



Quiet Supersonic Technology (X-59 QueSST) X-Plane Testing, Analysis, and Progress

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from

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Cleveland OH

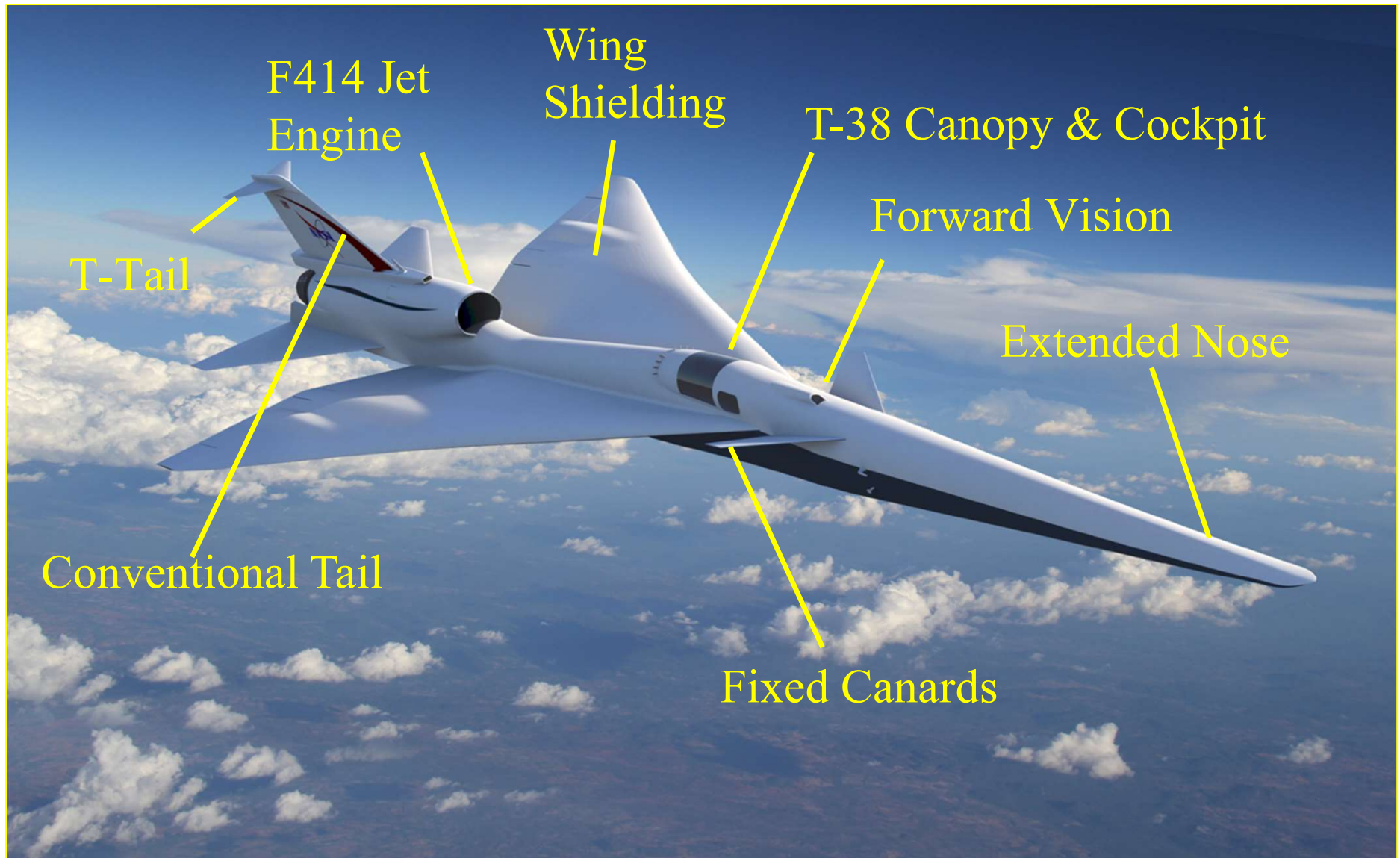


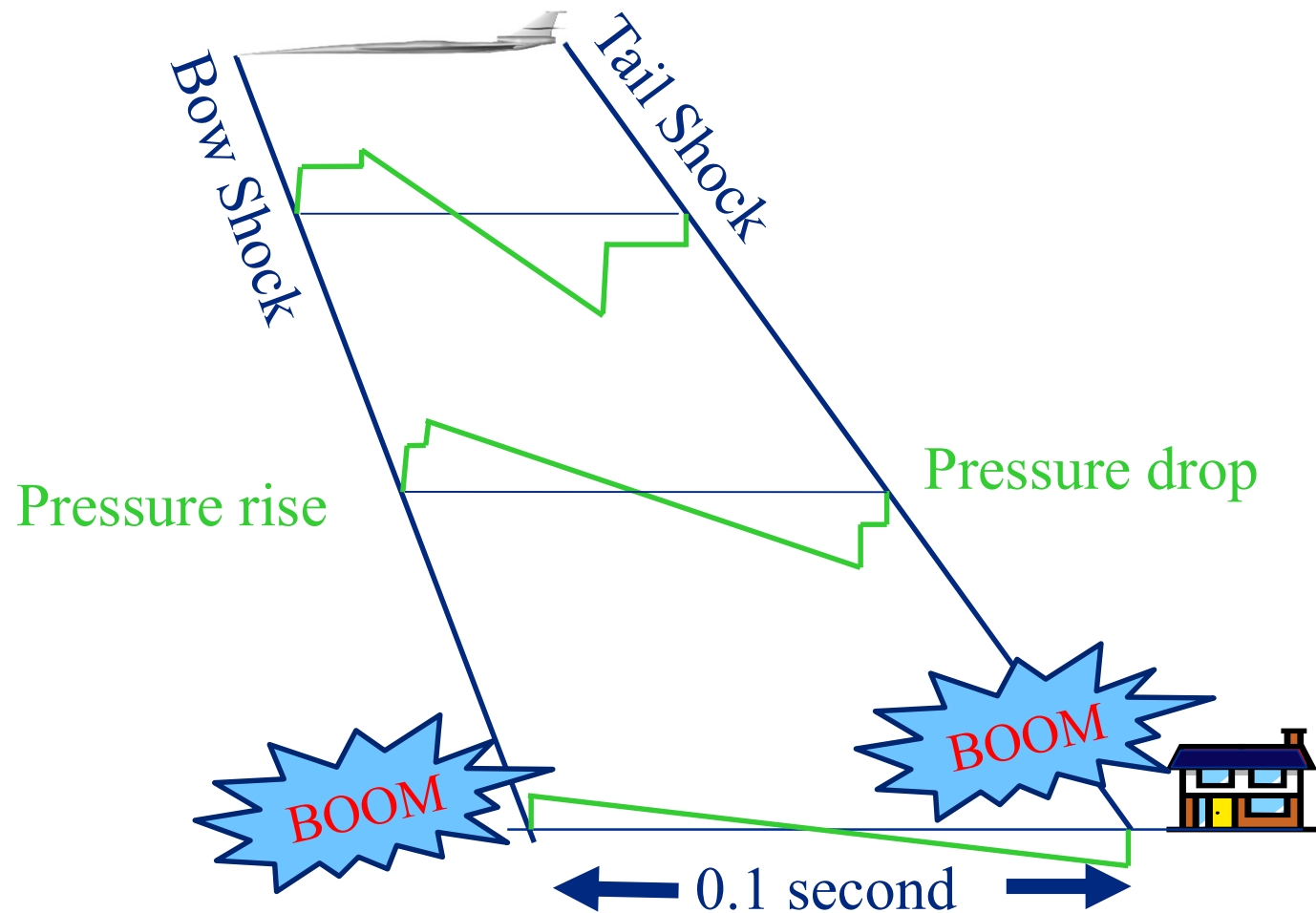
Outline

- Why QueSST?
- 8x6 Wind Tunnel
- QueSST Model
- Results

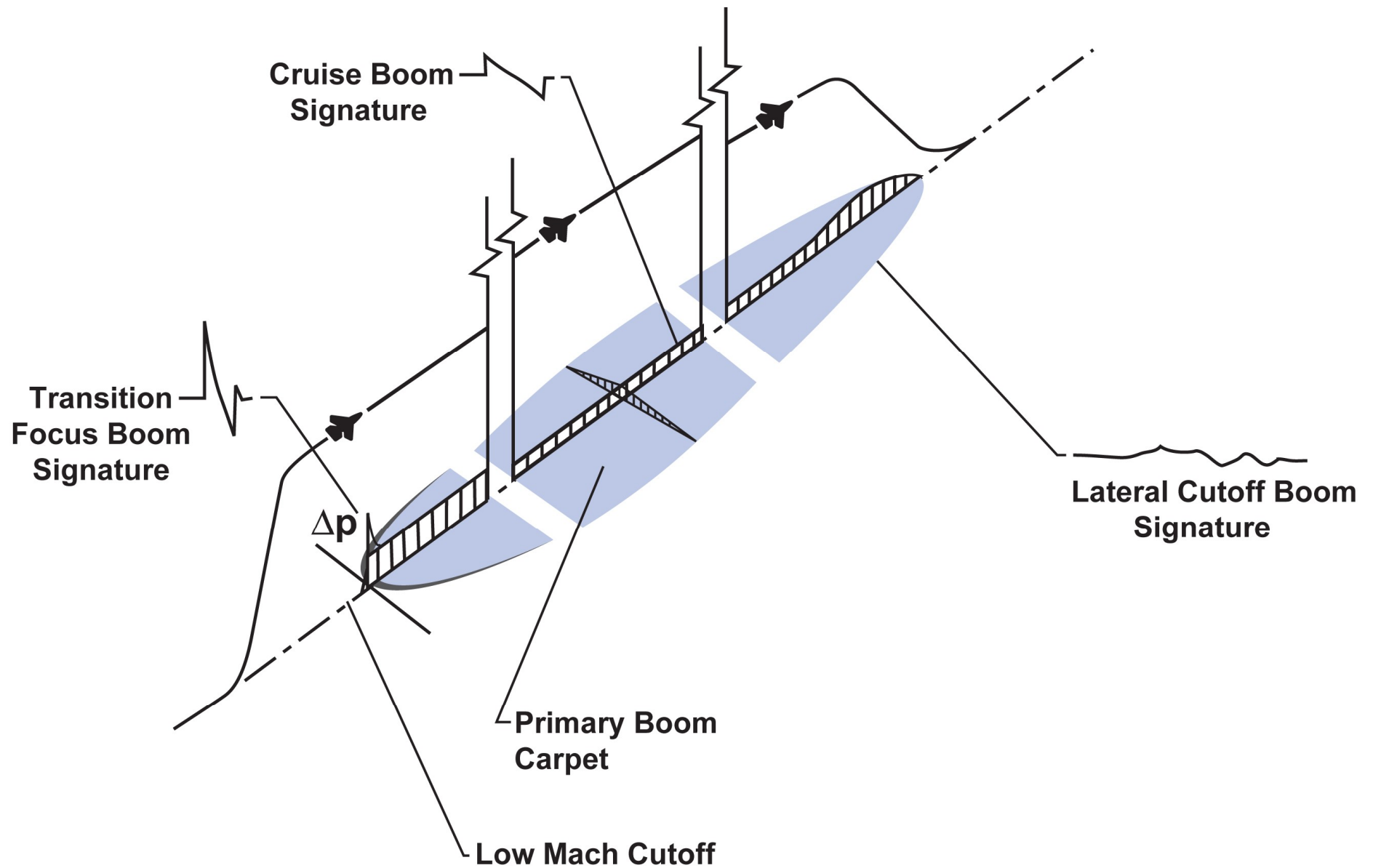


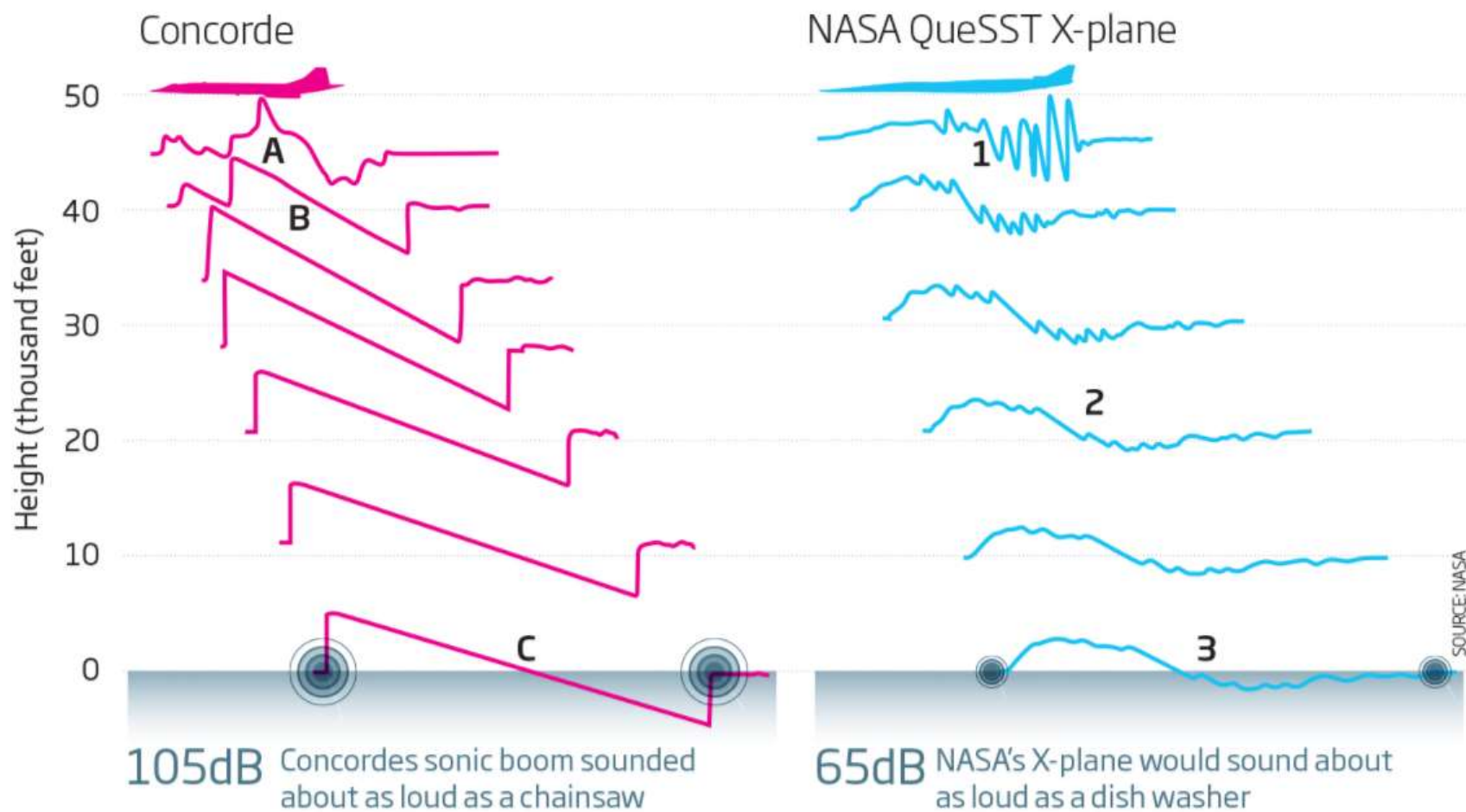
WHY QUESST?







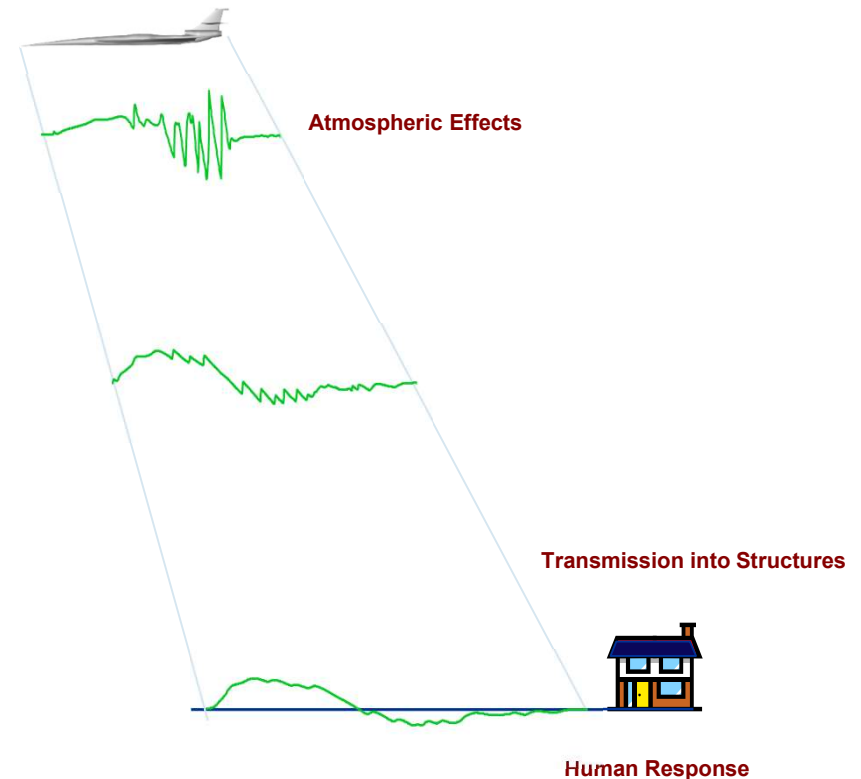






NASA Sonic Boom Research:

- Low Boom Vehicle Design
- Atmospheric Propagation
- Outdoor & Indoor Acoustics
- Human Response
 - Laboratory Studies & Metrics
 - Field Studies & Community Response





Human Response

Community tests



Specialized simulation facilities



Jury tests





Next Step – Low Boom Flight Demonstration X-59

QueSST Vehicle

Awarded to Lockheed Martin

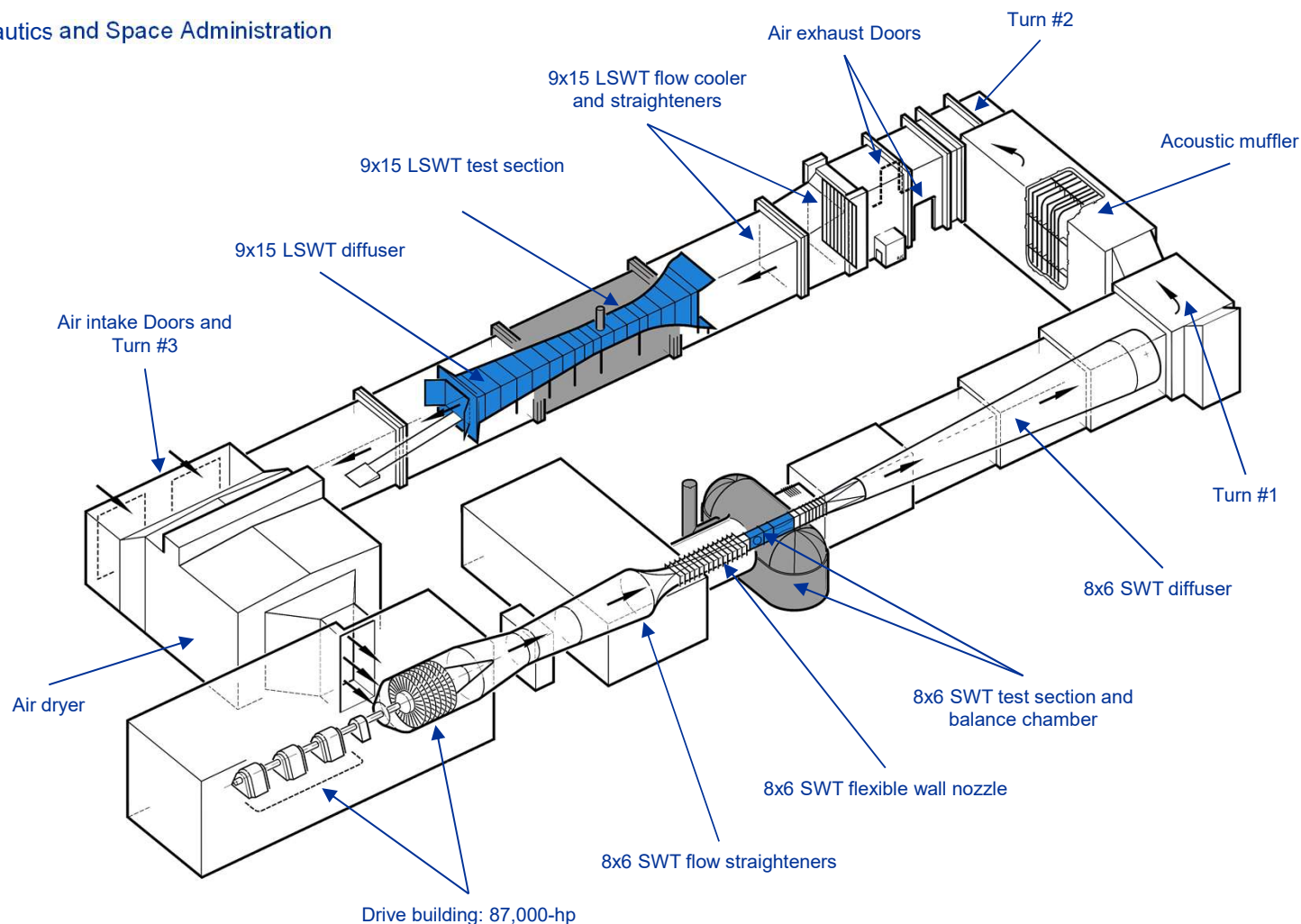
First Flight 2021

Wind Tunnel Testing at 8'x6' SWT

Propulsion Performance

Verified Vehicle S&C





8- BY 6-FOOT AND 9- BY 15-FOOT WIND TUNNEL COMPLEX



8- by 6-foot and 9- by 15-foot Wind Tunnel Complex



1949 overhead image of 8x6 complex



2015 overhead image of 8x6/9x15 complex



Historical Relevance



↑ C-1960-54465

↓ C-1983-6425



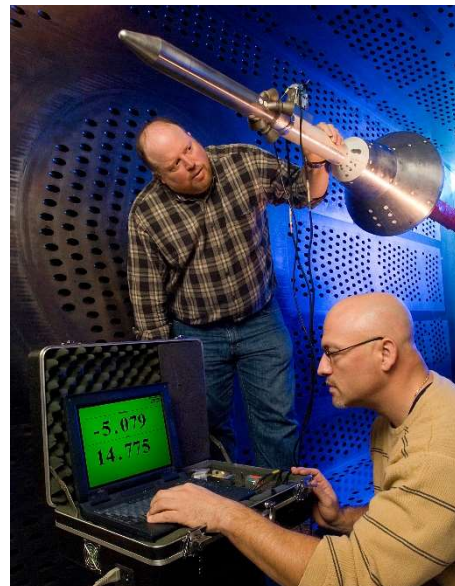
↓ C-2007-2471



↑ C-1986-4703

↓ C-1970-1385

↑ C-1964-72479

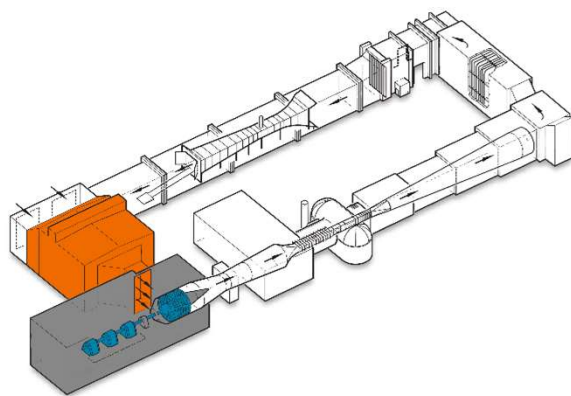




Wind Tunnel Drive & Air Dryer



Three 29,000-hp drive motors set in series drive a single shaft



Air-dryer beds
upstream of
compressor with
8-layers of
desiccant



C-1945-23277

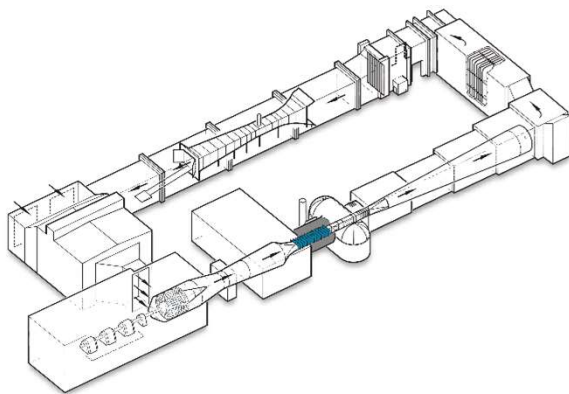
7-stage axial compressor
with outer shell opened
for inspection;
max 870-RPM and 2500-
lbs/sec mass flow



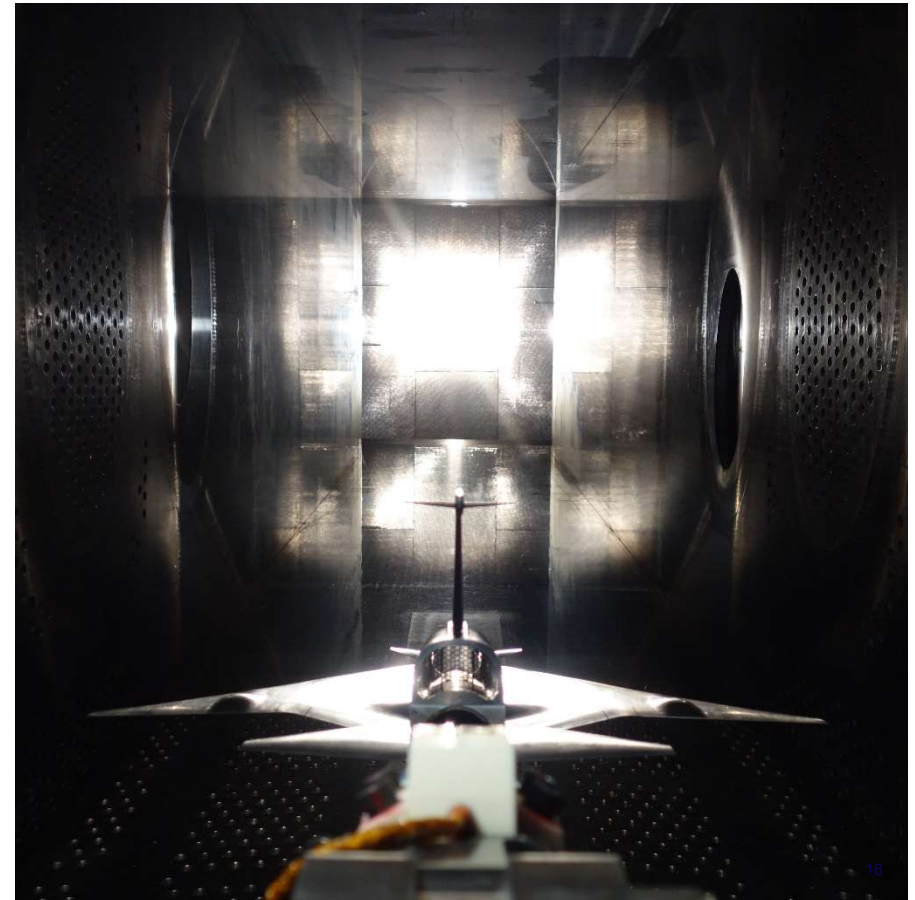
Flexible Walled Nozzle



Hydraulic stations that drive a single wall and the cams that dictate wall movement



QueSST model installed in 8x6 SWT test section and the flexwall visible upstream





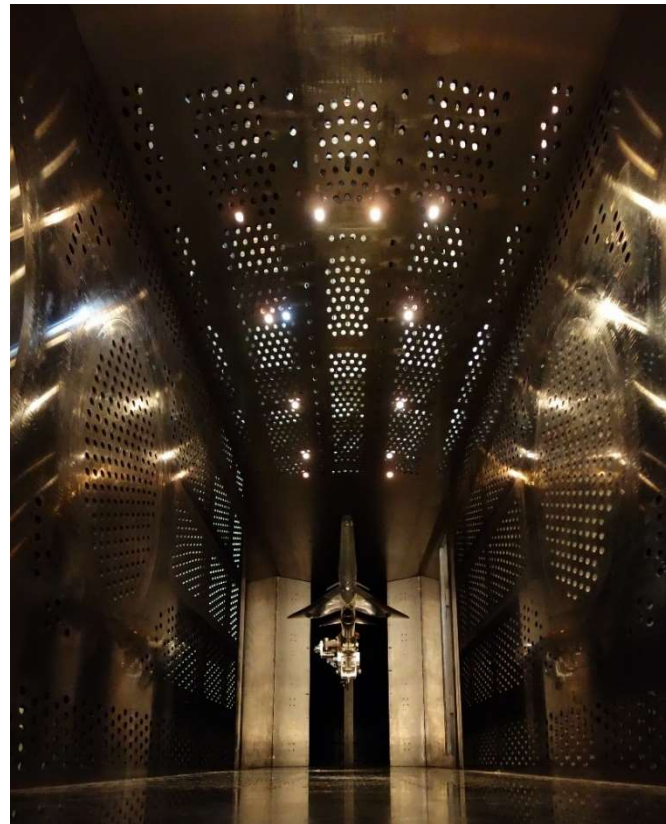
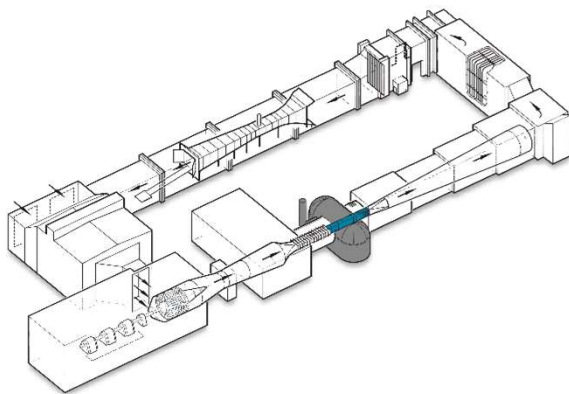
Test Section

“South wall” of test section showing both smooth and porous sections with both Schlieren windows and porous blanks



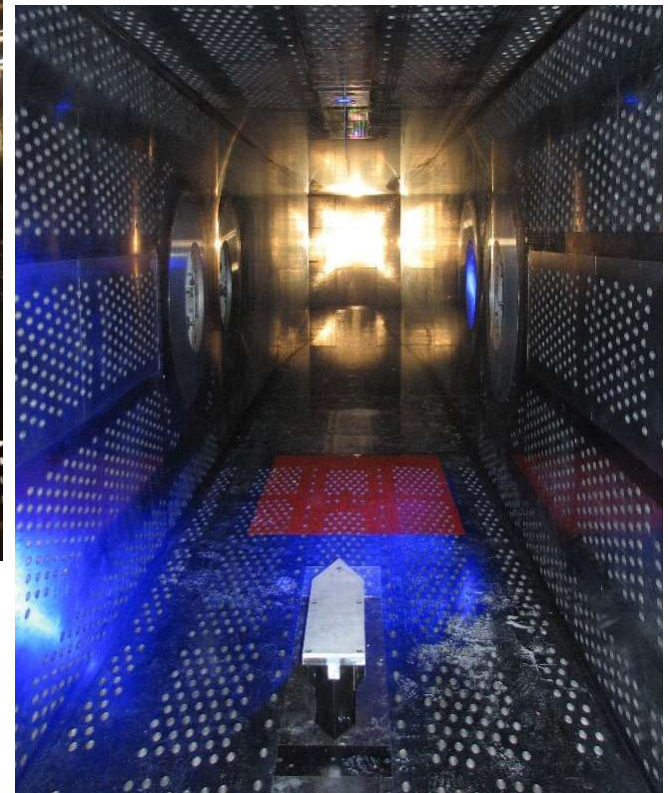
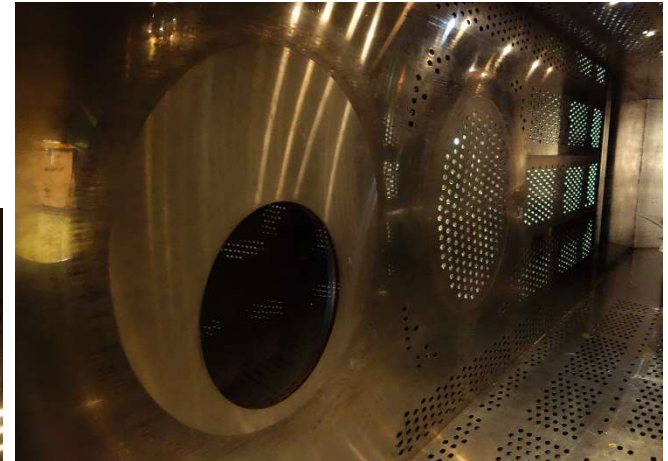
C-1956-42930

Porosity hole drilling operation in 8x6 SWT, 1956



QueSST model installed in 8x6 SWT test section

Looking upstream; flow imaging installation and full view of 8x6 SWT test section

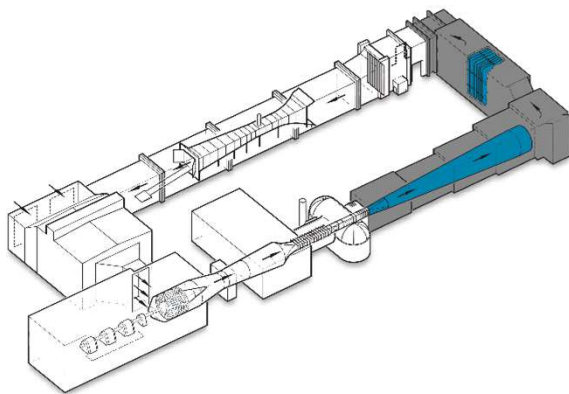




Diffuser & Acoustic Muffler



8x6 diffuser as seen from the test section looking downstream; visible person is halfway down



C-1950-26414
End of 8x6 SWT diffuser, into Turn #1, and into triple-storied Acoustic Muffler





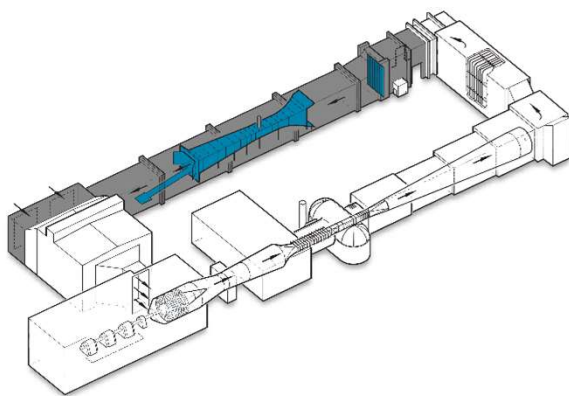
Closing the Circuit and the 9x15 LSWT



C-1990-4389
McDonnell Aircraft Company
279-3C STOVL model



9x15 test
section
upgrades
in 2017-
2018



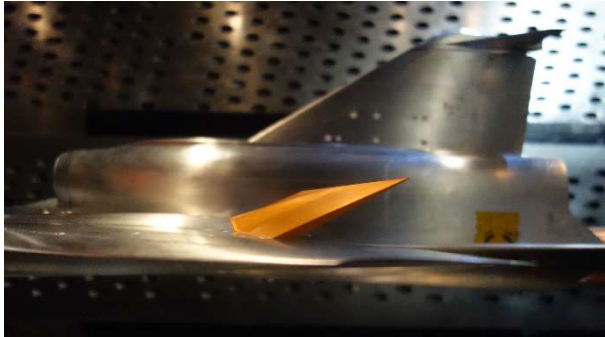
C-1994-01831L
Turbfan model using
compressed air as fan
drive; installed in
legacy 9x15 LSWT



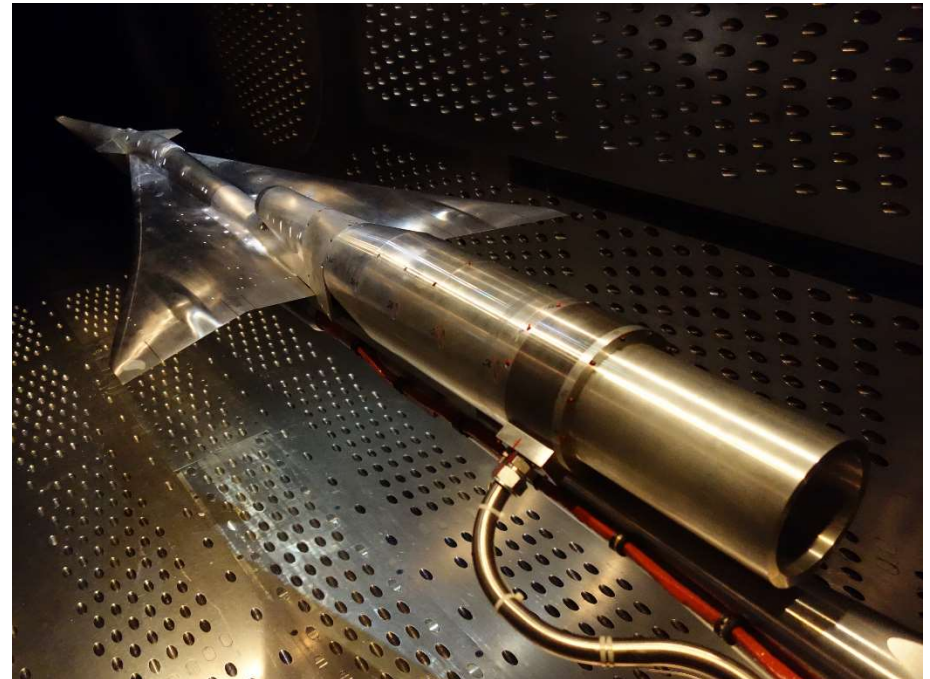
INSTALLATION OF QUESST



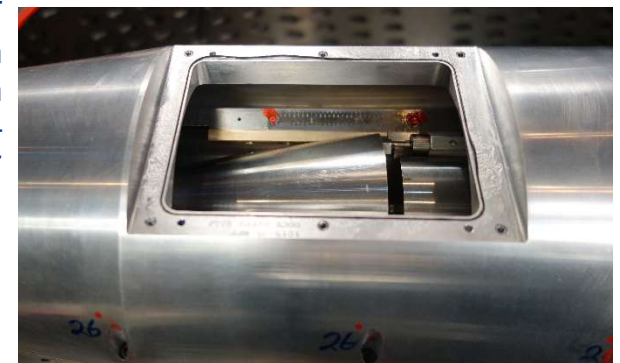
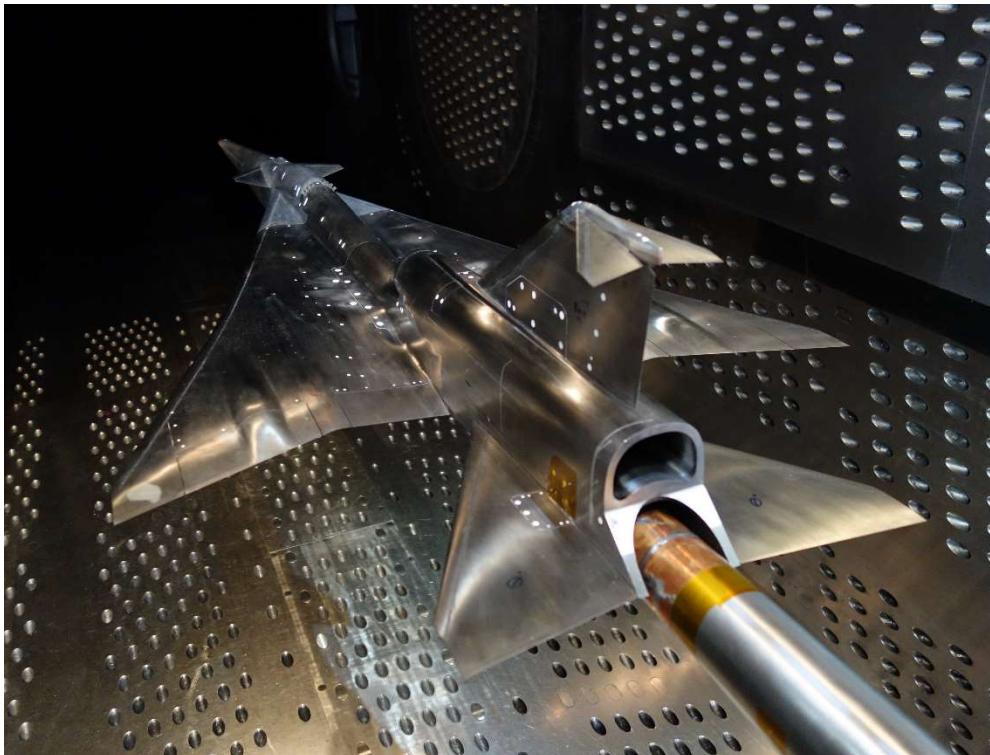
QueSST Test Phases



QueSST
aerodynamic
installation
February 2017 –
March 2017

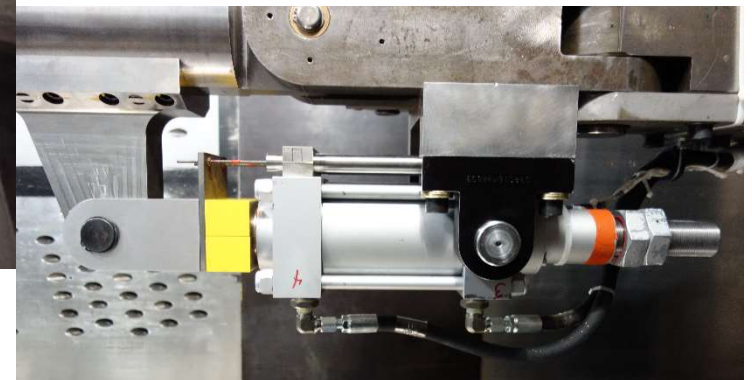


QueSST
propulsion
installation
April 2017 –
May 2017

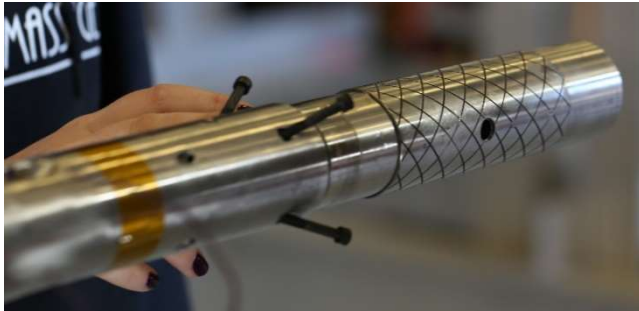




Components of the QueSST Supports



Prep Room Installation & Checkloads



Balance installation in-progress

Model
support
stack-up
installed on
model
positioning
system



1,080-lbs loading in the Normal, or “Lift” component



Model instrumentation work in
preparation area



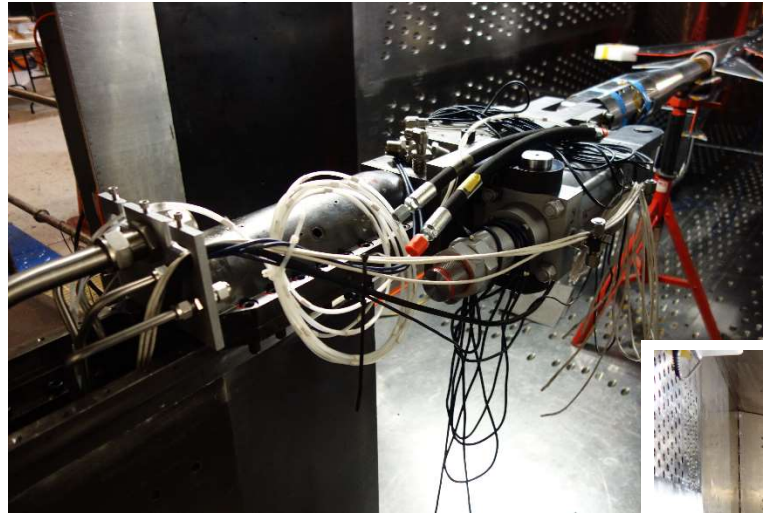


Test Section Installation



Lift of QueSST model into tunnel through downstream 16-foot hatch

Support structure hydraulics and instrumentation cleaned up for run



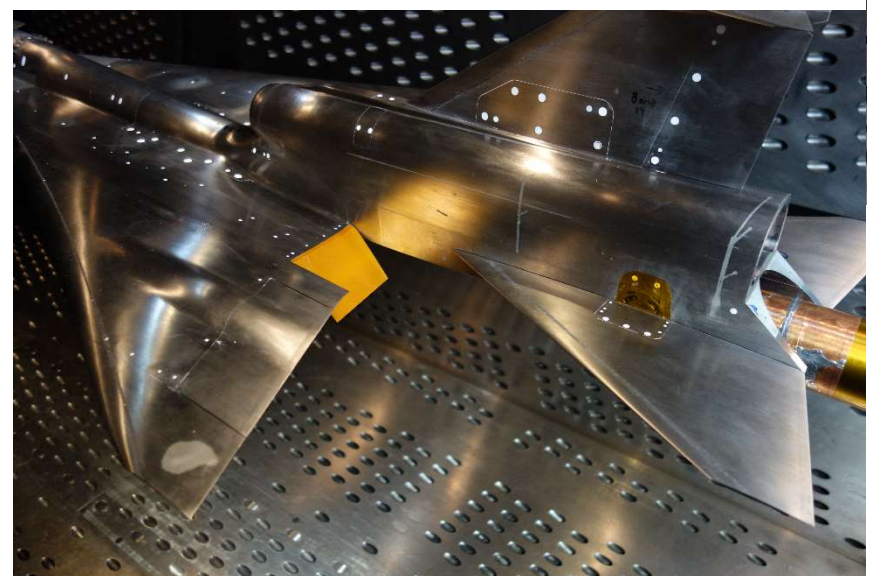
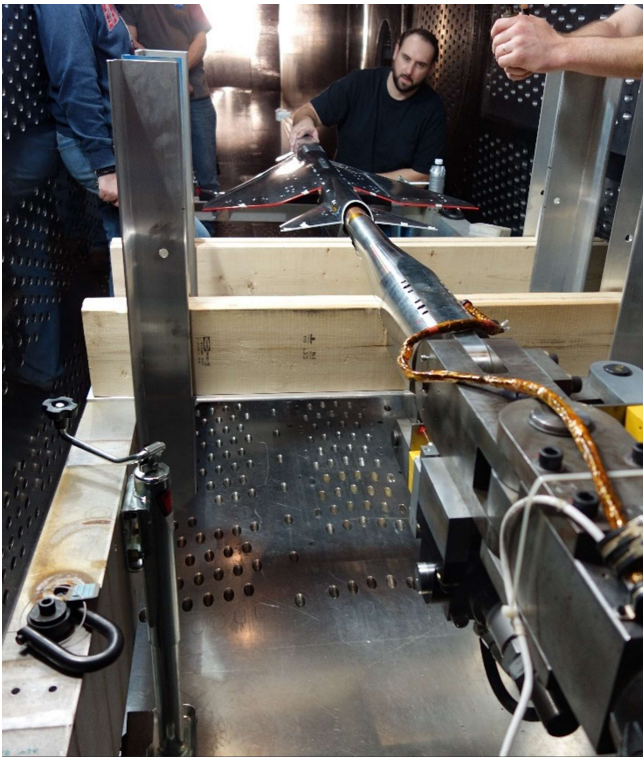
QueSST model installed, lifted off cart, cart pushed forward and disassembled

QueSST assembly and data system validation checkloads as installed in test section

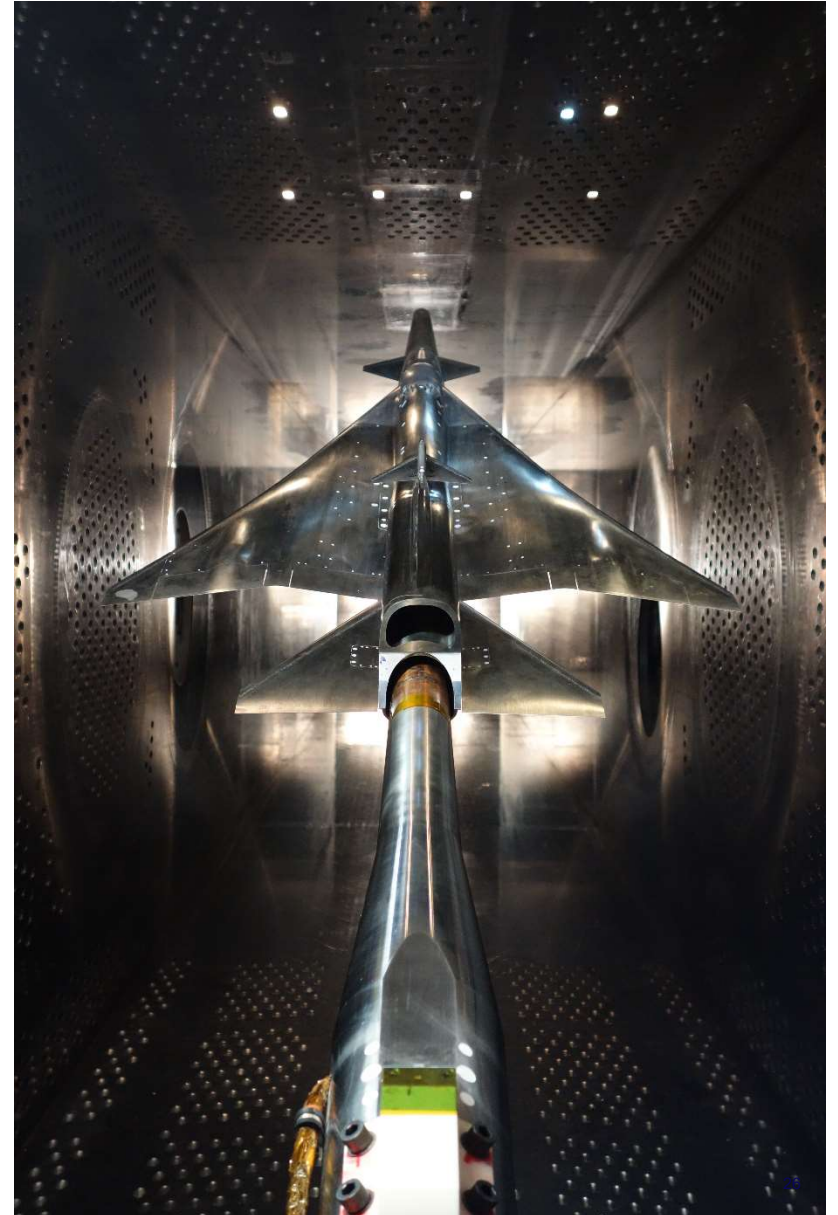
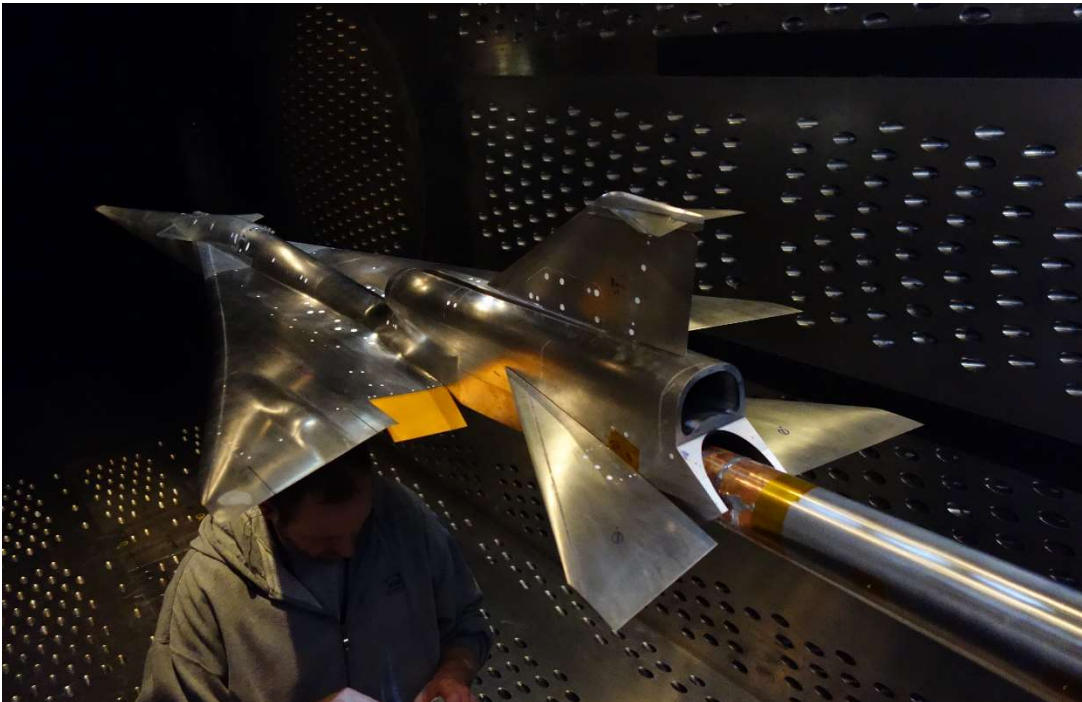
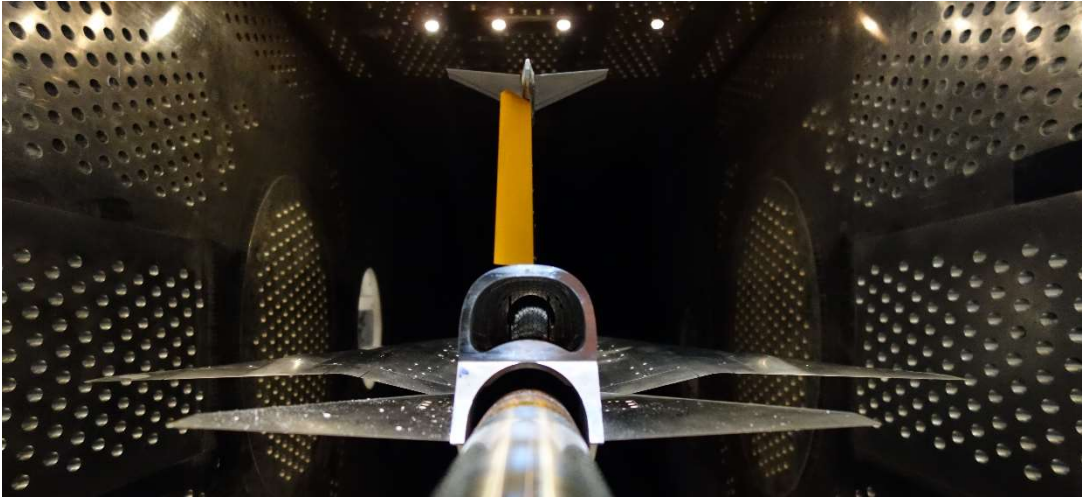




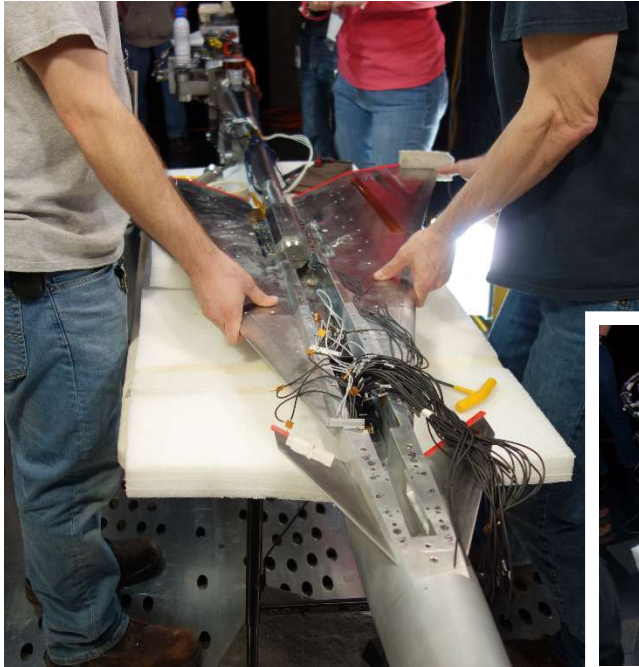
Testing - Aero



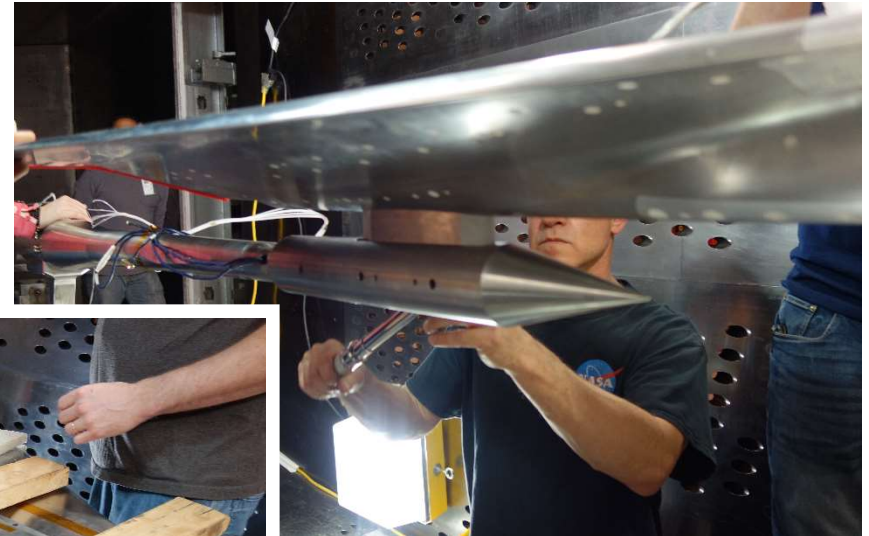
Testing - Aero



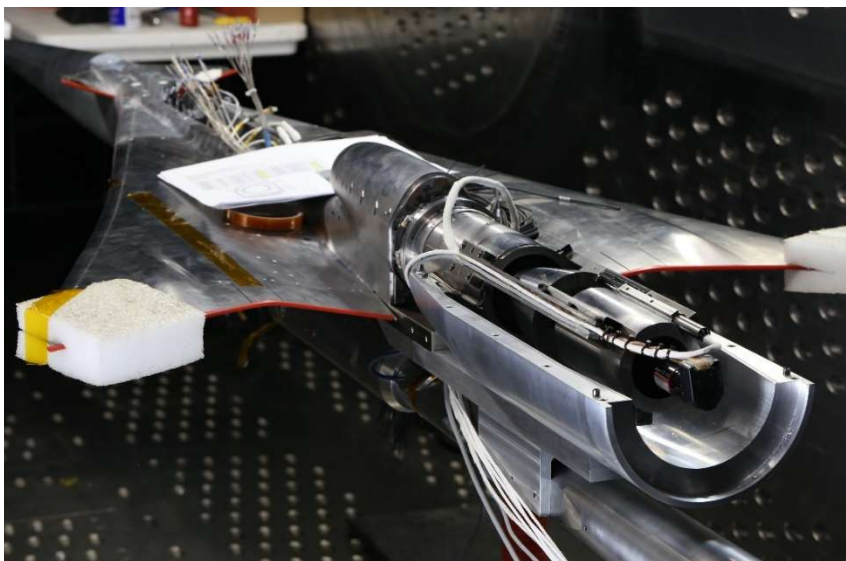
Model Change from Aero to Prop



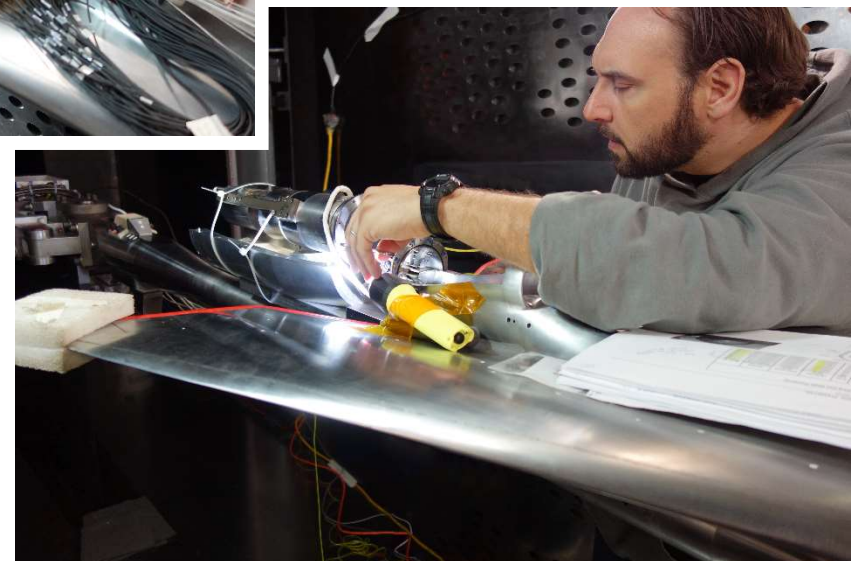
Aero tail geometry, internal balance mounting block, and balance removed; Model re-installed on offset blade to allow for MFP can



Propulsion geometry, rakes, and instrumentation routed and hooked up



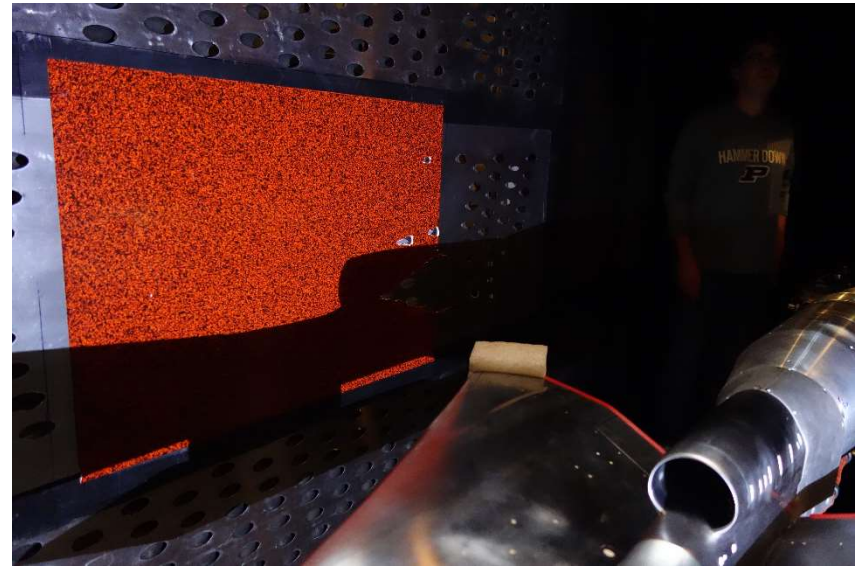
MFP installed and motion checked out





Testing - Propulsion

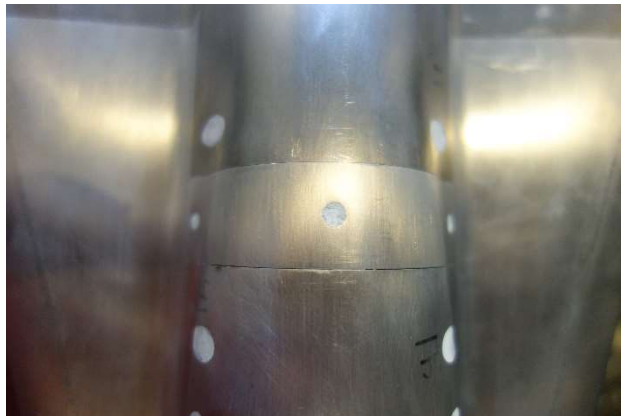
Inlet boundary layer rake installed



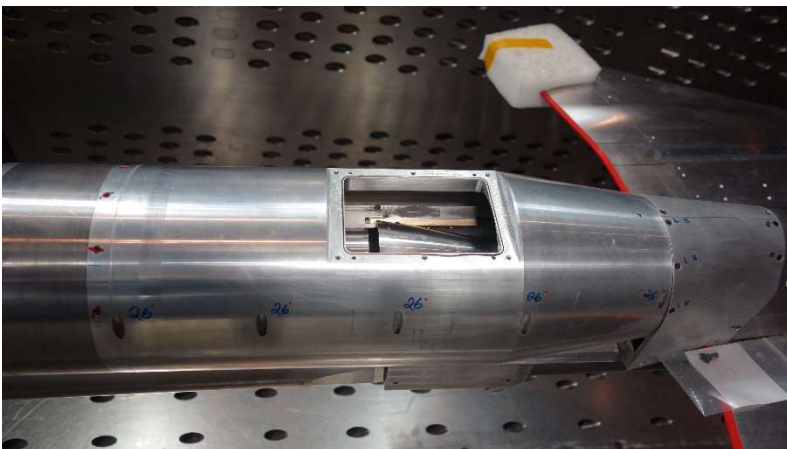
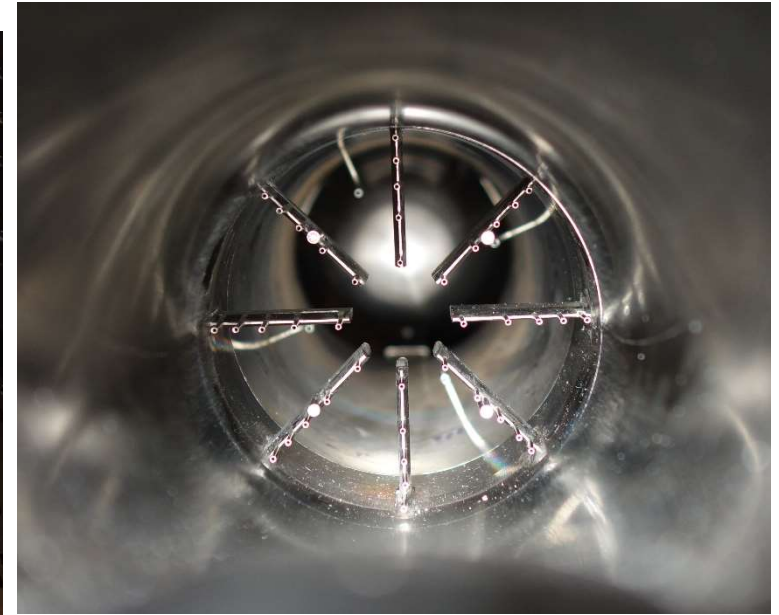
Background Oriented Schlieren (BOS) installed



Three different vortex generator (VGs)
installed for propulsion inlet testing



Testing - Propulsion



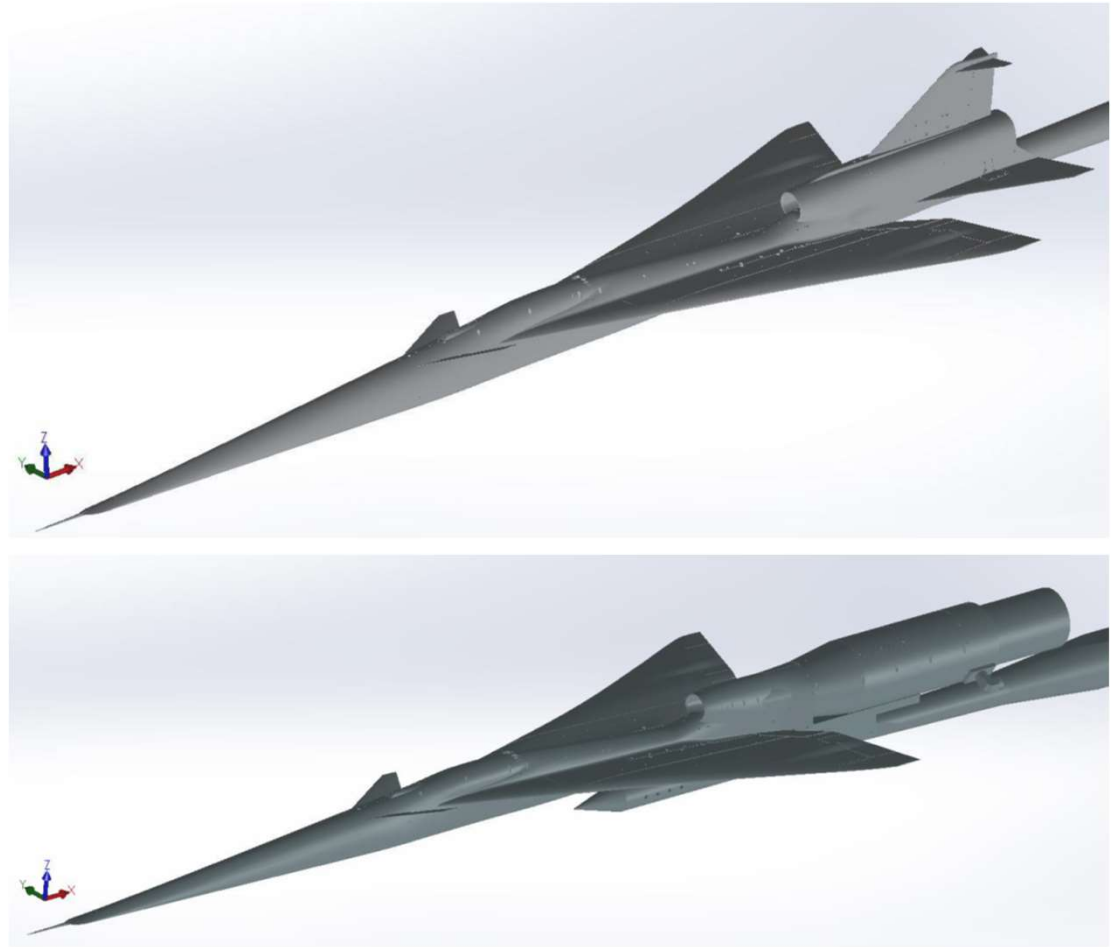
Low Boom Flight Demonstrator

- Preliminary design vehicle
- Single pilot x-plane
- Mach 1.43
- Replicate sonic boom of commercial aircraft
- Propulsion shielded by airframe
- Top centerline inlet challenges
- Diverter-less bump inlet



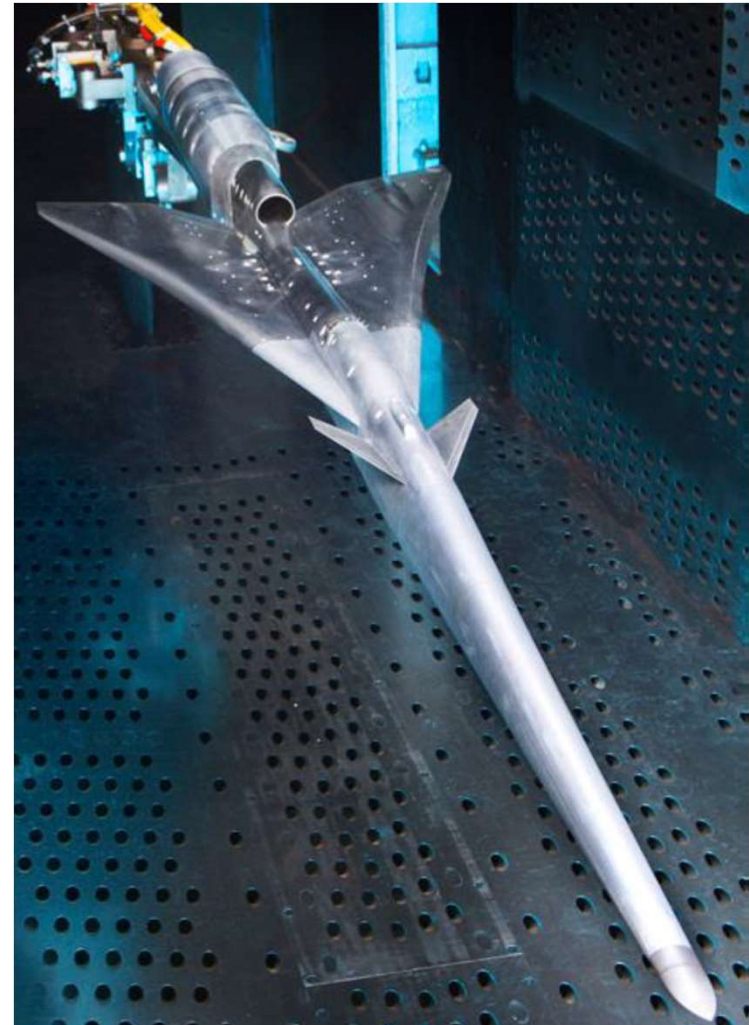
8- by 6- Foot Supersonic Wind Tunnel Model Description

- Aerodynamic and propulsion
- C607 and C608 inlet configurations
- Key features:
 - Long nose
 - Canards
 - Camera fairing
 - Vortex generators
 - Centerline top mounted diverter-less bump inlet



Propulsion-Airframe Integration Testing

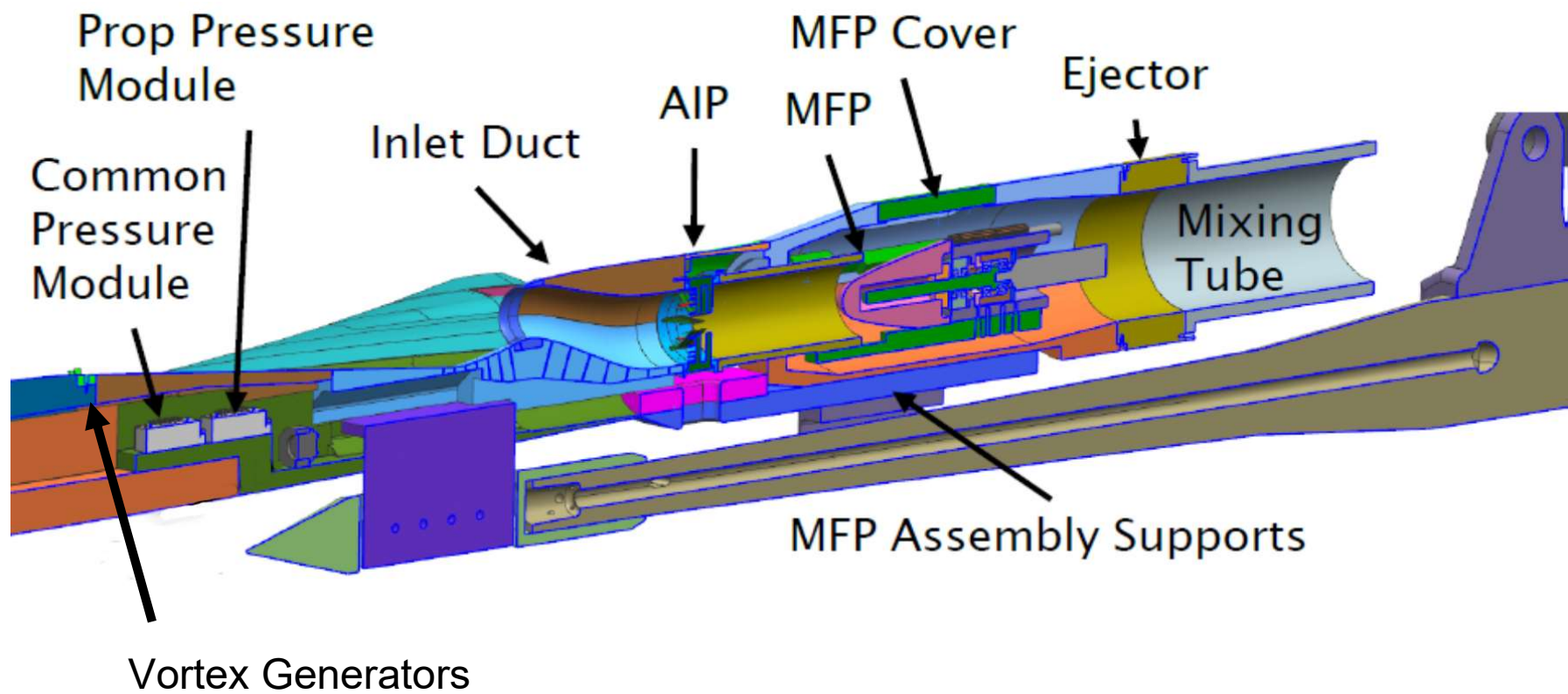
- Performance largely unknown for this top-mounted supersonic inlet
- CFD pre-test prediction variation
- Needs drove model to 9.5% scale
- Largest full vehicle in 8x6 SWT
- 3-inch diameter inlet
- Reynolds number 4 times lower than flight
- CFD performed at both flight and wind tunnel conditions



Model

- Four vortex generator configurations
- Two inlet types, C607 and C608
- 40-probe AIP array, steady-state
- Calibrated mass-flow plug
- Air ejector for subsonic operation
- Angle of attack:
 - supersonic -2° to 5°
 - transonic -2° to 8°
 - subsonic -4° to 14° .







**C607 No
vortex generator**



**C607 Baseline, 8 VG's at 15°
0.263 in. high, 0.421 in. chord**



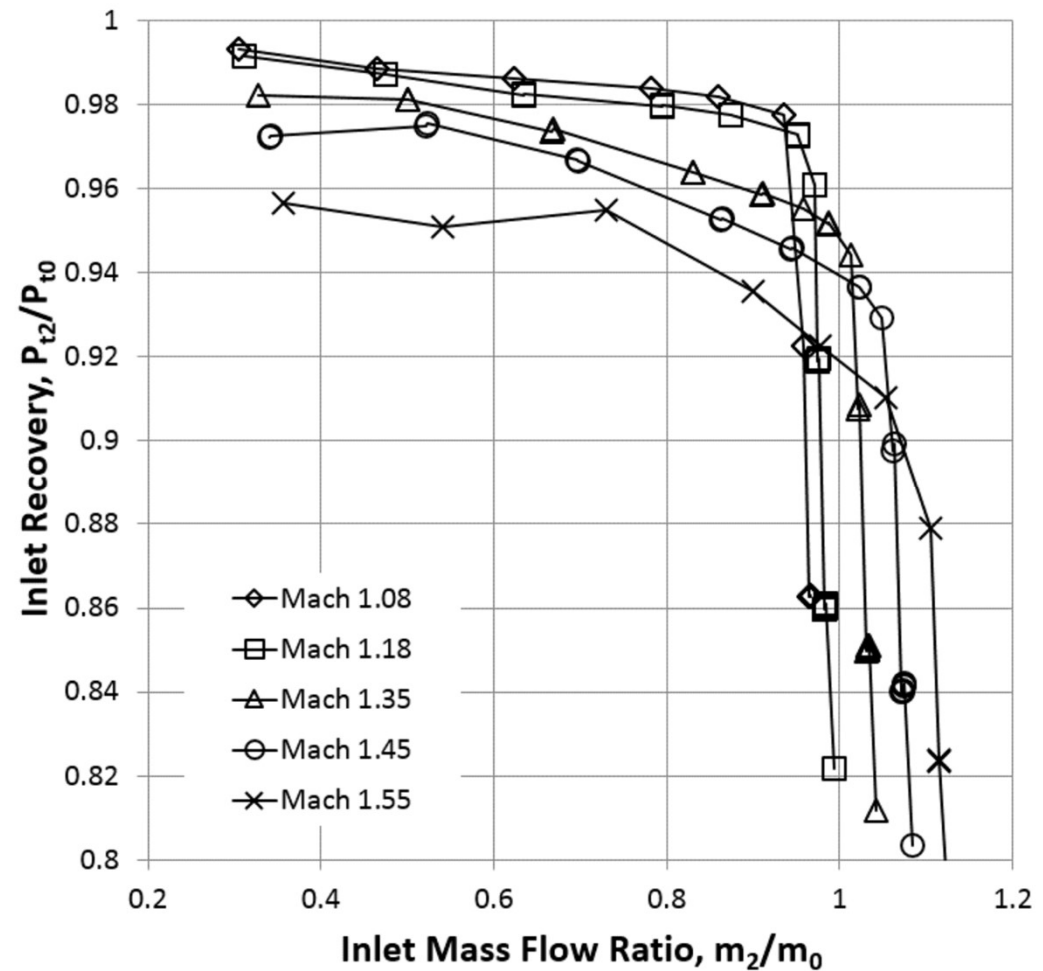
**C607 Alternate, 16 VG's at 20°
0.053 in. high, 0.263 in. chord**



**C608 Baseline, 8 VG's at 20°
0.105 in. high, 0.526 in. chord**

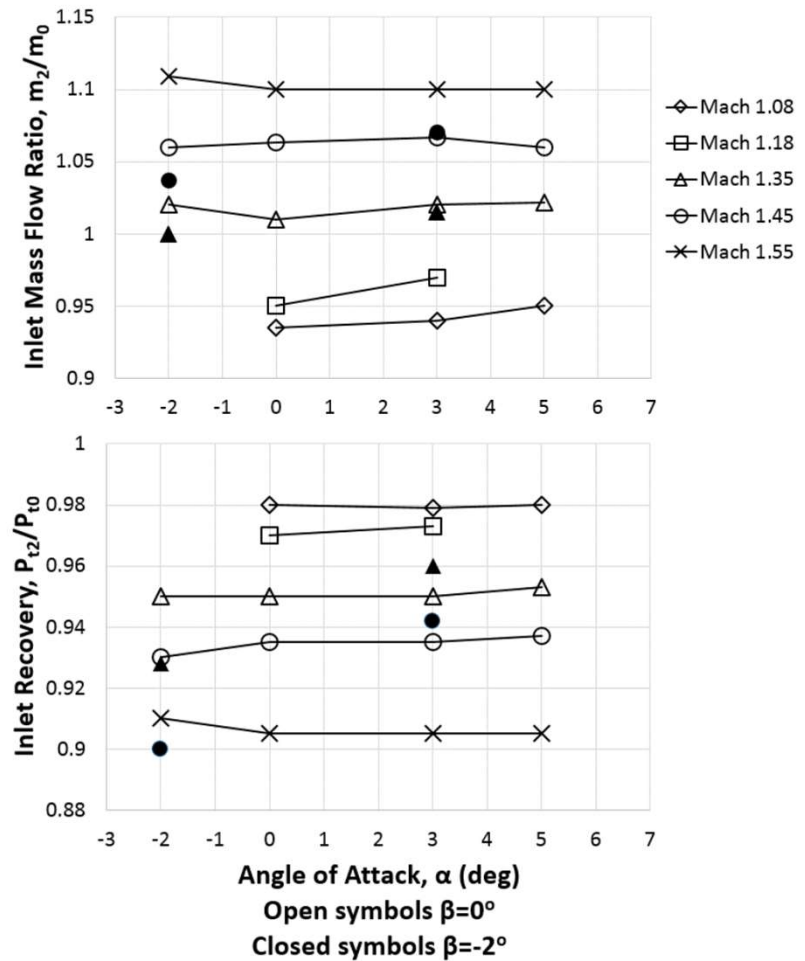
C607 Supersonic Results

- Inlet Recovery vs. Mass Flow Ratio (>1 w PAI)
- Critical point data reported
- Bump inlet can be operated subcritical
 - Operation can trade spillage drag for higher recovery



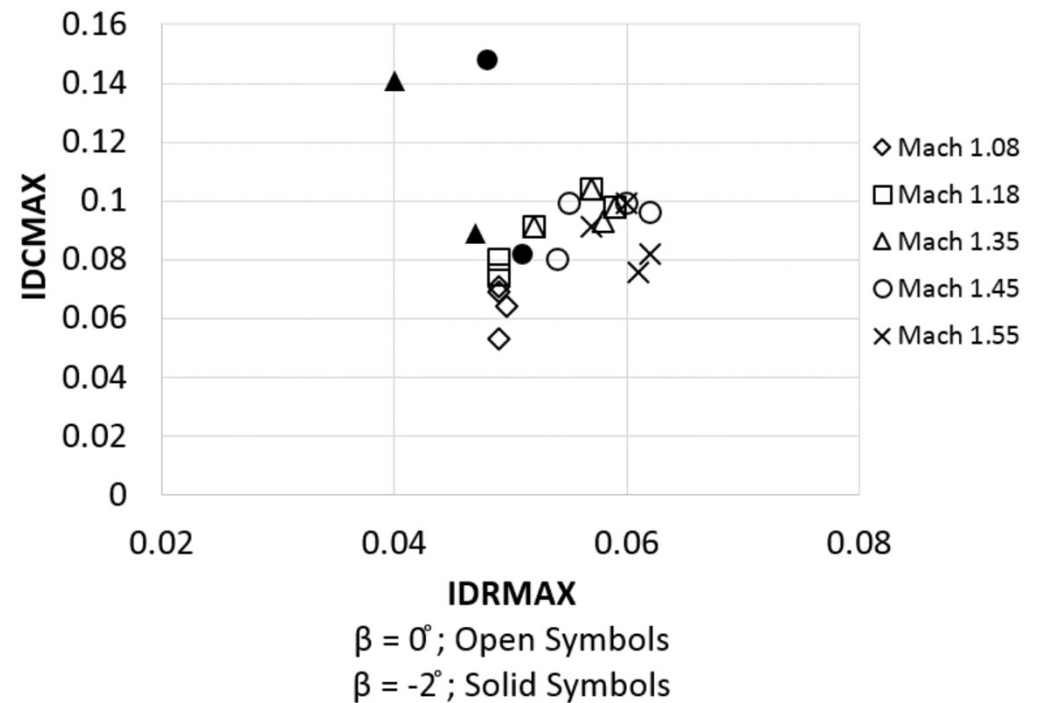
C607

- Mass flow ratio increased as Mach number increased
- Low sensitivity to α
- Recovery decreased as Mach number increased
- Also low sensitivity to α
- Sensitive to $\beta = -2^\circ$



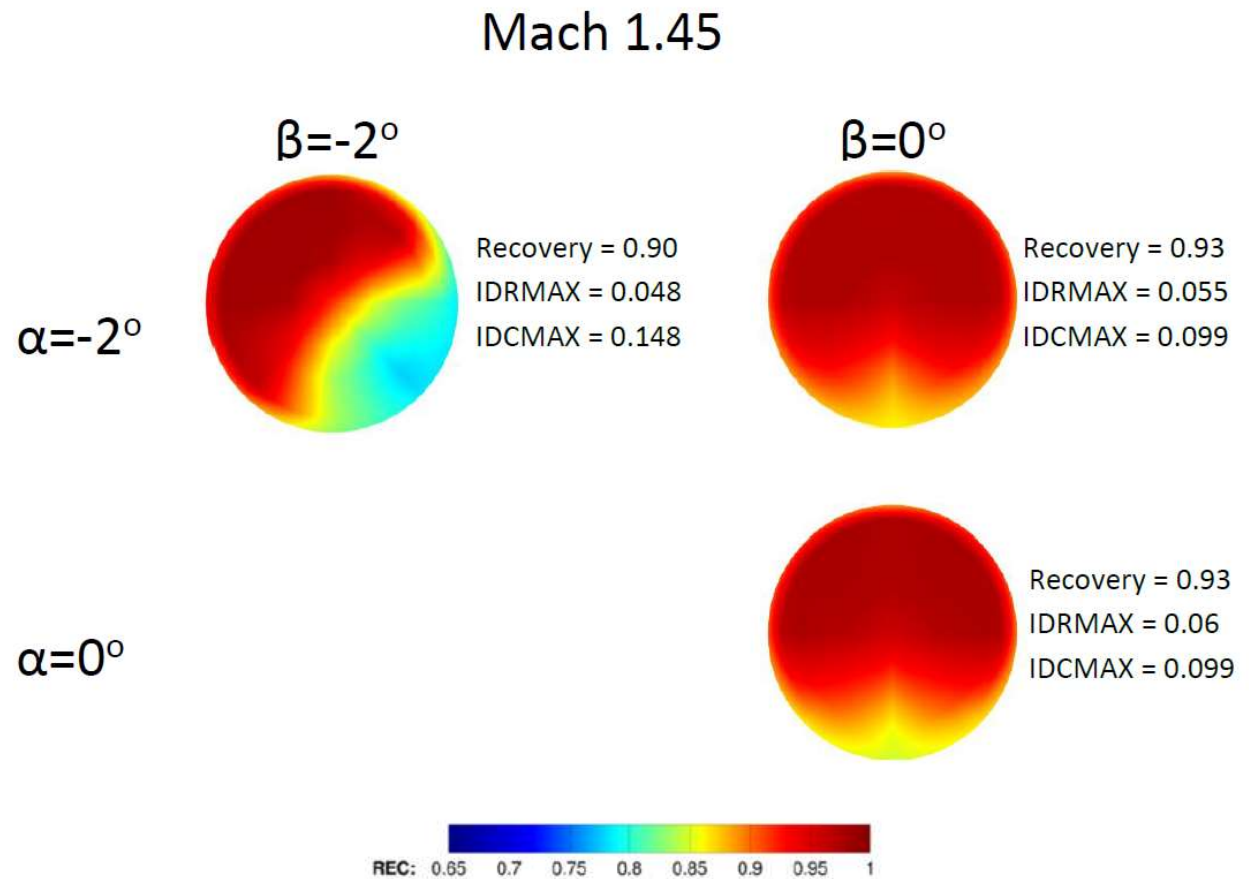
C607 Distortion

- Supersonic distortion at critical point
- Highest levels at $\beta = -2$
- Steady-state distortion values
- Dynamic values can be higher
- Comparison to engine operability limits needed



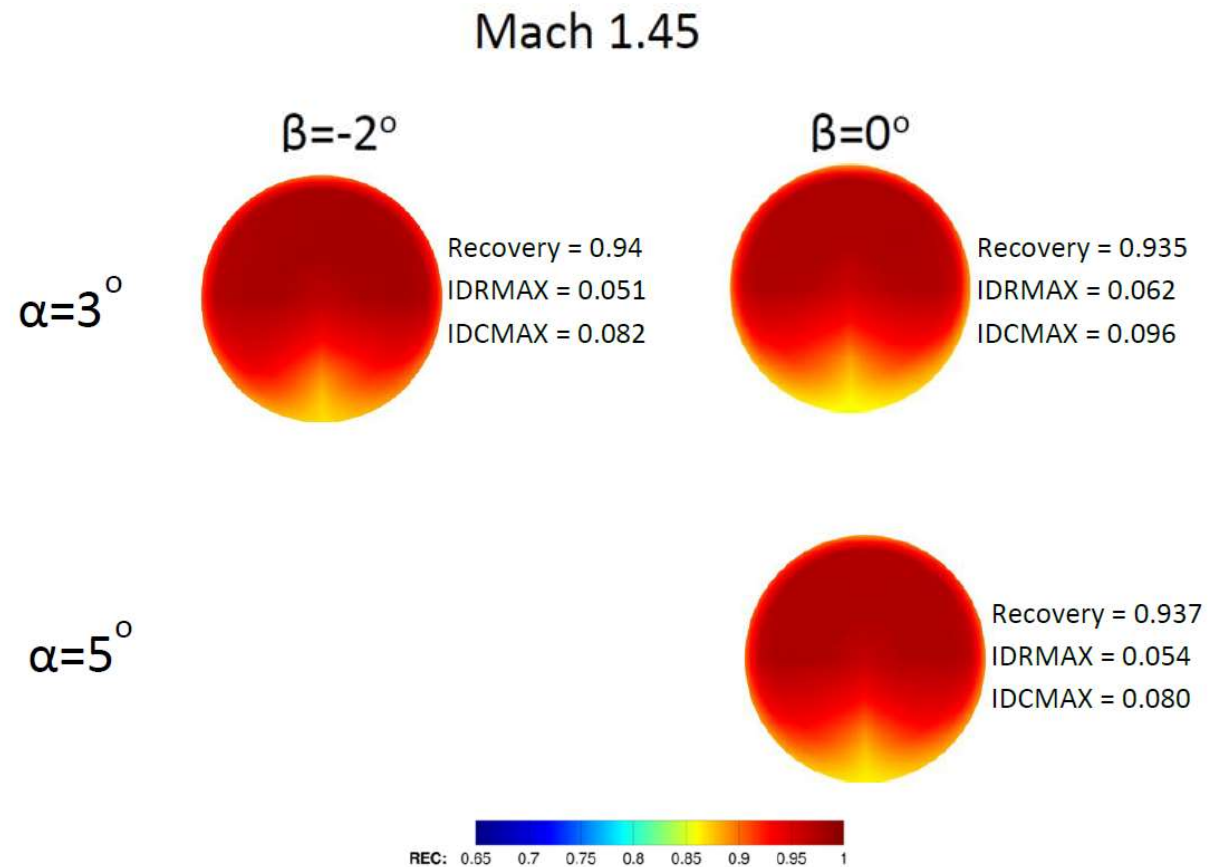
C607

- Mach number contour plots
- Insensitive to vehicle attitude
- Sensitive to $\alpha = -2^\circ$ and $\beta = -2^\circ$



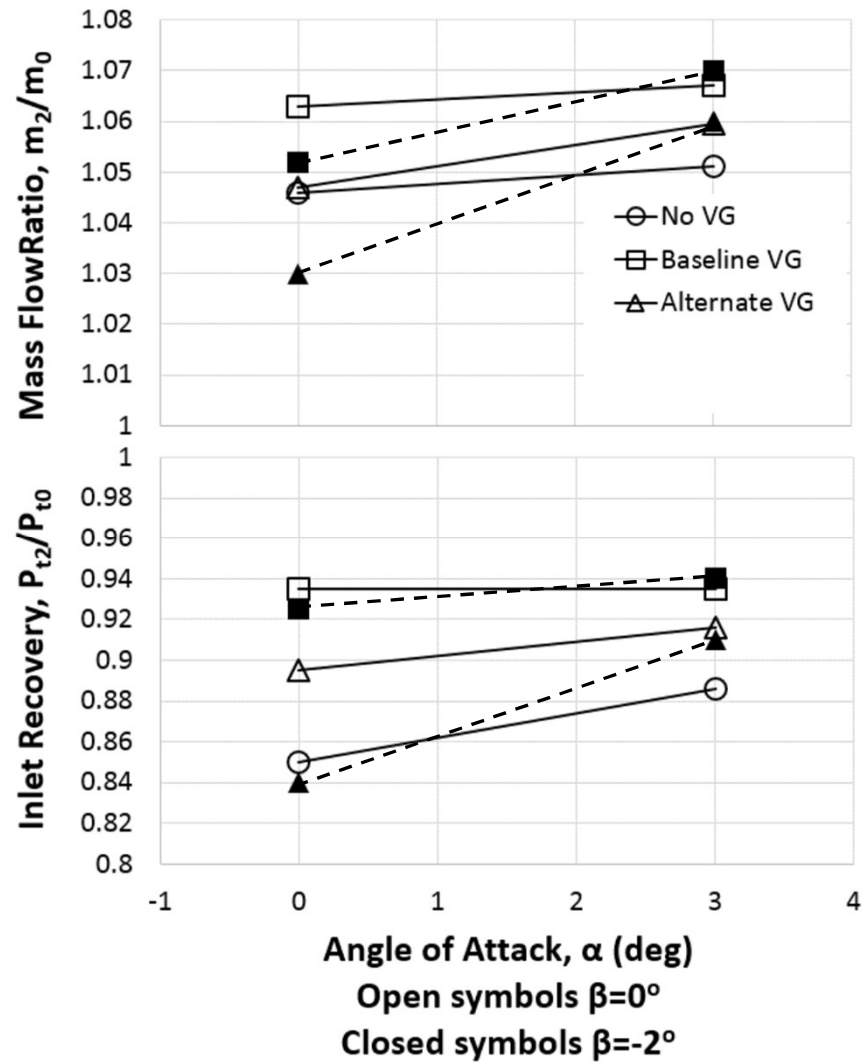
C607

- Trend was the same at all Mach numbers



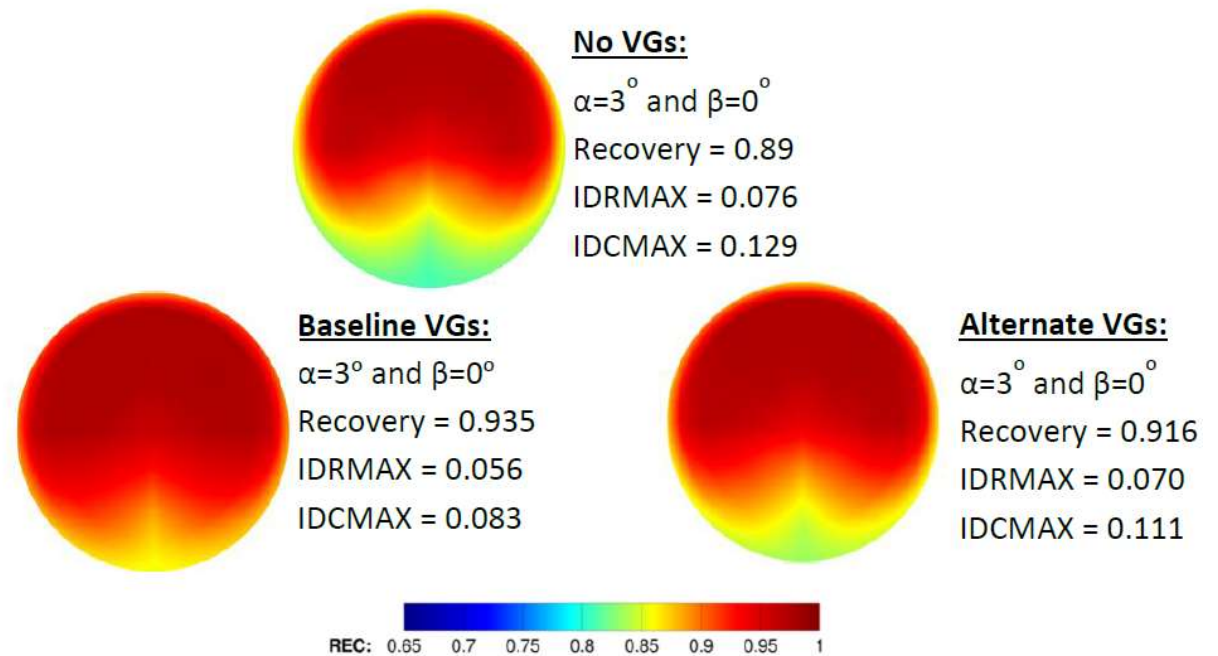
Vortex Generators

- Mach 1.45
- Three C607 vortex generator configurations:
 - None
 - Baseline
 - Alternate
- Best performance with baseline
- Sensitive $\beta = -2^\circ$



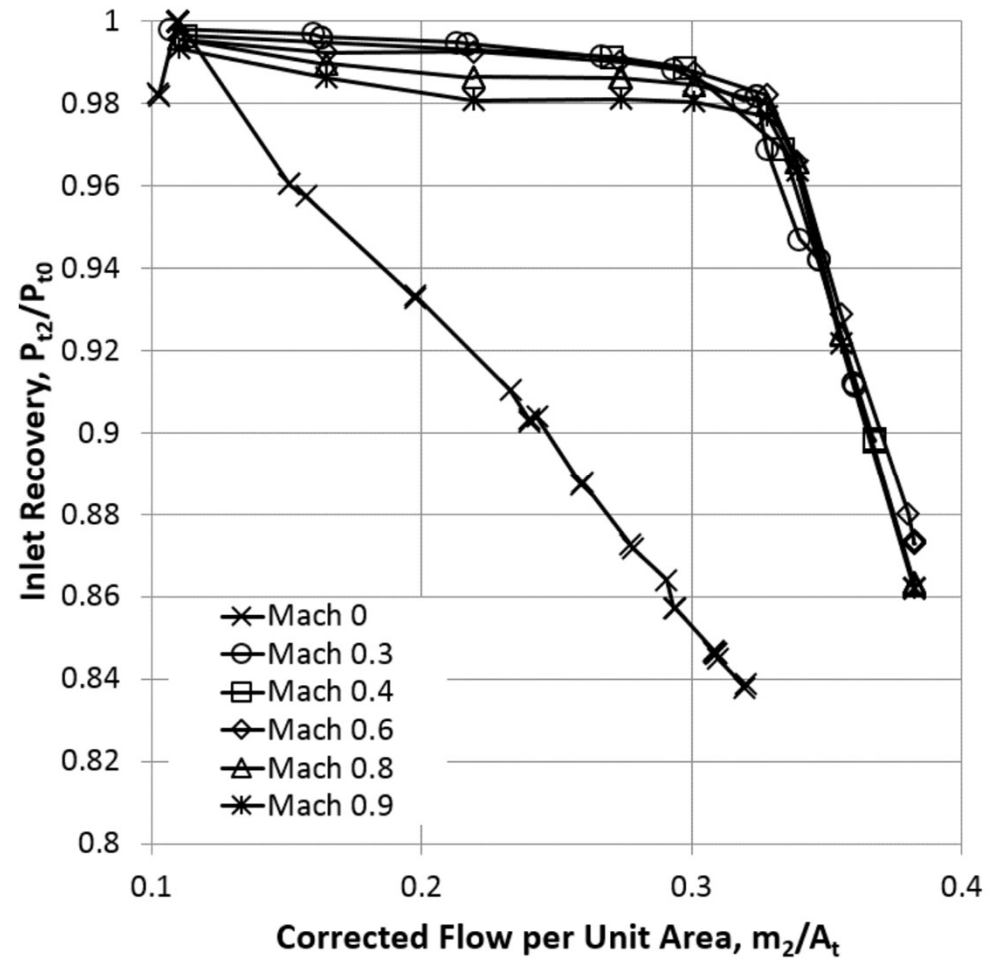
Vortex Generators

- Mach number contour plots
- Vortex generators were critical for high inlet performance with low distortion



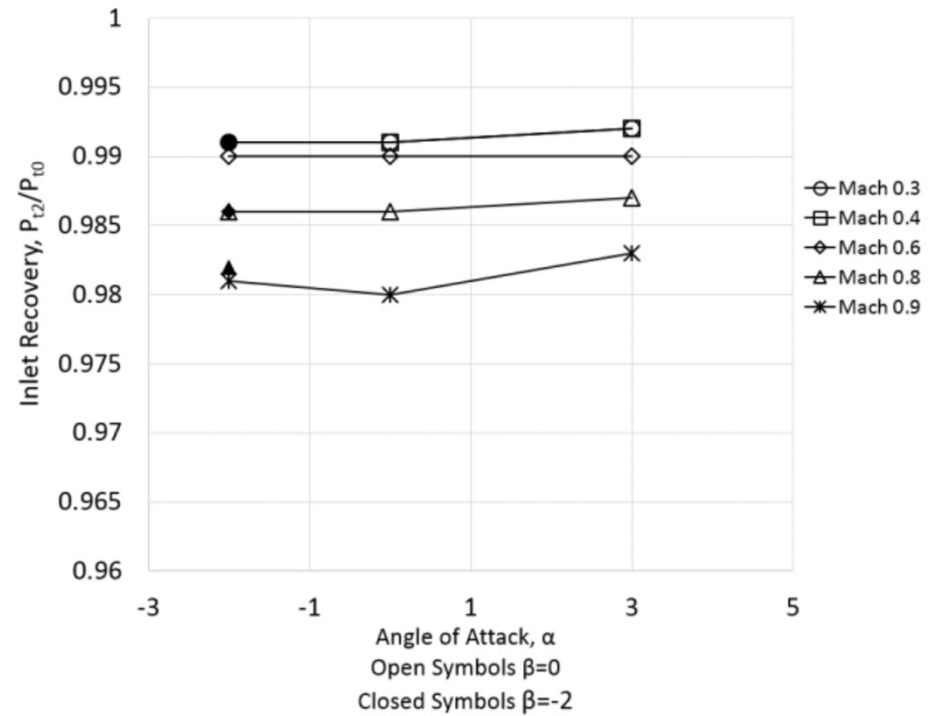
C607 Subsonic

- Inlet recovery vs. mass flow per unit area
- Data reported at a constant mass flow per unit area
- Mach 0 data reduced performance as expected



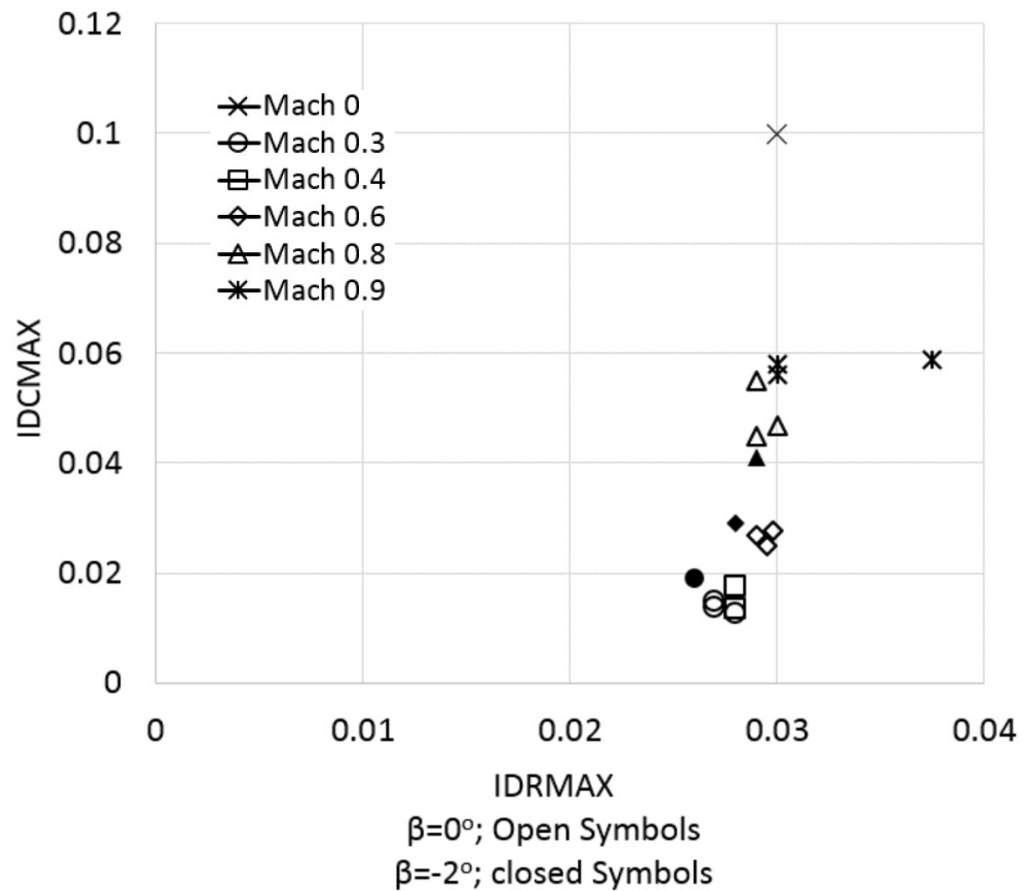
C607 Subsonic

- Insensitive to changes in angle of attack
- Reductions at $\beta = -2^\circ$



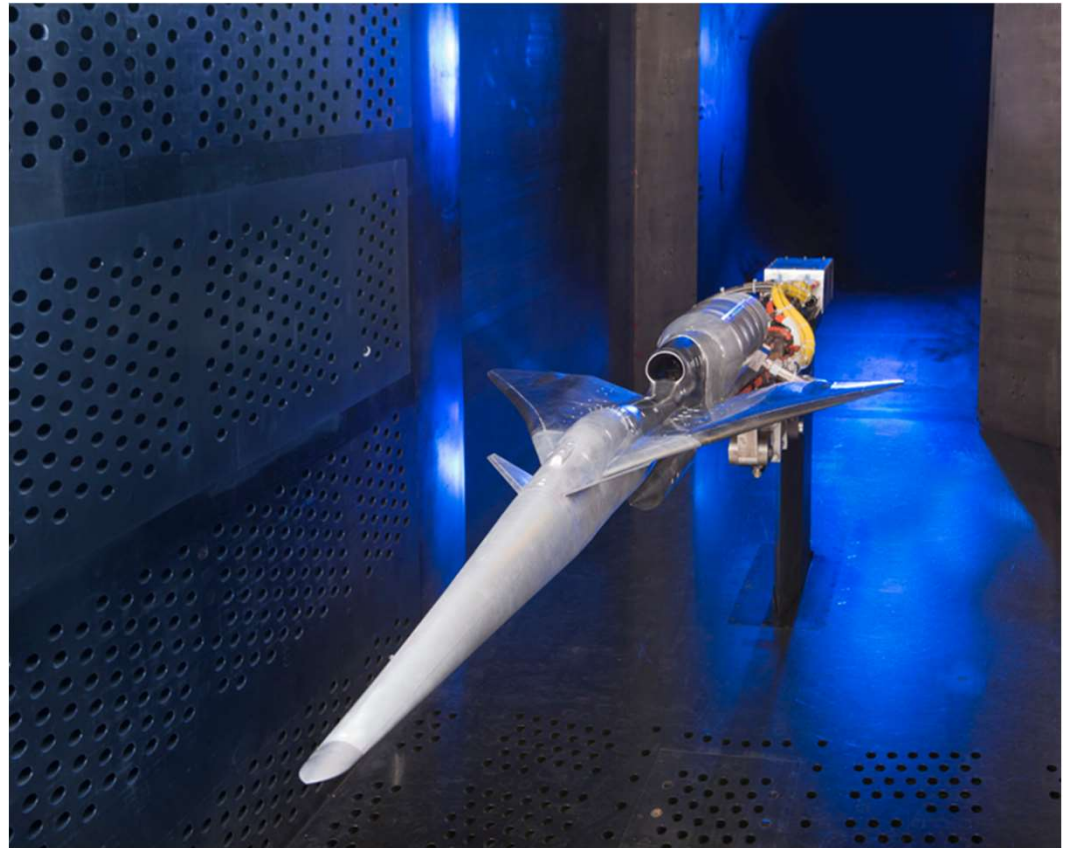
C607 Distortion

- Subsonic distortion
- Not sensitive to vehicle attitude
- Maximum values at static conditions



C608 Key Comparisons

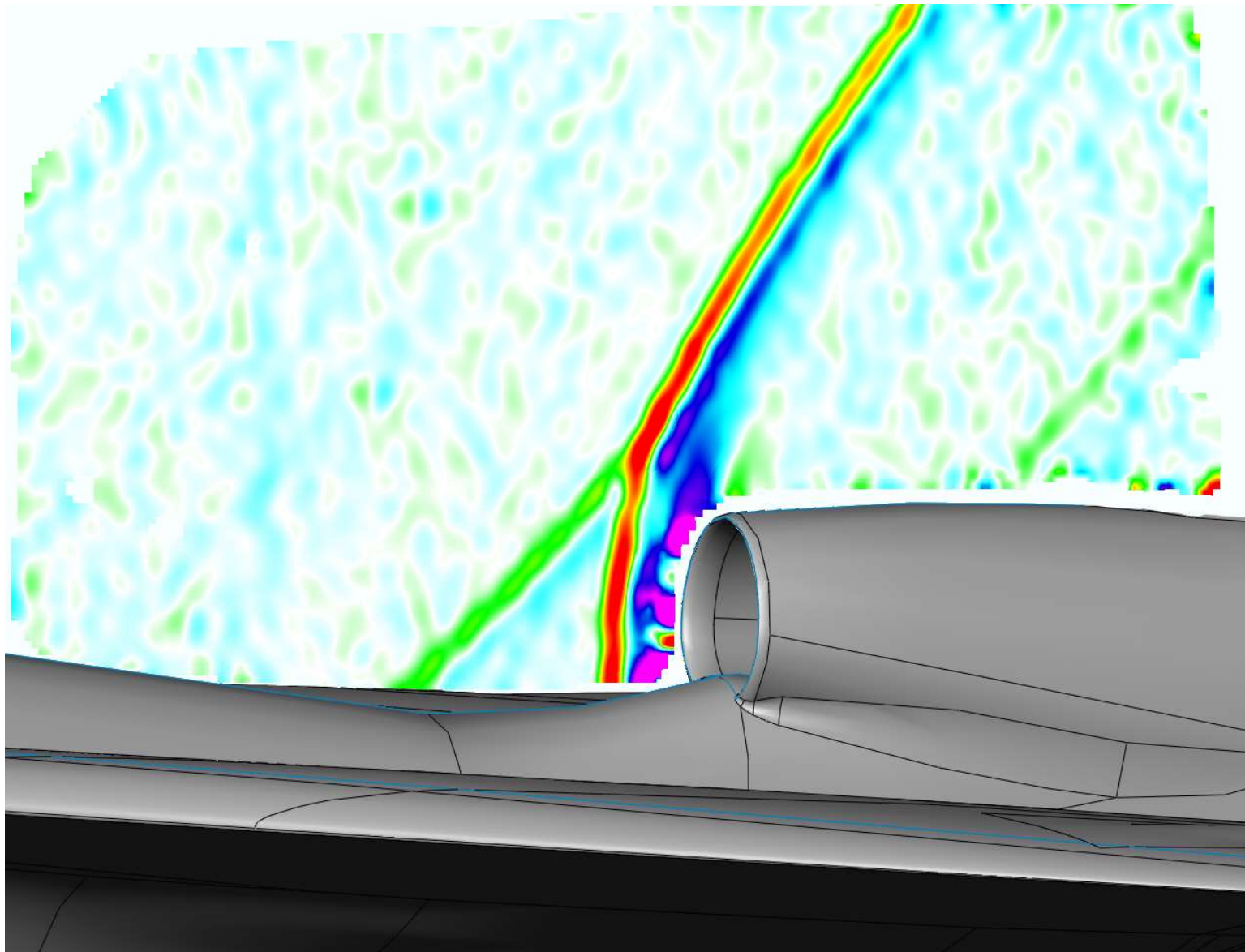
- Supersonic results at critical point were comparable to the C607 inlet
- Insensitive to angle of attack
- Increased sensitivity to sideslip
- Subsonic results nominally a 0.5% increase in recovery over C607
- Static performance nominally a 1% increase in recovery

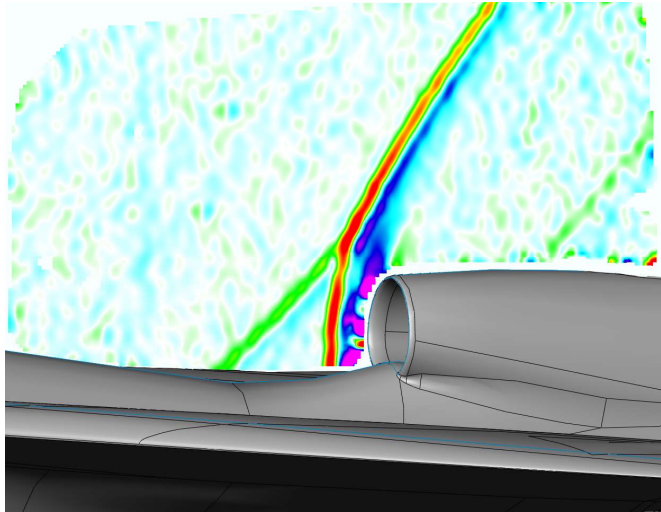


Summary/Conclusions

- Top mounted inlet performance critical to vehicle preliminary design
- Full vehicle plus inlet model was a successful approach, 9.5% scale
- Inlet Data was successfully collected:
 - Supersonic recovery and distortion were insensitive to α
 - Sensitive at $\beta = -2^\circ$
 - Dramatically affected by vortex generators
 - Well behaved subsonic performance, low performance as expected at static conditions









LBFD High Speed Inlet Distortion Test

Quick Look Data Analysis

Objective

- HSIDT: To “evaluate the inlet/engine compatibility and operability,” focusing on “the inlet/engine face dynamic effects” using 9.5%-scale propulsion model.
- NASA Quick Look Analysis: To provide an initial assessment of the X-59 inlet distortion based on data collected during the HSIDT.

Approach

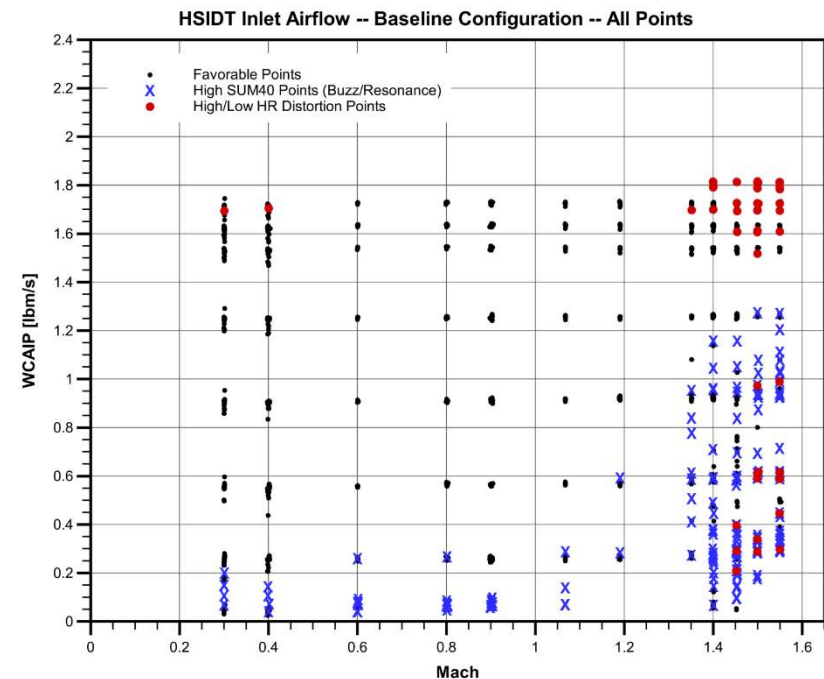
- Collected dynamic distortion data during HSIDT: IDC_{MAX}, IDR_{MAX}, SUM40 (buzz).
- Plotted data points as inlet corrected flow vs Mach, denoting point outside distortion and SUM40 limits.
- Systematically eliminated points outside of distortion and SUM40 limits using Alpha and Beta limits and engine airflow lines (i.e., max power, idle, windmill).

Status

- Flight between Idle and Max Power air flow for Mach=0.3 to 1.45 is free of inlet buzz/resonance and within dynamic distortion limits.
- X-59 can fly Mach=1.35 to 1.55 between Idle and Max Power without inlet buzz and within dynamic distortion limits but must limit throttle back when decelerating from Mach>1.45 to avoid buzz.
- Windmill air start for Mach=0.3 to 1.19 should be free of inlet resonance and within dynamic distortion limits.

Significance

- HSIDT and data analysis showed that inlet should be compatible with engine.
- Only a few control limits will be needed to fly safely within distortion and SUM40 limits.
- **GE will provide the complete inlet/engine compatibility and operability assessment.**





X-59 Sonic Boom Test in Glenn 8x6 Wind Tunnel

Objective:

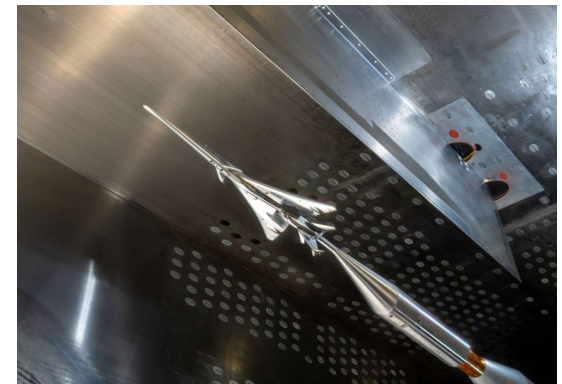
- Collect sonic boom signatures in the wind tunnel for comparisons to CFD predictions and future X-59 flight tests. Validate and improve CFD tools.

Approach:

- First test in the 8x6 smooth-wall supersonic test section, located upstream of the 8x6 porous wall transonic test section:
 - Identified as a favorable location in 2012
 - Mach stability assessments in 2014 using 14"sonic boom measurement rail
 - Test section calibration in 2016 and 2020
- Boom data obtained at Mach 1.36, 1.40, 1.47 (Sept/October 2021)
- 3 heights, 3 angles of attack, roll angles 0° to 45°
- Configurations included baseline control deflections, plus incremental deflections of stabilator, flaps, ailerons (all $\pm 0.5^\circ$), T-tail ($\pm 1^\circ$)

Results

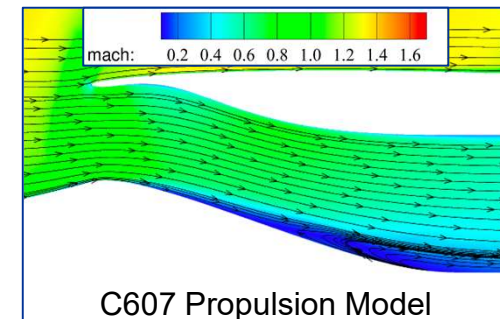
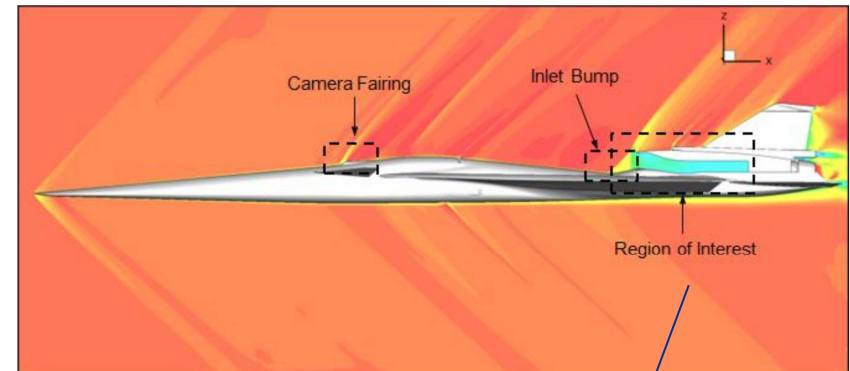
- Sonic boom signatures collected, and comparisons made to CFD predictions.
- Accurately captured vehicle shock features and locations.
- Forward work includes detailed assessments and CFD refinements.





LBFD Inlet CFD

- CFD Performed:
 - Full vehicle geometry
 - Wind tunnel and Full Scale
- Challenges:
 - Under-prediction of inlet recovery
 - Over-predict distortion
 - Grid adaptation and increased mesh refinement increased uncertainties.
 - Current state of the art for aft-mounted, top-mounted inlet requires anchoring the CFD solutions to experimental data and performing a grid study
 - Further fundamental research and study recommended before CFD can be relied on for predictions
- References
 - NASA TM 20210022214
 - AIAA-2018-3861



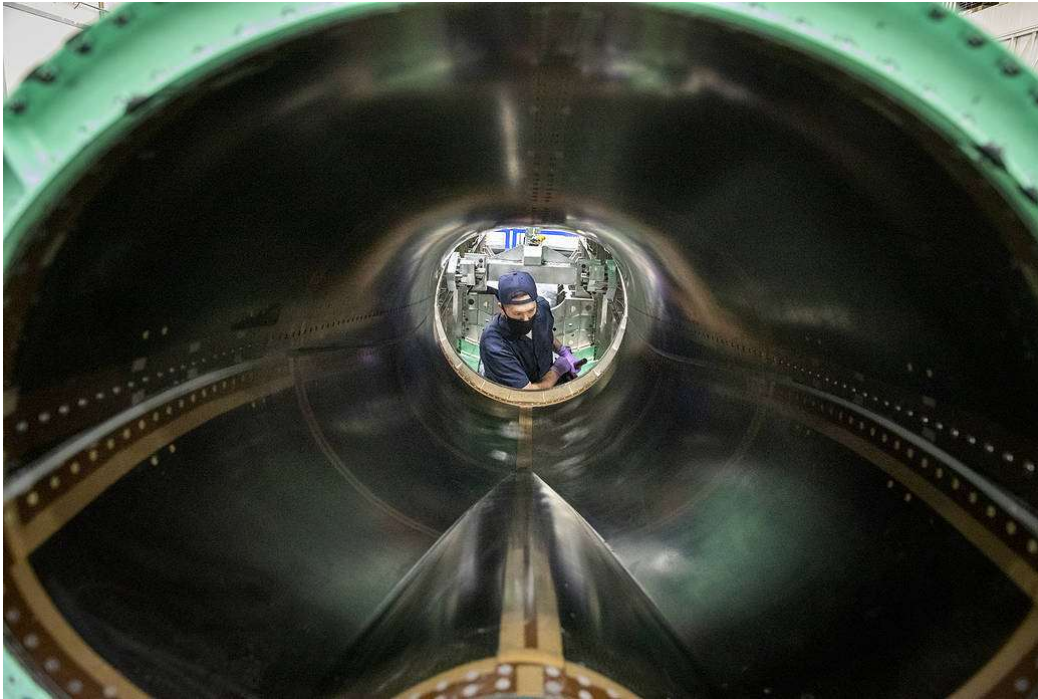


Update

- 2022 is a big year for LBFD
 - Final Assembly of the Vehicle
 - **Ship to Ft. Worth for Loads Test**
 - Air Data Probe 8x6 Wind Tunnel Test
 - Deliveries of NASA systems complete
 - Subsystem Check Outs (SCOs), Proof & Cal Tests, Ground Vibration Test
 - Engine Installation
 - Flight Readiness Review (FRR)



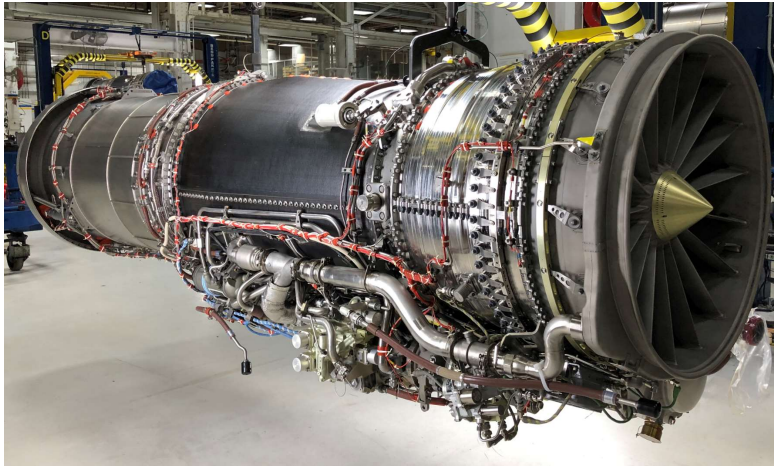






Engines Delivered August 2020

- Two F414-GE-100 engines
- Shipped from GE Lynn MA to AFRC





LBFD Propulsion Team Activities 2022

- Propulsion CFD: plume/aft-deck interaction, hydrazine exhaust
- Engine Field Service Instructions (SiC nozzle flaps)
- Engine flight test instrumentation checkouts
- Propulsion control room preparations/training
- Propulsion cockpit simulator integration
- Engine fit check in the aircraft
- Engine installation and system checkouts
- Flight Readiness Review
- Engine ground testing (in vehicle)
- First flight

AFRC Flight Control Room

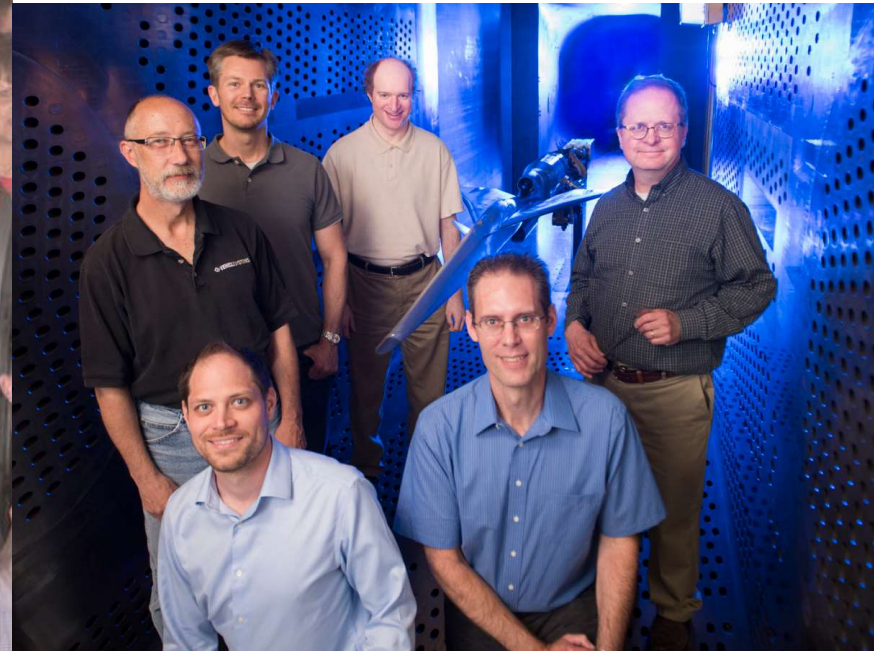


AFRC Cockpit Simulator



Tie-down ground testing example

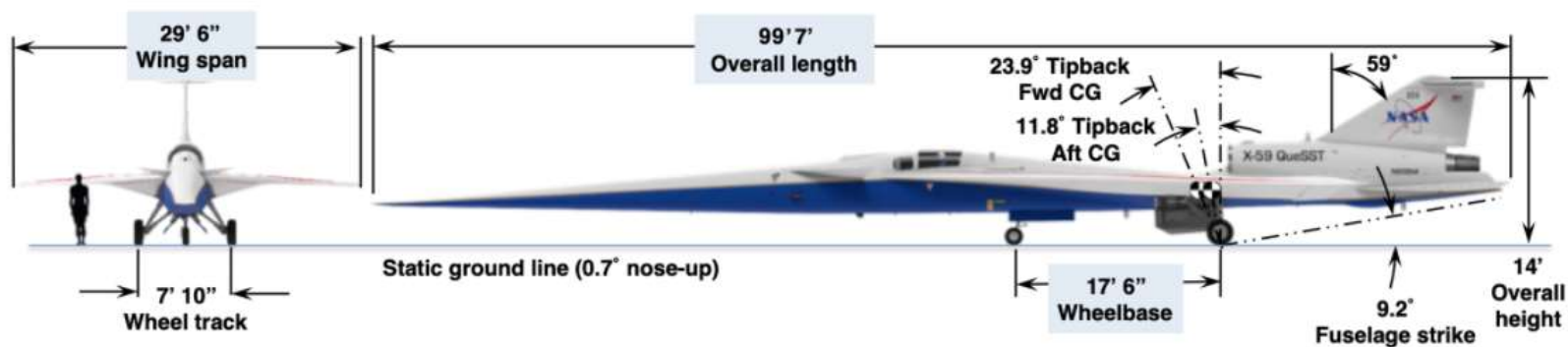
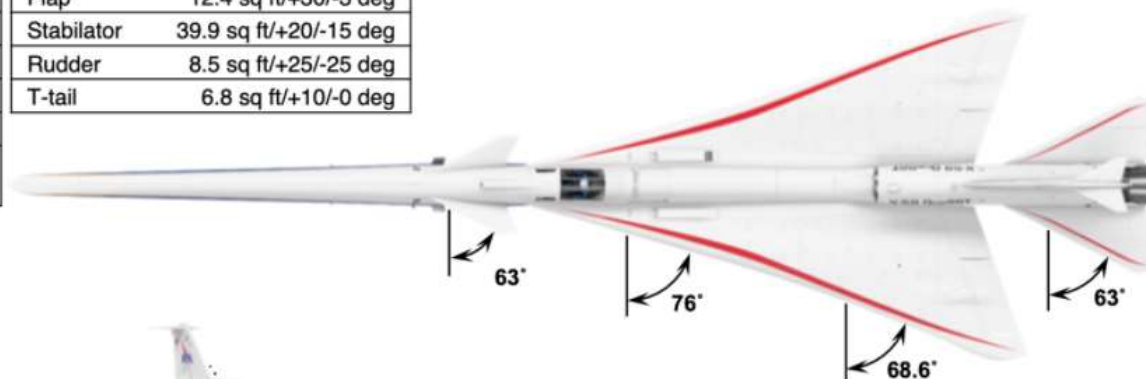


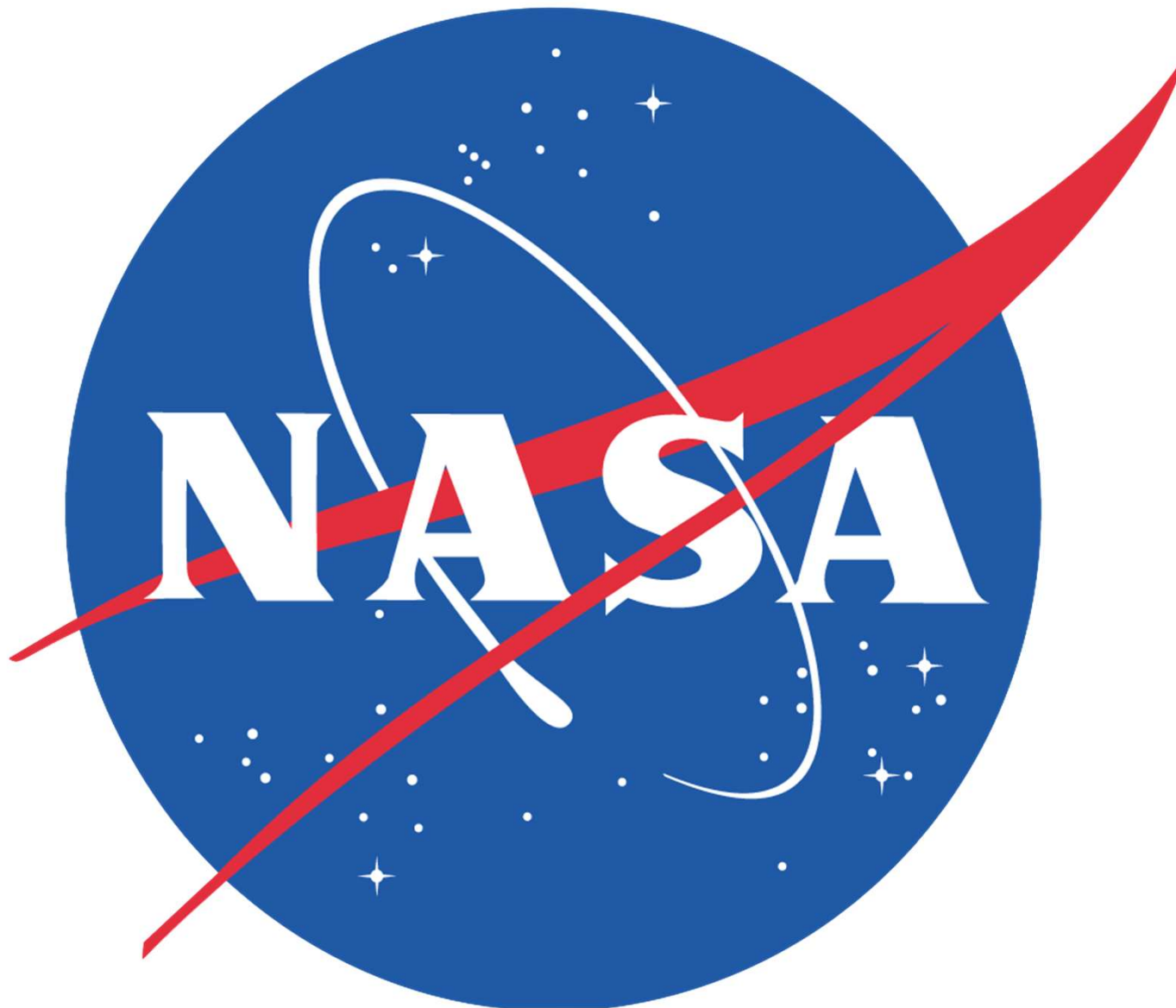


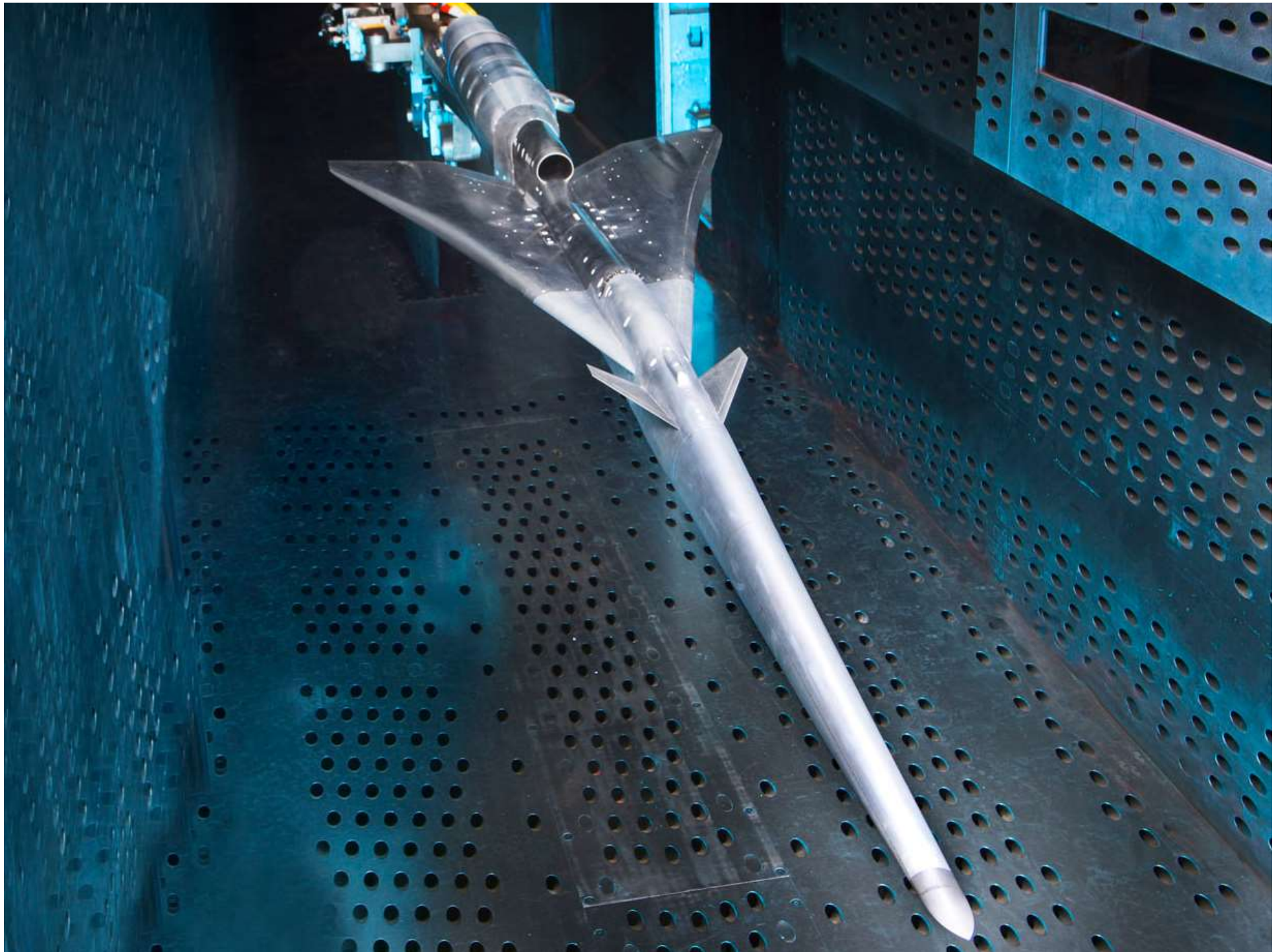


Configuration C612	
MDGW	25,000 lbs
Fuel (Max)	8,700 lbs
Payload	600 lbs
Design Mach	1.4
Loudness	<75 PLdB
Engine	1xF414-GE-100
Landing Gear	F-16 Blk25 NLG F-16 Blk25 MLG

Control Surfaces	
Aileron	12.9 sq ft/+35/-25 deg
Flap	12.4 sq ft/+30/-3 deg
Stabilator	39.9 sq ft/+20/-15 deg
Rudder	8.5 sq ft/+25/-25 deg
T-tail	6.8 sq ft/+10/-0 deg









Supersonics Research

Sonic Boom Community Response

Aeroservoelastic Analysis and Design

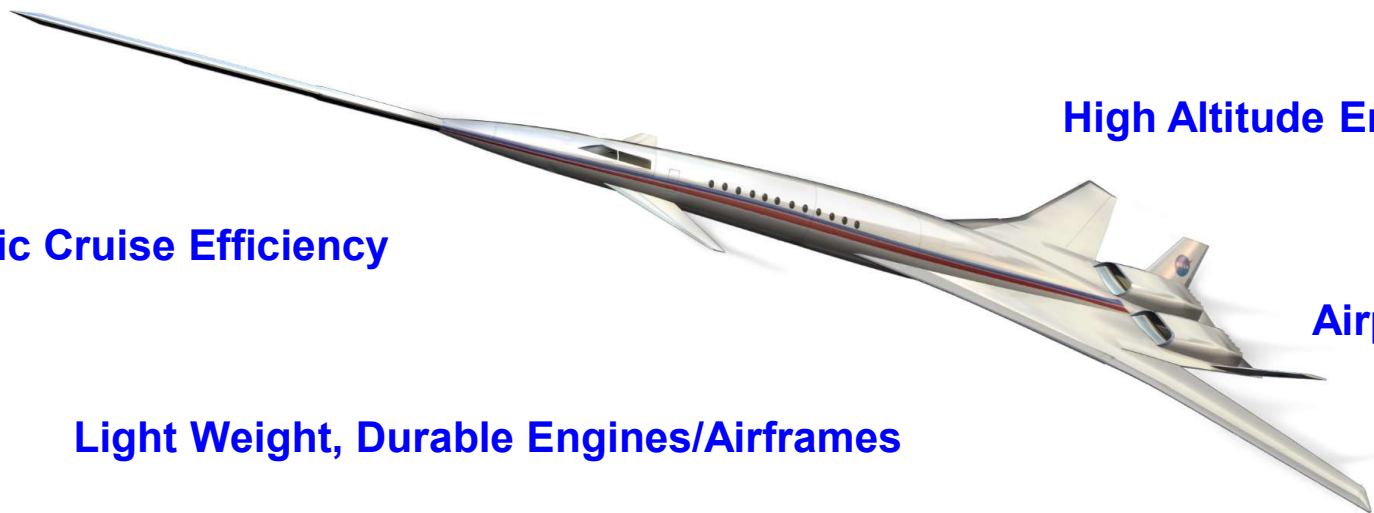
High Altitude Emissions

Supersonic Cruise Efficiency

Airport Noise

Light Weight, Durable Engines/Airframes

Integrated Multi-Discipline System Design



Low Boom Flight Demonstrator (LBFD) Update



- Fabrication of X-59 vehicle to be completed in 2022 at Lockheed Martin in Palmdale, CA.
- Recent activities
 - Ft. Worth structural load and fuel system tests
 - Air Data Probe 8x6 Wind Tunnel Tests, 2 entries
 - CST 8x6 Wind Tunnel X-59 sonic boom test
- Upcoming activities
 - Systems Checkouts
 - Engine Installation
 - Ground Vibration Test
- Flight Readiness Review in 2022
- Ground Tests and First Flight by end of 2022



X-59 Nose

Probe





CST.03.31.1 Inlet Distortion Prediction Best Practices for LBFD

Objectives

- Investigate impact of modeling and simulation parameters on inlet predictions for configurations representative of LBFD using NASA Langley's FUN3D CFD code
- Assess accuracy of FUN3D for predicting inlet performance on relevant configuration and provide recommendations for best practices

Level 3 Milestone Complete

- Studies performed for three inlet configurations using FUN3D
 - One isolated (unit) inlet and two installed inlets
- Results of studies and best practice recommendations documented in two-part NASA Technical Manuscript (TM)
 - Identification of Best Practices for Predicting Inlet Performance Using FUN3D Part 1: Isolated S-Duct Inlet
 - Identification of Best Practices for Predicting Inlet Performance Using FUN3D Part 2: Installed Inlets

Highlights

- Best practice recommendations provided for both isolated and installed inlets
- Accuracy of FUN3D predictions evaluated for predicting inlet performance on relevant configuration over range of flight conditions
- Results of studies provide insight to enable improved inlet predictions and to increase confidence for future assessments

