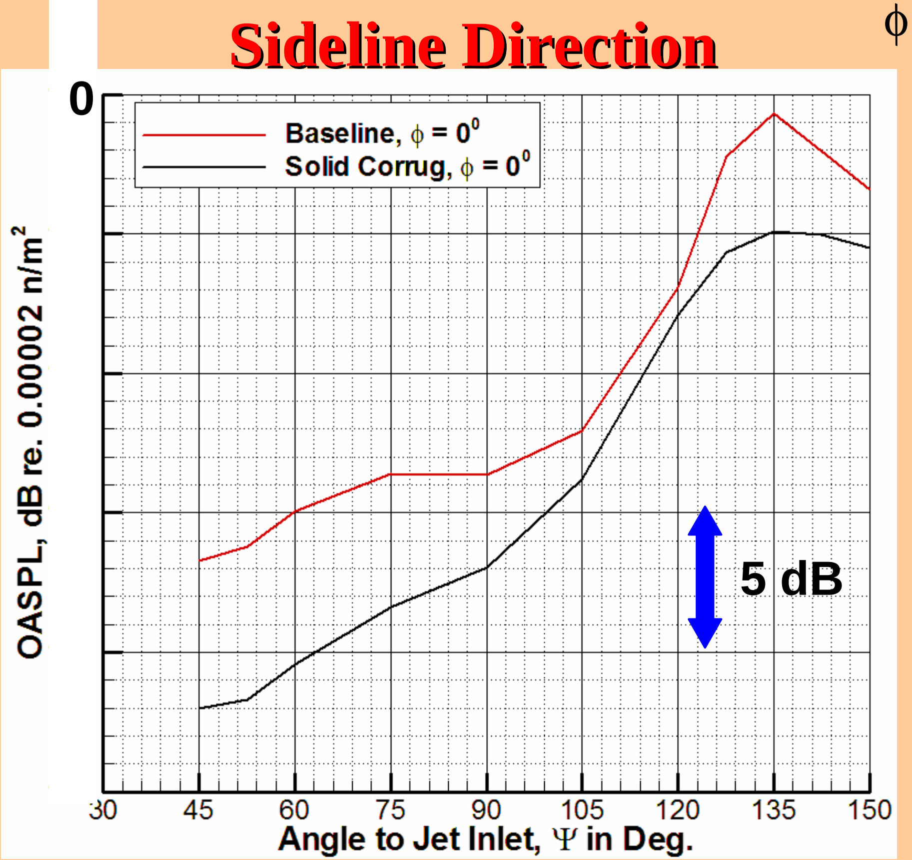


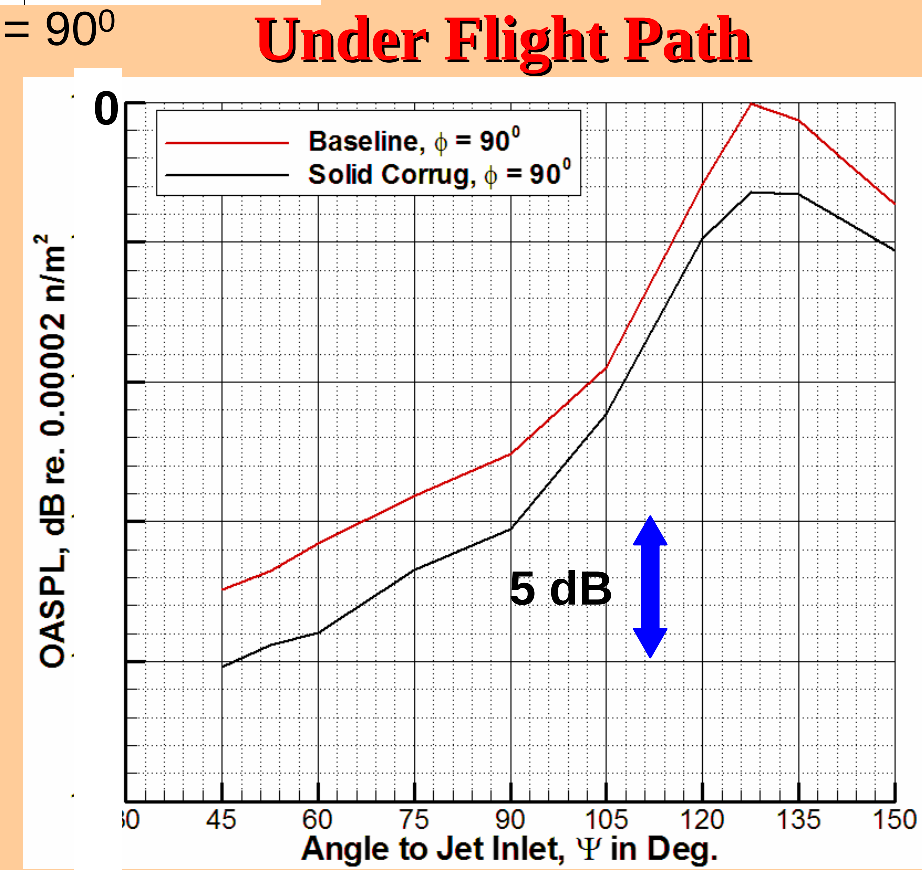
$\phi = 90^0$

Corrugated Seal & Baseline Faceted Twin Jet Nacelle Acoustics



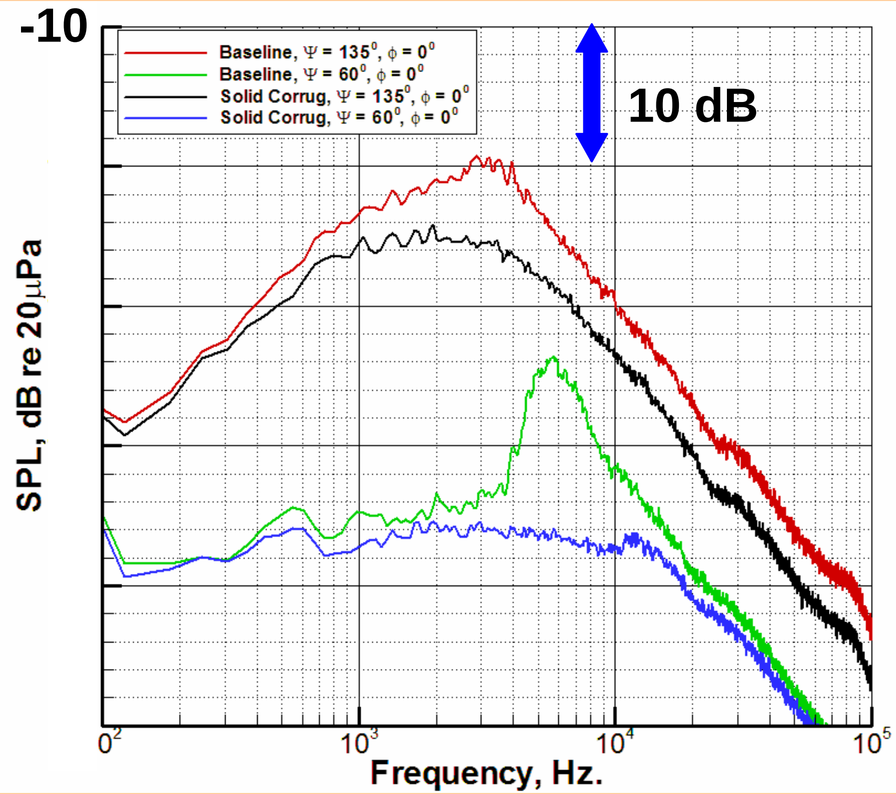
$\phi = 90^0$



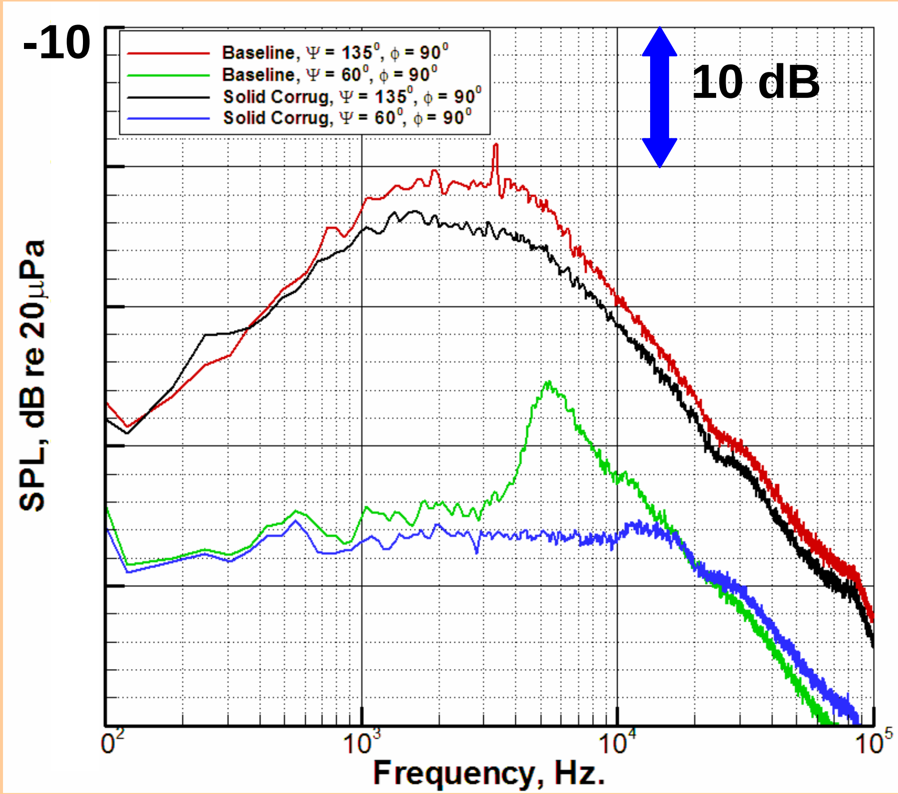


Narrow Band Spectra at Principle Mach Wave and Shock Emission Angles

Sideline Direction

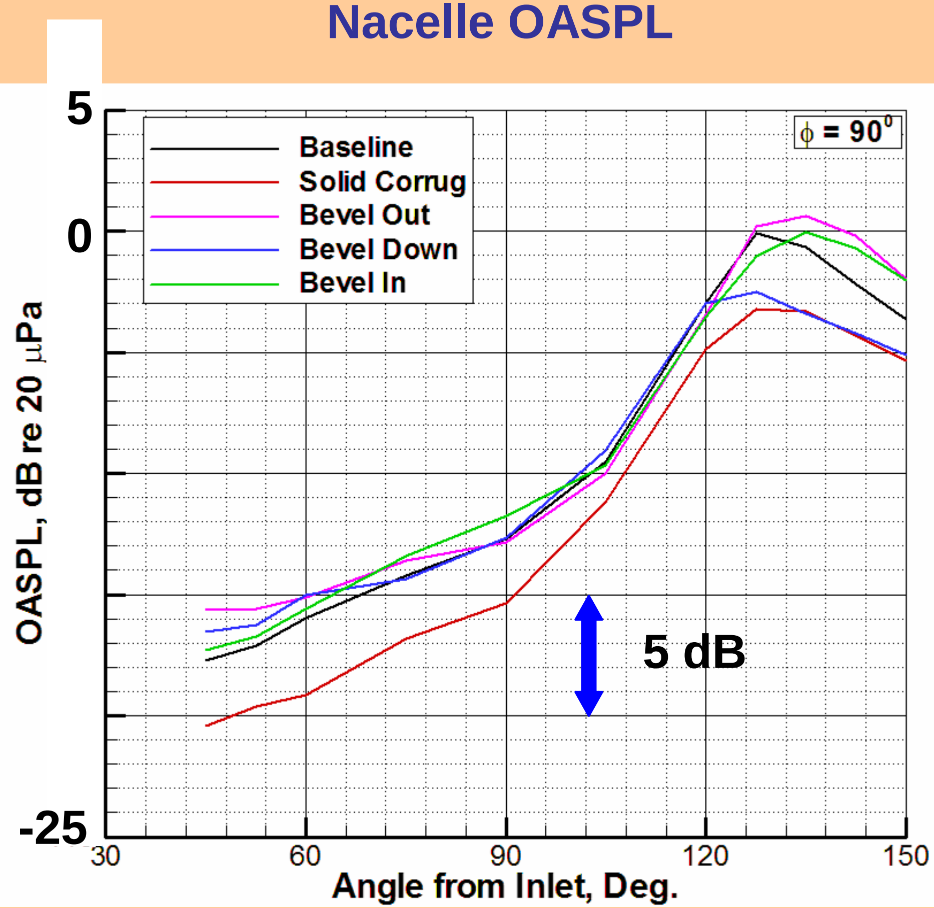


Under Flight Path

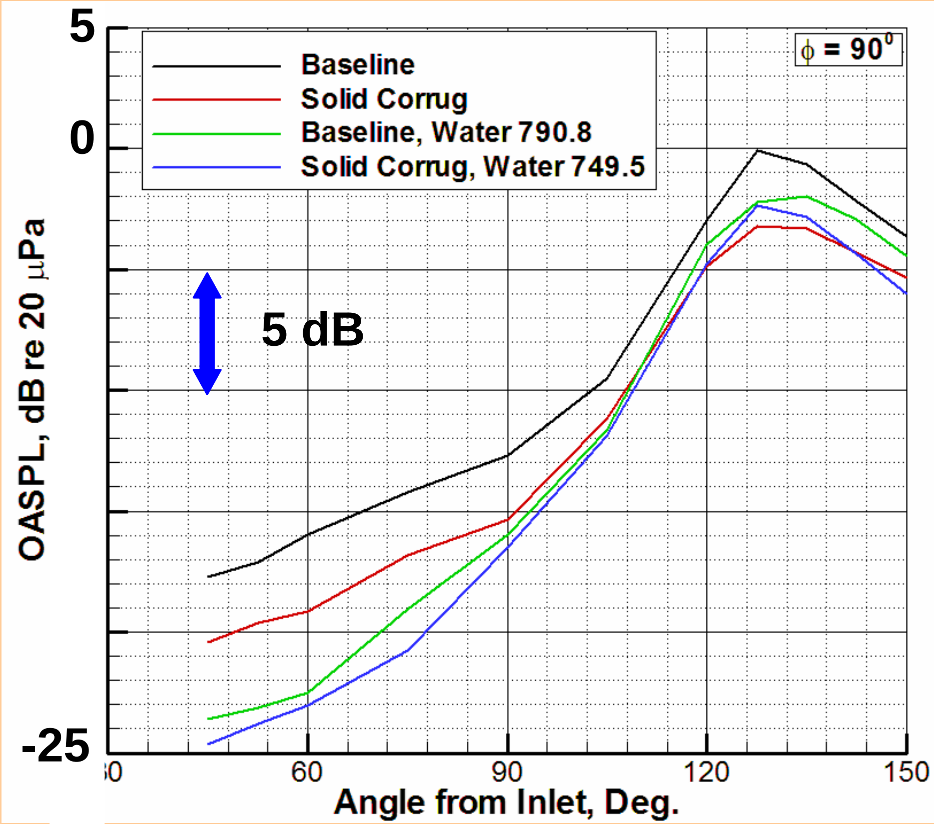


Noise Radiated to Ground Plane

Baseline, Corrugations & Beveled Nacelle OASPL

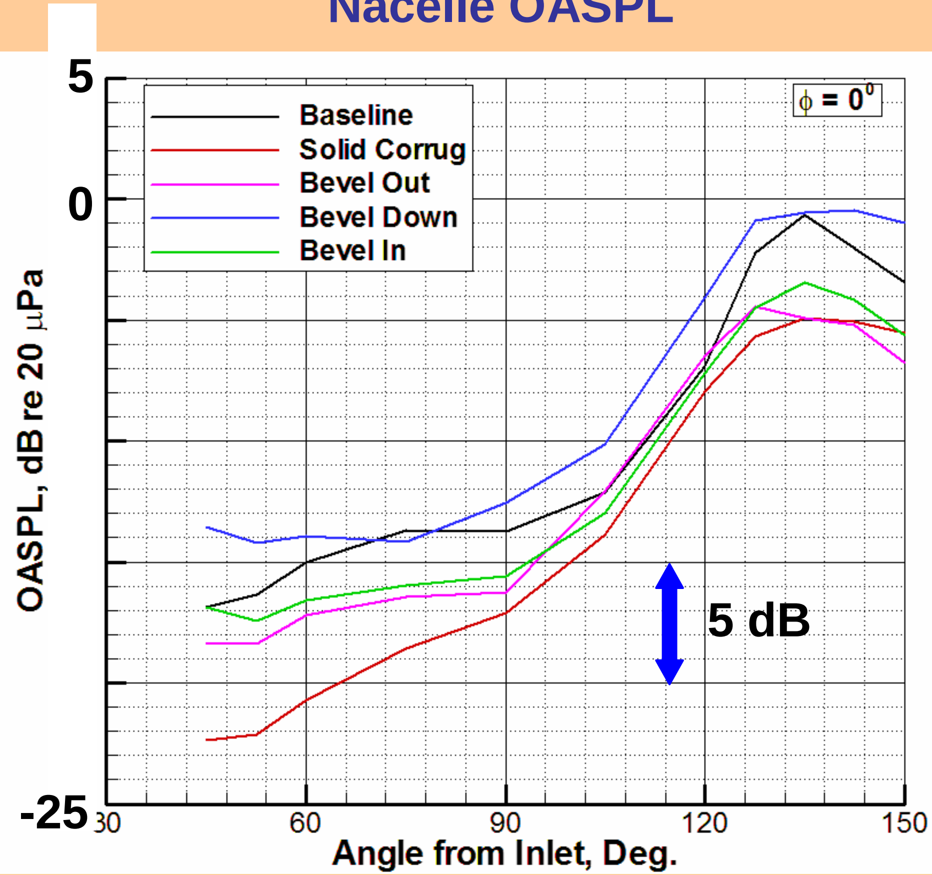


Baseline, Corrugations & Microjets Nacelle OASPL

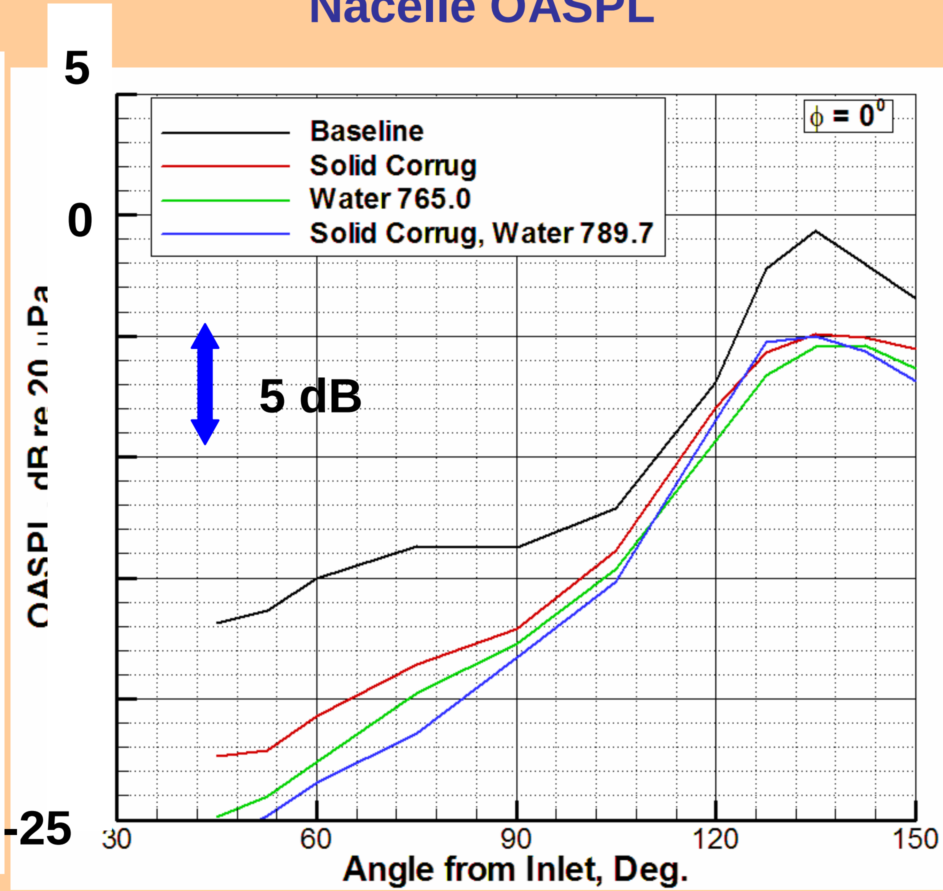


Noise Radiated to Sideline

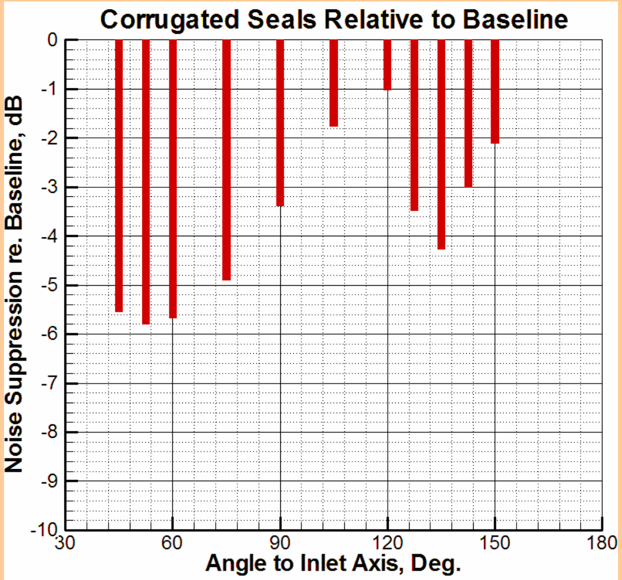
Baseline, Corrugations & Beveled Nacelle OASPL

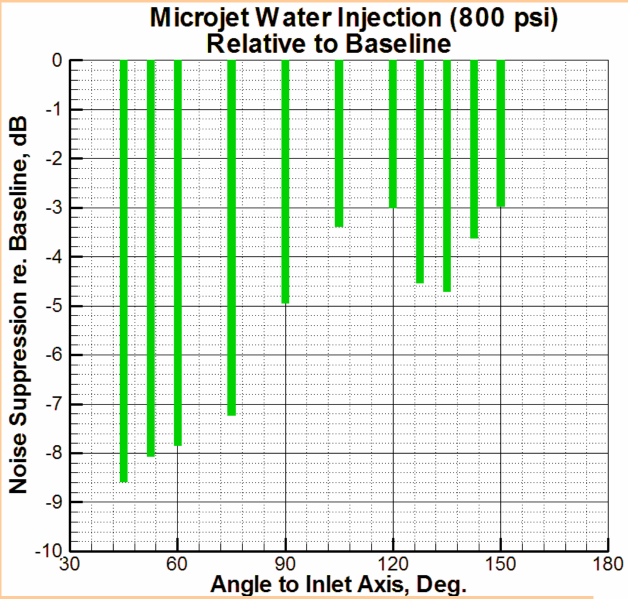


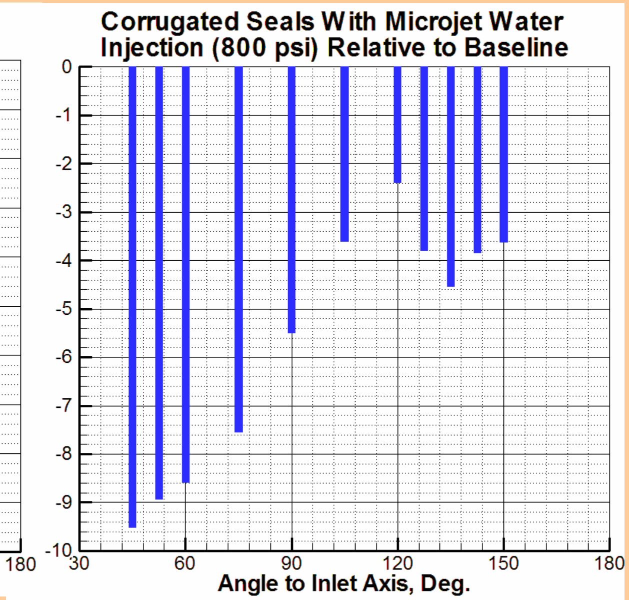
Baseline, Corrugations & Microjets Nacelle OASPL



Noise Suppression of Twin Jet Nacelle







Conclusions

- Model Testing Completed With 1/10'th Scale Twin Jet Nacelle.
- Improved Noise Suppression With Twin Jet Relative to Faceted Baseline.
- Beveled Nacelle Produces Strong Non-Axisymmetric Noise Field With Increased Levels In Certain Directions.
- Model Static Results Show 4.5 dB Reduction in Rear Arc and 9.5 dB in Forward Arc.
- All Concepts Lead to Aero-Performance Gain.
- Forward Flight Enhances Suppression.