Low Boom Aircraft and the Future of Commercial Supersonic Transports

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Outline

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  - Barriers to Practical Commercial Supersonic Transportation
  - NASA-Shaped Sonic Boom Demonstration Vehicles
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  - Advancements in CFD
  - Advancements in Sonic Boom Wind Tunnel Testing
- X-59 Low Boom Flight Demonstrator
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Commercial Supersonic Transports

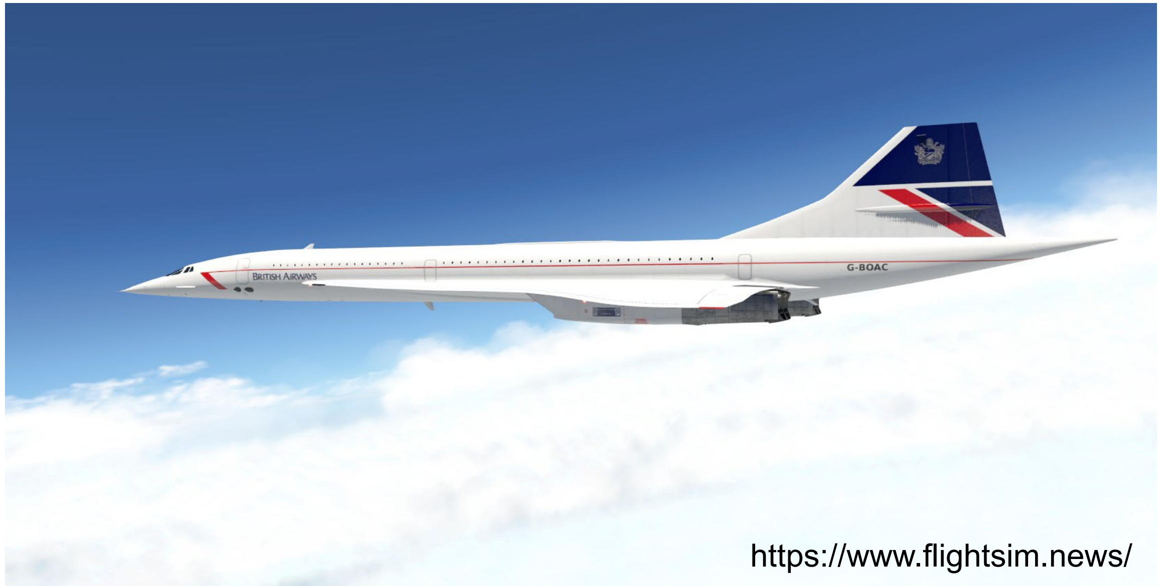
Tupolev Tu-144

- 16 aircraft built. (Aeroflot)
- 1^{st} flight: 12/31/68
- Cruised at Mach 2 @ 52,000 ft
- Passenger service from 1975 to 1978

NASA Photo

Concorde

- 20 aircraft built. (British Airways and Air France)
- 1st flight: 3/2/69
- Cruised at Mach 2 @ 43,000 ft
- Passenger service from 1969 to 2003



https://www.flightsim.news/

Barriers to Practical Supersonic Commercial Aircraft

Environmental Barriers

Airport Noise
- Noise levels not louder than subsonic aircraft at appropriate airports

Sonic Boom
- Design for low noise sonic boom
- Understand community response

Emissions
- Minimal long-term impact at supersonic cruise altitudes
- Improvements at subsonic conditions
- Greater environmental restrictions anticipated

Efficiency Barriers

Light Weight, Durable Vehicles
- Low airframe and propulsion weight in a slender flexible vehicle operating at supersonic cruise temperatures

Efficient Vehicles
- Efficient airframe and propulsion throughout flight envelope

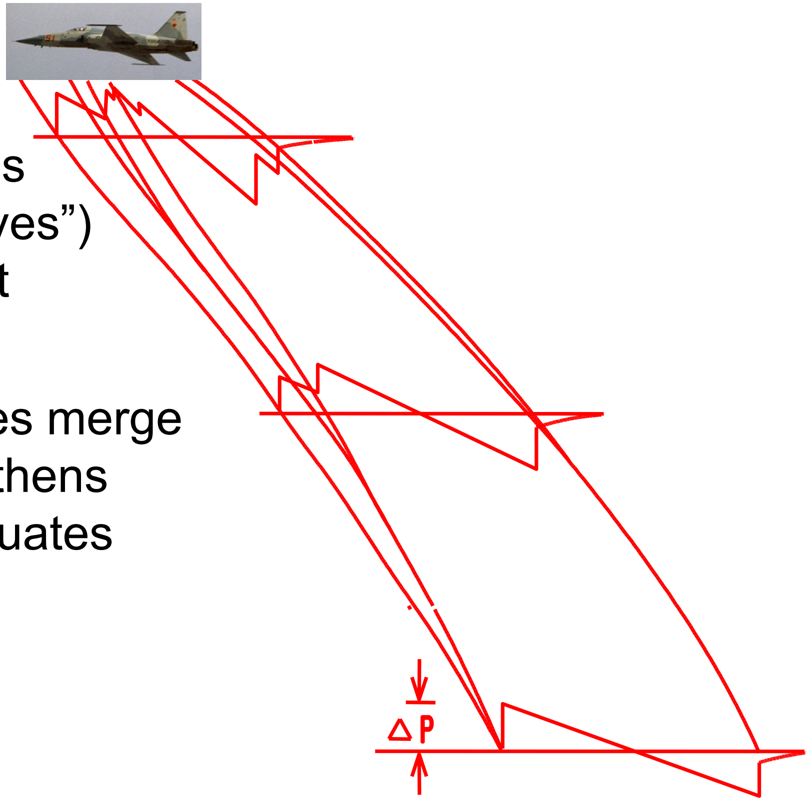
Efficient Operations
- Airspace-vehicle interaction for full utilization of high speed

Sonic boom noise and overland flight restrictions are the biggest barriers to market growth

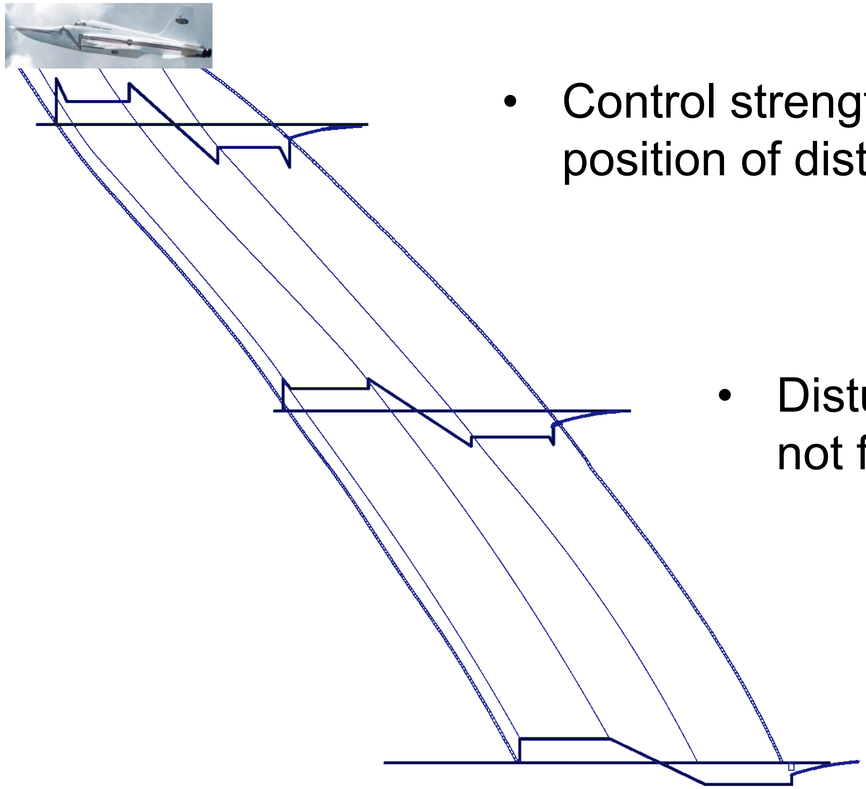
Practical Approaches to Sonic Boom Reduction: Minimization Through Aircraft Shaping

- Multiple disturbances ("shock waves") near aircraft

- Disturbances merge
- Signal lengthens
- Noise attenuates



- Shocks coalesce into "N-wave"



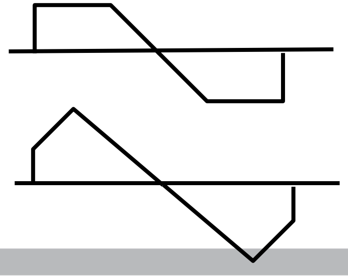
- Control strength and position of disturbances

- Disturbances do not fully merge

- Shaped boom at the ground

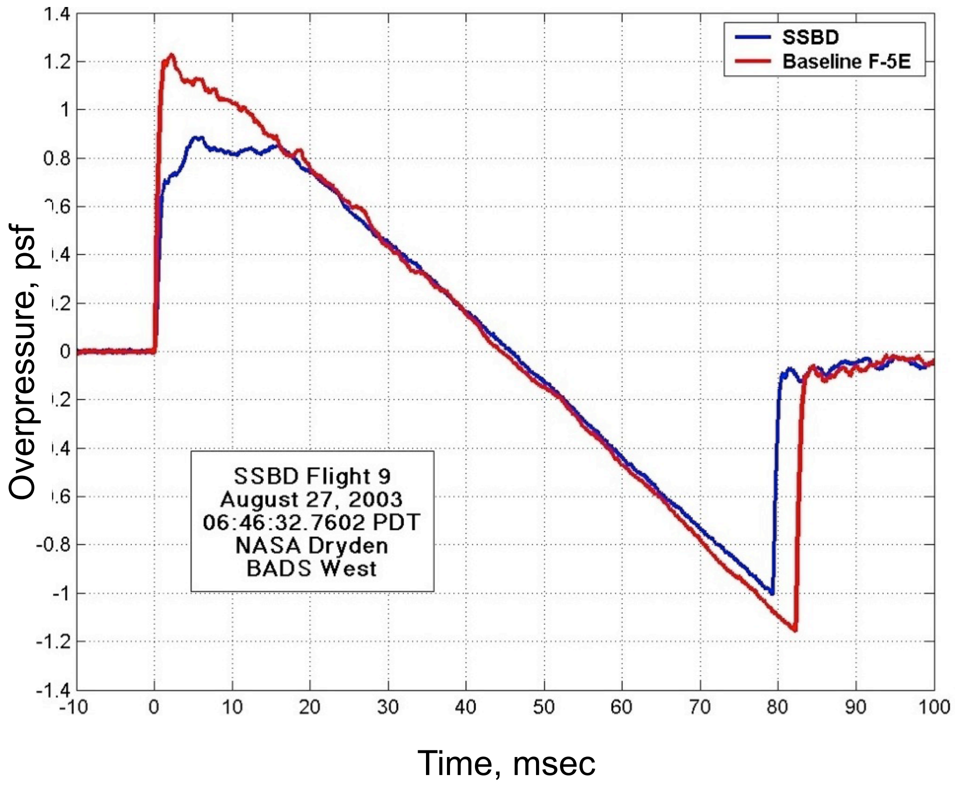
Minimum Overpressure

Minimum Initial Shock



NASA-Shaped Sonic Boom Demonstration Vehicles

- First-ever shaped sonic boom recorded 27 August 2003
- Signatures recorded during NASA Shaped Sonic Boom Demonstration (SSBD) back-to-back data flights in the Edwards AFB supersonic flight corridor
- Flight conditions:
  Mach 1.36⁺ @ 32,000 ft

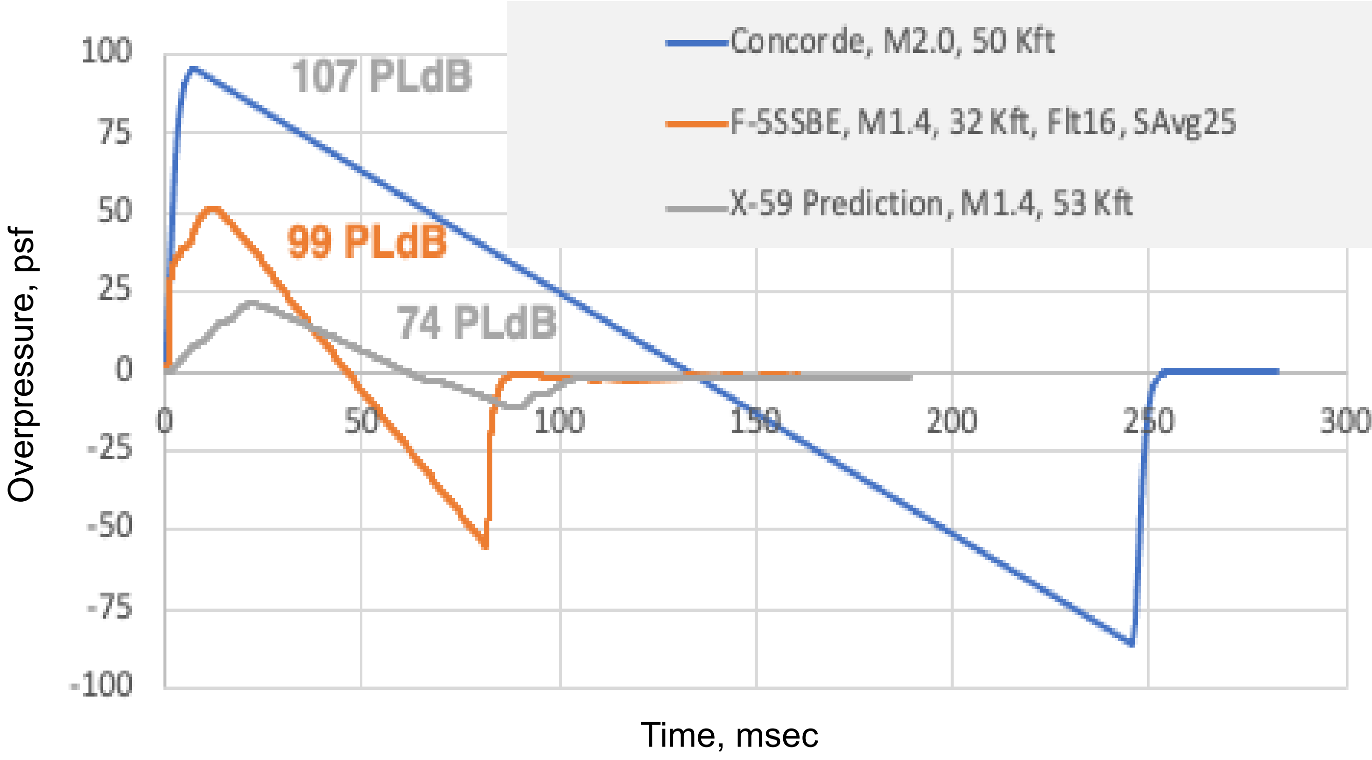


NASA's Approach to Design for Quiet Supersonic Flight

Approach

- Develop and validate tools and design approaches to enable the development of supersonic airliners with very little perceived sonic boom noise with 75-80 PLdB
- Build on 40+ years of research in sonic boom minimization
- Improve usability, accuracy and speed of high-fidelity analysis tools for inclusion in the design process
- Develop new near-field & ground signature design targets that produce less noise, and allow more design flexibility
- Conduct validation studies in wind tunnels and in flight
- Conduct sonic boom acceptability studies

Ground signature comparison

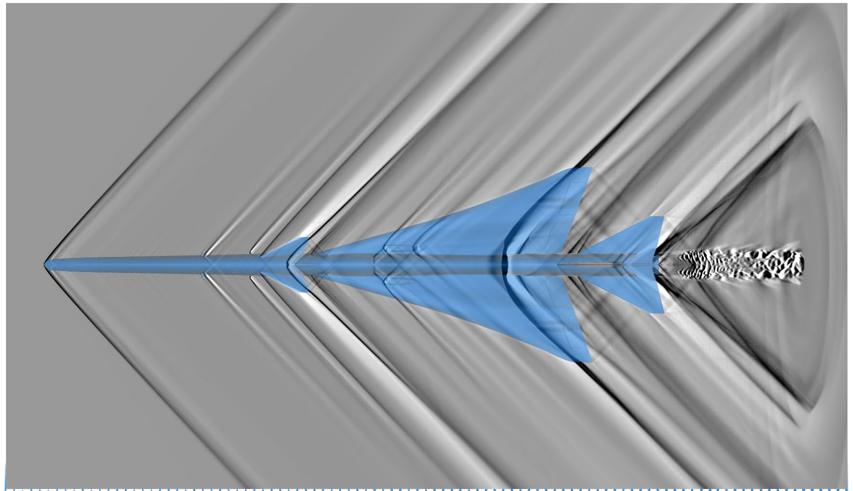


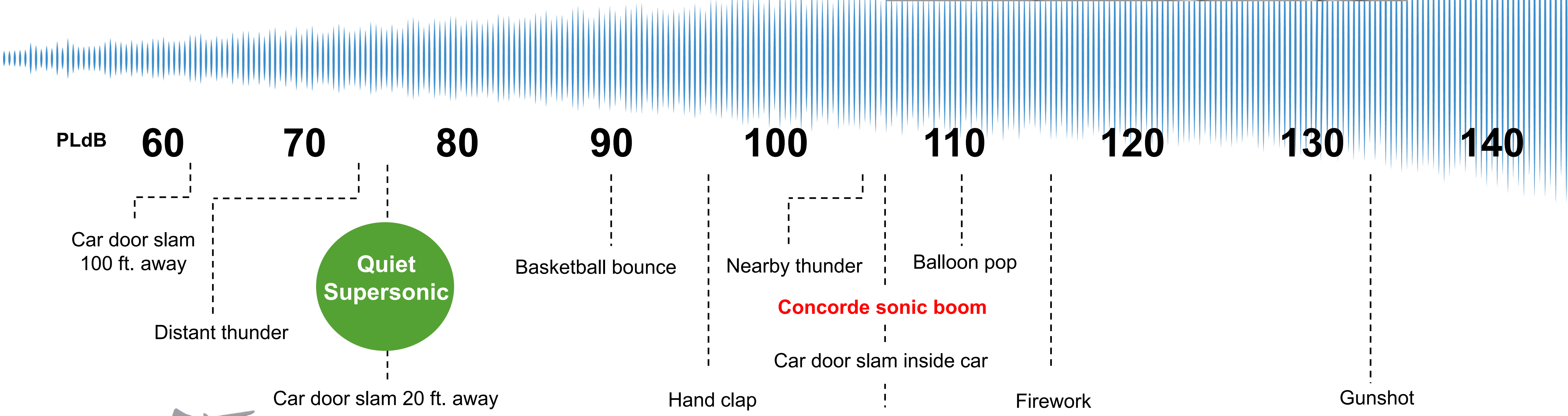
How to Quieten the Boom?

Acoustic pressure waves are “shaped” by controlling the strength and position of shock waves generated by aircraft components

Important advances:

- Innovative thinking
- Integrated design systems
- Higher fidelity analysis
- Faster computers

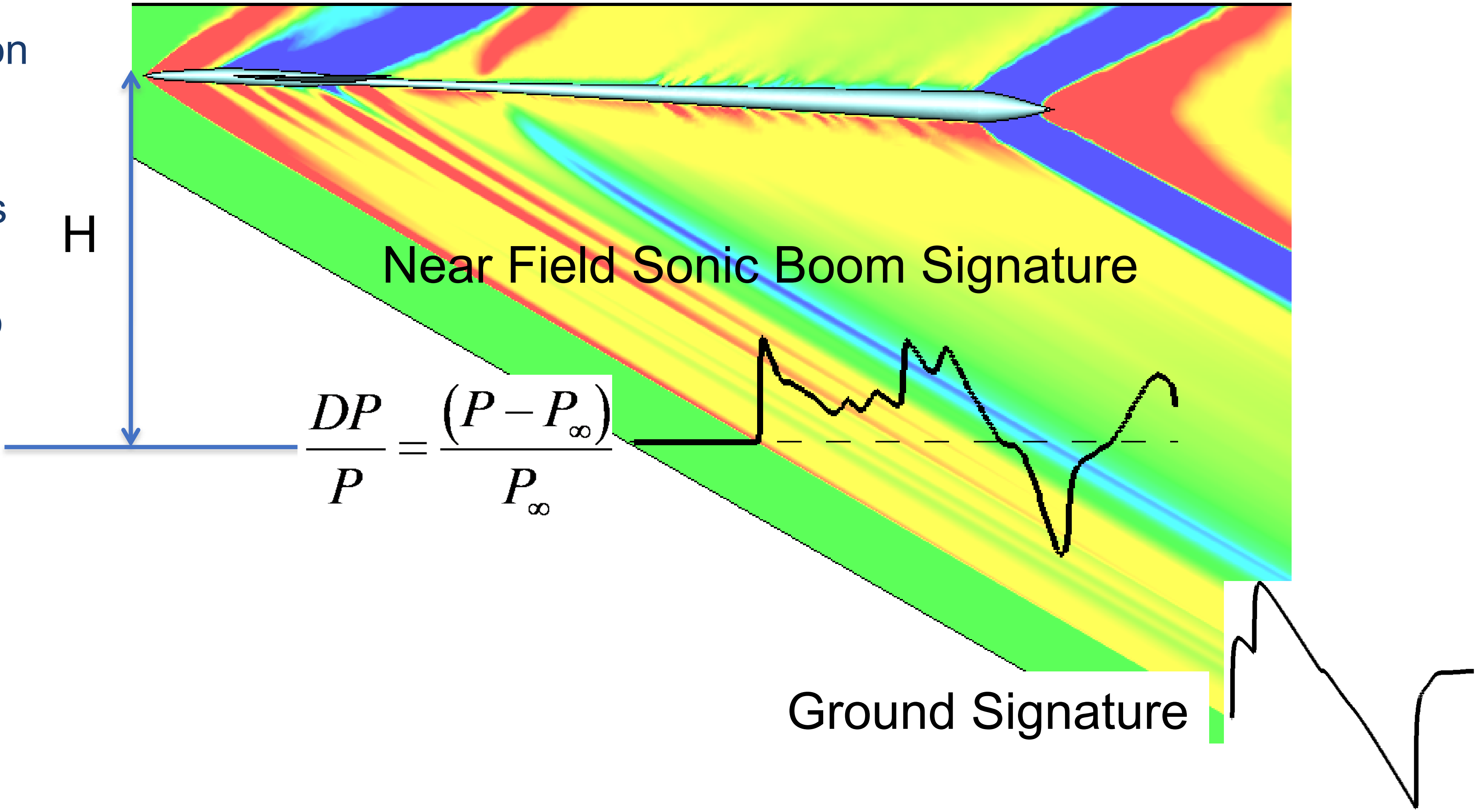




Advancements in CFD

High Fidelity Analysis and Design Processes

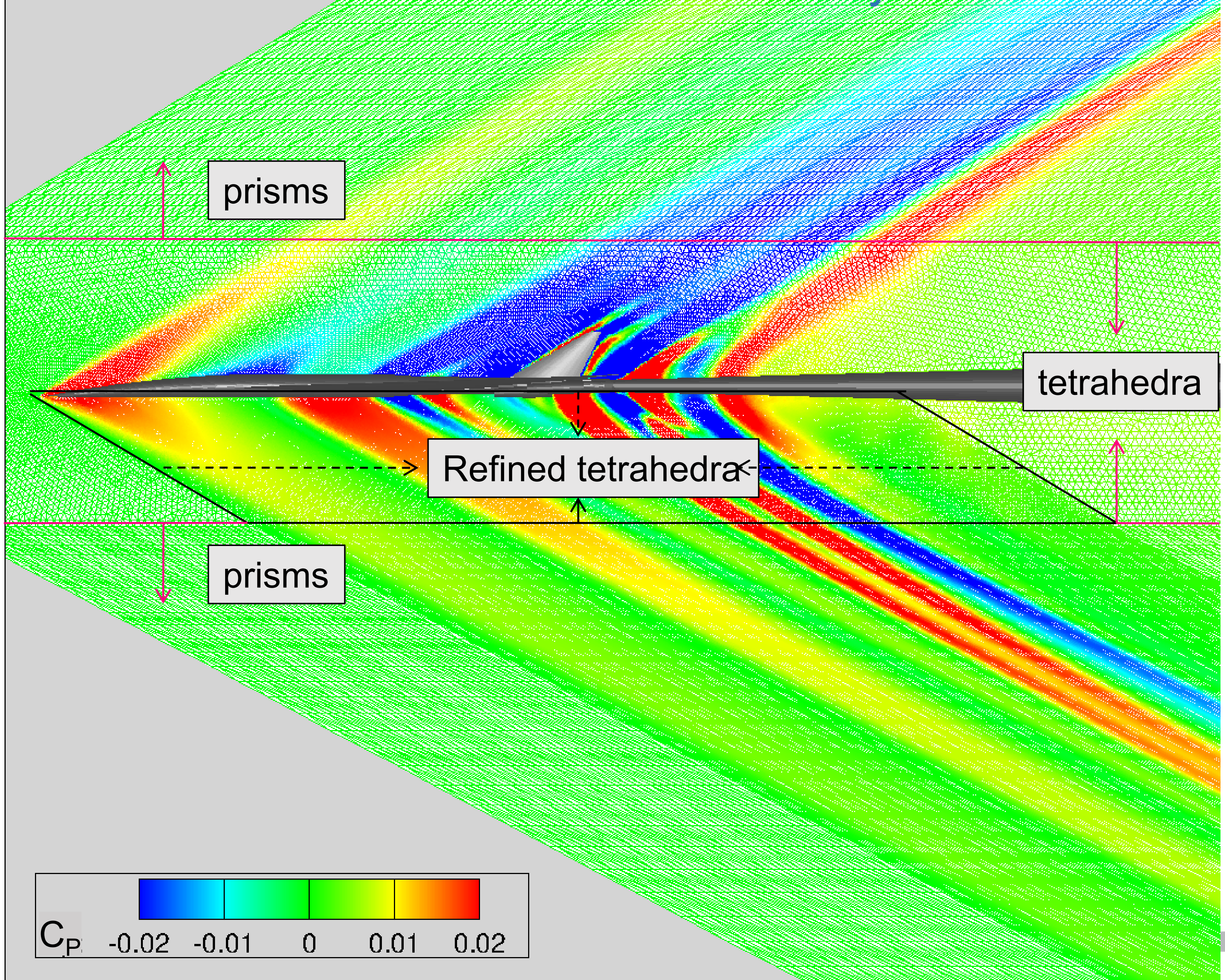
- High fidelity CFD codes
- Enhanced grid generation methods
- Adaptive gridding and gradient adjoint methods
- Flow visualization techniques developed to capture/validate shocks and off-body pressures more precisely and crisply



$$\frac{DP}{P} = \frac{(P - P_\infty)}{P_\infty}$$

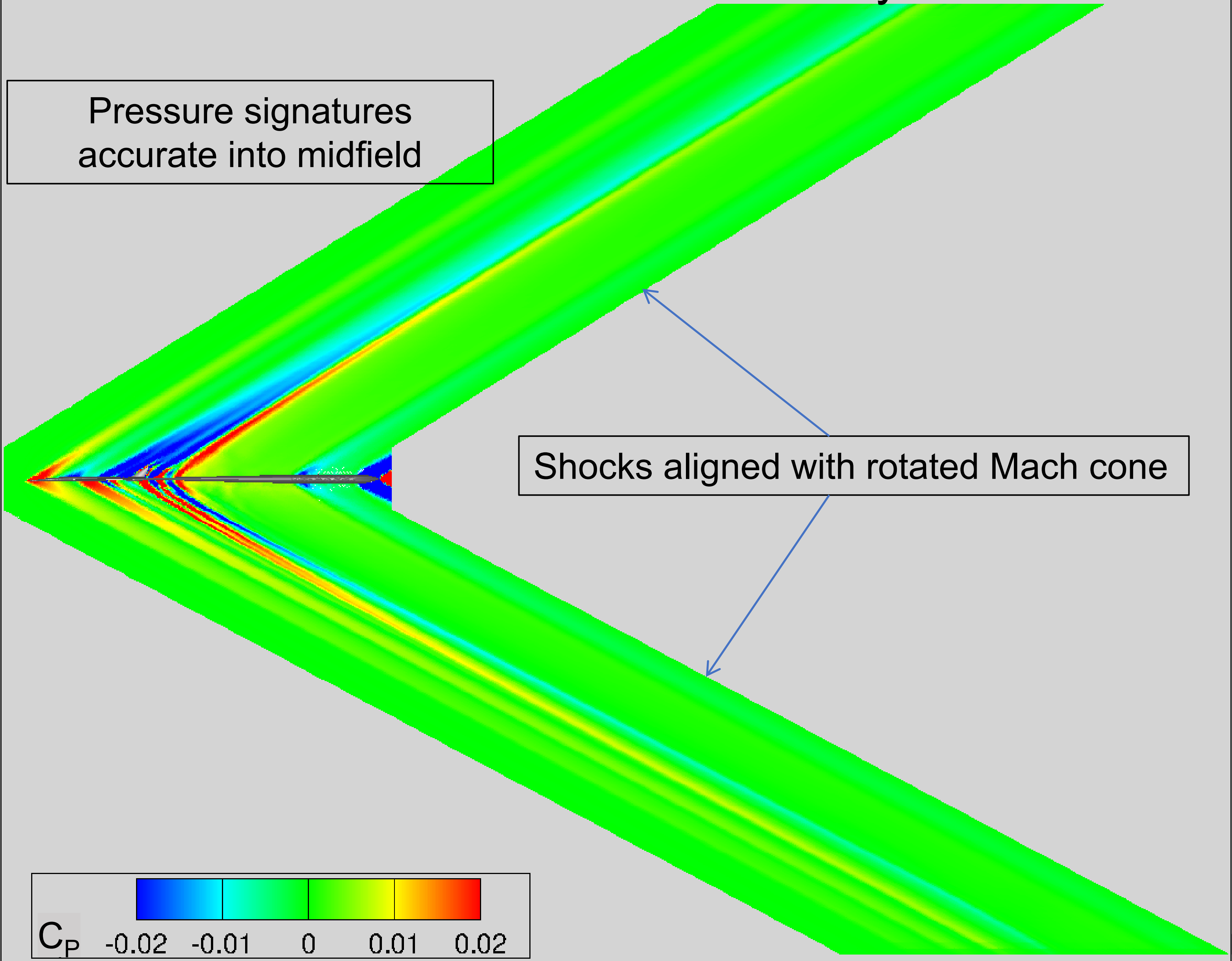
Tetrahedral Meshes with Extruded Sheared-Stretched Prisms for Sonic Boom Analysis

- Extruded prism meshes can be aligned with the Mach cone angle for all azimuthal angles



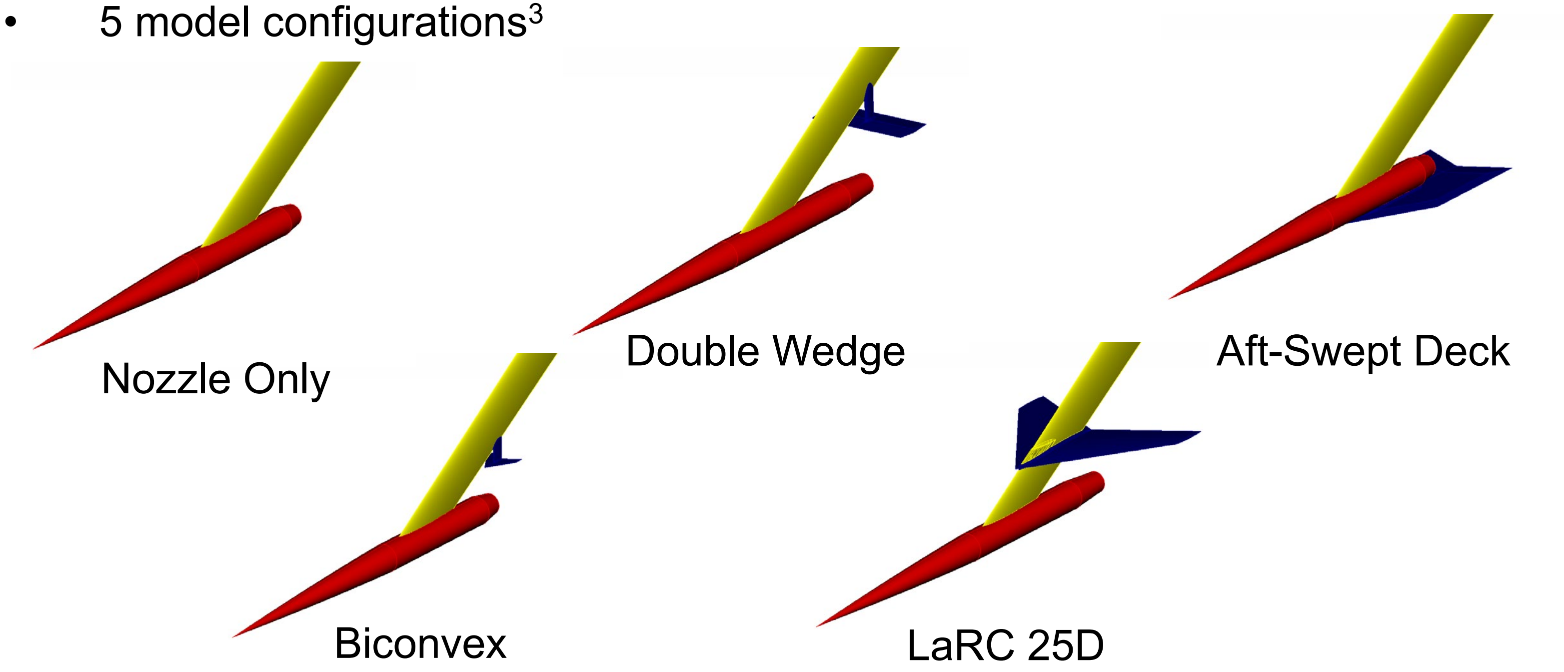
Tetrahedral Meshes with Extruded Sheared-Stretched Prisms for Sonic Boom Analysis

- Offers accurate pressures without the computational time required for mesh adaptation
- Offers a single flow solver solution compared to hybrid unstructured /structured methods



Experiments to Evaluate CFD in Nozzle Shock Plume Interactions

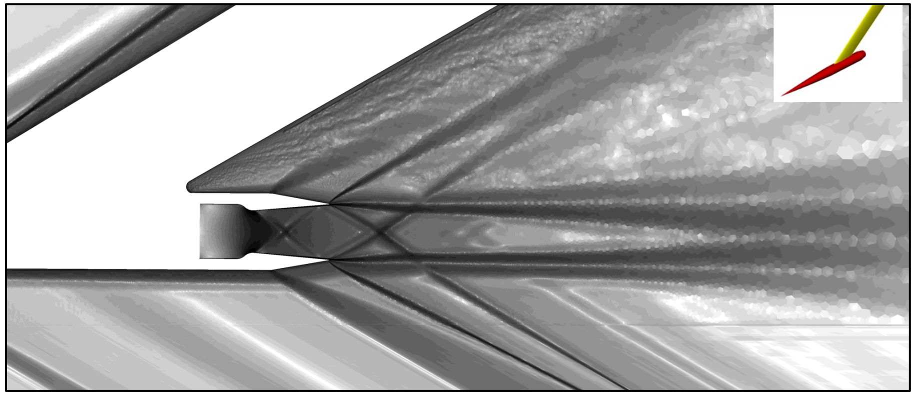
- A small-scale experiment was performed in the NASA Glenn 1x1 Foot Supersonic Tunnel to examine shock/plume interaction (2014)[1]
  - Pressure signature taken at 1 nozzle diameter (1.0'')
  - 1 model configuration
- A larger-scale shock/plume test was performed in the NASA Ames 9x7 Foot Supersonic Wind Tunnel that provided data for models that were representative of realistic aft geometries (2016)[2]
  - Pressure signatures up to 23 nozzle diameters (35'') with a 1.5" nozzle diameter
  - 5 model configurations[3]



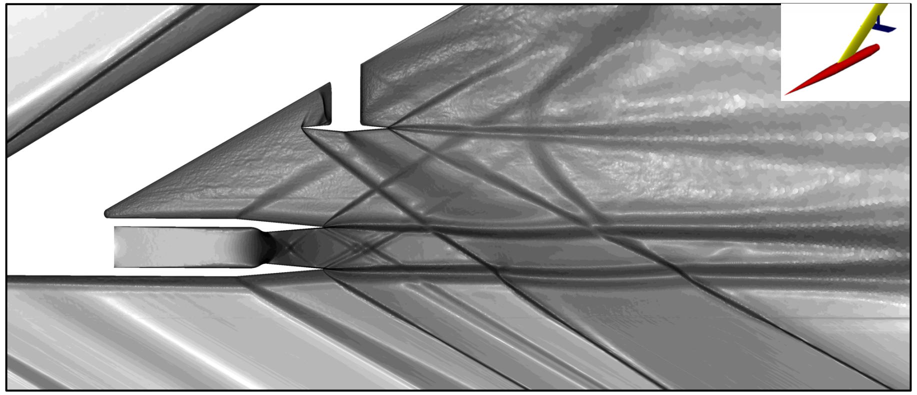
[1]Castner et al, AIAA 2015-1046, [2]Durston et al, AIAA 2017-0041, [3]Cliff et al, AIAA 2016-2035

Density Gradient Comparison

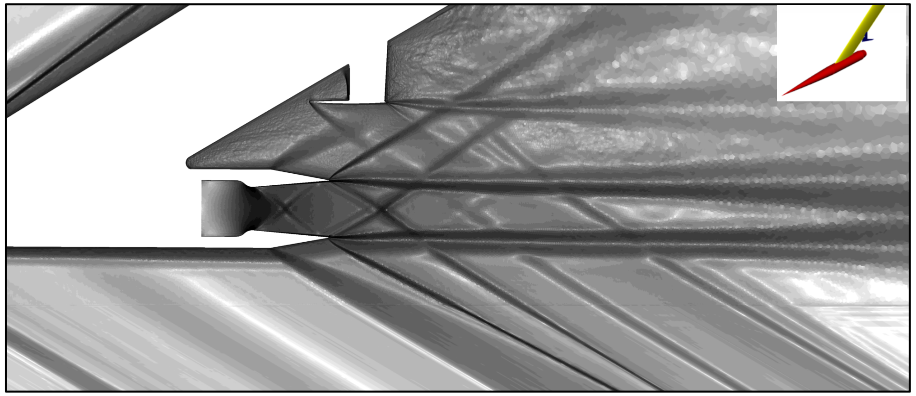
Nozzle Only



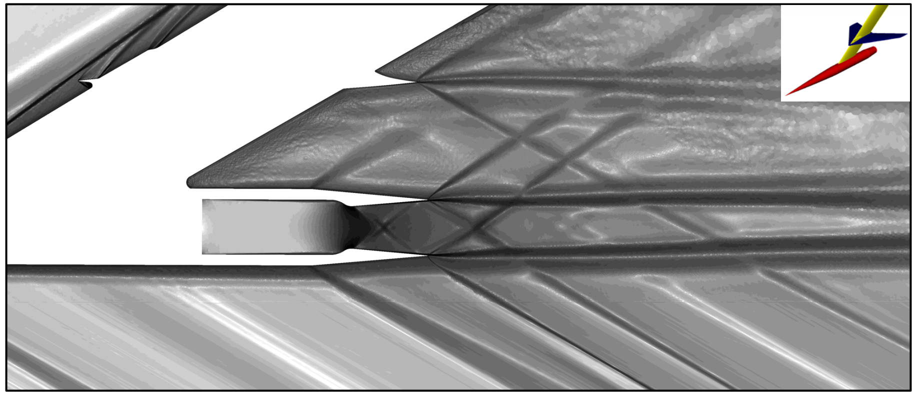
Double Wedge



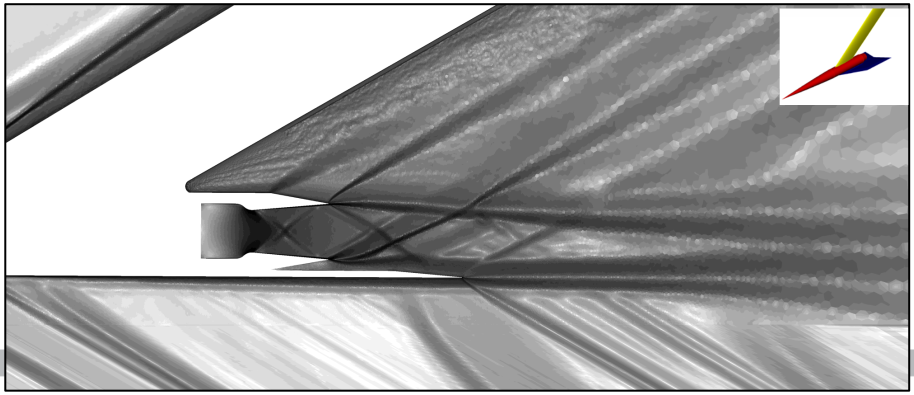
Biconvex



LaRC 25D

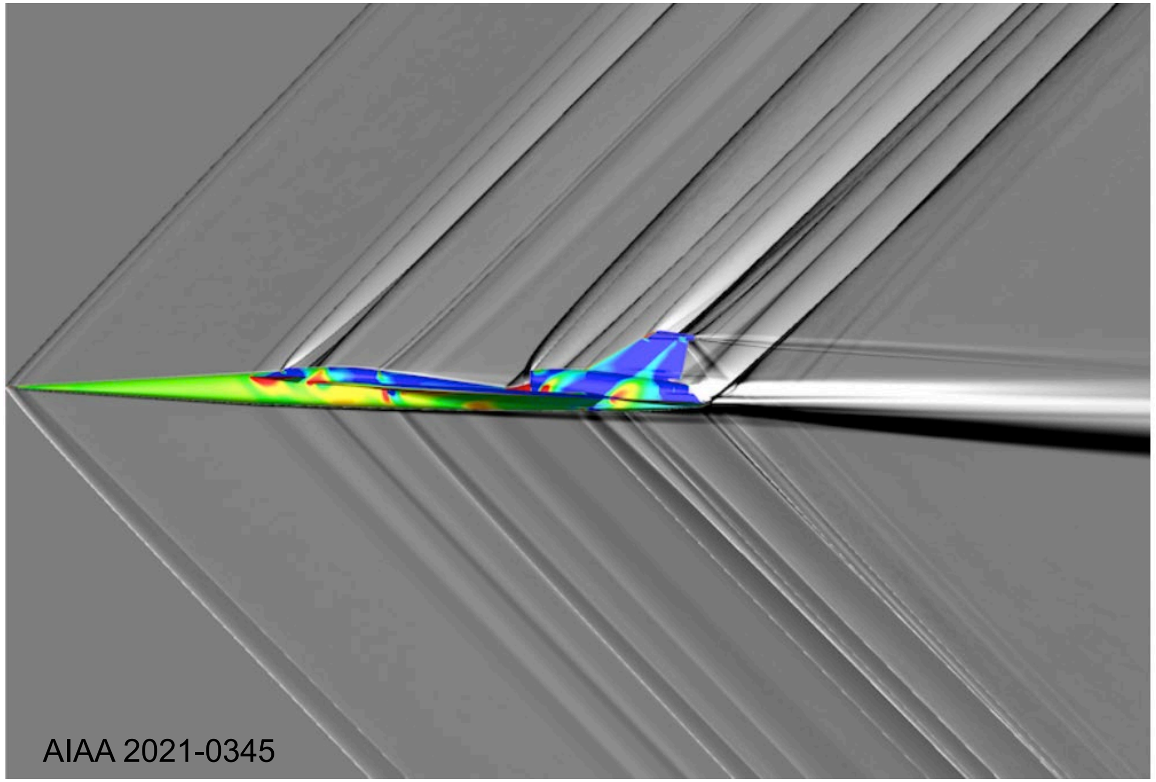


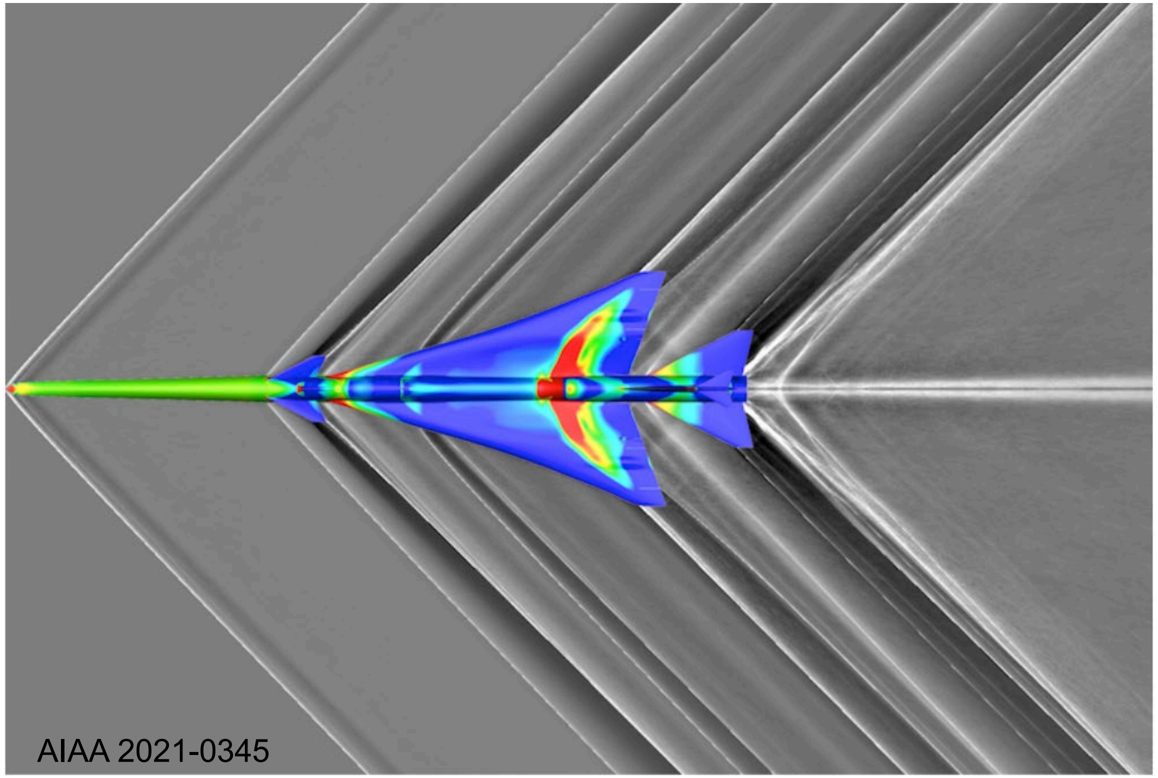
M=2.0, Nozzle Pressure Ratio (NPR) = 8
(Double Wedge NPR=10)



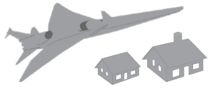
Aft-Swept Deck

Lockheed Low Boom Flight Demonstrator in Supersonic Flight





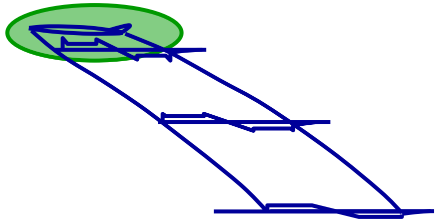
C608 Density gradient and surface pressures
M_{∞} = 1.4, α =2.15°, Re = 109,776 per in.

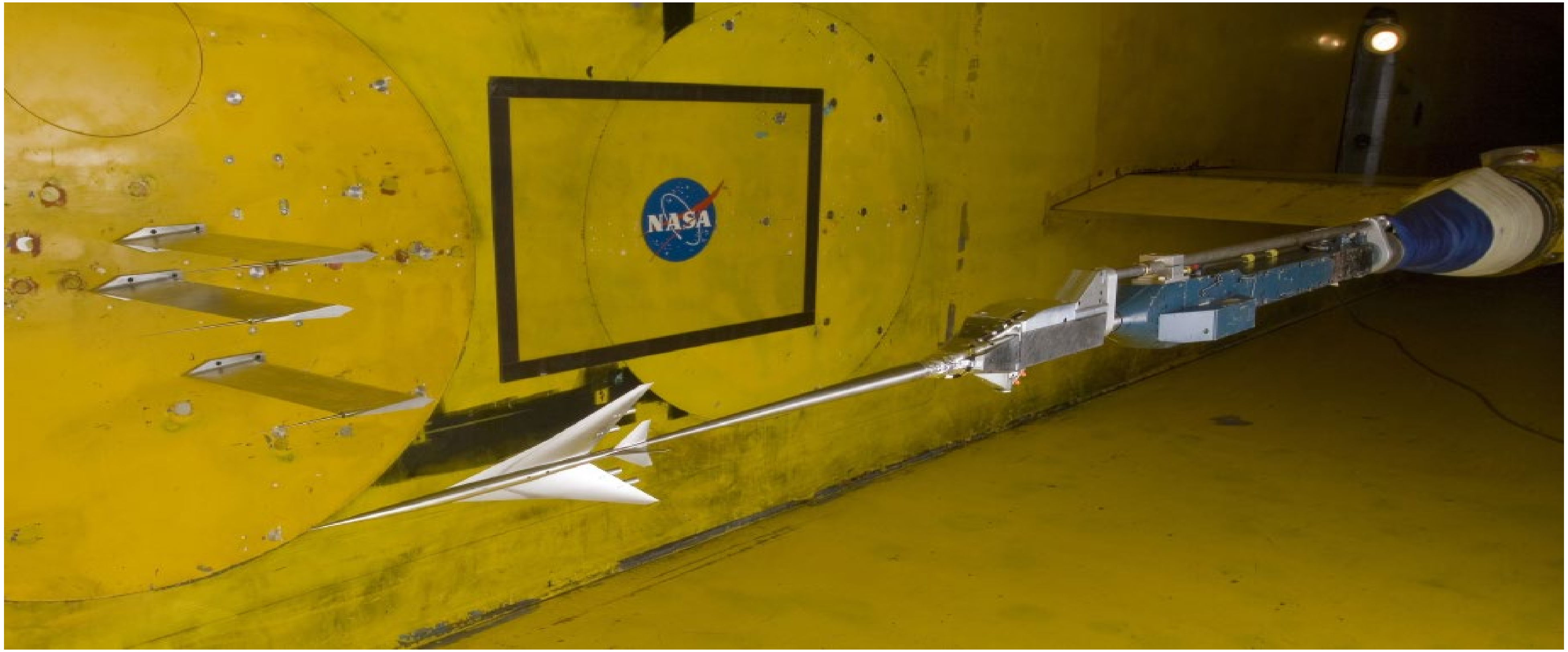


Advancements in Sonic Boom Wind Tunnel Testing

Experimental Validation of Boom Reduction Concepts Using Pressure Probes

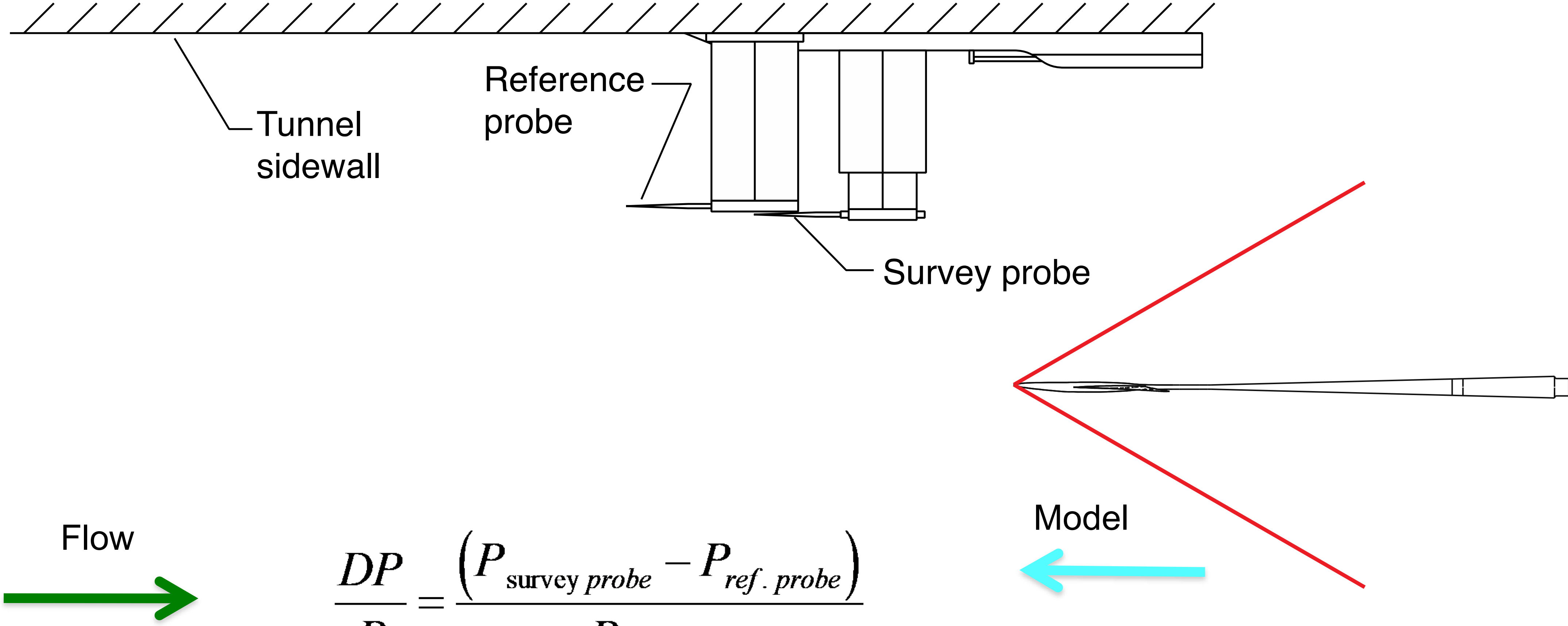
- Scale model tests in supersonic wind tunnels
- Historic model traverse technique with single overpressure probes (on and off- track)





NASA Ames 9x7-Ft SWT

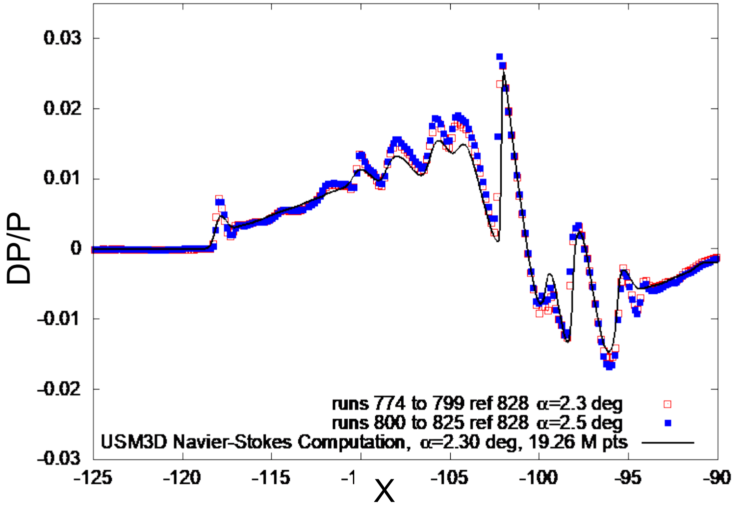
Top View of Reference and Survey Probes



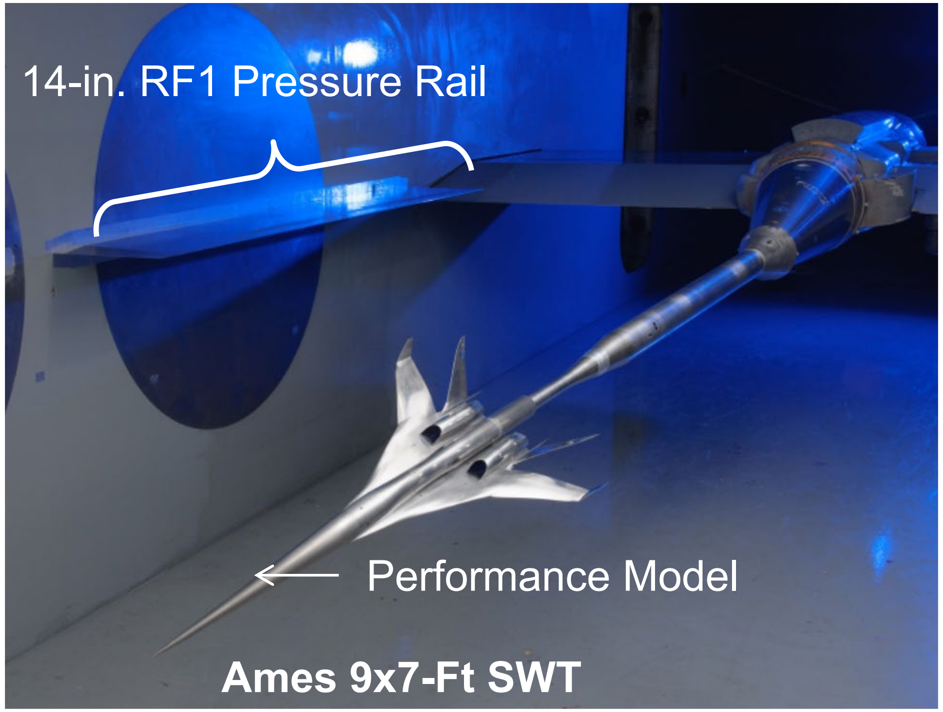
$$\frac{DP}{P} = \frac{\left(P_{survey\ probe} - P_{ref.\ probe}\right)}{P_{ref.\ probe}}$$

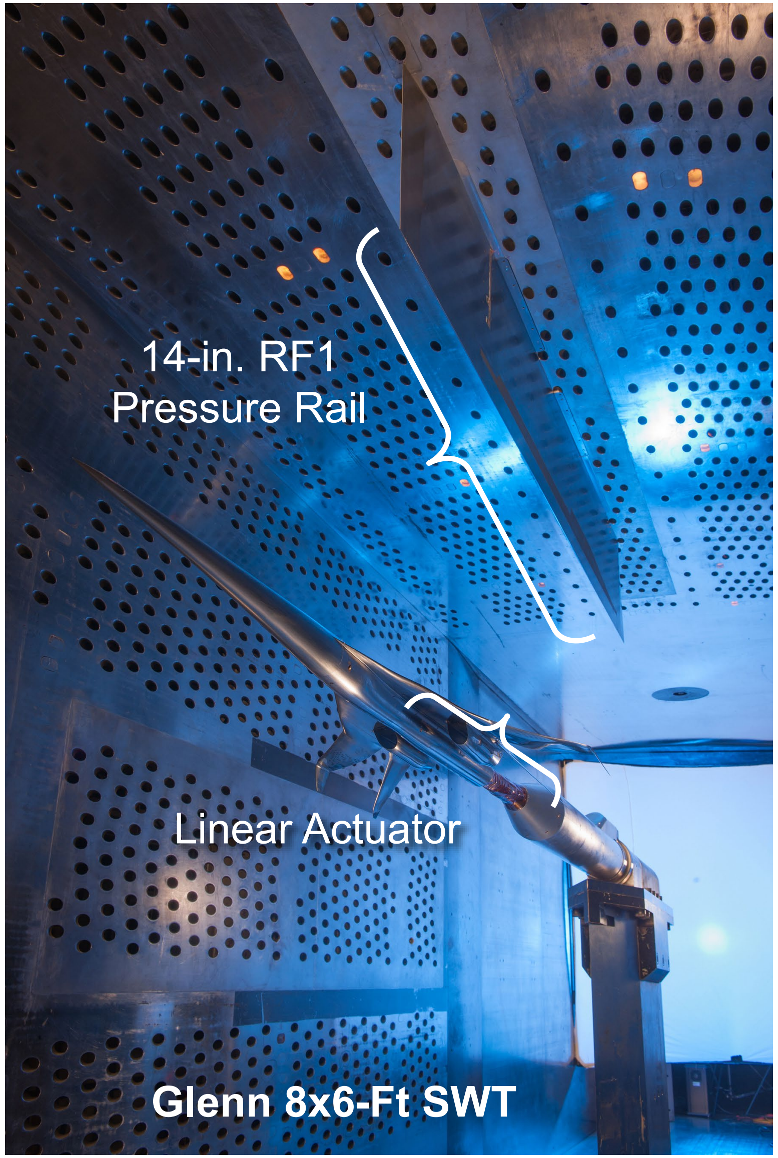
Wind Tunnel Test to Validate New Designs

- Rail-based testing greatly improves the efficiency and reduces the uncertainty of sonic boom test data
- Ames 9x7 and Glenn 8x6 Supersonic Wind Tunnels
- Mostly Mach 1.6 and 1.8
- High quality, publicly accessible database for future research



NASA/TP-2015-218483



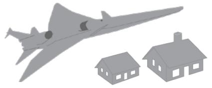


X-59 NASA’s Low-Boom Flight Demonstration

NASA's X-59 Low-Boom Flight Demonstration

Photo credit: Lockheed Martin

- The mission aims to provide U.S. and international regulators with statistically valid data required to approve new rules that could allow commercial supersonic flight over land.
- The X-59 is not a prototype for a commercial airliner. It is, however, equipped with quiet supersonic technologies that aircraft manufacturers may choose to include in their future designs



Overview of X-59 Aircraft Features

X-plane approach that meets key requirements in a cost-effective design

External and forward visions systems for forward visibility

T-38 aft canopy and ejection seat to minimize qualification cost and schedule

Long nose to shape forward shock

Fixed canard for nose-up trim at low-boom design point

Large, unitized skins reduce parts count and manufacturing cost

T-tail to minimize aft shock

F-16 landing gear and other systems from high performance aircraft to minimize qualification cost and schedule

Wing shielding to minimize impact of inlet spillage on sonic boom

Single GE-F414 engine with standard nozzle to minimize cost and schedule

Conventional tail arrangement to simplify stability and control considerations

Design Parameters
- **Length: 96.8 ft**
- **Span: 29.5 ft**
- **Speed: Mach 1.4 (925 mph)**
- **Altitude: 55,000 ft**

Image Credit :Lockheed Martin

Low-Boom Flight Demonstration Mission Overview

Phase 1 – Aircraft Development

In progress (FY18-23)

- Design, fabricate a quiet supersonic research aircraft
- Prove performance in test range flights
- Prove safety for flights in normal airspace

Phase 2 – Acoustic Validation

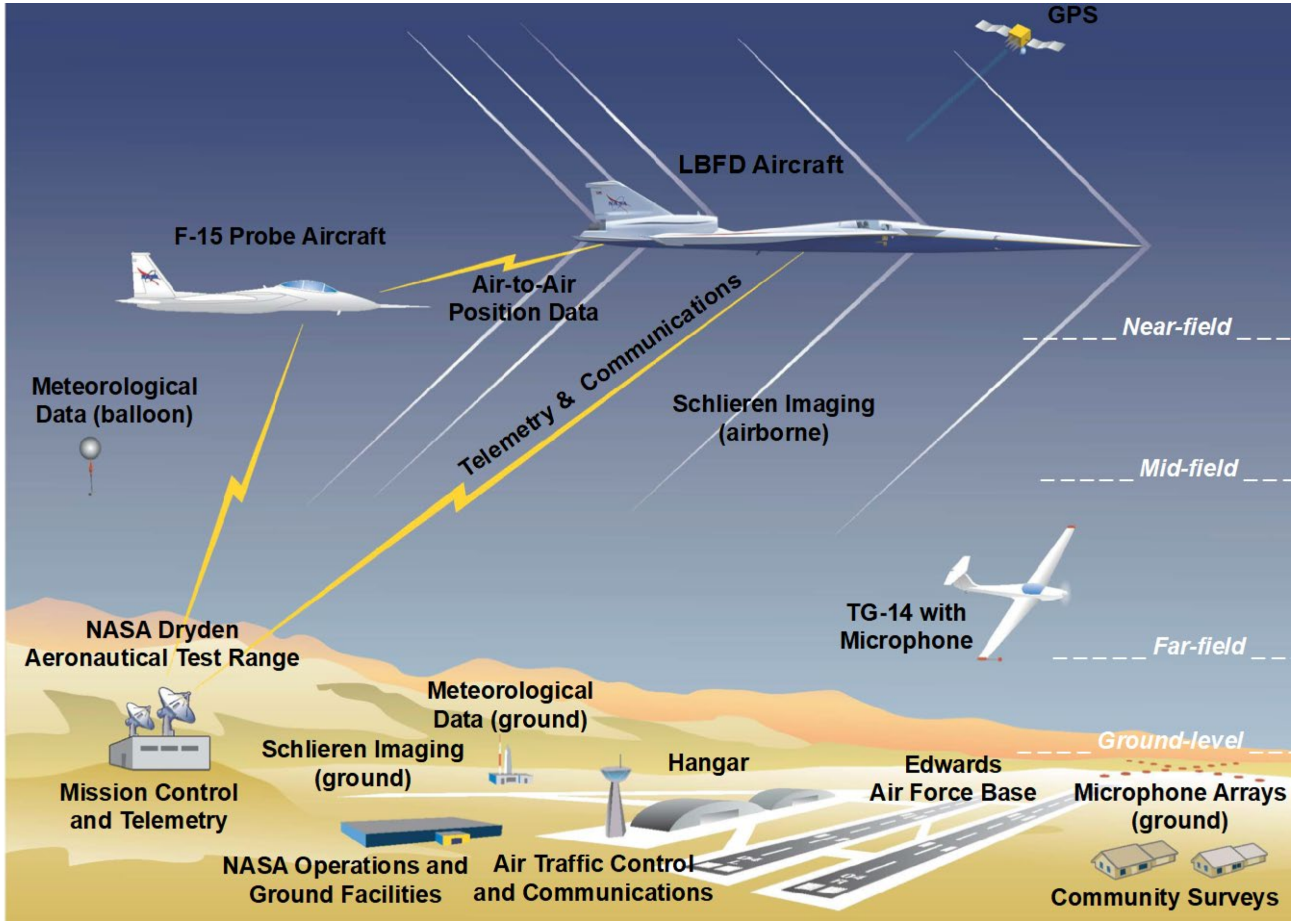
Preparation in progress (FY18-23), Execution (FY23-24)

- Prove the acoustic characteristics match design targets
- Detailed in-flight and ground measurements in test range

Phase 3 – Community Response Testing

Preparation in progress (FY19-23), Execution (FY24-27)

- Conduct community tests
  - Select communities
  - Plan surveys and recruit participants
  - Collect ground measurements



Commercial Supersonic Travel Over Land

NASA will give regulators a complete database from community overflights in 2027, allowing an opportunity to lift the current bans on supersonic flight over land

Concluding Remarks

- Long & rich history of research and development of sonic boom minimization technology
- Breakthrough achievement of acceptable pressure signatures for integrated supersonic designs
- NASA has a dual role in achieving the vision of the supersonics community
  - Innovative technology development to overcome barriers
  - Creating quality science-based data for standards
- New Environmental Standards are needed to open the market to supersonic flight
- Supersonic aircraft manufacturing offer the opportunity to establish a new market segment
- Commercial supersonic flight represents a potentially large new market for aircraft manufacturers and operators world-wide
- Technologies reducing the environmental impact of supersonic aircraft


Thank You

Backup slides

Supersonic Flight and Sonic Boom: A Brief History

1947 First supersonic flight

Sonic boom a novelty

1950s Rapid development of supersonic military aircraft

Noise and damage concerns

1960s Supersonic Commercial aircraft proposed

Community Studies determine sonic boom exposure is unacceptable

1973 US Federal ban, International limits

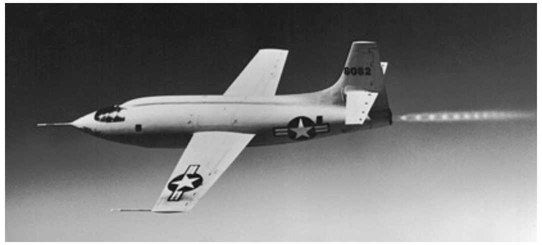
1976 – 2003 Concorde commercial service

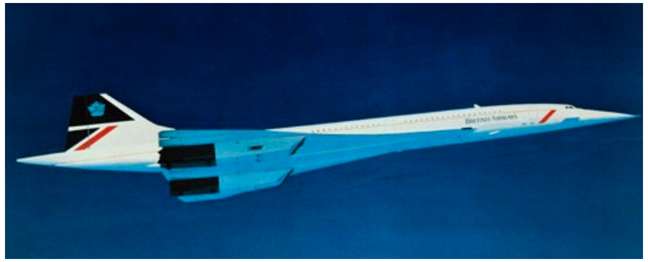
Supersonic operation only over the ocean

2003 DARPA-NASA Shaped Sonic Boom Demonstration

First flight demonstration of theory for ”shaping” boom signature

2018-2023 **Low Boom Flight Demonstrator X-59**



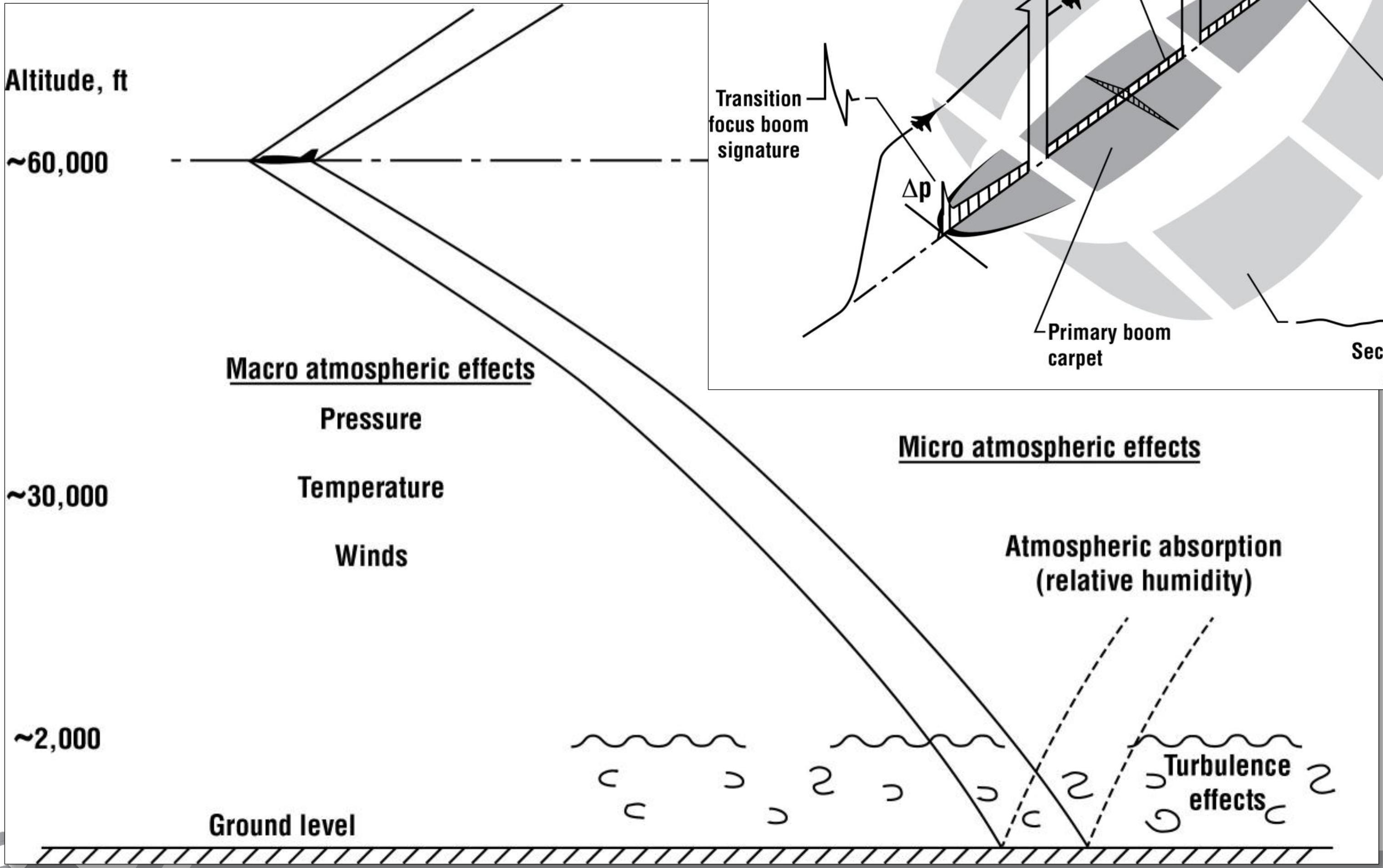


NASA's Supersonic Programs

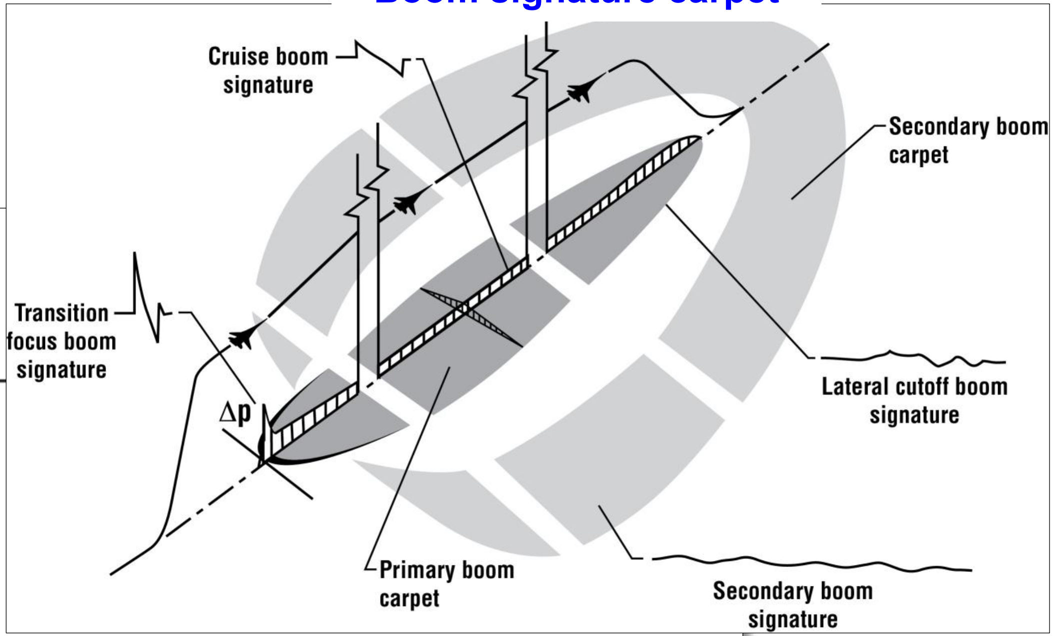
- **SCAT (Supersonic Commercial Air Transports) 1958-1966**
  - Sonic Booms measured from flight and wind tunnel testing (N-waves) B-58, XB-70 Aircraft
- **SST (American Supersonic Transport Program) 1960s -1971**
  - Flat-top signatures, linear theory
- **AST/SCAR/SCR (Advanced Supersonic Technology Program) 1972-79**
  - F-Function minimization and geometric acoustics propagation
- **HSR (High Speed Research) 1981-1999**
  - Phase I Sonic boom focus (1981-1992)
  - Phase II Performance focus (1993-1999)
- **QSP (Quiet Supersonic Platform) 2001-2004**
  - NASA SSBD aircraft (modified F-5) flat-top signatures with lower sonic boom
- **AST (Advanced Supersonics Technology) CST (Commercial Supersonic Transport) Project 2005- Now**
  - CFD advancements and wind tunnel testing improvements
  - X-59 NASA low boom flight demonstrator

Sonic Boom 101

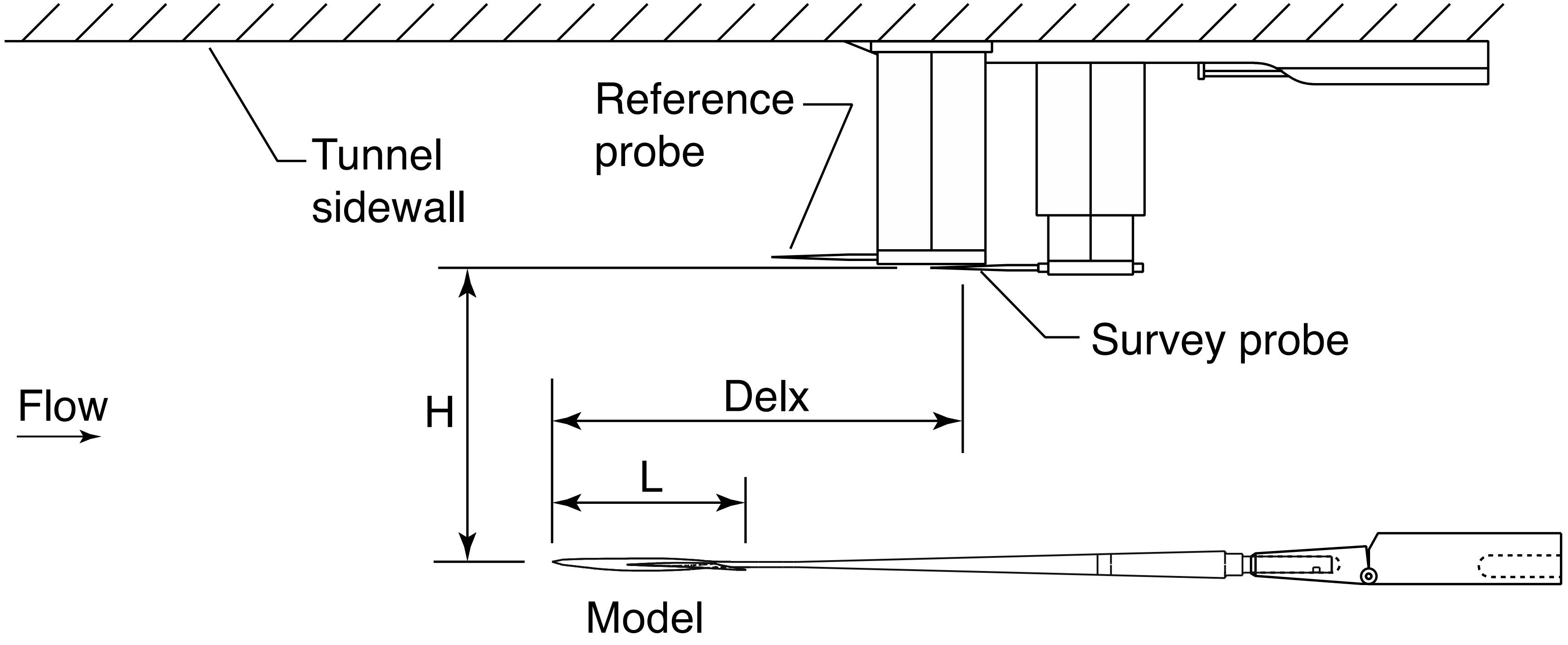
Sonic boom with atmospheric effects



Boom signature carpet



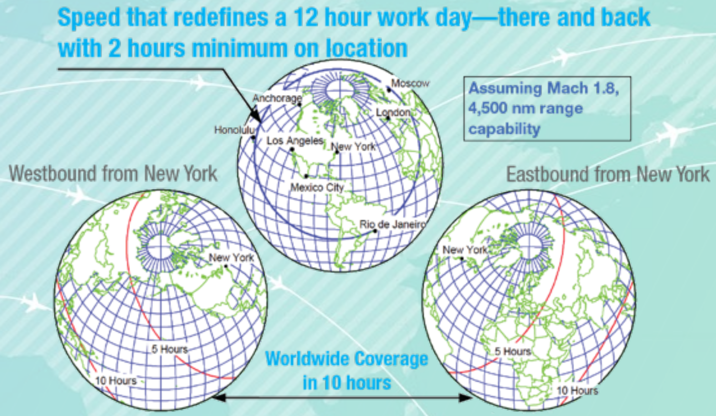
Top View of Reference and Survey Probes



$$\frac{DP}{P} = \frac{\left(P_{\text{survey probe}} - P_{ref.\,probe}\right)}{P_{ref.\,probe}}$$

Innovation in Commercial Supersonic Flight

WHY? **Commercial supersonic flight represents a potentially large new market for aircraft manufacturers and operators world-wide**



- Global demand for air travel is growing, which places a demand on speed
- Supersonic aircraft manufacturing offer the opportunity to establish a new market segment with significant export opportunity and high-tech job growth
  - Large potential market predicted: - business aircraft followed by larger commercial aircraft
  - Technology leadership established through initial products will lead to development of larger, more capable airliners
- Technologies reducing the environmental impact of supersonic aircraft may benefit subsonic aircraft as well

Innovation in Commercial Supersonic Flight

WHY?

Higher speed will transform the air travel experience for long distance flights by cutting flight time in half

- **The high-speed aircraft market attracting the interest of US innovators**

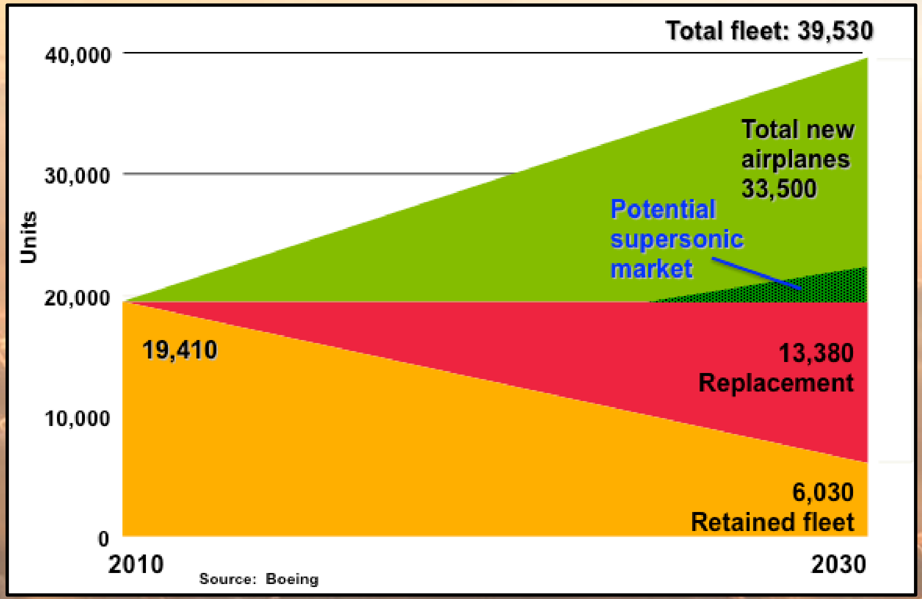
- **NASA contributes science and technology for expanding access and enabling sustainability**

Market Growth & Economic Benefit

Initial market is supersonic business jets (est. 350+ aircraft) followed by supersonic commercial transports as technology matures. Supersonic civil aircraft market could grow to an estimated 1250 – 1700 aircraft.

Economic benefit from manufacturing and employment alone would be on the order of $20B - $60B per year (assume 100 a/c per year). The economic benefit to business and leisure passengers is difficult to quantify, but would be substantial on a global scale.

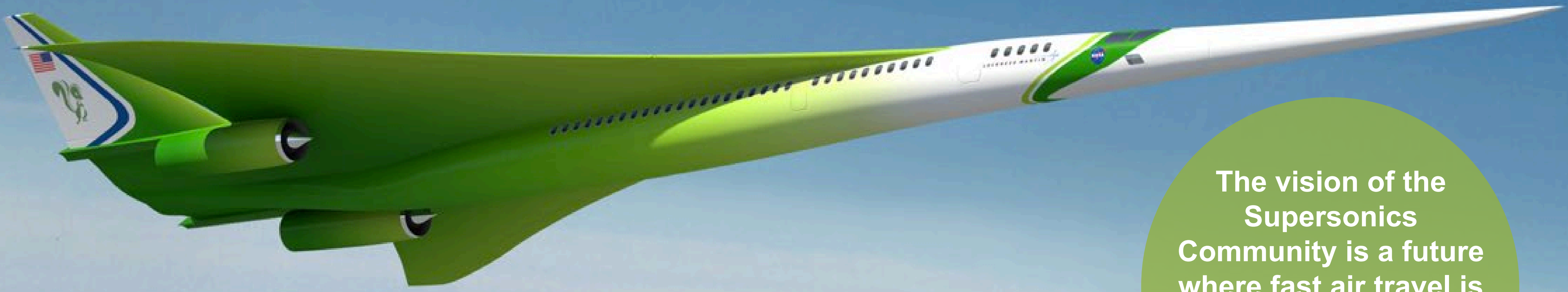
Demand for Commercial Aircraft



Credit: Lockheed Martin

The Vision for Commercial Supersonic Flight

- FAA banned supersonic overland flight in U.S. in 1973 because of the sonic boom
- There is strong renewed interest in civil supersonic aircraft
- Numerous companies are vying to build supersonic business jets and small airliners



The vision of the Supersonics Community is a future where fast air travel is available for a broad spectrum of the traveling public

Future supersonic aircraft will not only be able to fly overland without creating an "unacceptable sonic boom," but compared to Concorde will be efficient, affordable and environmentally responsible

Image credit: Lockheed Martin Corporation

Sonic Boom Basics

- Supersonic flight → aircraft flies faster than speed of sound
  - Shockwaves travel away from vehicle
  - Shockwaves merge as they travel through the atmosphere
  - Heard on the ground as a sonic boom
- For traditional supersonic aircraft
  - Shockwaves eventually merge into bow and tail shocks
  - Sonic boom is an "N-wave" signature