National Aeronautics and Space Administration

NASA’s Quiet Supersonic Aircraft

Tom Jones

NASA Aeronautics Research Mission Directorate

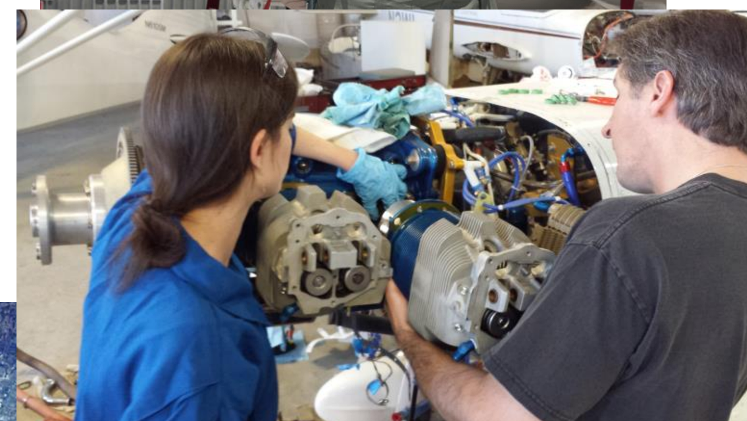
2017 EAA AirVenture, Oshkosh, WI
July 28, 2017
Armstrong Flight Research Center

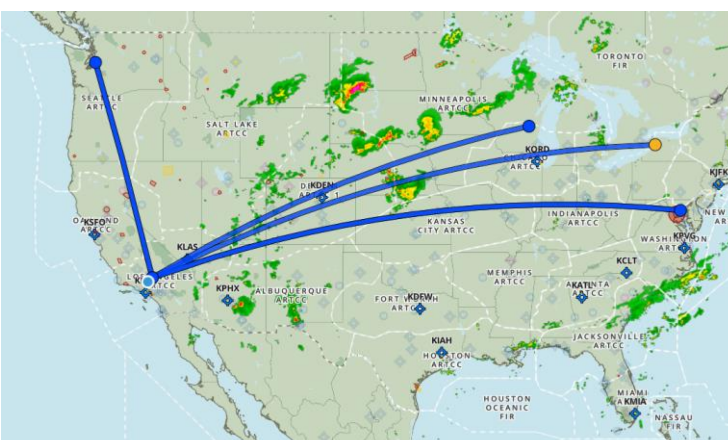
Morning Agenda

- Who am I and Where is NASA Armstrong?
- Boom 101 and Operational Testing
- Why a Low-Boom Flight Demonstration? Why now?
- The QueSST X-plane Preliminary Design Overview
- What’s Happening Now/Next?
- Q & A

Tom Jones

- Originally from Buffalo/Niagara Falls, NY
- Earned Private Pilot in 2004, Instrument in 2007, joined EAA in 2008
- Lived and flown in So Cal, Seattle, and Washingnton D.C.
- Own, maintain, and fly a Thorp T-18
- Flight Test Engineer in NASA F/A-18Bs and F-15B/Ds for supersonic research
- 20 years at NASA Dryden/Armstrong
- Now Operations Manager for QueSST





"Mystery creates wonder and wonder is the basis of man's desire to understand."

– Neil A. Armstrong

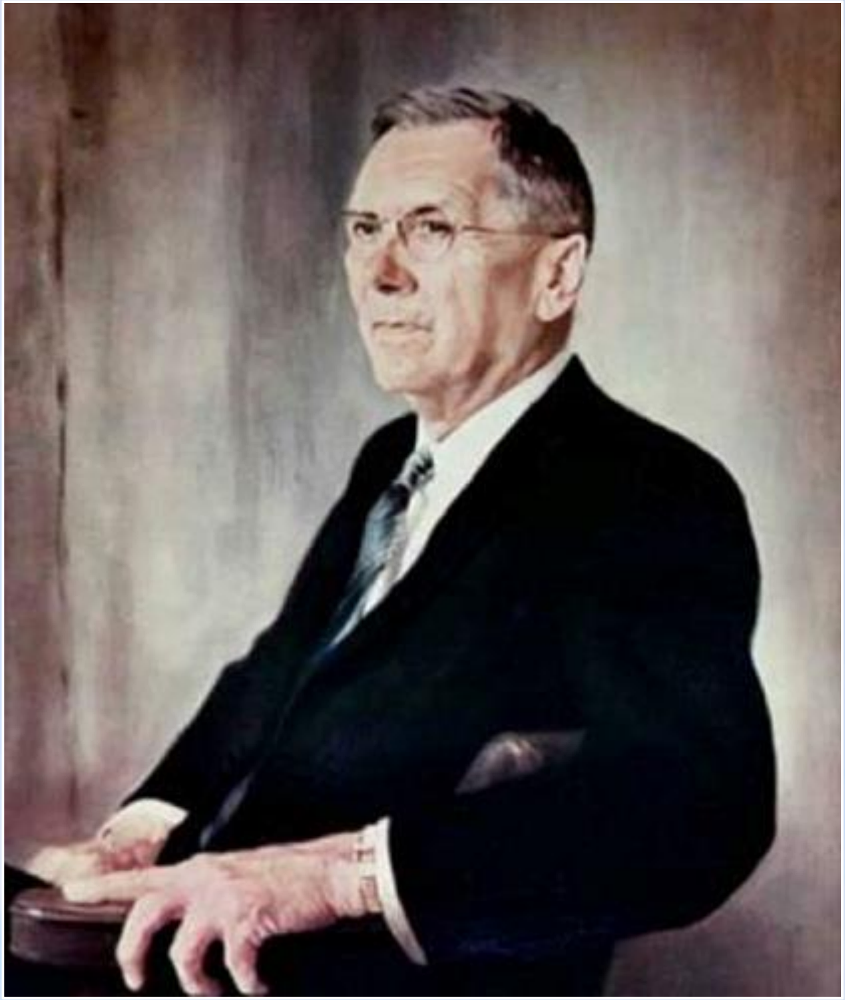
Naval Aviator (1949-1960)

NASA Test Pilot and Astronaut (1955-1971)

The purpose of flight research is

"… to separate the real from the imagined and to make known the overlooked and the unexpected."

– ***Dr. Hugh L. Dryden***
Administrator of NACA (1949-1958)
First Deputy Administrator of NASA (1958-1965)

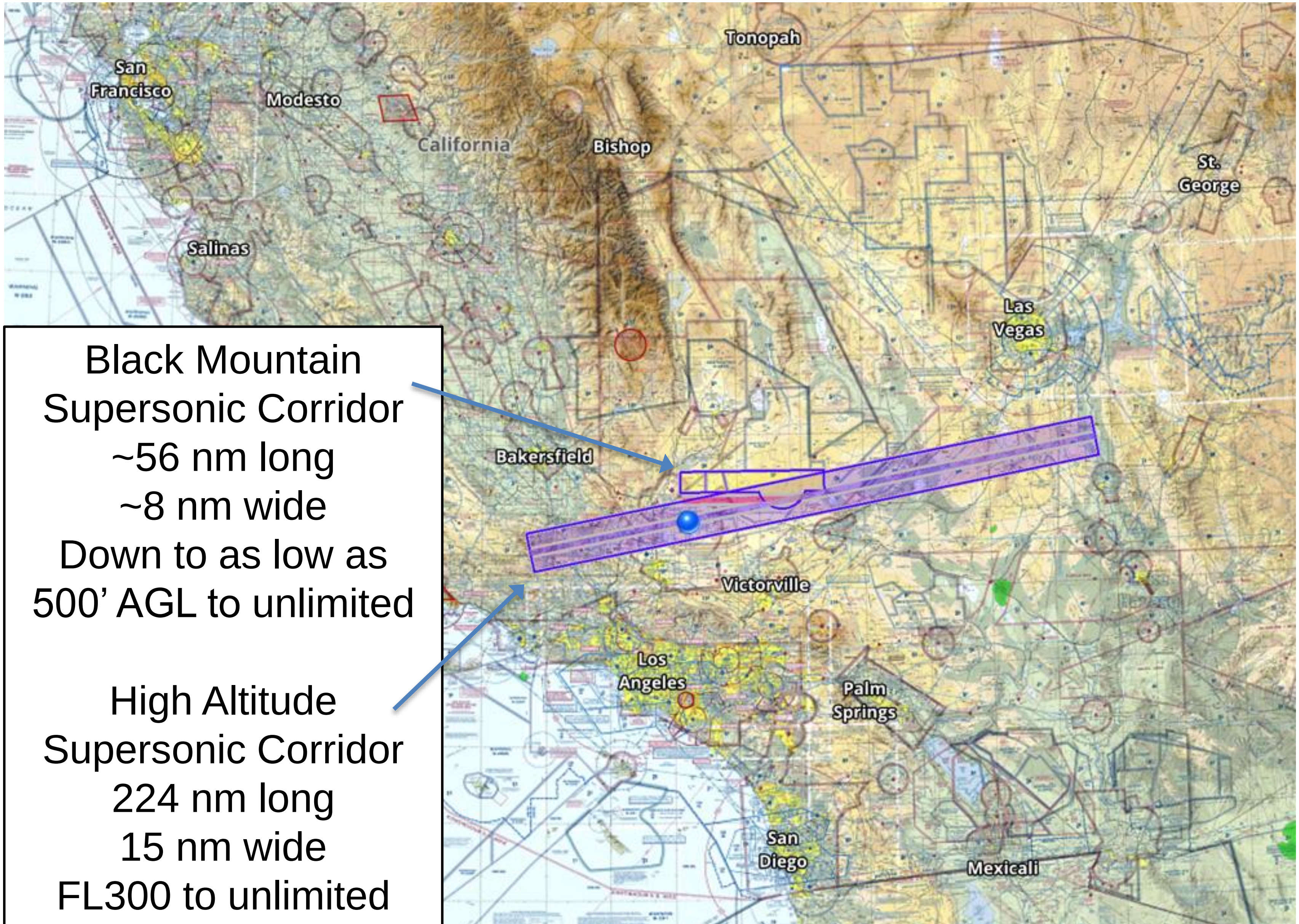


Armstrong Flight Research Center

Edwards AFB, California, main campus:

- Year-round flying weather
- 350 testable days per year
- 68 miles of lakebed runways
- 29,000 feet of concrete runways
- 301,000 acres remote area
- Extensive range airspace
- Supersonic corridors

Supersonic Corridors



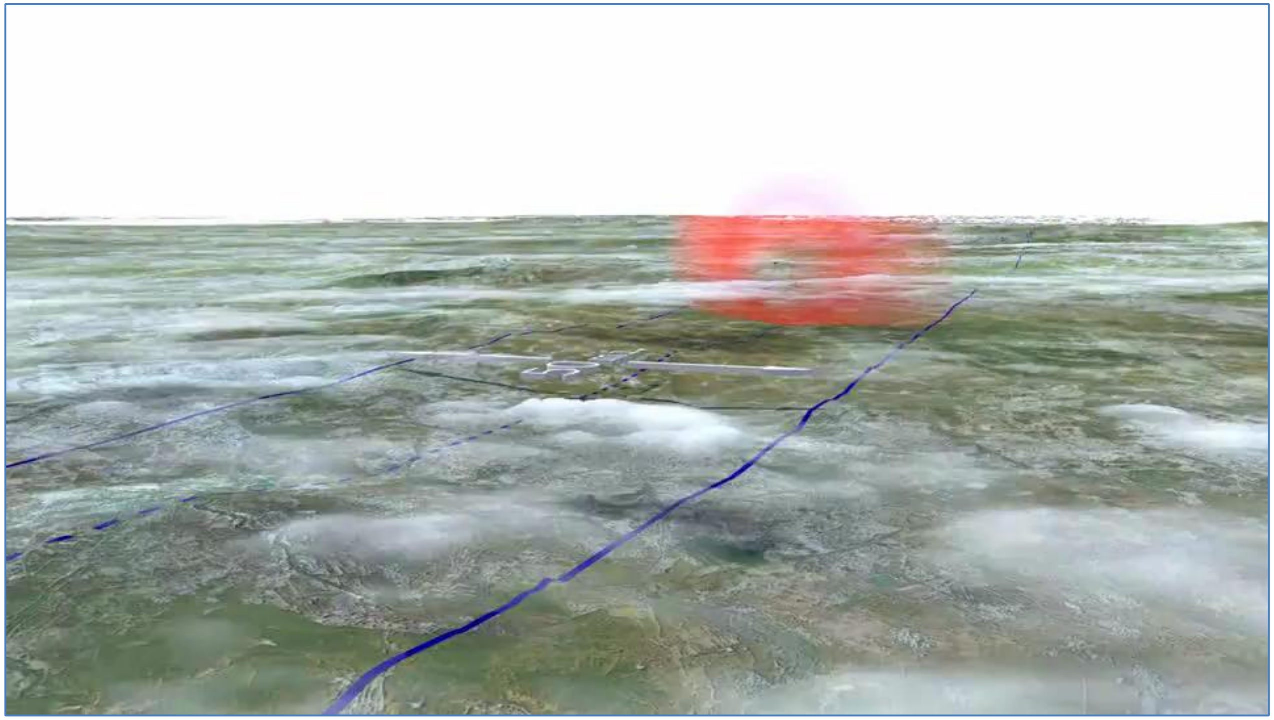
Black Mountain Supersonic Corridor
~56 nm long
~8 nm wide
Down to as low as 500' AGL to unlimited

High Altitude Supersonic Corridor
224 nm long
15 nm wide
FL300 to unlimited

Sonic Boom 101 & Operational Testing

Barriers to Success of Supersonic Aircraft

Sonic Boom Basics

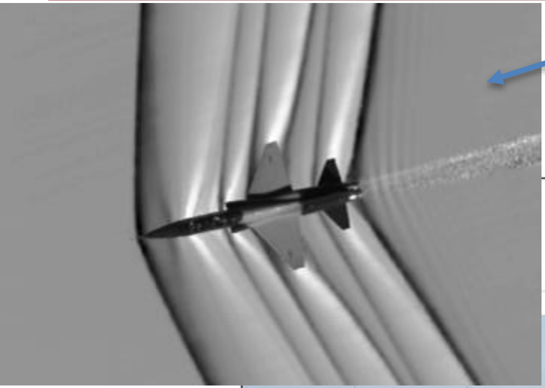


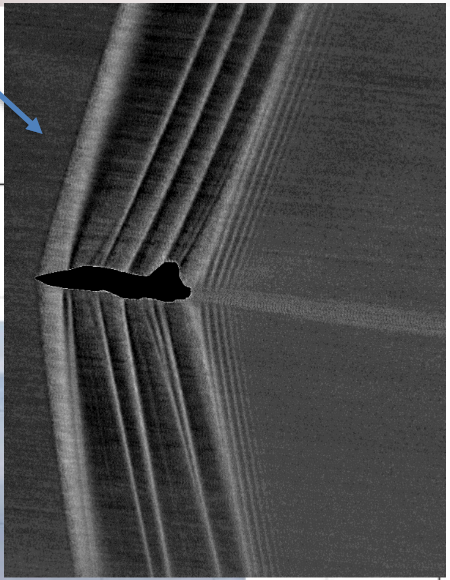
- At supersonic speeds, air pressure rises sharply through shockwaves
- Shock system is dragged behind it like the wake from a boat
- As the shockwave passes a person on the ground, a “sonic boom” is heard
- Booms are heard along the entire length of the supersonic flight
- A large“Carpet” on the ground is exposed to booms as the aircraft flies
- Noise is reduced at the edge of the carpet

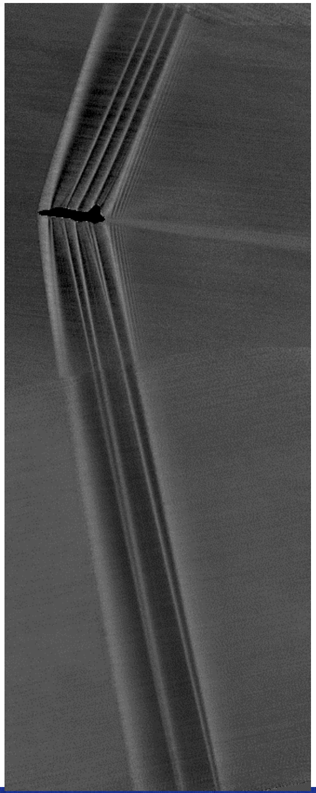
Concorde, US SST sonic boom noise led to the current ban on supersonic overland flight

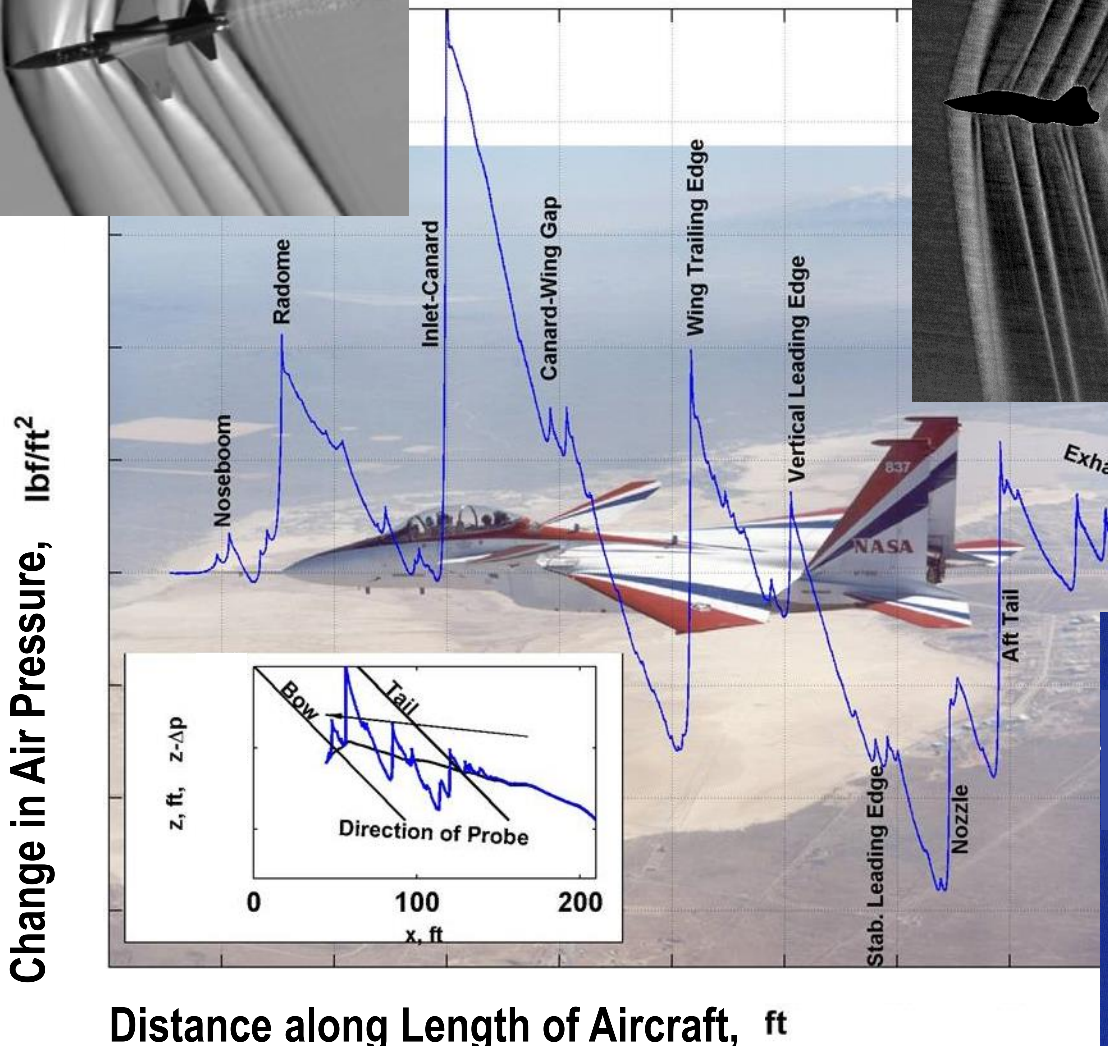
What Shockwaves Look Like

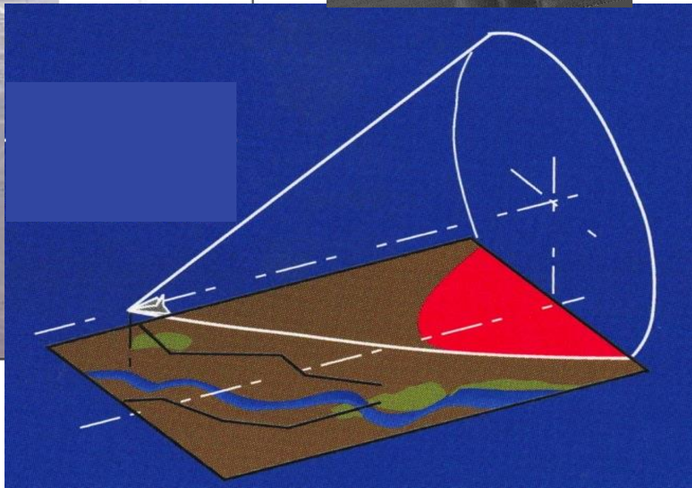
T-38 Shockwave images



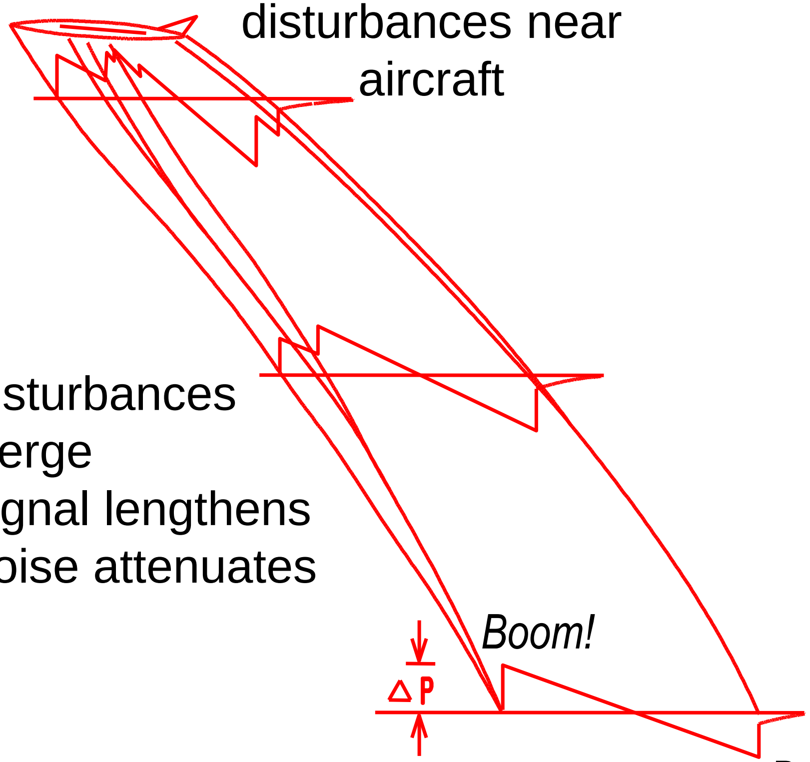








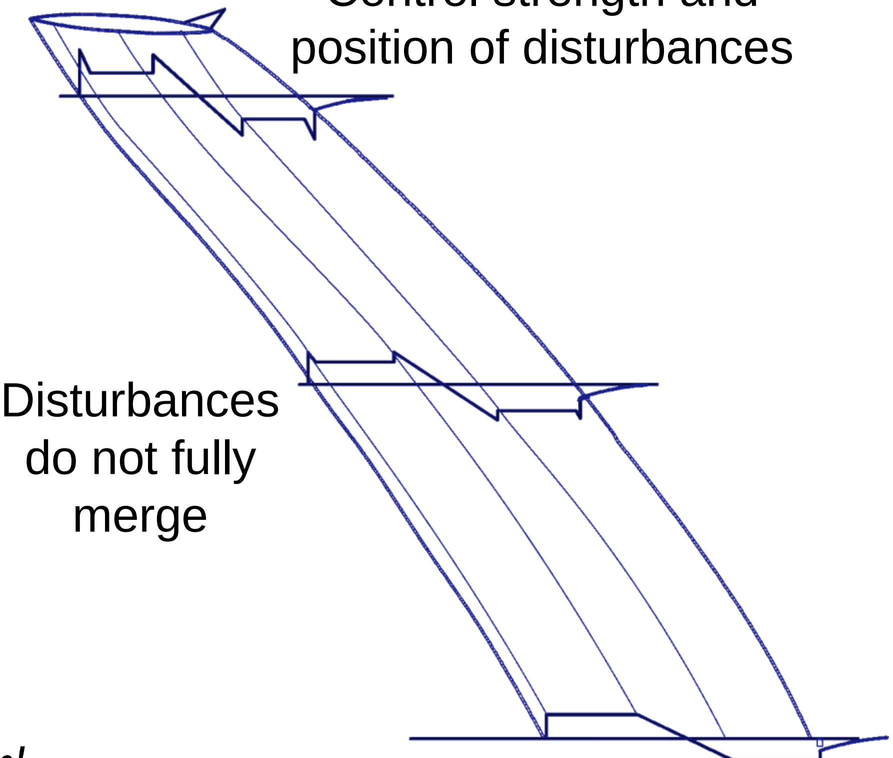
Sonic Boom Reduction by Aircraft Shaping



- Disturbances merge
- Signal lengthens
- Noise attenuates

- Two disturbances remain
- Signal has a characteristic “N” shape
- Called an “N wave” boom “signature”

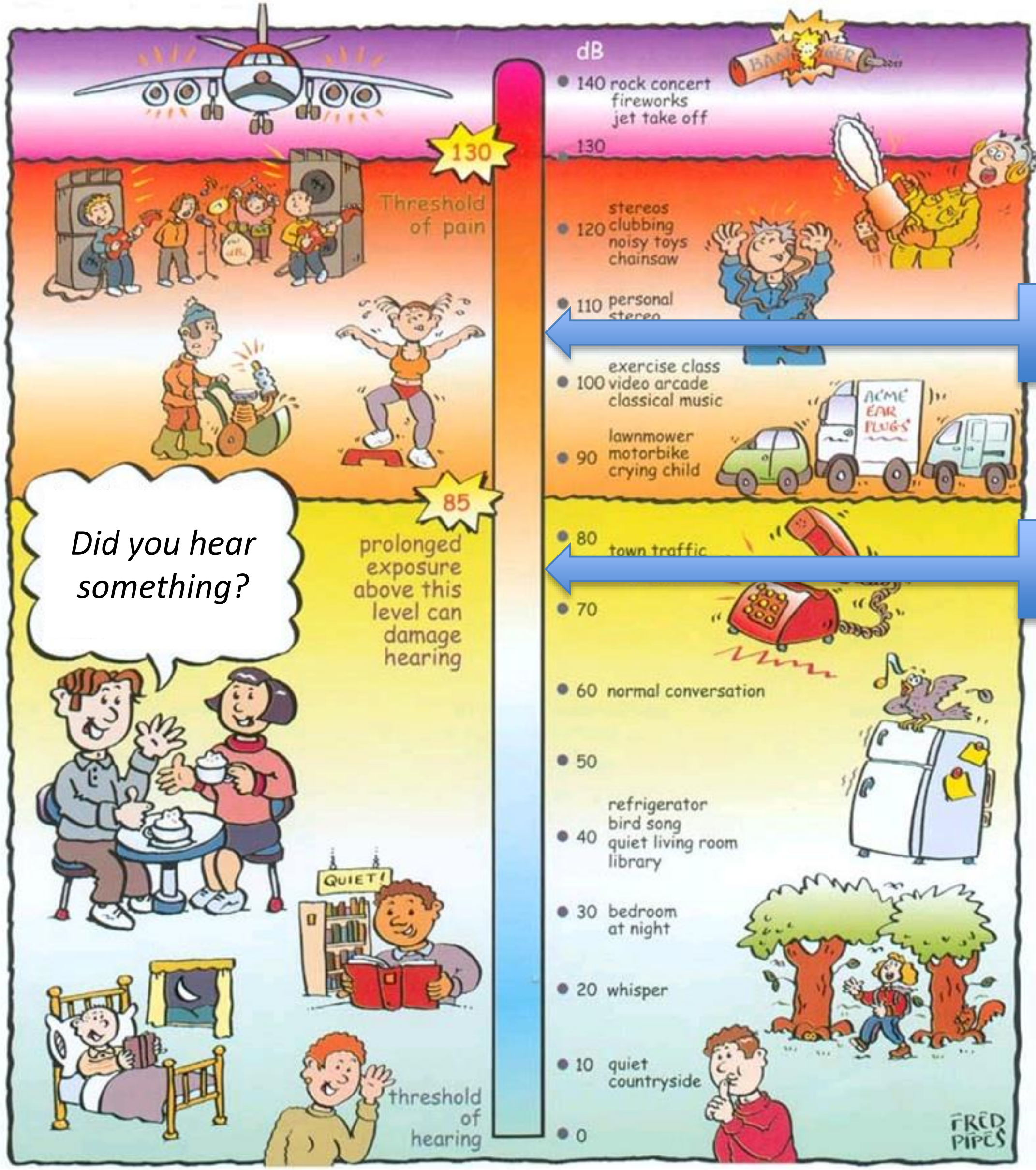
Typical Supersonic Design



- Shaped boom at the ground
- Results in more of a “thump”

Specially Shaped Boom Design

Sonic Booms and loudness on decibel scale



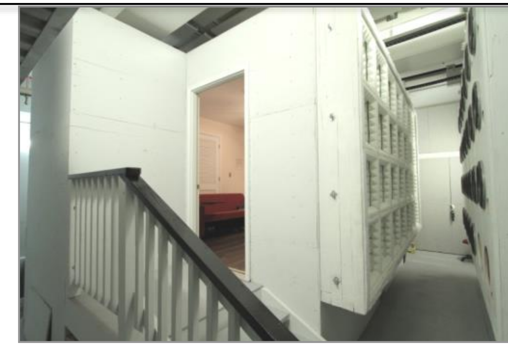
NORMAL BOOM – 106PLdB

LOW BOOM – 75PLdB

How do We Measure Response?
1 – Boom Simulators

Simulation of booms heard outdoors

- Sophisticated boom simulators
  - Unique National capability
- Accurate reproduction of sonic boom noise
  - Consistent, repeatable test conditions
  - Wide variety of signature shapes and levels
- Study elements of boom that create annoyance
  - Goal: Understand how annoyance is related to spectrum, level, rattle, vibration

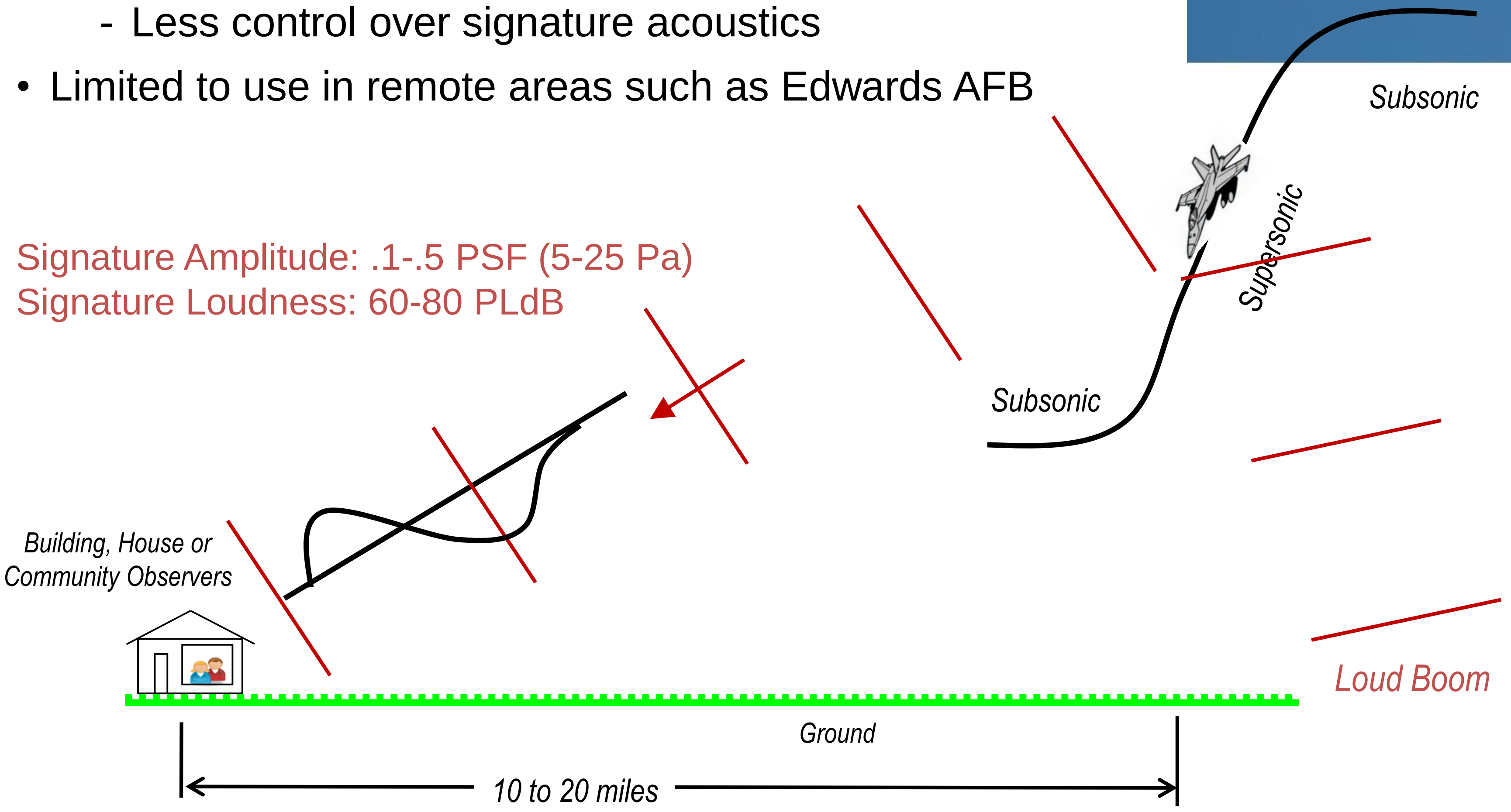


Simulation of booms heard indoors

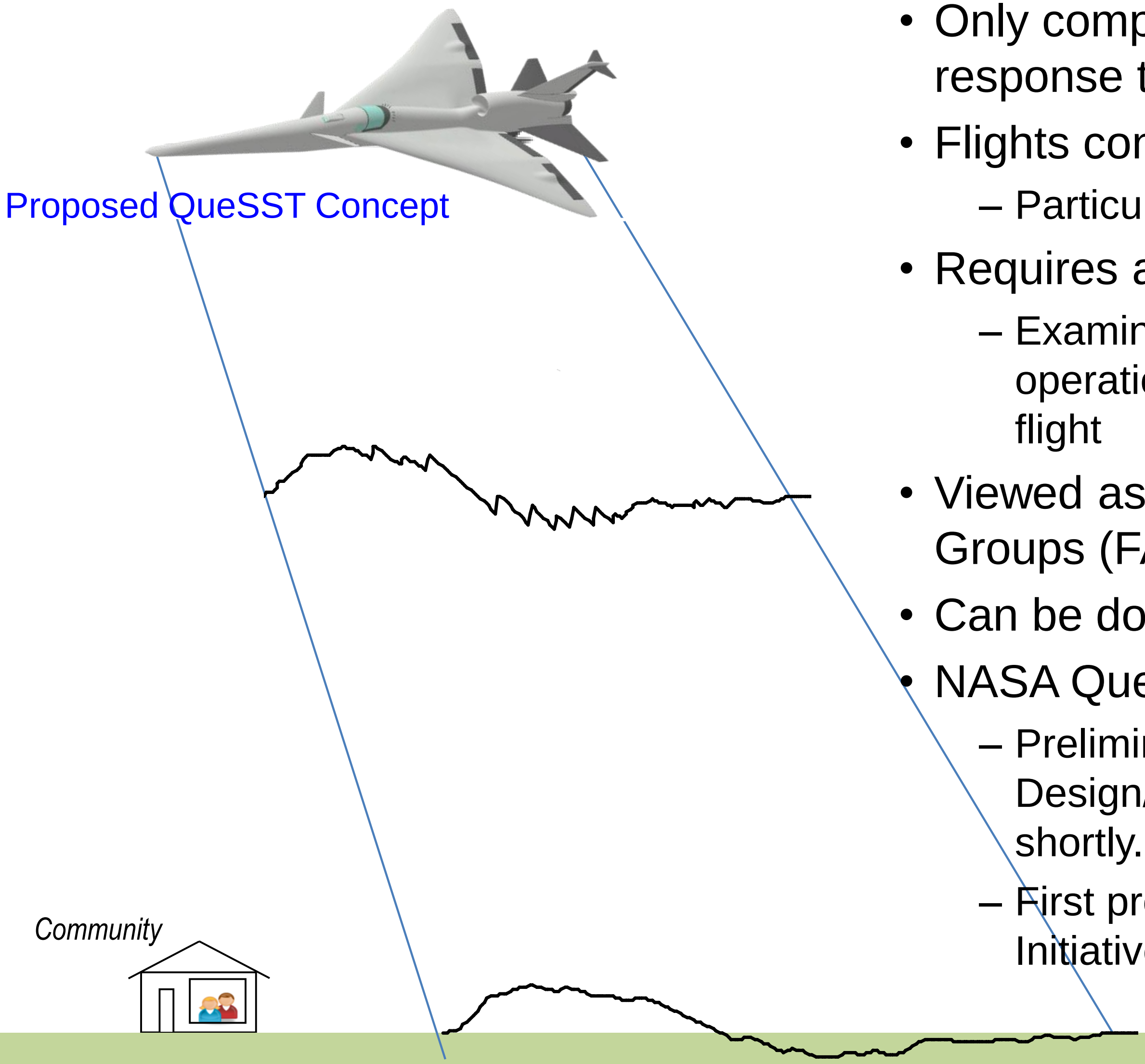
How do We Measure Response?
2 – Flight Research with Specialized Aircraft Maneuver

- Current aircraft cannot generate low booms during level flight
- Simulated low boom can be generated by dive maneuver
- Effective tool for research in more relevant environment
  - Less control over signature acoustics
- Limited to use in remote areas such as Edwards AFB

Signature Amplitude: .1-.5 PSF (5-25 Pa)
Signature Loudness: 60-80 PLdB

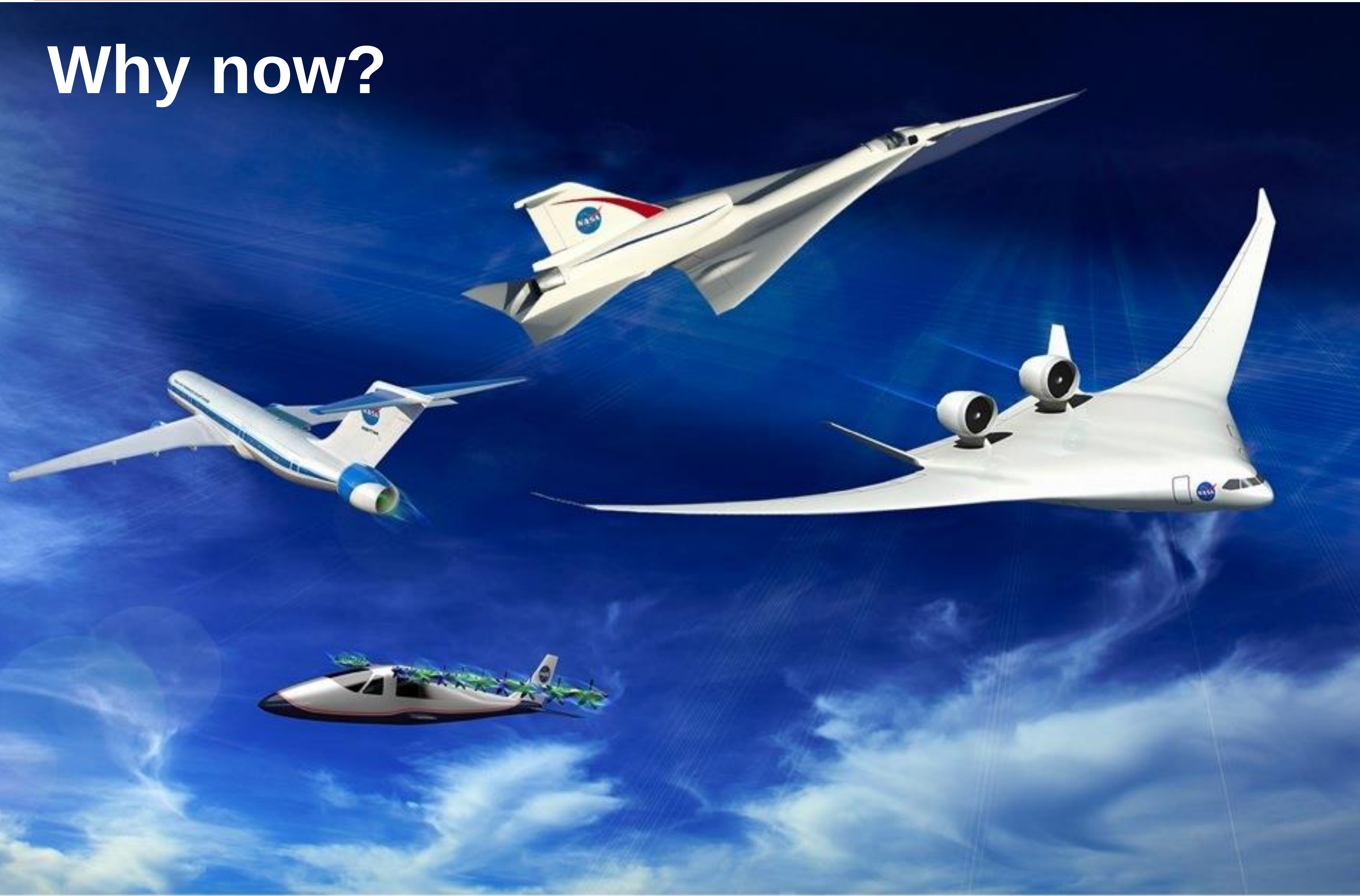


How do We Measure Response?
3 – Quiet Supersonic Technology Demonstration



- Only completely realistic way to measure response to quiet supersonic overflight
- Flights conducted over many communities
  - Particularly without prior exposure to booms
- Requires a unique research platform
  - Examines design, atmospheric, and operational elements of Quiet supersonic flight
- Viewed as critical step by Regulatory Groups (FAA, ICAO)
- Can be done with a relatively small aircraft
- NASA QueSST X-Plane
  - Preliminary Design completed in June and Design/Build/Test RFP expected very shortly.
  - First project in the New Aviation Horizons Initiative

Why a Low-Boom Flight Demonstration?



Why Supersonics?

- Supersonic flight over land enables large reduction in travel time
  - Valuable to business travelers, cargo shippers, National Security and traveling public
- Opportunity for US to take the lead in new class of aircraft manufacturing
- Market potential has been validated in numerous studies
  - Business Aircraft: 350-500 units
  - Civil Airliners 500+ units
- Maintains or increases Aviation's impact on US GDP and has high value jobs
  - Aviation manufacturing contributes $76.1B to the US trade balance, as of 2012
  - Aviation is the #1 exporter of US goods, as of 2011
  - Aviation contributes to 11.5M direct and indirect jobs in civil and general aviation, as of 2012

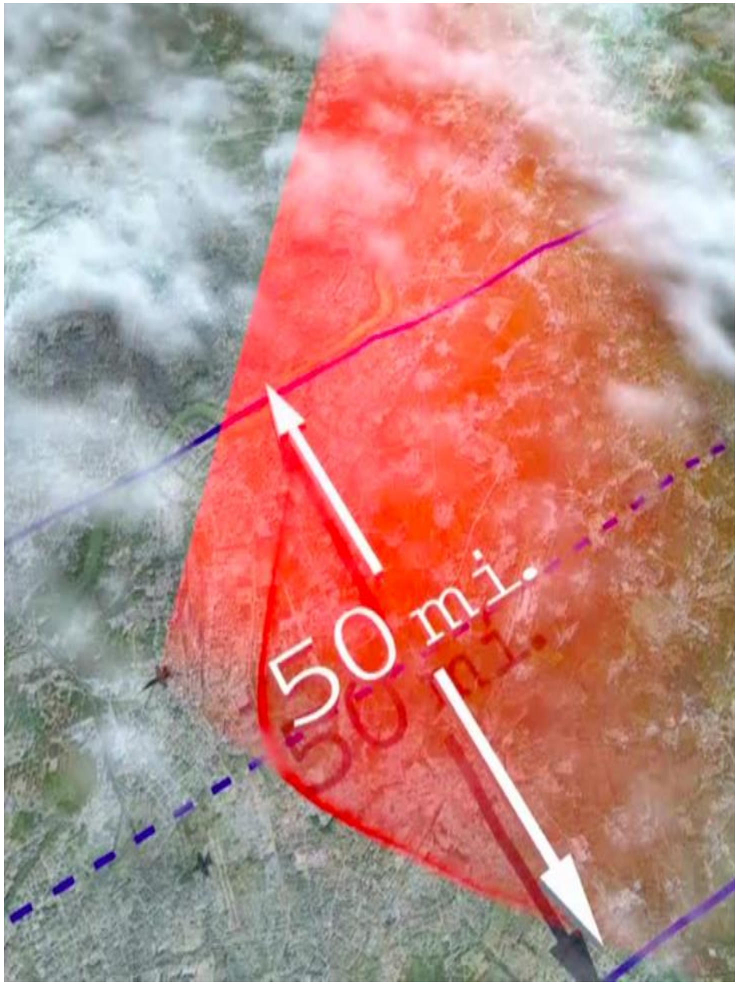



2025 **~2030** **~2040**

NASA investment in fundamental technology for supersonics enables continued US leadership in global civil aviation

Supersonic Civil Overland Flight is Prohibited Because of Sonic Boom

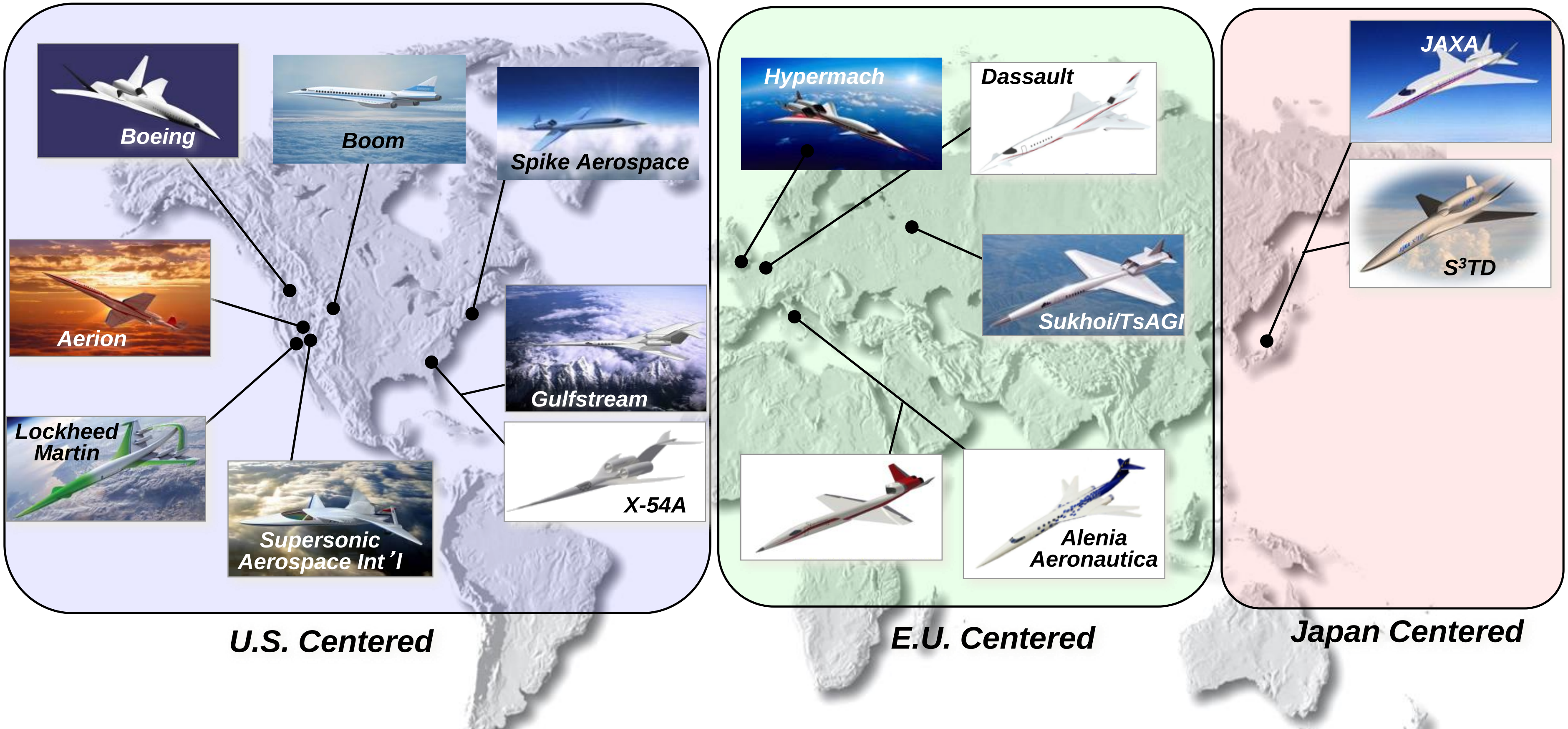
- Since ~1973, U.S. (FAA) and Int'l Civil Aviation Org. (ICAO) regulations prohibit flight that creates sonic boom over populations
  - US: No flight at Mach >1.0 over land
  - ICAO: "no unacceptable situations for the public due to sonic boom"
- Overland flight is required for economically feasible supersonic operations
- An international sonic boom noise standard is required to open the supersonic civil aviation market
  - US FAA and other countries regulatory orgs align their standards to ICAO



Rationale: Supersonic Overland Flight Creates an Opportunity for Future US Civil Aviation Leadership

- Global demand for air travel is growing
  - More travelers in existing markets
  - New markets appearing rapidly
  - The distance between some population centers is great (especially considering the growth in the Asia-Pacific region), which places a greater value on speed
- New supersonic products lead to more high-quality jobs in the US.
  - Even though the initial products are expected to be higher-end general aviation aircraft, such products expand design and manufacturing employment.
  - Technology leadership is established through initial products will lead to development of larger, more capable airliners.
- A new supersonic capability developed in the US will further support a positive balance of trade
  - Other countries have a significant need for high speed transport because it can connect them to Western markets more effectively.
  - There is new “wealth” in other regions (e.g. China and the Middle East) that could be spent on a new product built in the United States.

International Industry & Entrepreneurial Interest



"The United States is not the only sponsor of supersonic technology development and once the capability is developed users in the US and other countries will purchase it regardless of where it is manufactured." – NRC report "Commercial Supersonic Technology: The Way Ahead (2001)"

Why a Flight Demonstration?

- The research community and NASA have collected sufficient data to convince FAA/ICAO of the need for a new low boom standard, but the ICAO consensus is that a demonstrator aircraft will be needed to understand the response of the general public. This is now part of the ICAO plan.

Low-Boom Flight Simulation using F-18 Dive Maneuver

Field studies show the potential for acceptable low boom noise

Sonic Boom Acceptability Studies using Ground Simulators and in the Field

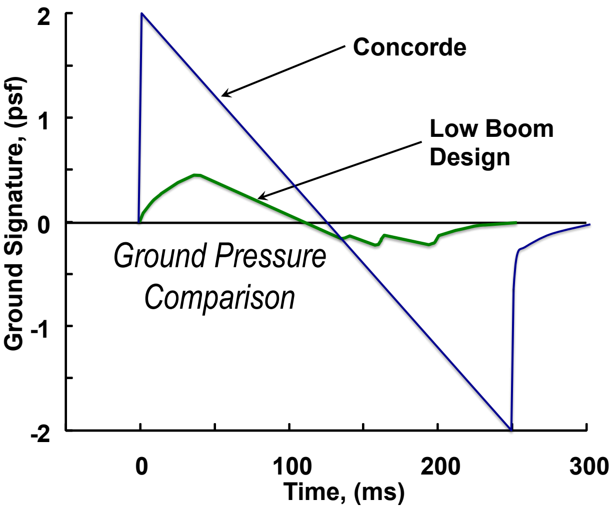
- The US lead in a demonstration X-plane will ensure that we have more influence on the eventual rule making process.
- In addition, flying first ensures that US industry has the lead in tools and technologies needed to dominate the new civil supersonic transport market.

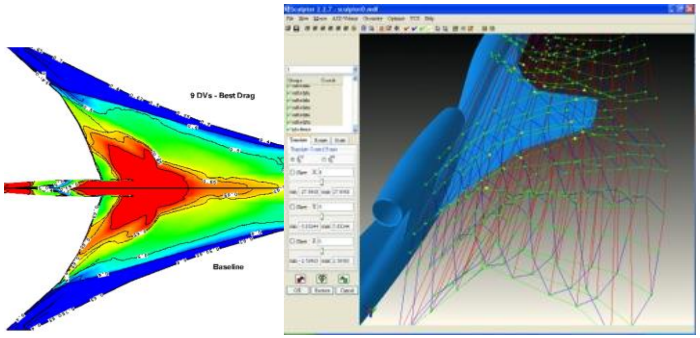
Questions Only a Flight Demonstration Can Answer

- Will overflown communities find these low-boom shaped cruise signatures acceptable?
  - Do we have appropriate, validated metrics and procedures for certification?
- Can the transition focus boom footprint be minimized to allow supersonic operations?
- What influence will turbulence and other atmospheric effects have on low-boom shaped signatures?

Technology is Ready for Flight Demonstration

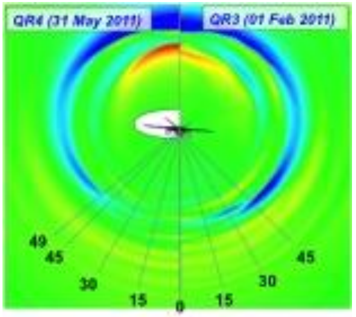
Recent NASA-led research has capitalized on 40+ years of investment to produce breakthroughs in boom noise reduction

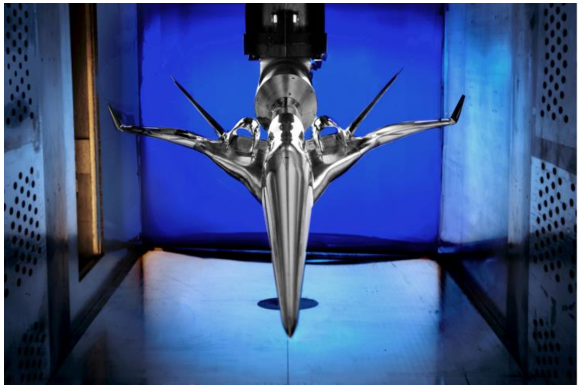




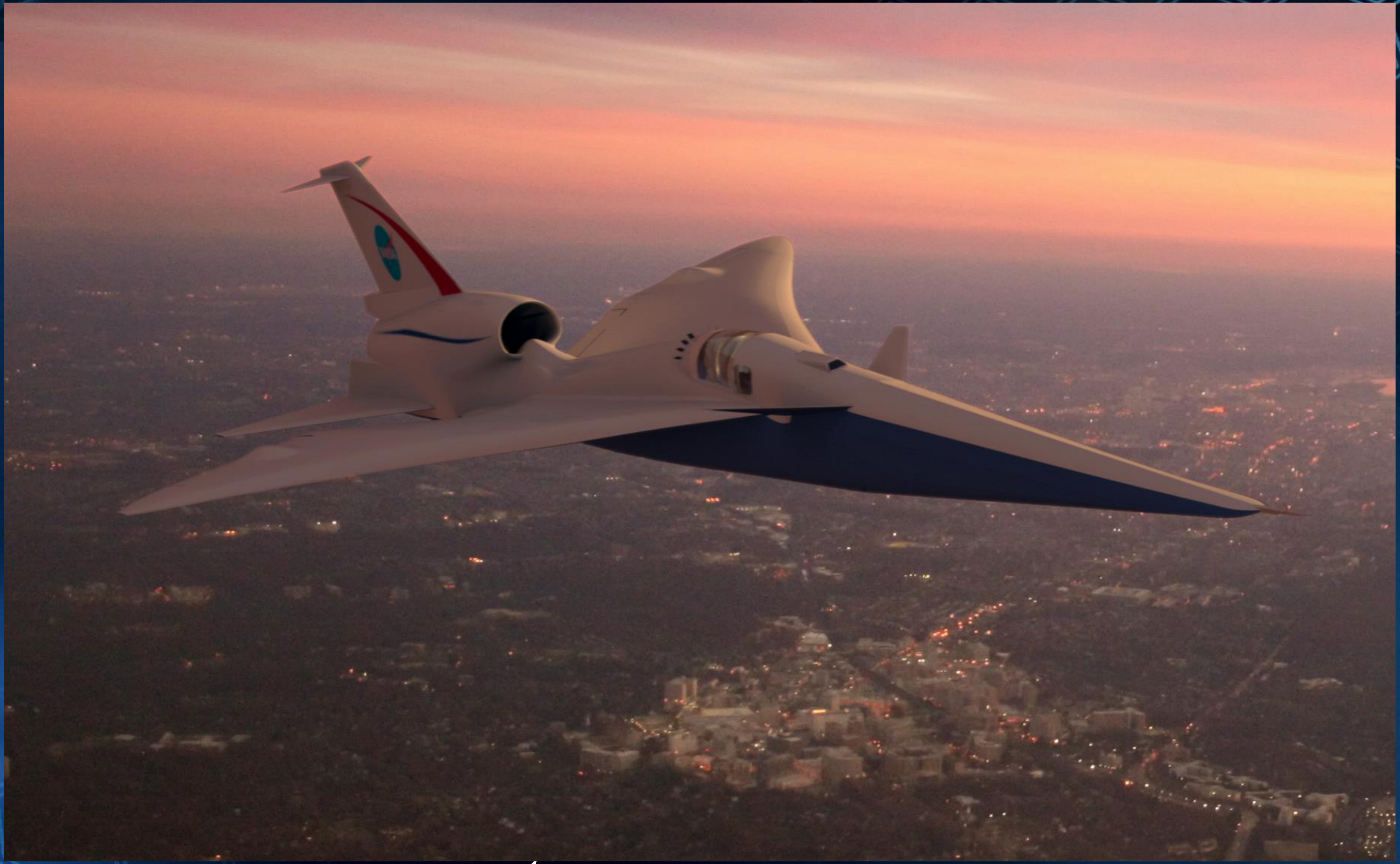
Extensive wind tunnel tests indicate that these new designs show the low-boom characteristics that were predicted

New advances in modeling tools allow us to design new low-boom configurations





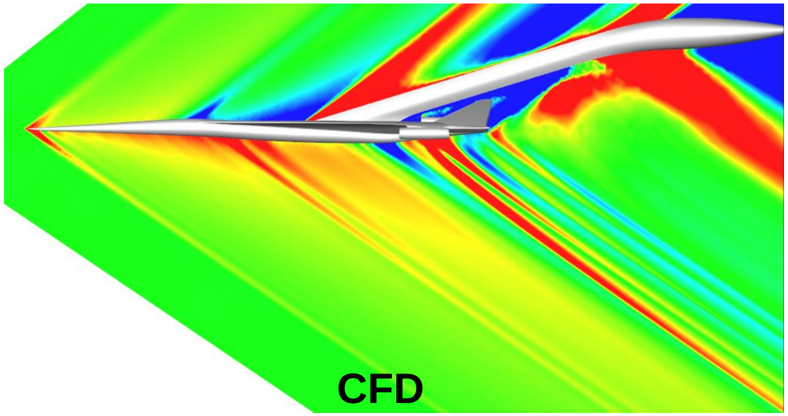
Quiet Supersonic Technology (QueSST) X-Plane Overview

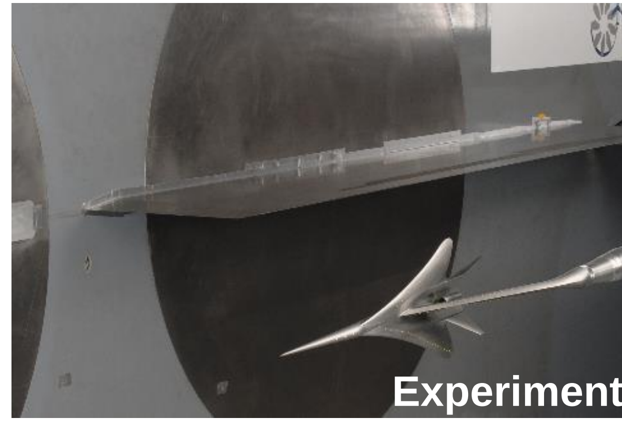


LOCKHEED MARTIN

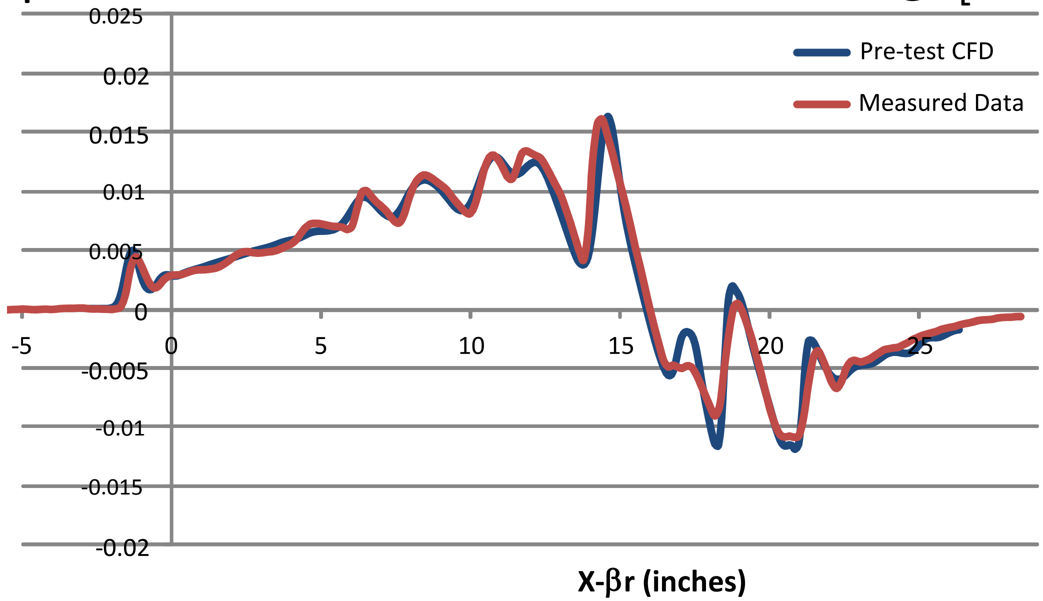
Michael Buonanno
LM QueSST Chief Engineer

Why Now for the QueSST X-Plane?





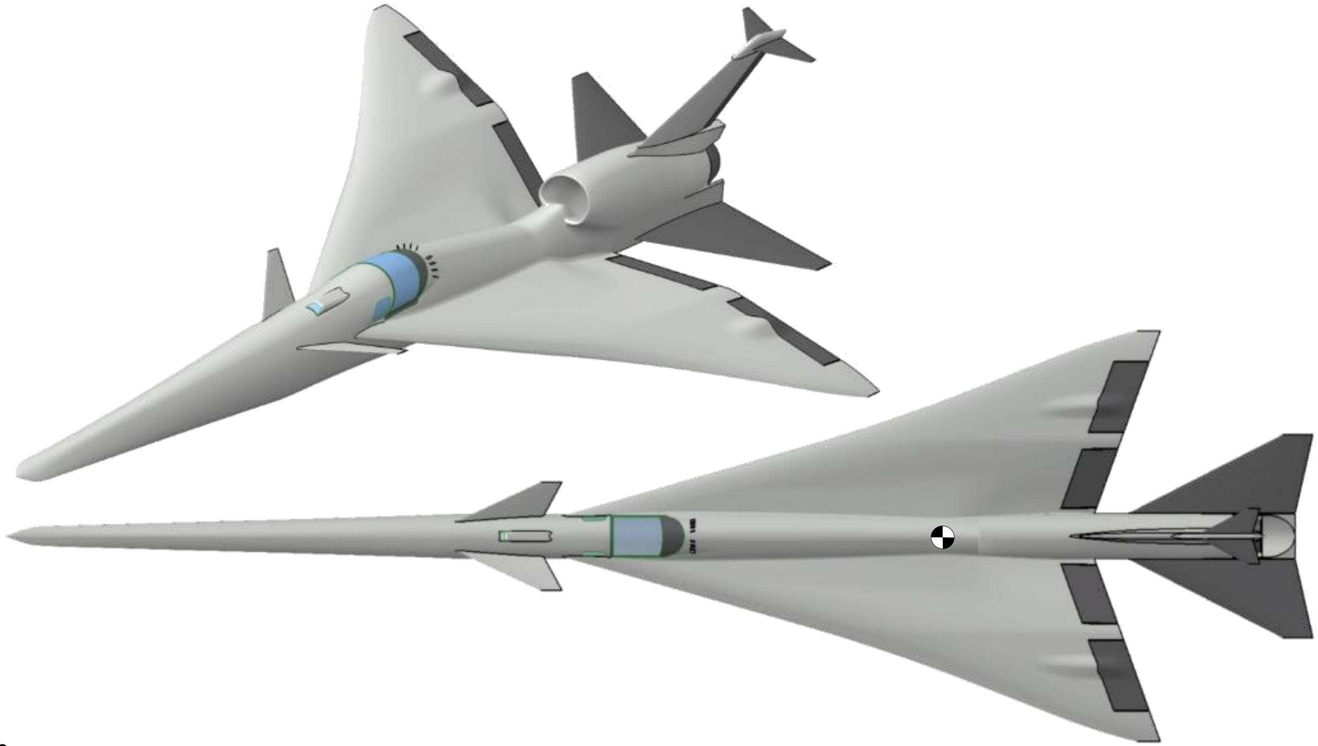
Comparison of Pre-test CFD and Wind Tunnel Measurements @ C_L = 0.142

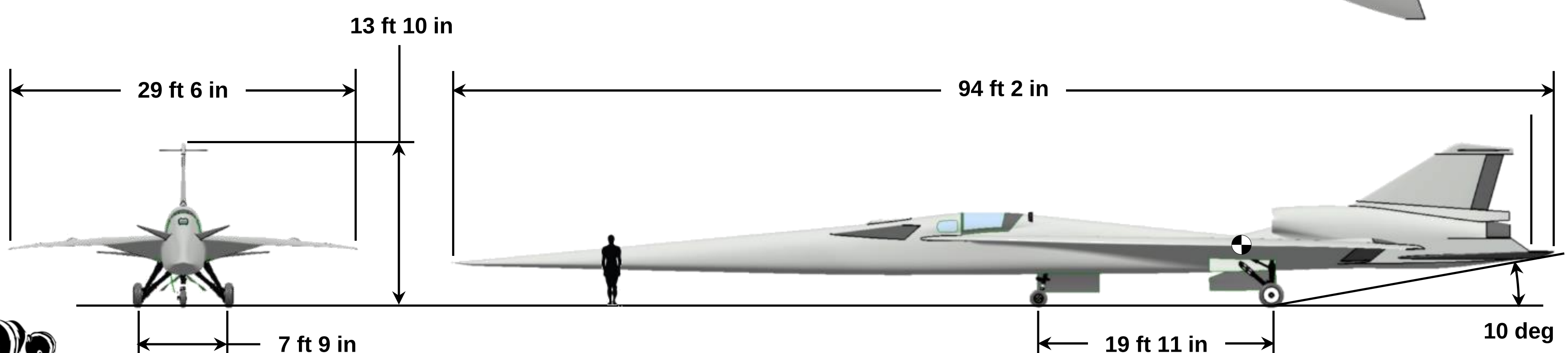


Work Done on N+2 Supersonic Validations Program Showed that Modern Design Tools are Adequate for Shaped Boom Design

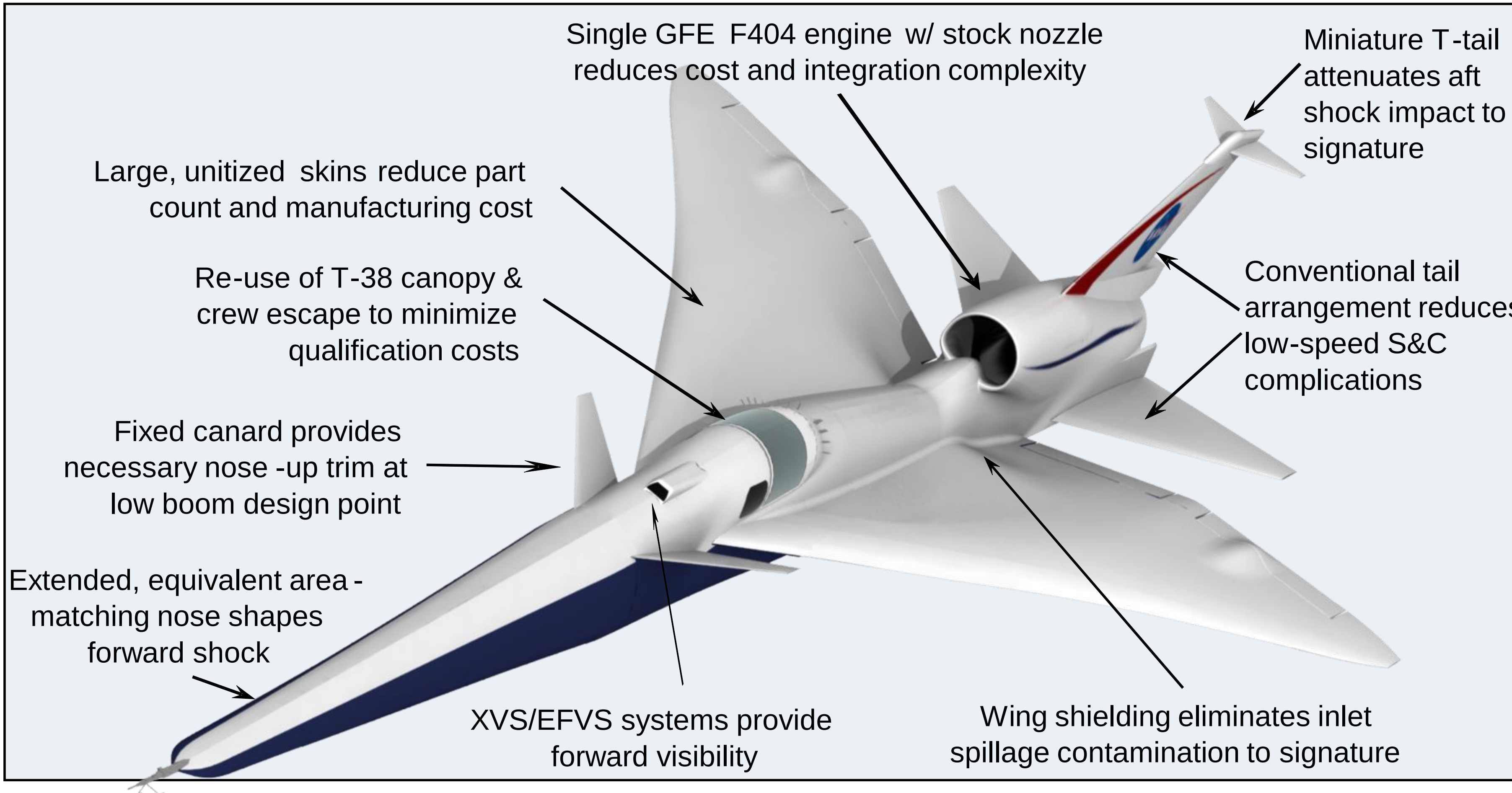
QueSST Configuration C606 Overview

Configuration C606	
MTOW	22,500 lb
Empty Weight	14,000 lb
Maximum Fuel	7,100 lb
Payload	500 lb
S_{ref}	486 sq ft
W/S	46 lb/ft^2
T/W	0.60
Engine	1xGE F404
Design Mach	1.42
Loudness	<75 PLdB



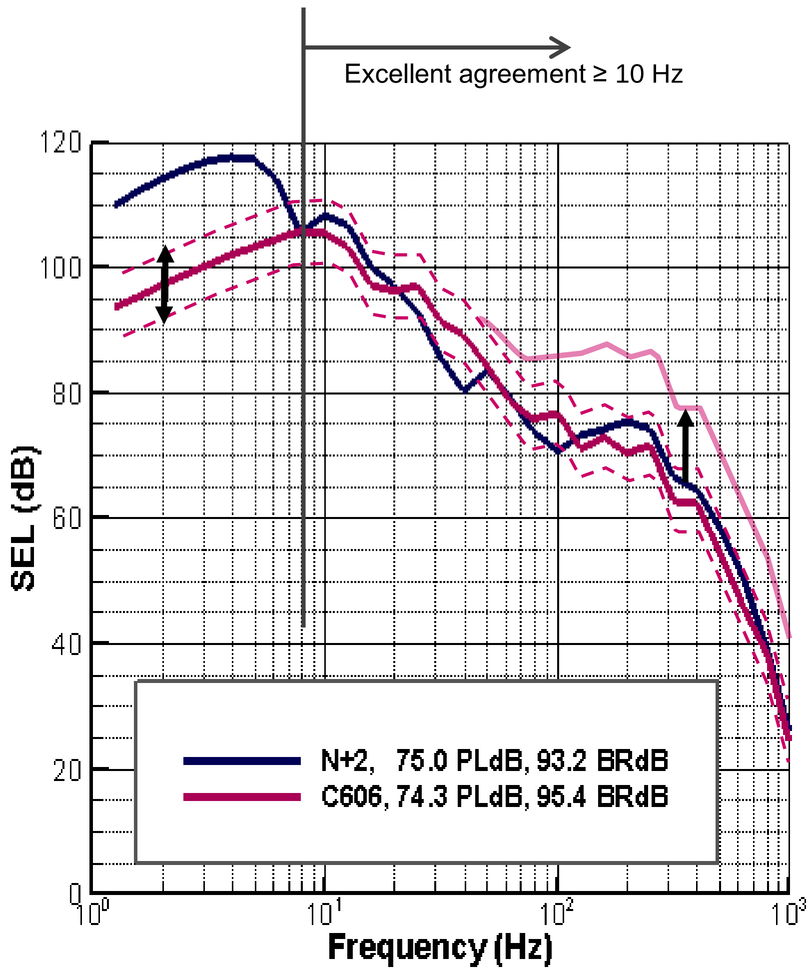


QueSST Design Features

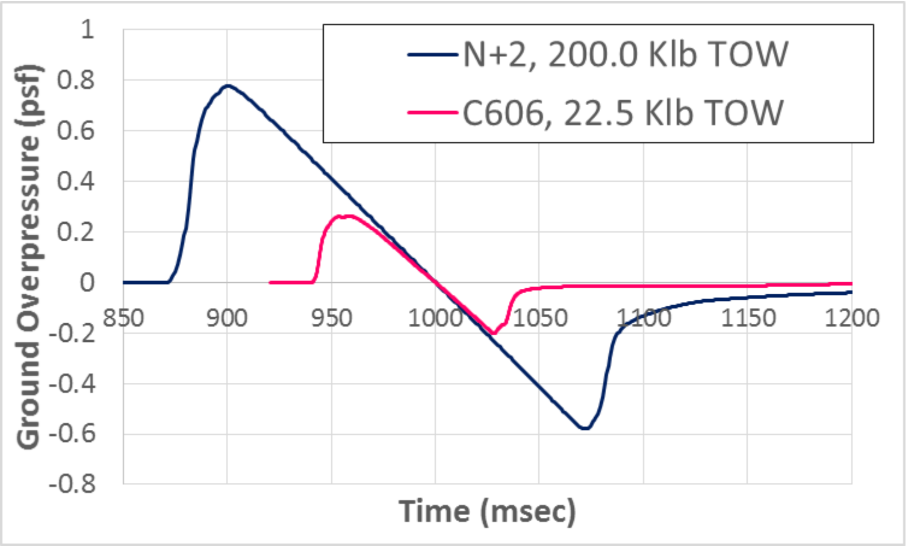


Skunk Works

Signature Traceability



- N+2 frequency content matched everywhere
- Variability at all frequencies and/or increased high frequencies to match a range of possible products



QueSST Size and Shape Provide Excellent Traceability to a Range of Future Commercial Products

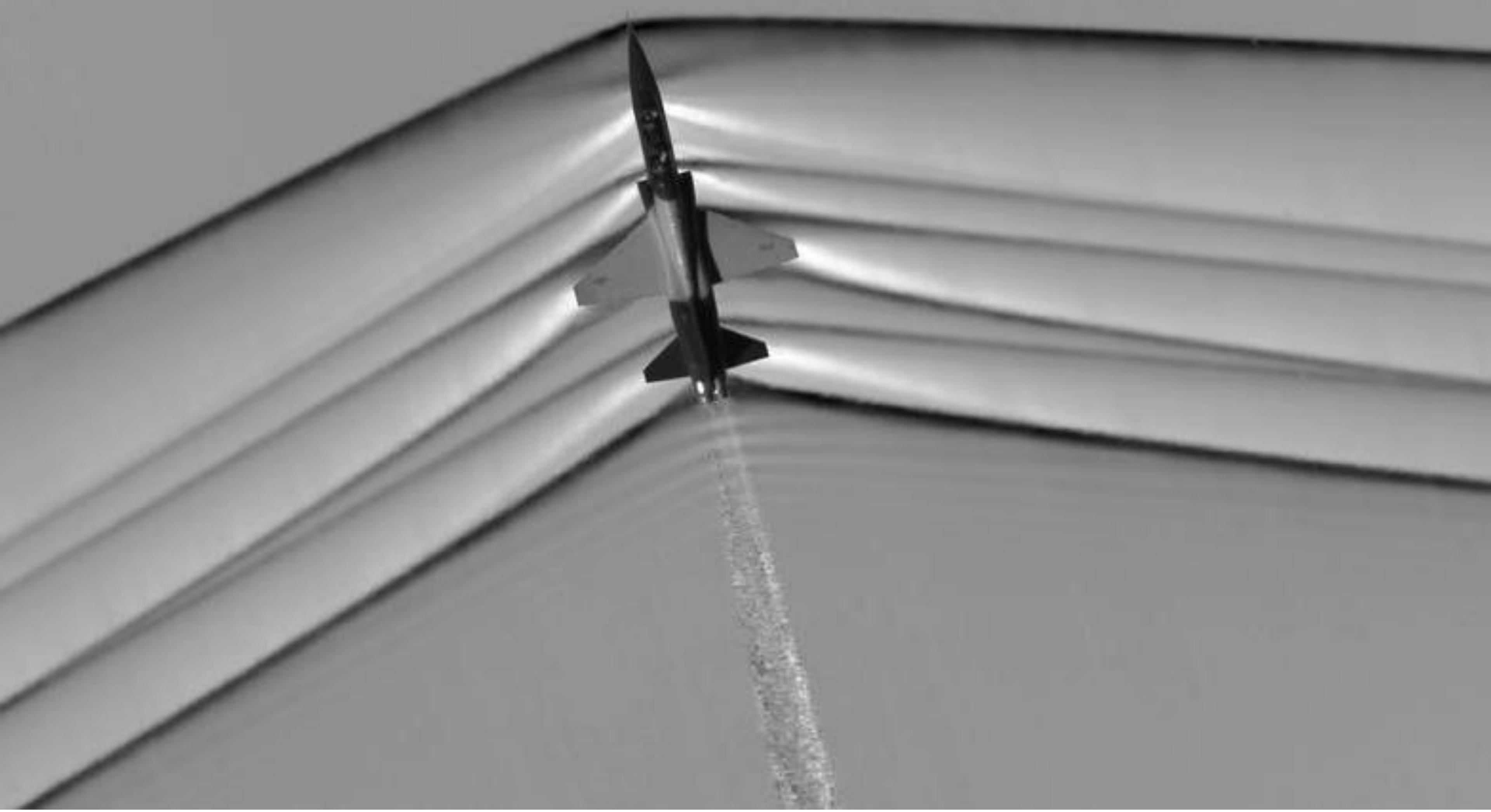
Skunk Works

Summary

- Work on the Low Boom Flight Demonstrator Concept Formulation and Refinement Studies established requirements and resulted in a closed airplane configuration capable of generating extremely quiet boom levels
- Current work on preliminary design will further mature the X-plane and lay the foundation for an eventual quiet commercial supersonic aircraft

Skunk Works

What’s Happening Now/Next?



Quiet Supersonic Technology (QueSST)
Preliminary Design Review (PDR) Completed

- *The QueSST PDR was held June 20 – 23 of 2017 in Palmdale, CA – 125+ participants including the NASA and LM teams*
- *The QueSST Team (NASA and LM teams) jointly provided a robust set of review materials and presentations per the QueSST PDR Terms of Reference*

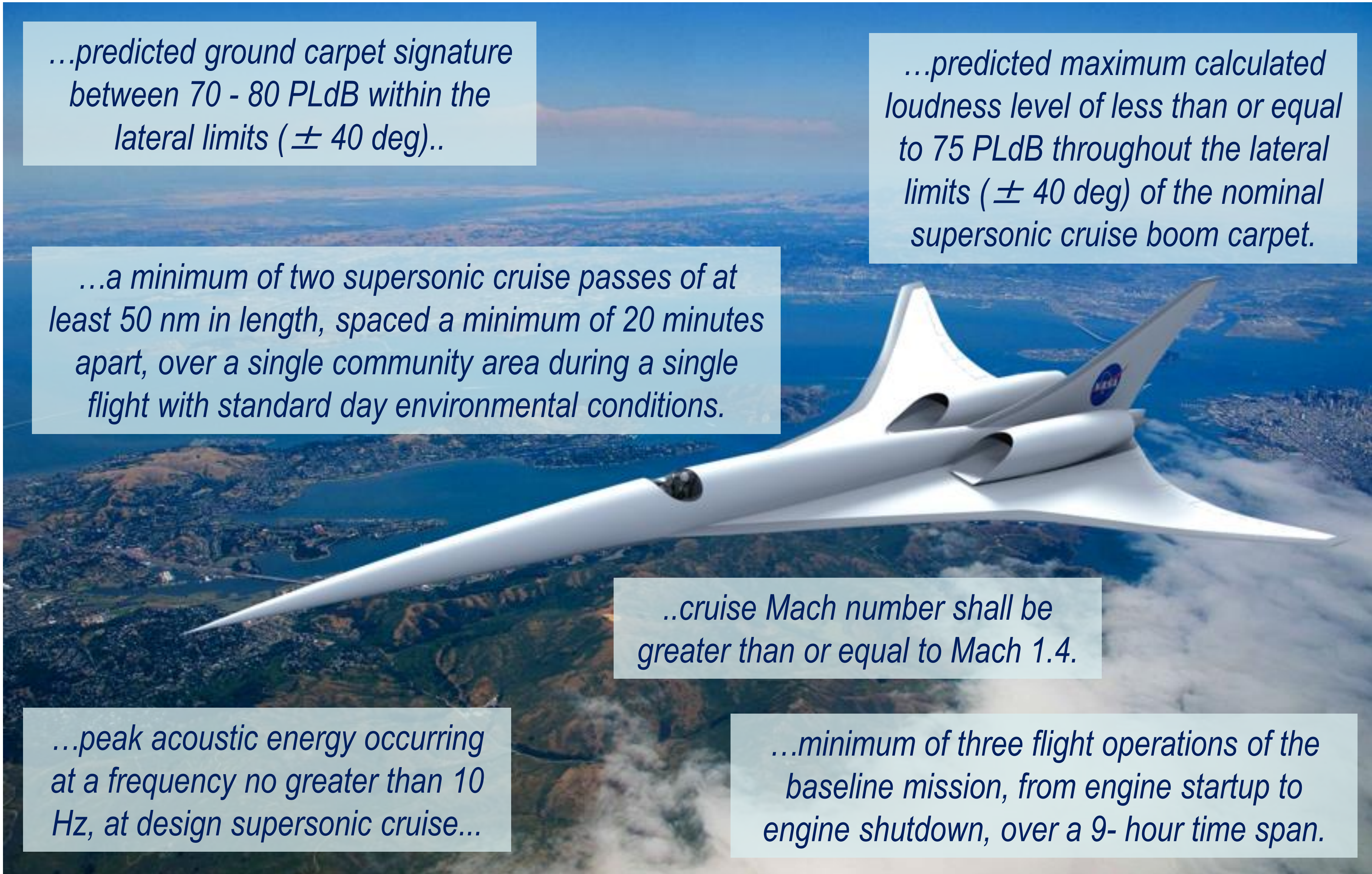
- *The PDR Independent Review Board & the Project Review Team were formed with a broad cross-section of over 25 subject mater experts from across the Agency. They reviewed the design materials for technical acceptability.*
- ***Initial assessment by the PRT was very positive with indications of a successful PDR.***

LBFD Timeline

2013 - 2014	Concept Exploration Studies
2014 - 2015	Concept Refinement Studies
Feb 2016	QueSST Preliminary Design contract awarded to Lockheed-Martin as part of NASA's New Aviation Horizons Initiative
Feb 2017	Sources Sought Notice Posted on FedBizOpps (https://www.fbo.gov/)
Jun 2017	Preliminary Design Review
Jun 2017	LBFD Design/Build/Test (DBT) Draft Request For Proposal (RFP) released on FebBizOpps
Aug 2017	LBFD DBT RFP release anticipated
2018	LBFD DBT contract award
2019	Critical Design Review
2021	First flight & Envelope Expansion
2022	Low boom acoustic signature validation complete
2023	Initial community response test (based at NASA AFRC)
2023 - 2025	Community response tests in US (remote based)

Dates in blue test are estimated and dependent on approval and funding

Example Req'ts from Sources Sought Posting



…predicted ground carpet signature between 70 - 80 PLdB within the lateral limits (± 40 deg)..

…predicted maximum calculated loudness level of less than or equal to 75 PLdB throughout the lateral limits (± 40 deg) of the nominal supersonic cruise boom carpet.

…a minimum of two supersonic cruise passes of at least 50 nm in length, spaced a minimum of 20 minutes apart, over a single community area during a single flight with standard day environmental conditions.

..cruise Mach number shall be greater than or equal to Mach 1.4.

…peak acoustic energy occurring at a frequency no greater than 10 Hz, at design supersonic cruise...

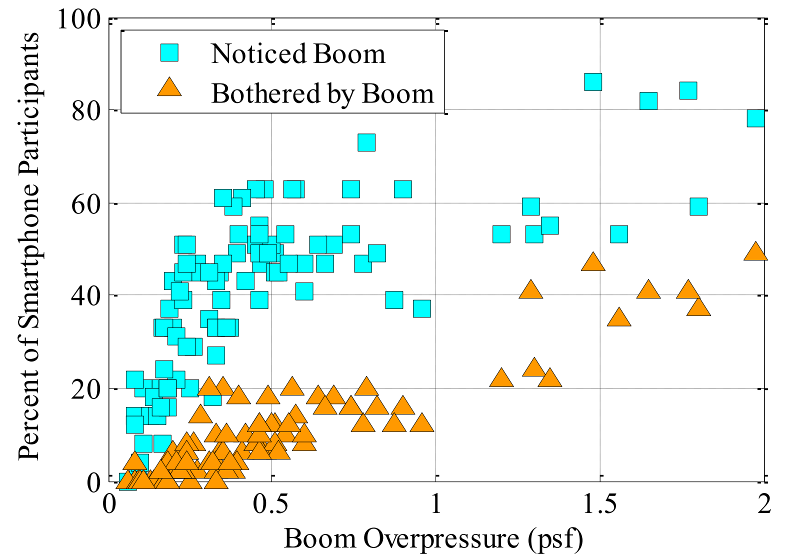
…minimum of three flight operations of the baseline mission, from engine startup to engine shutdown, over a 9- hour time span.

Quiet Supersonic Overflight
Community Test Concepts and Objectives

Objective: Create a robust dose – response relationship for community annoyance vs appropriate noise metric(s)

- Large populations, large number of representative responses.
  - 10k to 100k, depending on survey method employed
  - Varied community settings including representative:
    - Geography and climate
    - Home and building construction
    - Community demographics, etc.
- A range of exposure levels will be required, possibly including normal booms
- Up to a maximum of 6-8 of daily exposures
  - Night exposures may be required
- Sufficient test duration to establish effect of repeated exposure
- Account for test aircraft operational limitations
  - Airfield facilities
  - Operations tempo

Results from Edwards AFB community response pilot campaign



Concluding Remarks

- Supersonic Commercial Flight offers an unfulfilled promise of improved mobility
- Long & rich history of research and development of sonic boom & minimization technology at NASA
- Recent developments have resulted in a breakthrough achievement of very low boom levels for integrated supersonic designs.
- Low Boom Flight Demonstration X-Plane is the next logical step

Credit: The Boeing Company

Credit: Lockheed Martin


NASA
AERONAUTICS
WITH YOU WHEN YOU FLY
Any Questions?

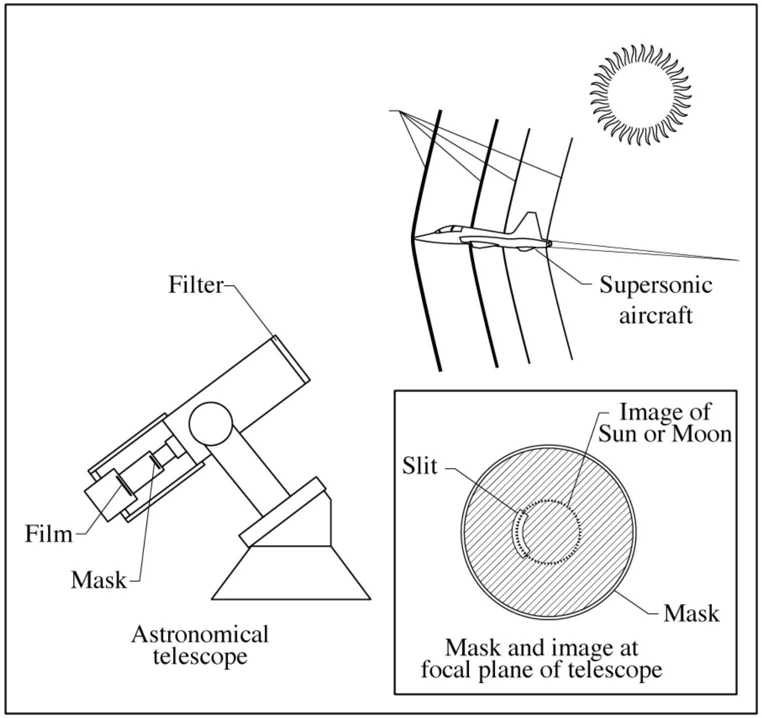
Backup slides

Density Changes

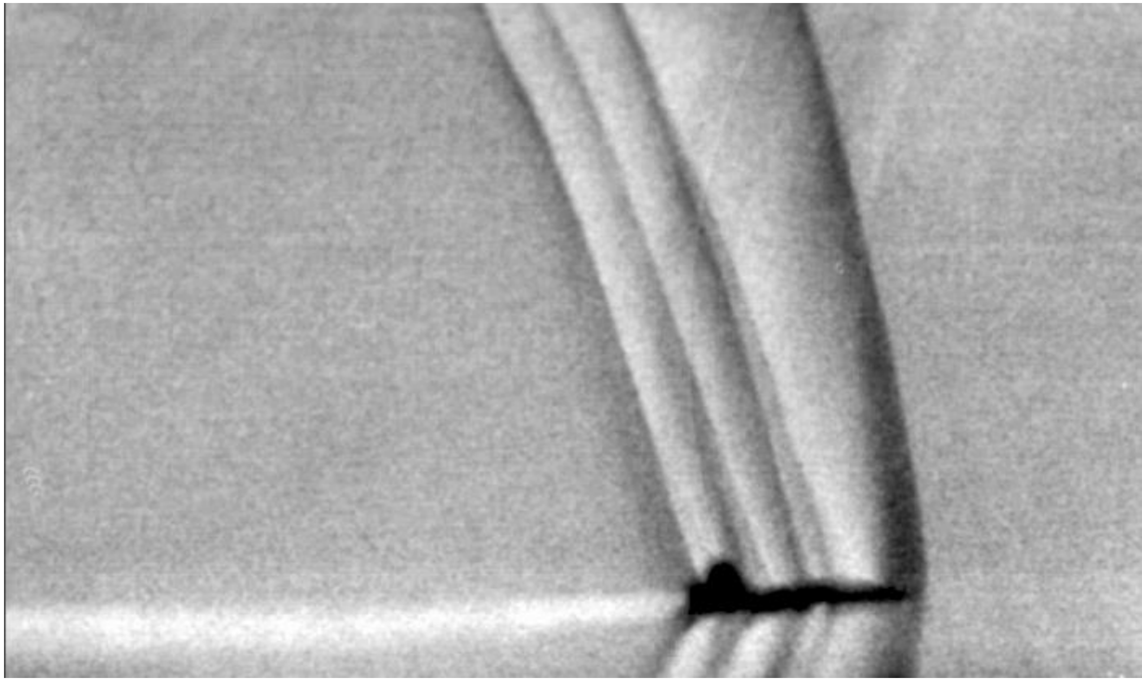
- Flow around aircraft changes air density, generally invisible
- Density changes can refract (bend) light

First In-Flight Image

- Schlieren, German word for “streak”, from 1665, used for making lenses
- First schlieren image of full-scale supersonic aircraft by Leonard Weinstein, NASA Langley, 12/13/1993
- Shock waves can be seen combining



8mm movie film



NASA Aeronautics Context

Strategic Implementation Plan (SIP) May 2015

3 Mega-Drivers

6 Strategic Research & Technology Thrusts

Safe, Efficient Growth in Global Operations
- *Enable full NextGen and develop technologies to substantially reduce aircraft safety risks*

Innovation in Commercial Supersonic Aircraft
- *Achieve a low-boom standard*

Ultra-Efficient Commercial Vehicles
- *Pioneer technologies for big leaps in efficiency and environmental performance*

Transition to Low-Carbon Propulsion
- *Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology*

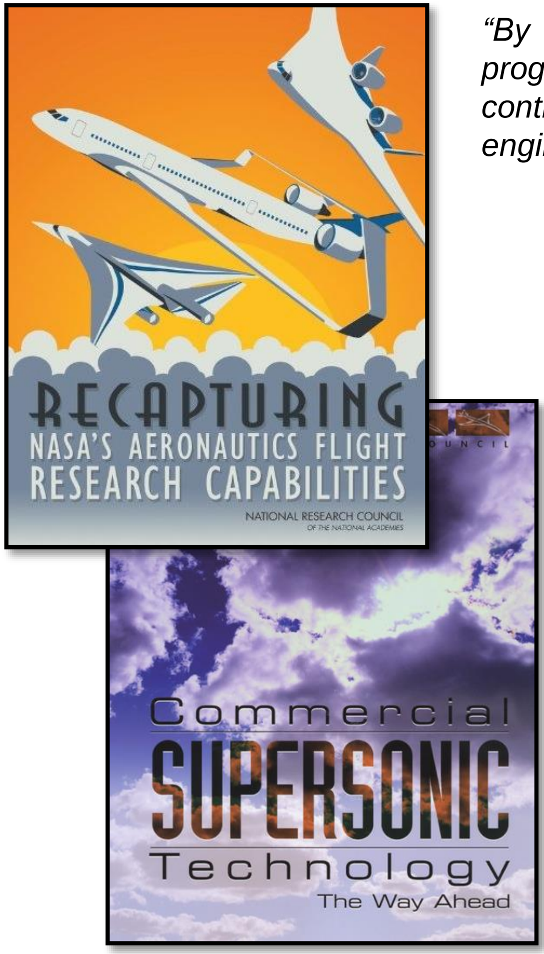
Real-Time System-Wide Safety Assurance
- *Develop an integrated prototype of a real-time safety monitoring and assurance system*

Assured Autonomy for Aviation Transformation
- *Develop high impact aviation autonomy applications*

http://www.aeronautics.nasa.gov/pdf/armd-strategic-implementation-plan.pdf

An Identified National Research Need

- Recent National Research Council reports identify NASA led flight research and a low-boom demonstrator X-plane as key elements of achieving regulatory change and inspiring our next generation



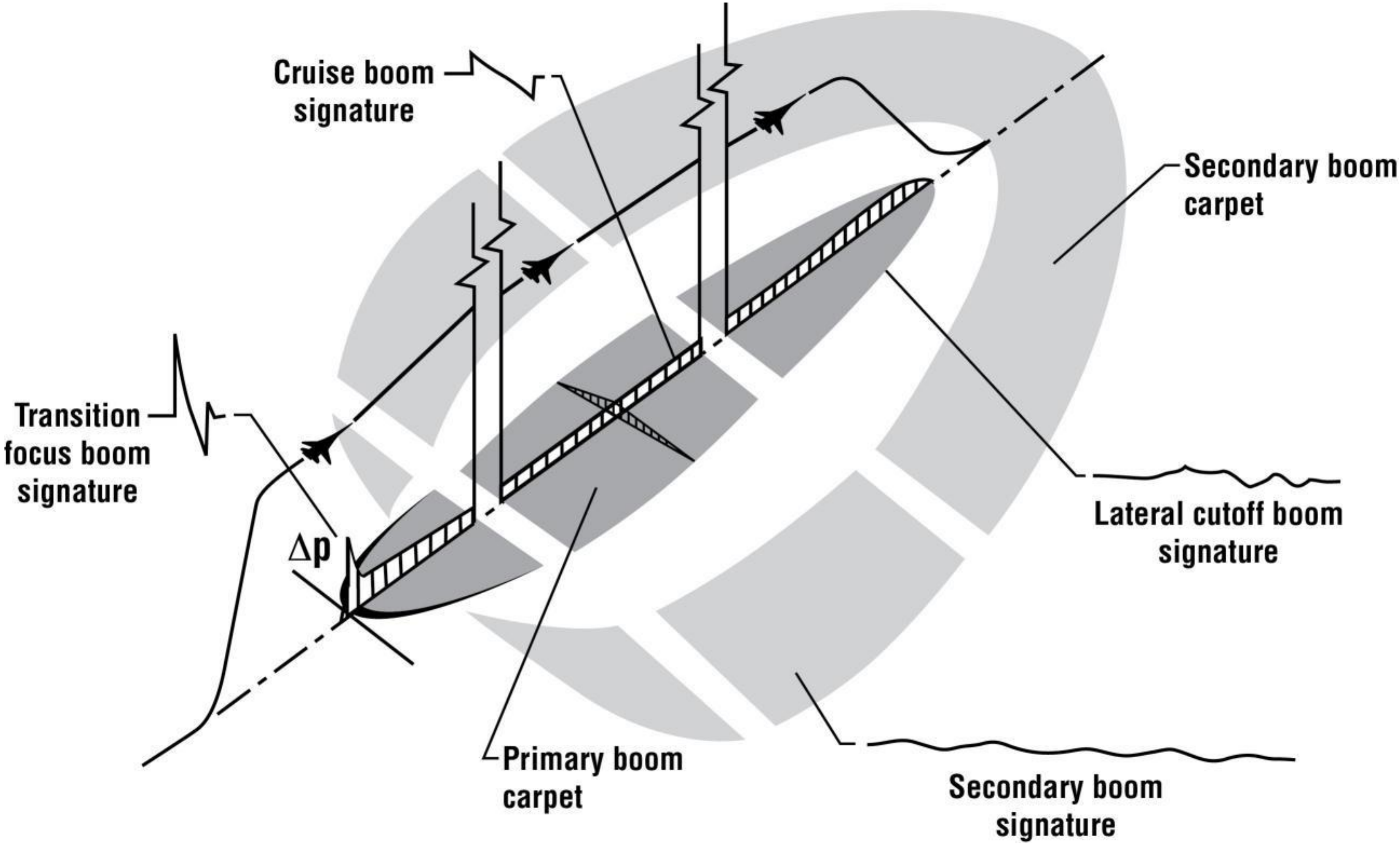
"By embarking on flagship aeronautical flight research programs that advance the frontiers of flight, NASA can contribute to inspiring the next generation of scientists and engineers."

"NASA's flight research programs are most effective when they are focused on achieving innovation in aeronautics."

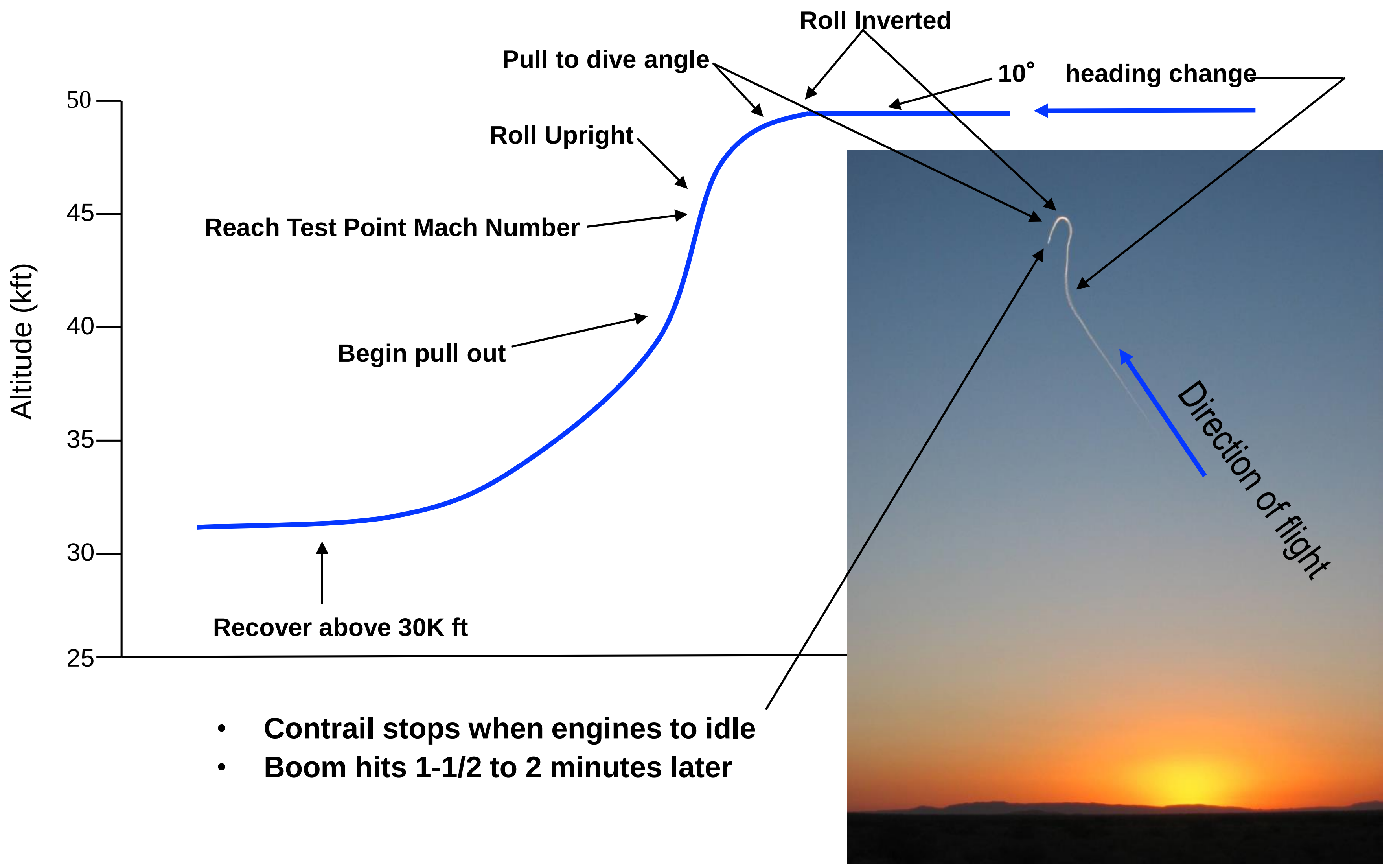
"…given the progress in low-boom technology that has been demonstrated over the past decade and in light of this research challenge being the principle remaining barrier to routine supersonic operations, NASA together with the FAA could proceed immediately with an integrated technology experimental aircraft program to validate low-boom acoustic ground signatures and establish a set of quantitative criteria for the sonic boom footprint over land."

"Sonic boom is the major barrier to the development of supersonic business jets (SBJs) and a major, but not the only, barrier to the development of supersonic transports with overland capability… …While NASA should have its eye on the prize – supersonic commercial transports – it is still quite appropriate for NASA to conduct sonic boom research, even when related to SBJs."

Sonic Boom Ground Exposures



Low Boom Dive

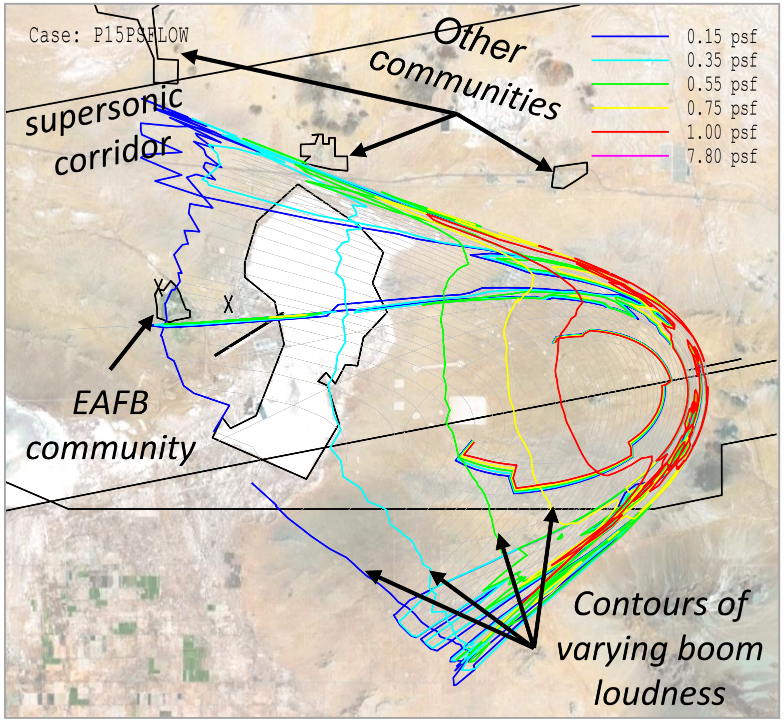


- Contrail stops when engines to idle
- Boom hits 1-1/2 to 2 minutes later

Low Sonic Boom Supersonic Dive
Video from Back Seat of F-18B

Boom Placement Considerations

- Low-boom dive maneuver results in large area of low magnitude N-waves, but smaller parabola of loud focused booms
- Flight will be planned to demonstrate varying levels of low magnitude N-waves
- Flight plan determined by target boom level and prevailing weather
  - Launch preflight weather balloon
  - Calculate maneuver waypoints
  - Avoid booming sensitive areas

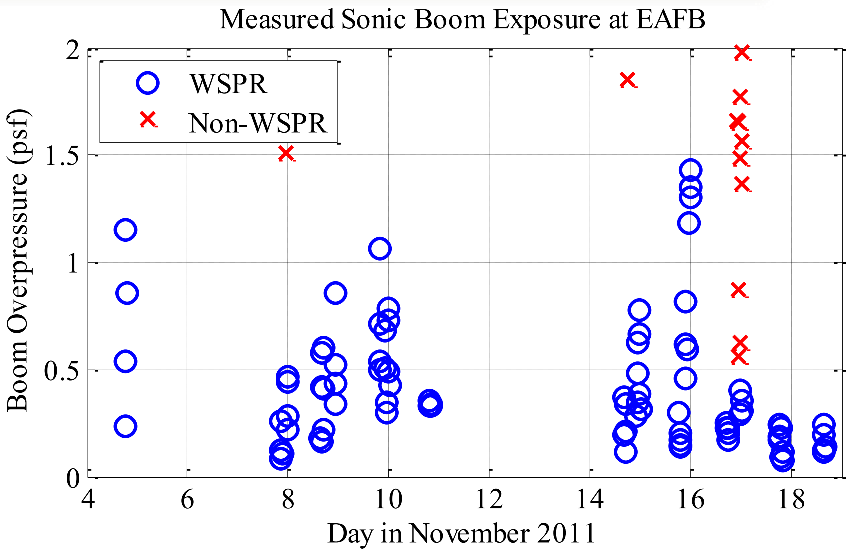


46

Community Response Pilot Test (Community Exposure Test Element)

Pilot test to prepare for future sonic boom community response studies

- Expose Edwards Air Force Base (EAFB) housing area to low-amplitude sonic booms
  - Two-week test period (Nov. 2011)
  - Range of boom amplitudes and number of booms/day
  - 2 Contractor teams (Wyle Laboratories and Fidell Assoc.) plus NASA in-house team
- Noise exposure
  - 3 low-boom target levels: 0.1, 0.3, 0.5 psf
  - 4-15 booms/day, 110 total booms
  - Desired range of sonic boom amplitudes was achieved



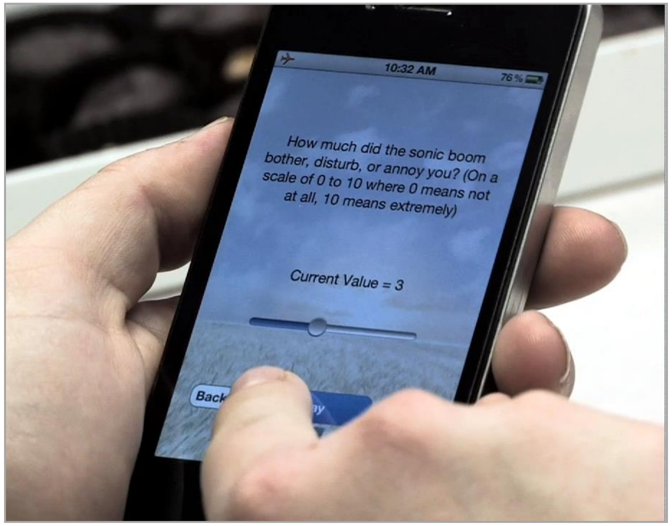
- Exposure range enables comparison with previous sonic boom studies
  - Non-WSPR high-amplitude booms also occurred during test period
- Sonic boom data analysis
  - Data for each boom at each monitor analyzed
  - Psychoacoustic metrics calculated

Community Response Methods

- Types of information collected
  - Residents' responses to each boom
  - Residents' daily responses to multiple booms

- Resident reactions collected by one of 3 methods
  - Paper
  - Website
  - Smartphone

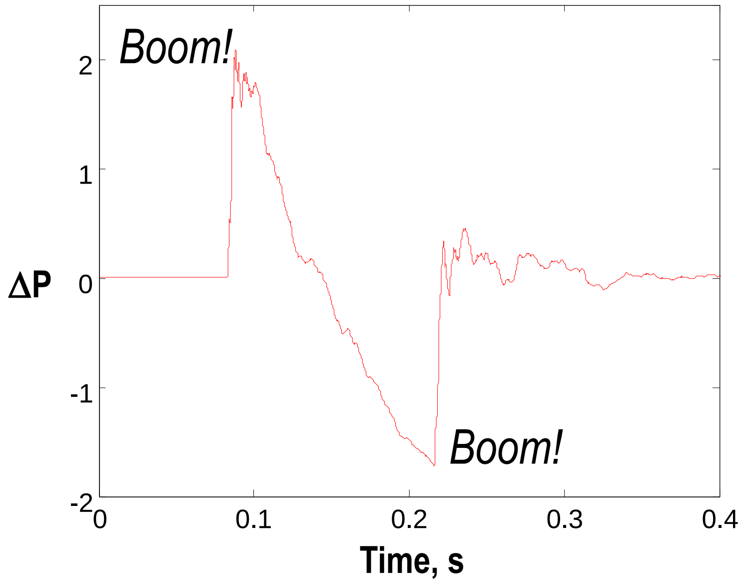
- Assessment of different methods
  - Test new data collection technologies
  - Evaluate data quality and completeness
  - Examine efficiency and cost-effectiveness
  - Assess respondent experience



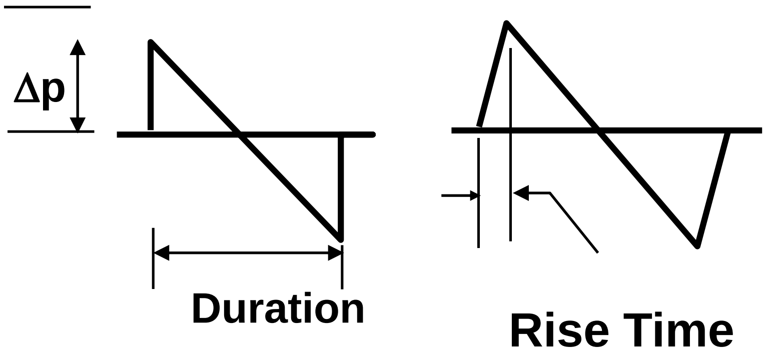
48

Sonic Boom Basics: The N-Wave

Measured Sonic Boom

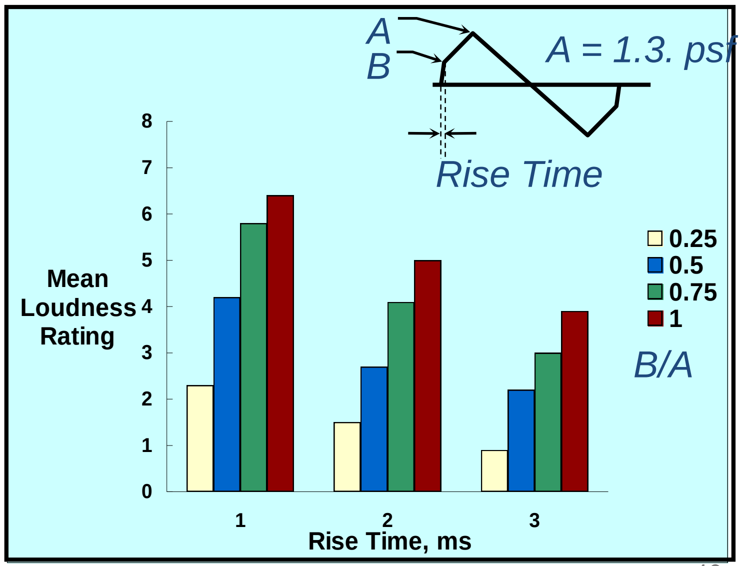


Overpressure Δp



Factors in N wave annoyance

Sullivan 1990



Commercial Supersonic Flight and Sonic Boom

A Brief History

1947 – X-1 breaks the sound barrier

1954 – First SST concept studies

1961 – St. Louis sonic boom study

1962 – Concorde agreement

1963 – US SST announced

1964 – Oklahoma City sonic boom study

1969 – Concorde first flight

1971 – US SST canceled

1973 – US prohibits overland flight

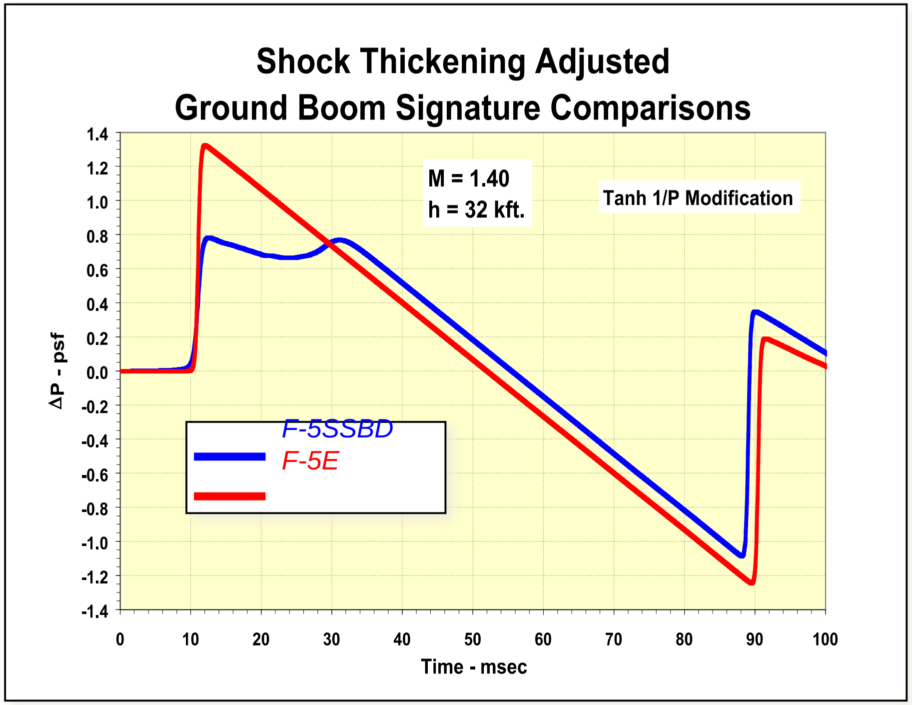
1976 – First commercial Concorde flight

2003 – Concorde retired

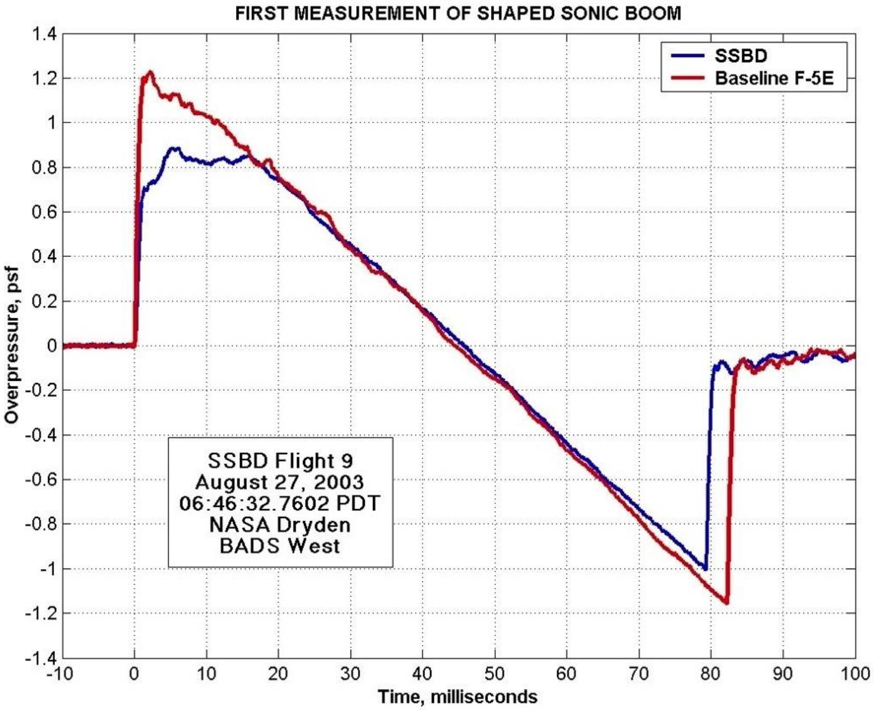
First Flight Demonstration of Shaped Sonic Boom DARPA-NASA SSBD-SSBE Project 2003

Back-to-Back Flights of Modified and Unmodified F-5s

First-Ever Shaped Sonic Boom Recorded 27 August 2003



Design



Flight Results