Zoom without the Boom

Nils Larson
NASA Armstrong Flight Research Center
Chief Test Pilot

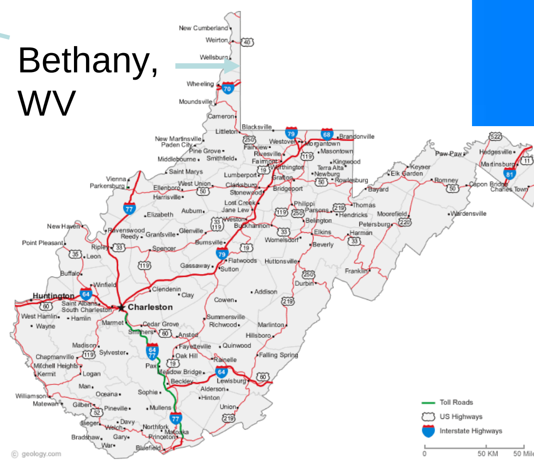
- My Path to NASA
- My NASA Test Work
- Low Boom Flight Demonstration Project
- X-59 QueSST

Where I grew up…

Gambia

Nigeria

Bethany, WV

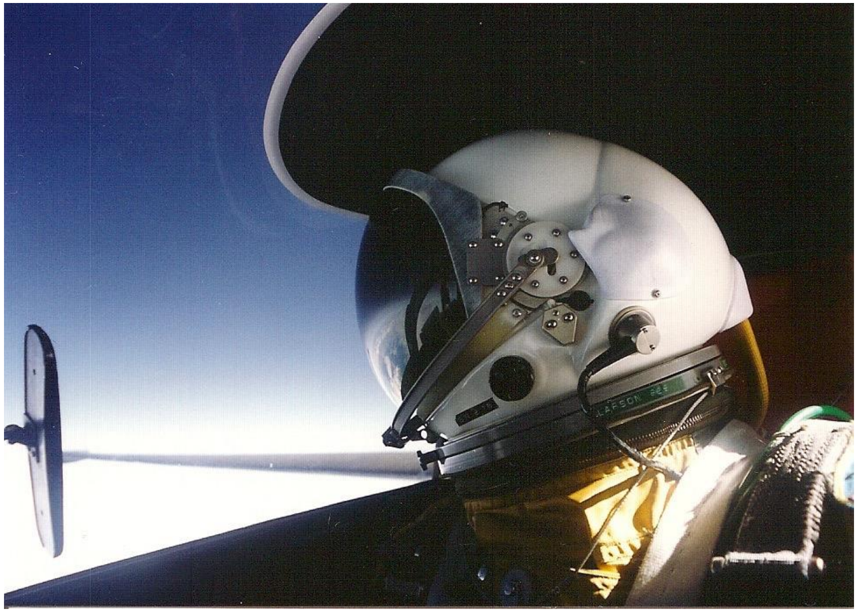


USAFA

Early Air Force Career

- T-37 IP at Williams AFB

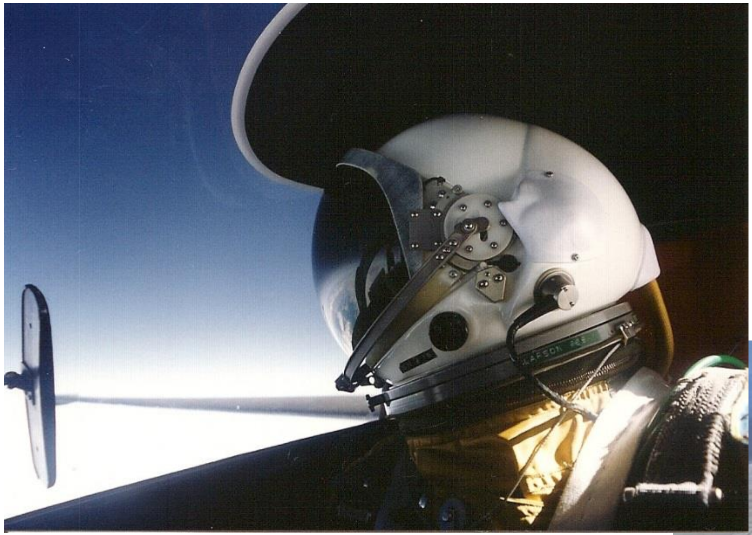
U-2 Pilot



Air Force Flight Test

Air Force Exchange Instuctor Test Pilot

Command Tours at Plant 42 & Edwards



NASA Flight Controls Research

- Adaptive Control Research
  - NF-15B
  - F-18 FAST

- X-48C Flight control work

NASA Spacecraft Component Tests

- Mars Science Lab (MSL) Landing RADAR Tests



- Space Launch System (SLS) Control Tests


NASA Collision Avoidance Test

- F-16 Ground Collision Avoidance Tests

Science and Flight Test Work

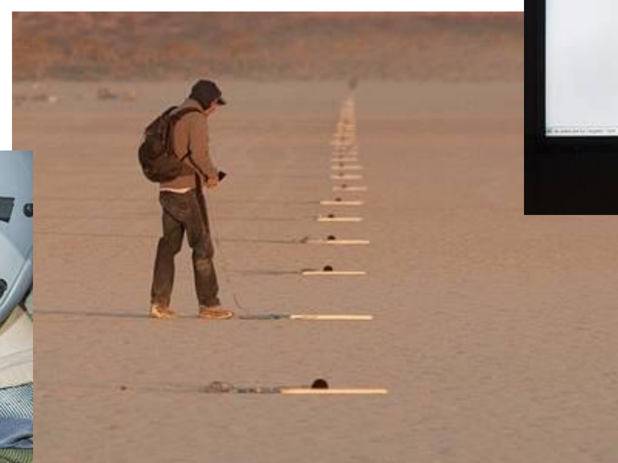
DC-8

ER-2

Supersonics work - External Wind Tunnel

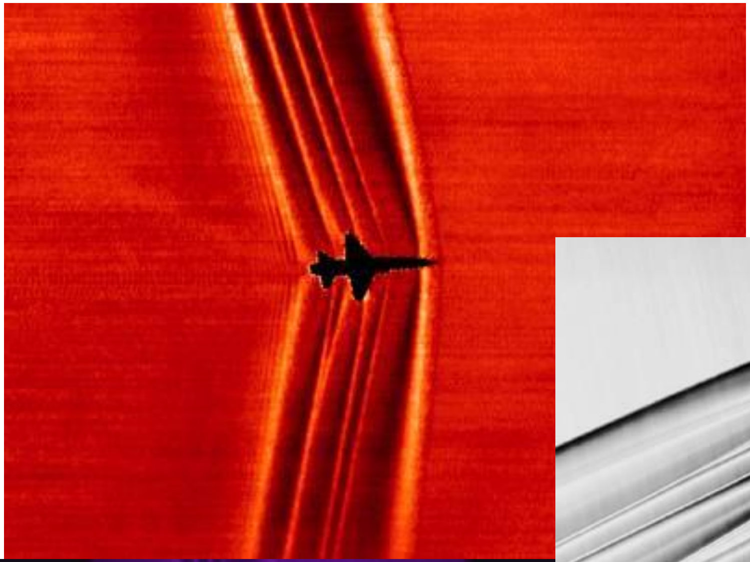
Supersonics – Boom modeling

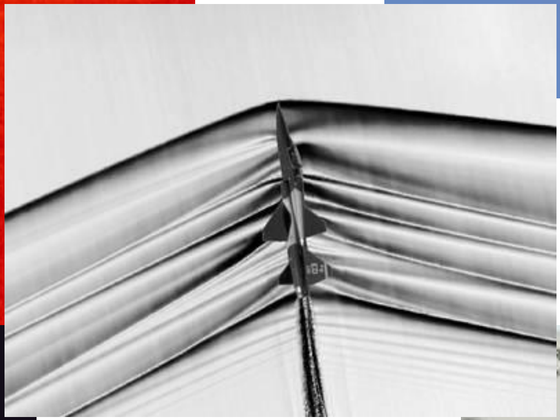
- Measuring the Boom
- Modeling the Boom
- Predicting the Boom

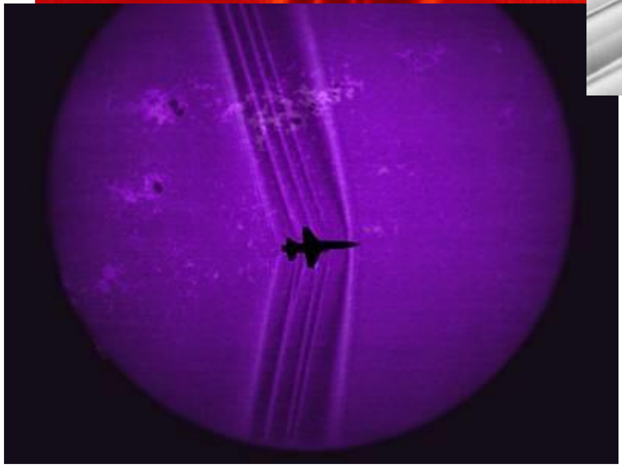


Supersonics – Shockwave

- Measuring the Shockwave



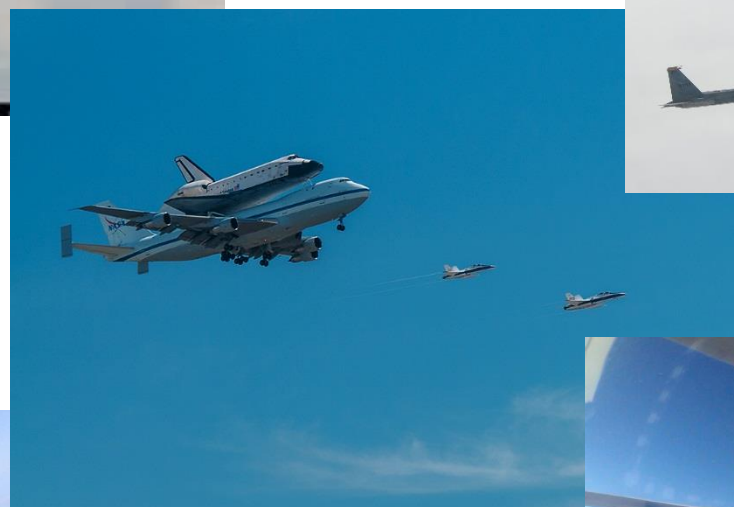




Supersonics – Effects Shockwave to Boom

- How do things effect the Shockwave as it transitions into the BOOM we hear? (eg. Aircraft Maneuvers, Atmosphere…turbulence, humidity, etc.)

Other



National Aeronautics and Space Administration

Low-Boom Flight Demonstration

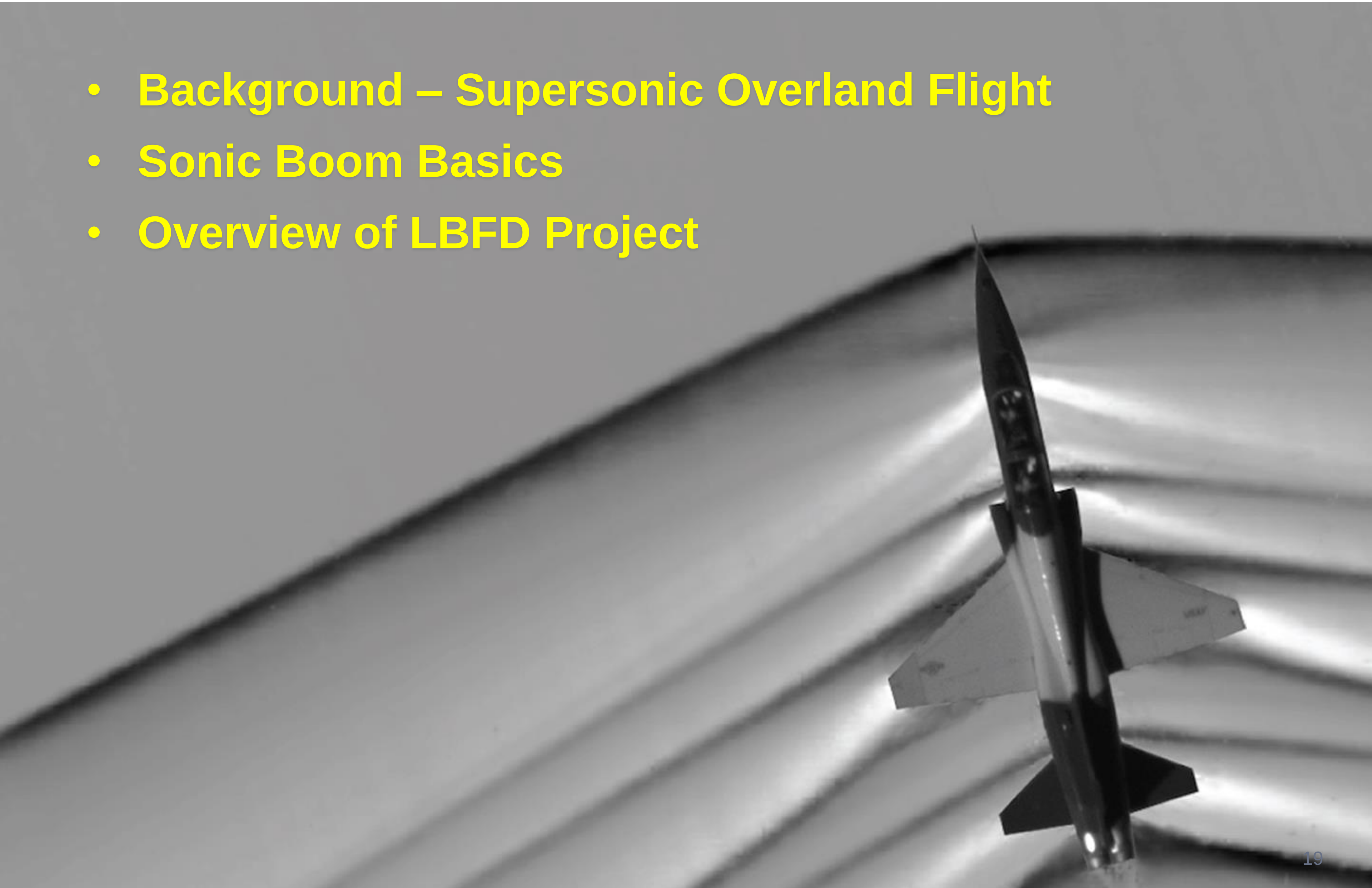
Credit: Lockheed Martin Corporation

Summary of the Quiet SuperSonic Technology (QueSST) Aircraft Preliminary Design and Low-Boom Flight Demonstration (LBFD) Mission

Author
Date

Outline

- Background – Supersonic Overland Flight
- Sonic Boom Basics
- Overview of LBFD Project

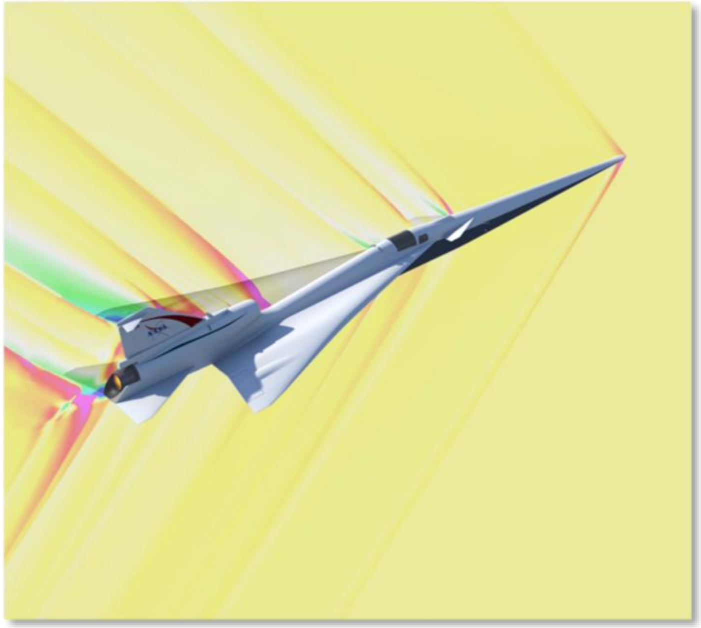


Background and Overview

Overcome the sonic boom barrier and open the door for development of a new generation of environment-friendly supersonic civil transport aircraft

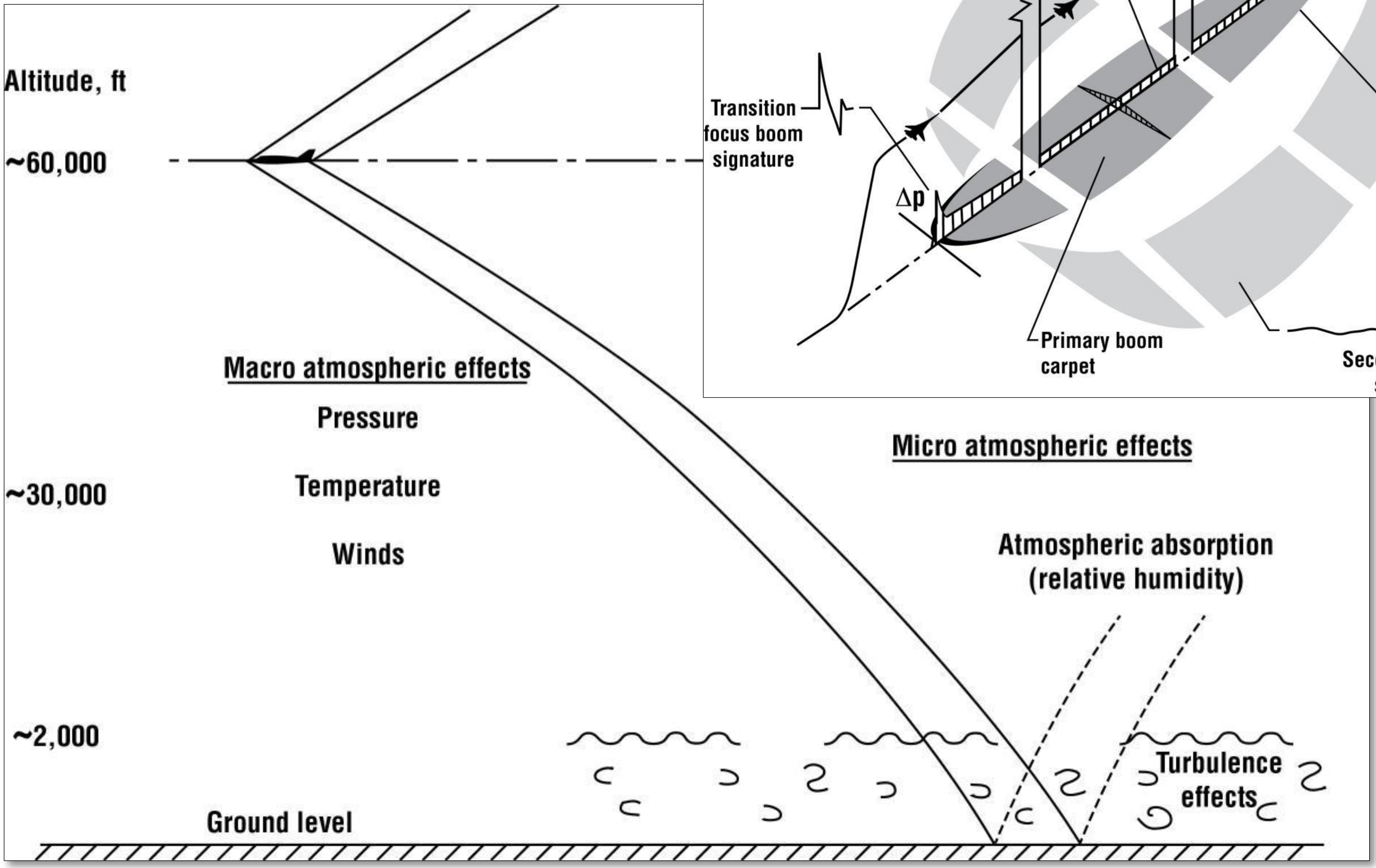
Overall Requirement

- Demonstrate that noise from sonic booms can be reduced to a level acceptable to the population residing under future supersonic flight paths
- Create a community response database that supports an International effort to develop a noise based rule for supersonic overflight

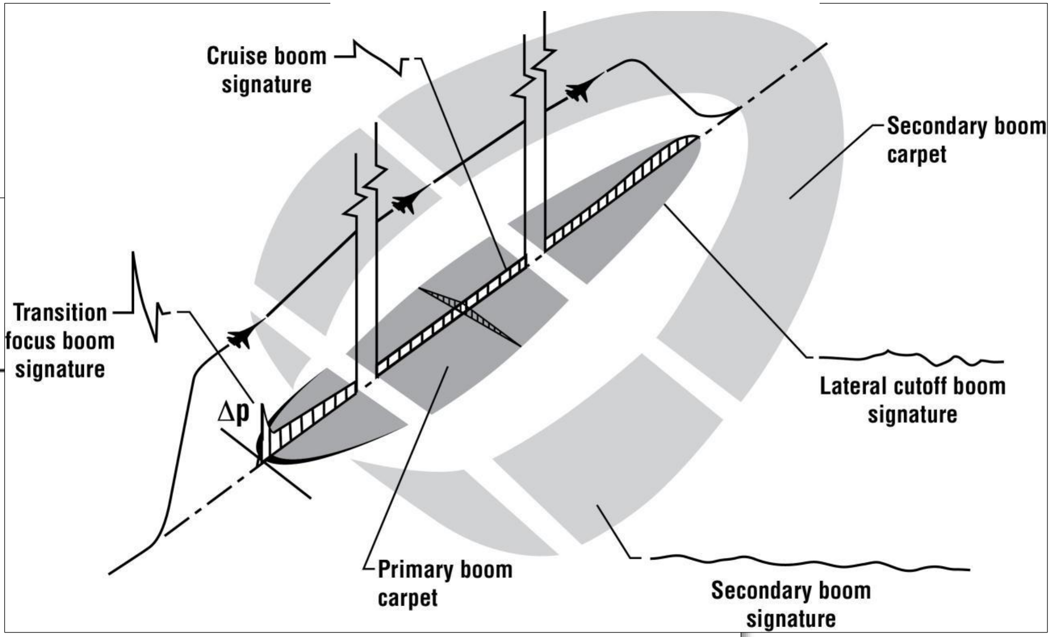


Sonic Boom 101

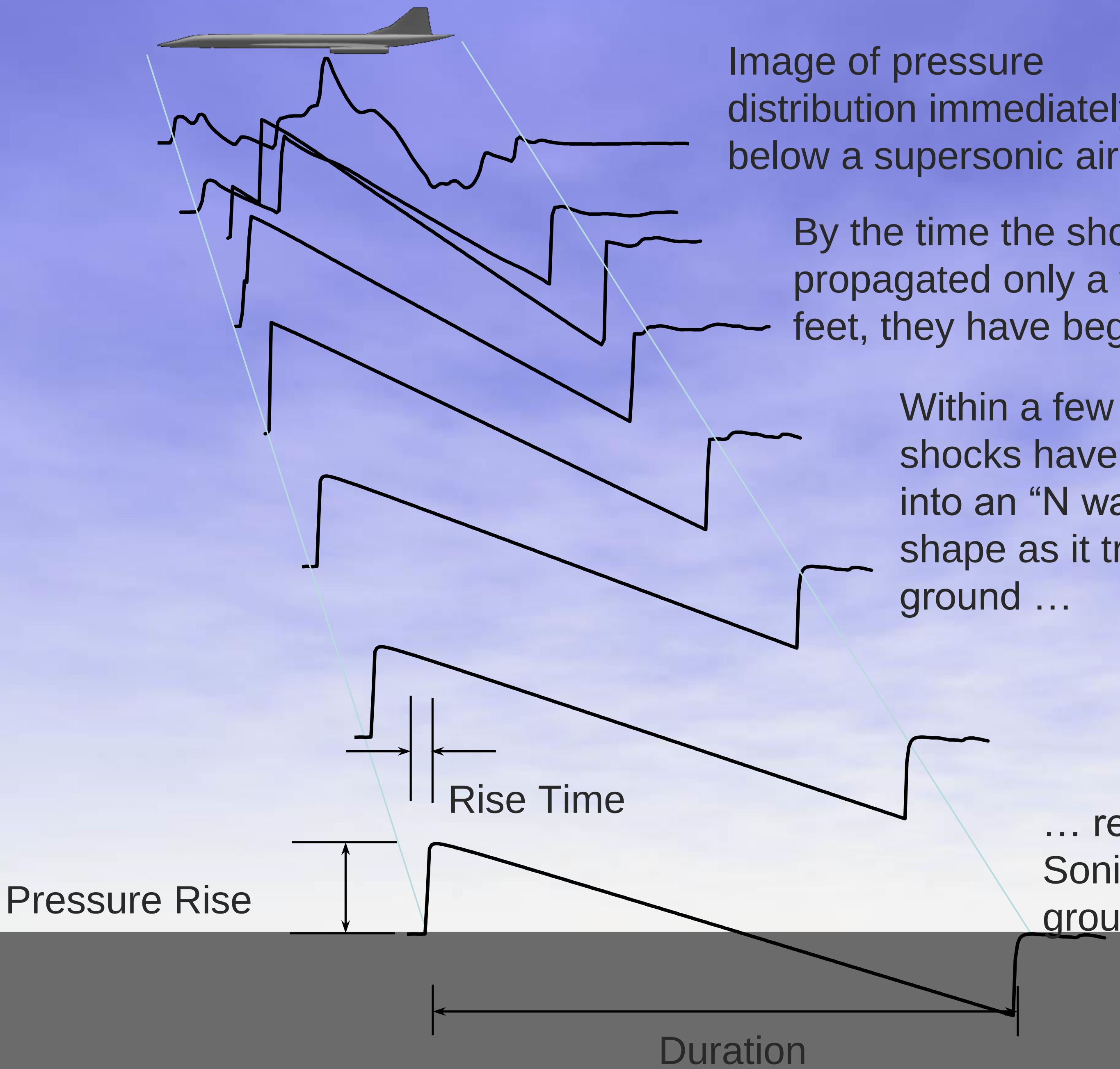
Sonic Boom
with Atmospheric Effects



Boom Signature Carpet



Sonic Boom Basics: N Wave Sonic Boom



Sonic Boom Basics: Shaped Pressure Signal

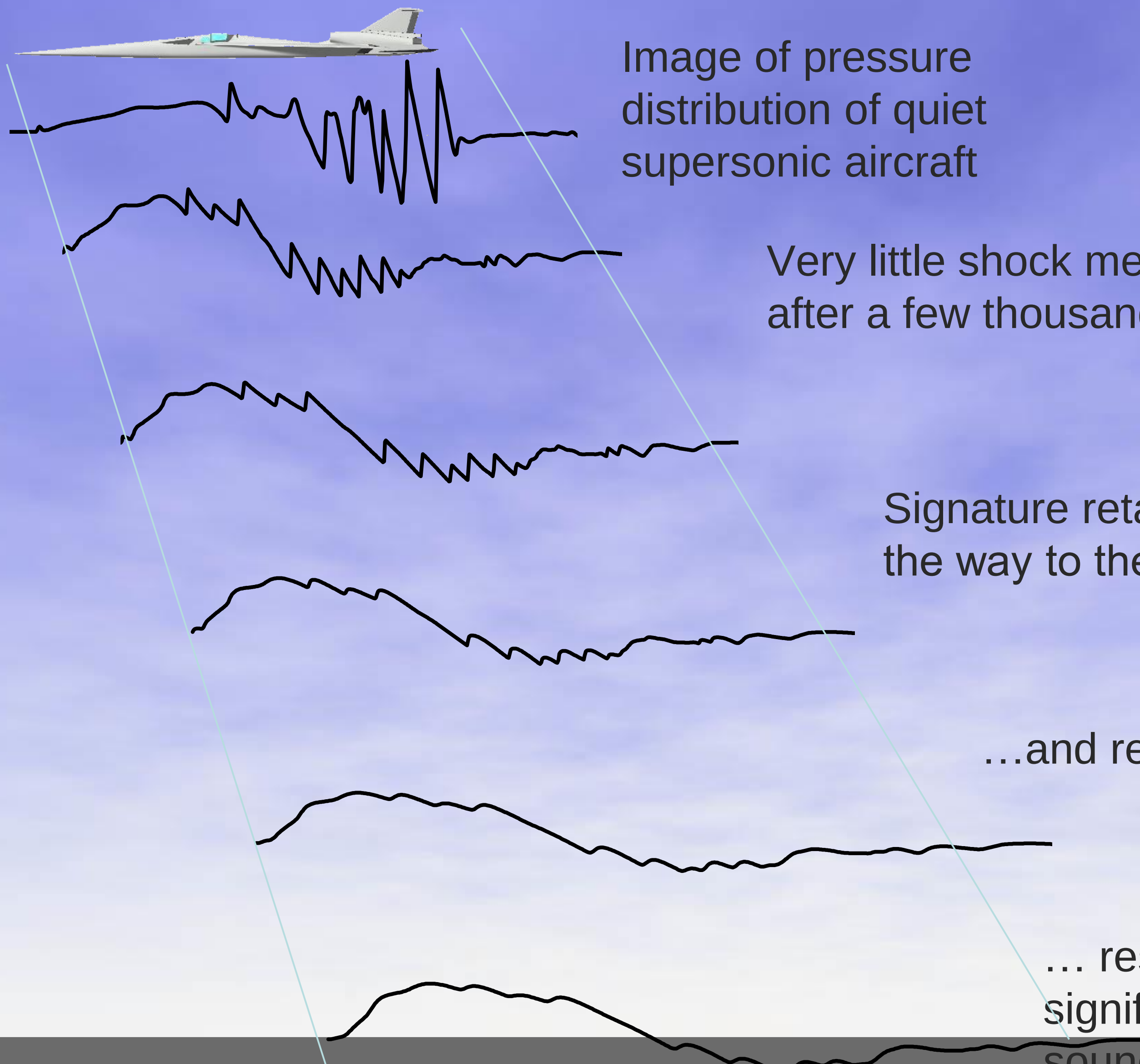


Image of pressure distribution of quiet supersonic aircraft

Very little shock merging after a few thousand feet

Signature retains it shape all the way to the ground …

…and reduces in strength …

… resulting in a significantly quieter sound at the ground

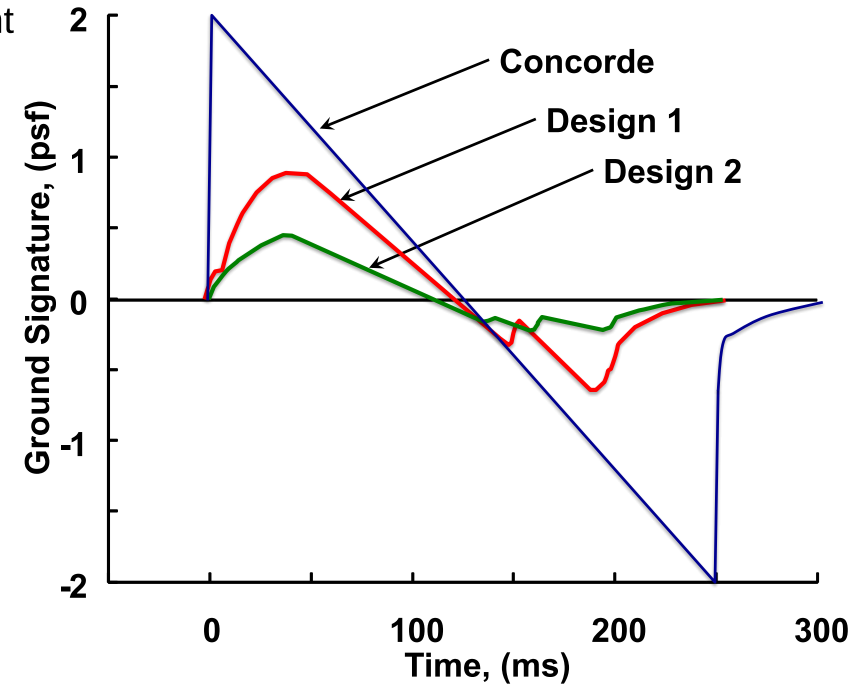
From Boom to Thump:
Quiet Supersonic Design Technical Challenge

Objective

- Develop and validate tools and design approaches to enable the development of supersonic airliners with very little perceived supersonic noise: <75 PLdB ~ 30 less than Concorde or typical military aircraft

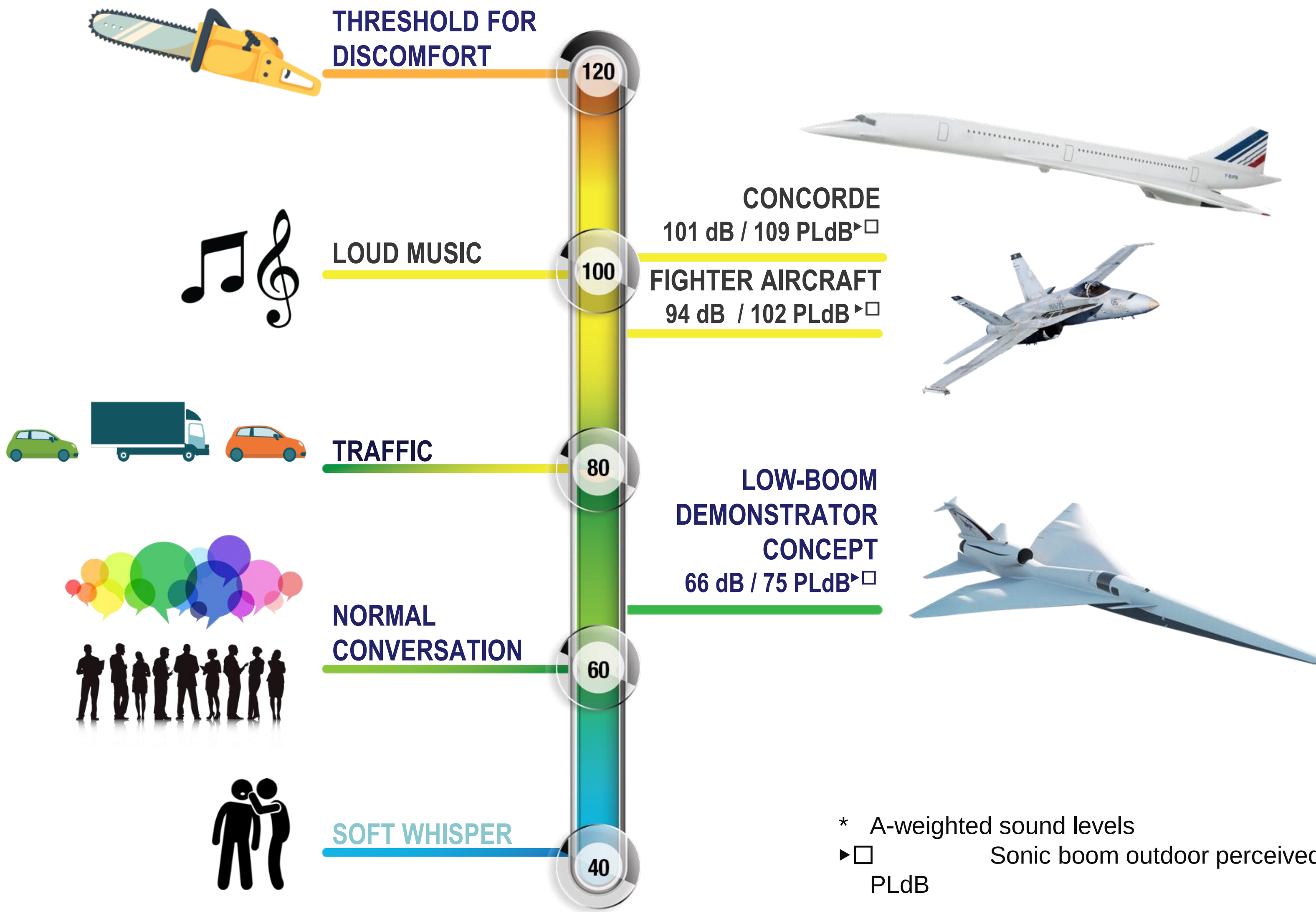
Approach

- 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 flexibility in the design process
- Conduct validation studies in wind tunnels and in flight
- Breakthrough technology development validated in wind tunnels, ready for flight demonstration



Supersonic Aircraft – Loudness Comparison

Decibel Scale (dB*)



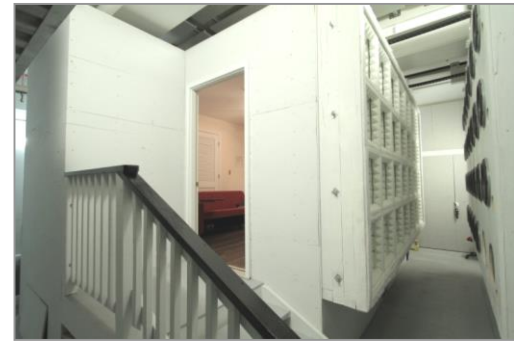
* A-weighted sound levels

▸☐ Sonic boom outdoor perceived levels, PLdB

What is a Quiet Supersonic Flight and How do We Measure Response? 1 – Boom Simulators

Simulation of boom 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

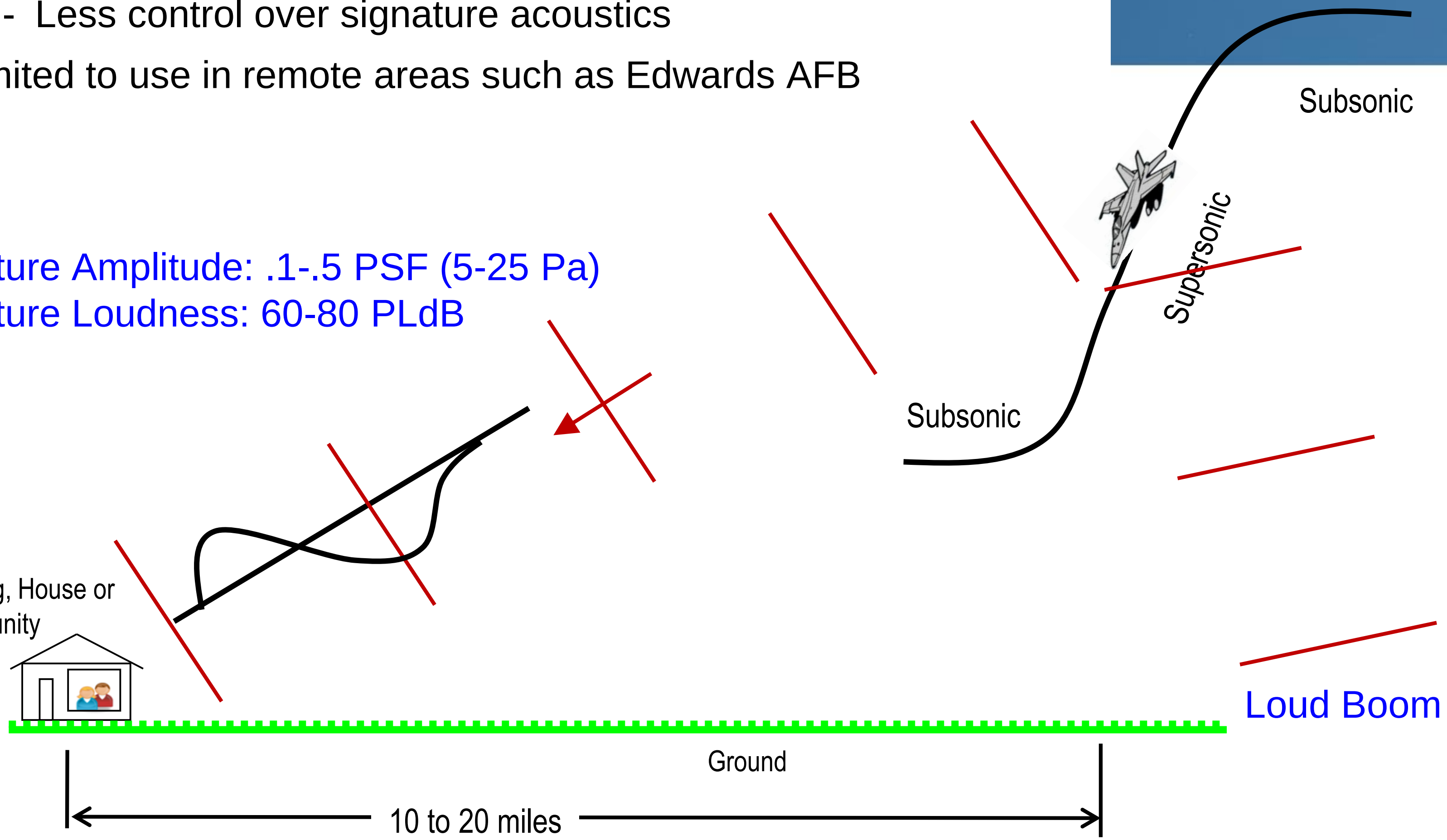


Simulation of boom heard indoors

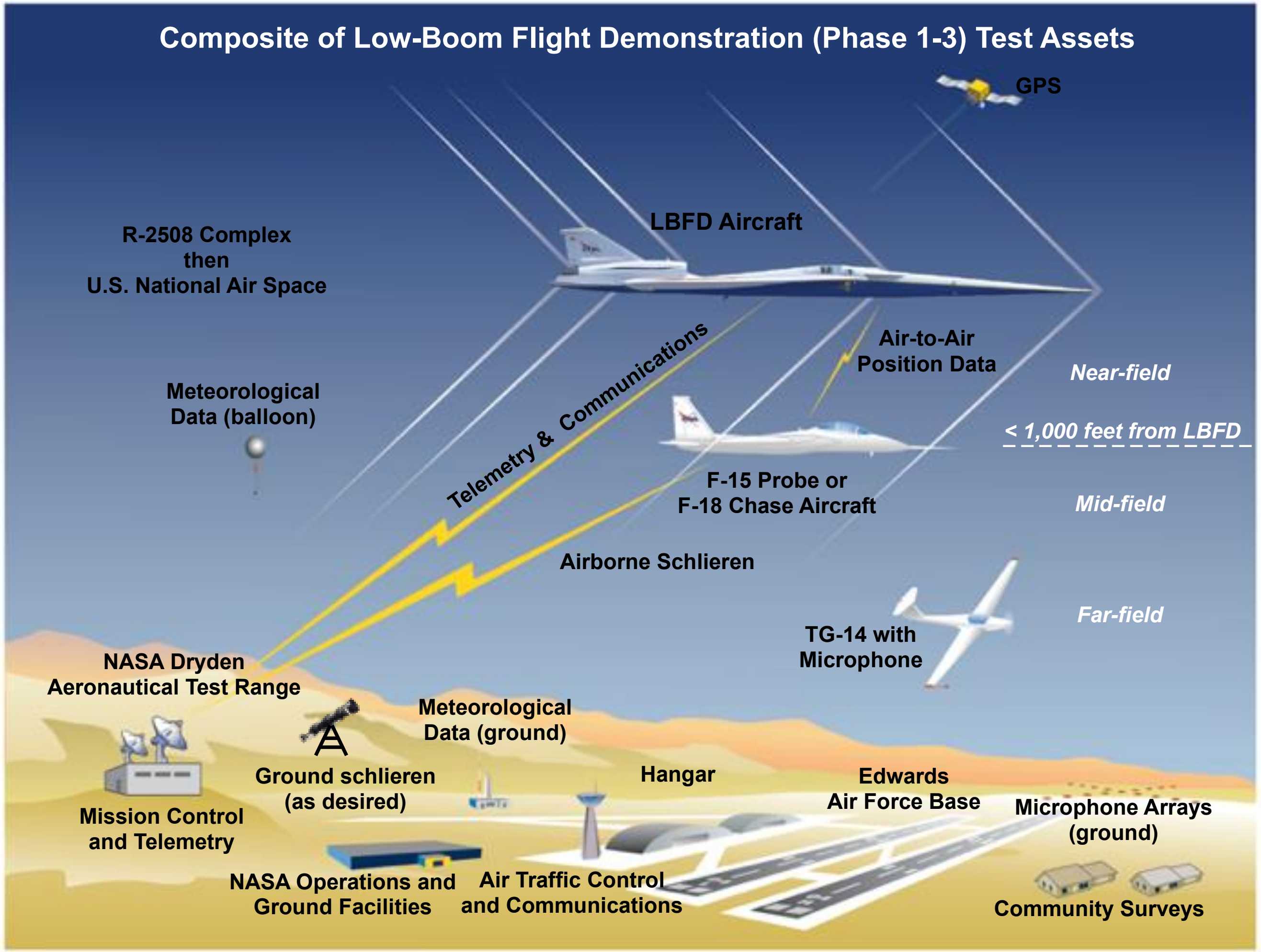
What is a Quiet Supersonic Flight and How do We Measure Response? 2 – Flight Research with Specialized Aircraft Maneuver

- 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



Concept of Operations



Project Phases

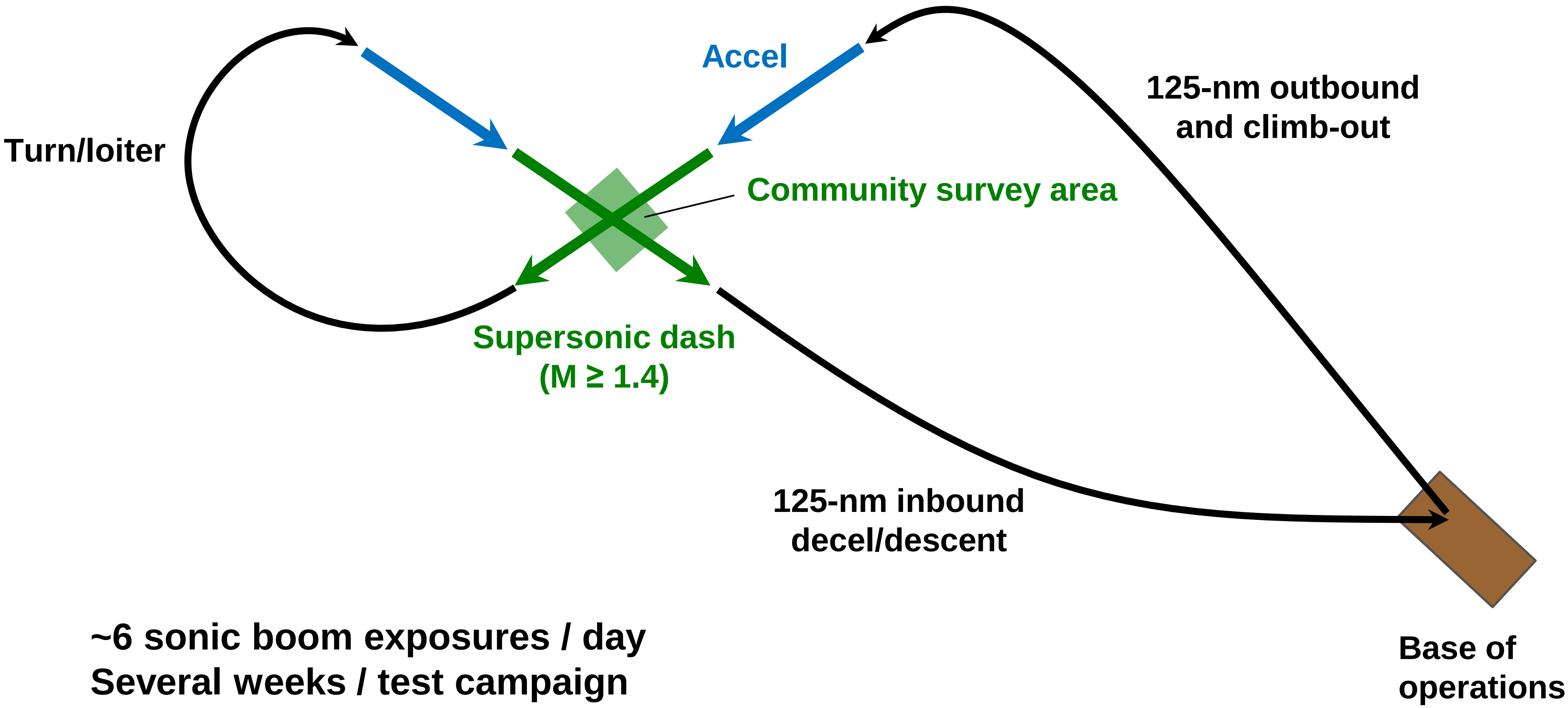
Phase 1 - Aircraft Development
- Detailed Design
- Fabrication, Integration, and Ground Test
- Checkout Flights
- Subsonic Envelope Expansion
- Supersonic Envelope Expansion

Phase 2 – Acoustic Validation
- Aircraft Operations / Facilities
- Research Measurements

Phase 3 – Community Response
- Initial community response overflight study
- Multiple campaigns (4 to 6) over representative communities and weather across the U.S.

Typical Phase 3 Flight Operation

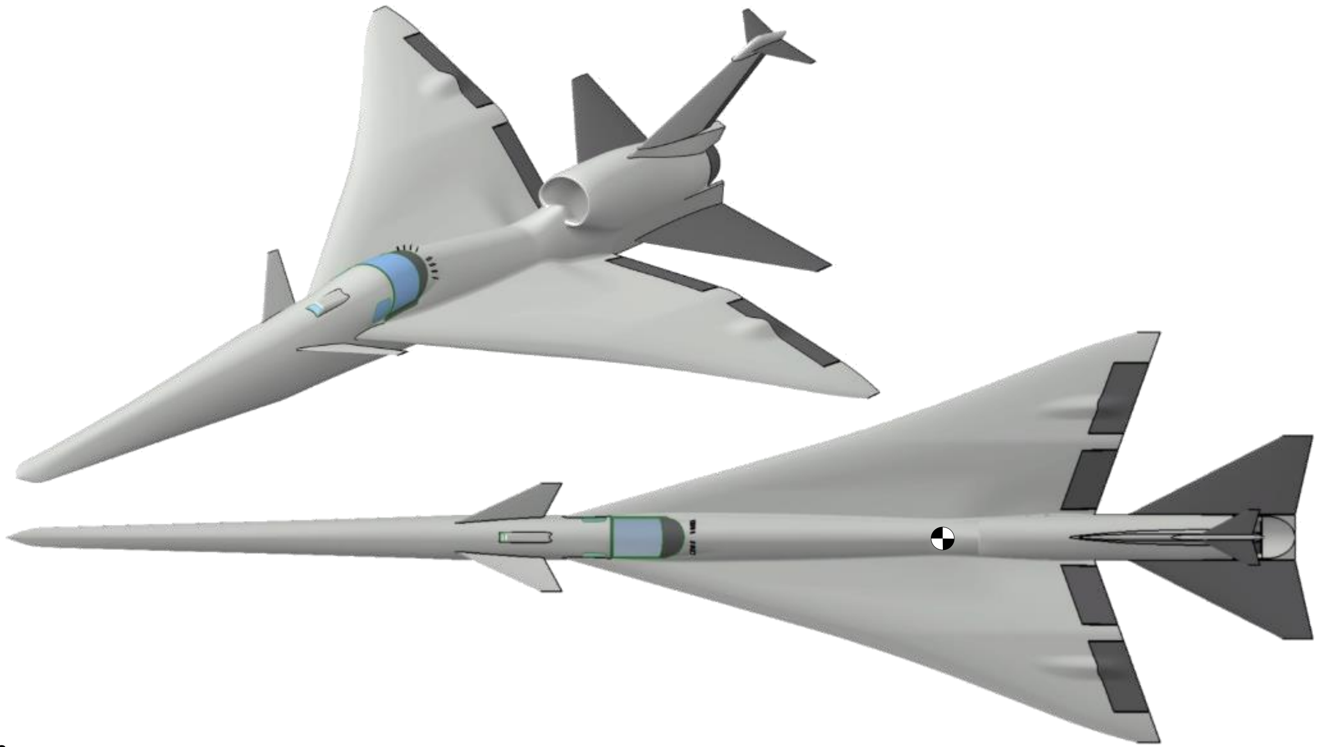
Baseline Mission – Figure 8

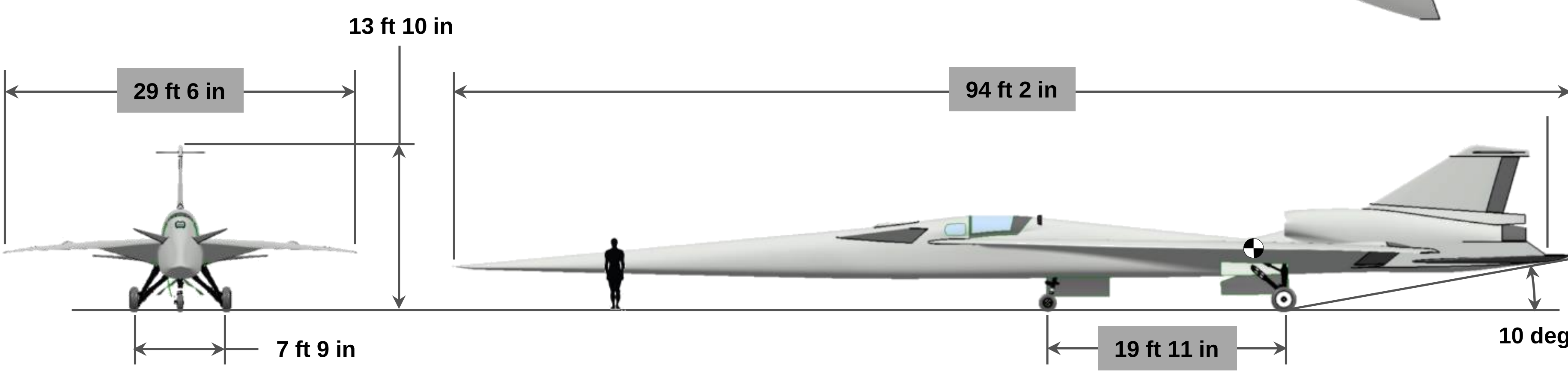


~6 sonic boom exposures / day
Several weeks / test campaign
2-3 representative communities / year

Lockheed Martin X-59 QueSST

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 F414
Design Mach	1.42
Loudness	<75 PLdB

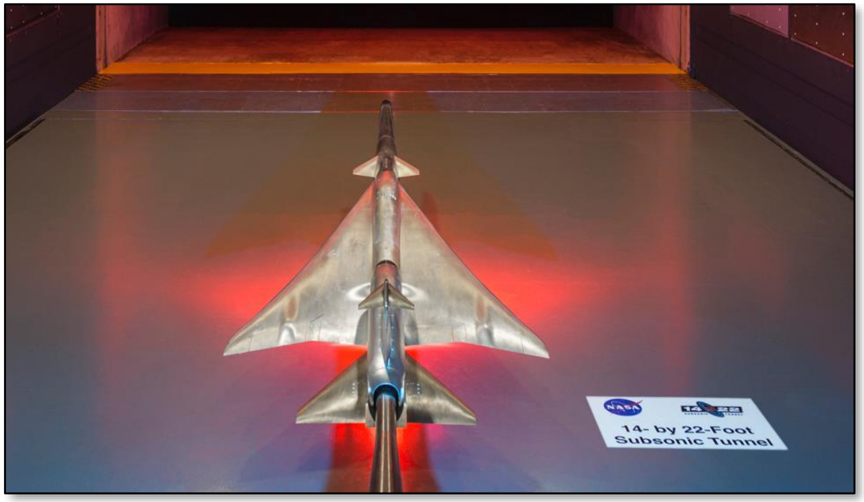


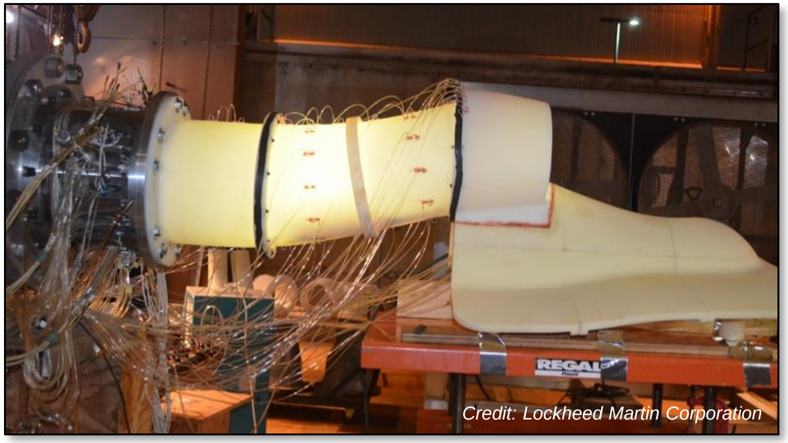


X-59 QueSST Preliminary Design Overview

Wind Tunnel Validations

Low-and high-speed Aerodynamic and Propulsion Airframe Interaction (PAI) wind-tunnel tests to validate predictions/data and ensure readiness of the QueSST Preliminary Design





Credit: Lockheed Martin Corporation

Crew Systems

- Cockpit is the back cockpit of a T-38
- Uses T-38 Martin Baker Ejection Seat
- Why?
  Less Testing Required

Life Support Systems

Flying up to 60,000 ft

- LOX….not OBOGS
- Need a Pressure Garment

Full Pressure Suit too Big

Partial Pressure Garment

Credit: Lockheed Martin Corporation

Remember….It's an X-Plane

Limited Forward Field of View (FOV)….eXternal Vision System (XVS)

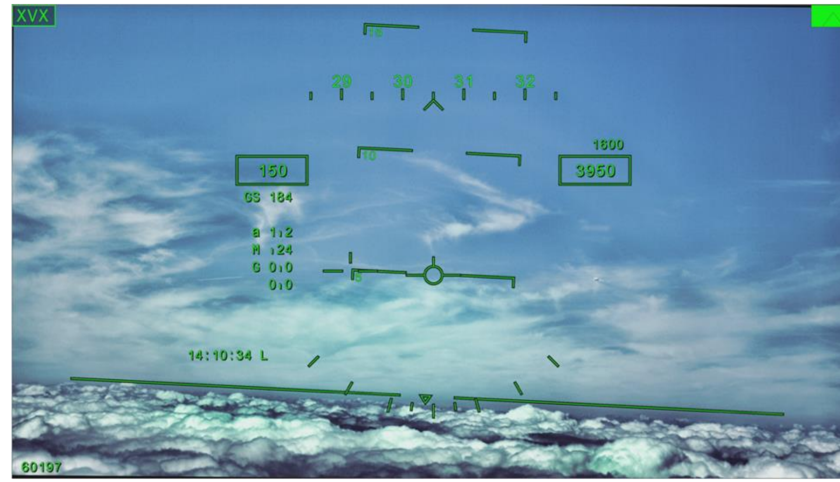
Taxiing should be interesting…camera's and ground crew to help

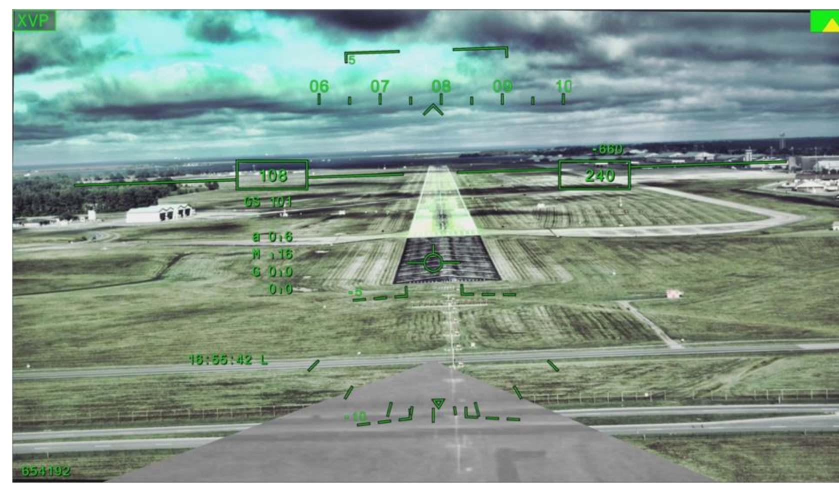
Fast Approach Speed / Center of Rotation probably ahead of pilot…
Open loop landing technique

Looks like a Fighter…handles more like a truck / big airplane…that's REALLY fast

eXternal Vision System (XVS)

XVS - enabling technology - combination of Ultra-High -Definition (UHD) sensor, display, and image processing technologies to provide visibility of the external scene for the flight crew and comparable to forward-facing windows in conventional aircraft





Any Questions?

Many Thanks for helping with this presentation to:

Mr. Dave Richwine
Mr. Tom Jones

Credit: Lockheed Martin Corporation

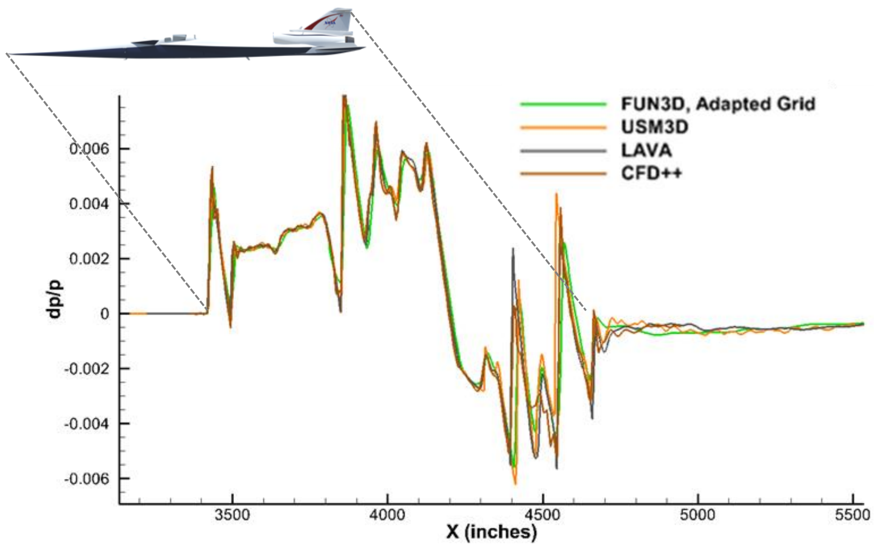
Backup Slides

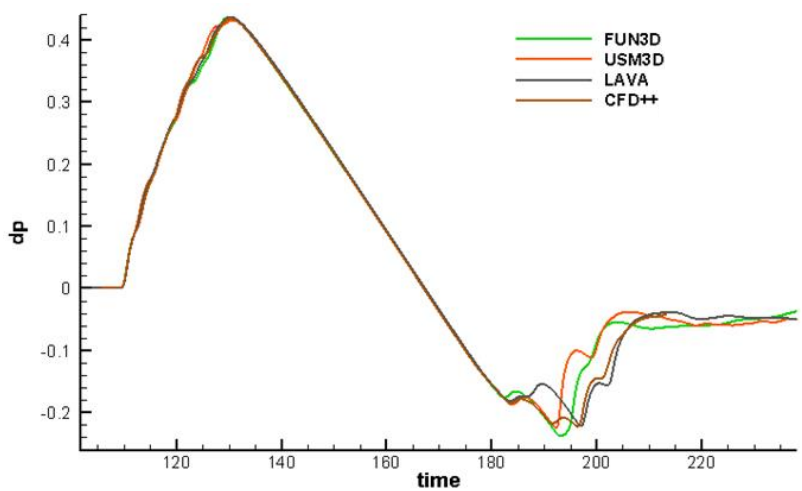
Mission Requirements

Key Mission Requirements
Ground signature traceability (indoor) - with peak acoustic energy ≤ 10 Hz
Ground signature loudness (outdoor) ≤ 75 PLdB throughout boom carpet
Ground signature variability 70 - 80 PLdB
Cruise deviations (turbulence) - ground signature ≤ 76 PLdB and ≤ 1.4 PLdB RMS
Cruise Mach ≥ 1.4
Two passes ≥ 50 nm in length per flight, passes ≥ 20 minutes apart
Three flight operations / day
Day and night flight operations in the public airspace
IFR flight operations
Forward visibility (see-to-avoid/land)
Low/no-focus supersonic acceleration/climb performance
Mission performance (hot day)

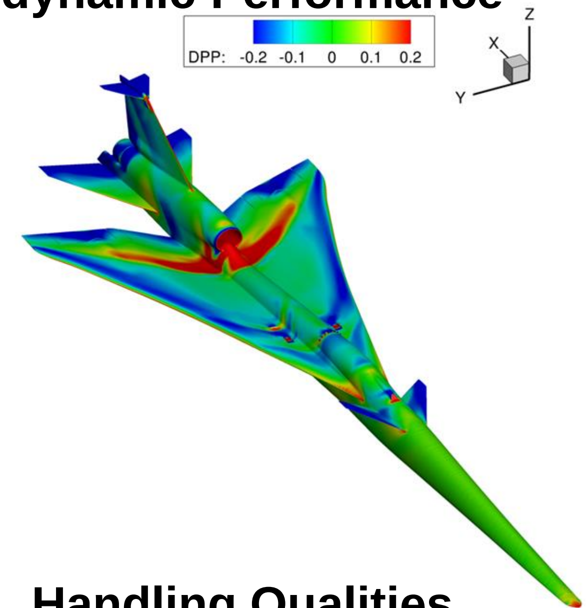
Concept Assessments

Sonic Boom

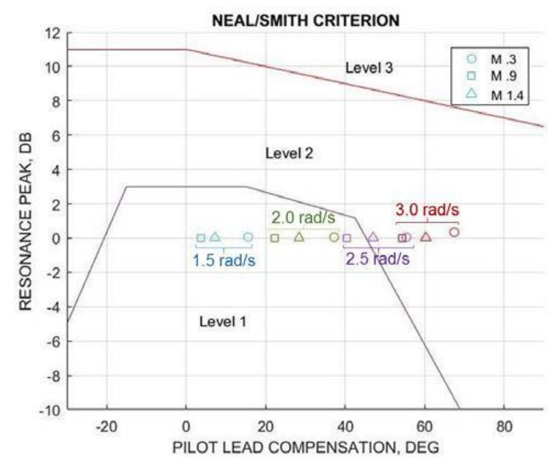




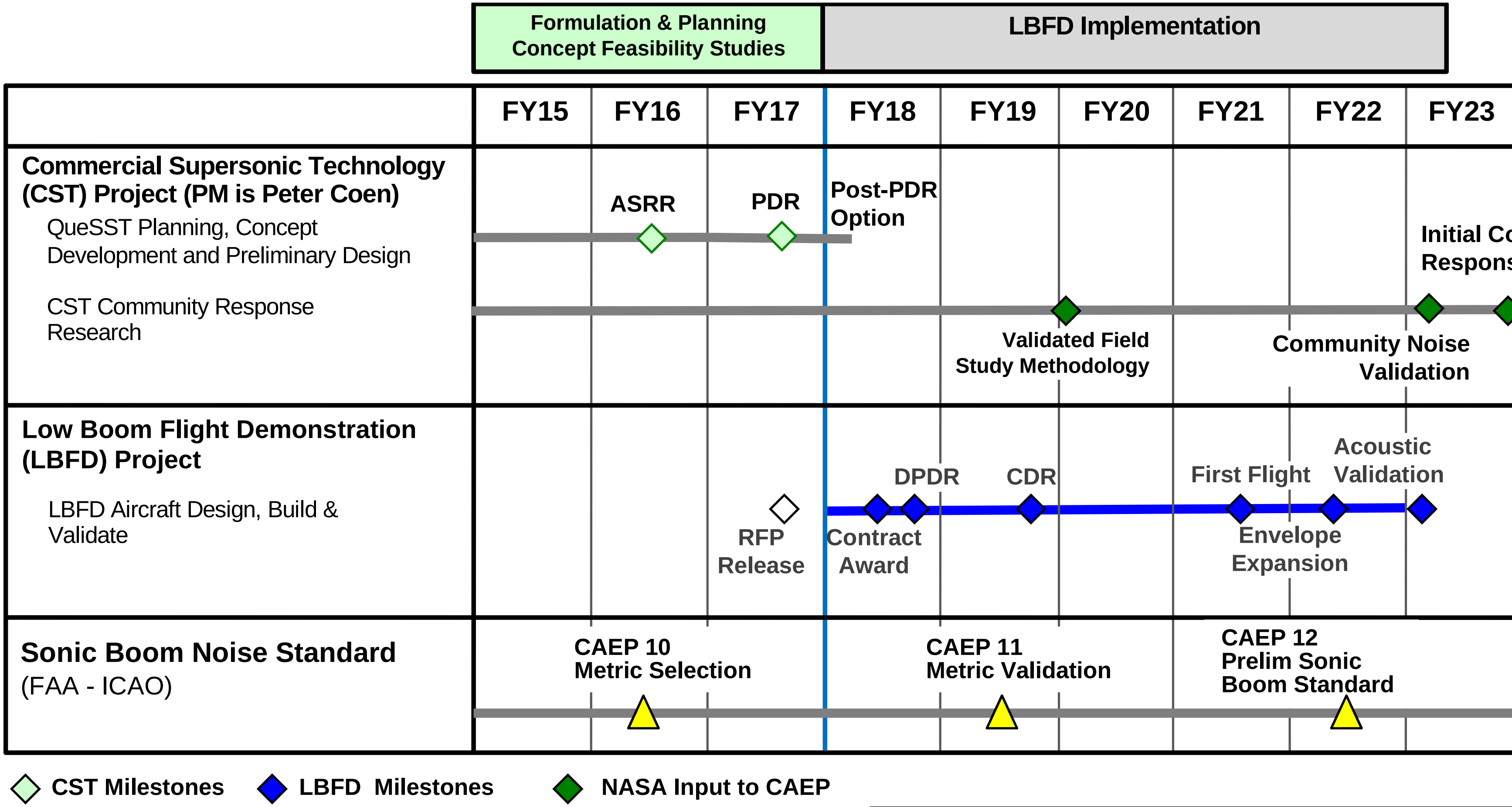
Aerodynamic Performance



Handling Qualities



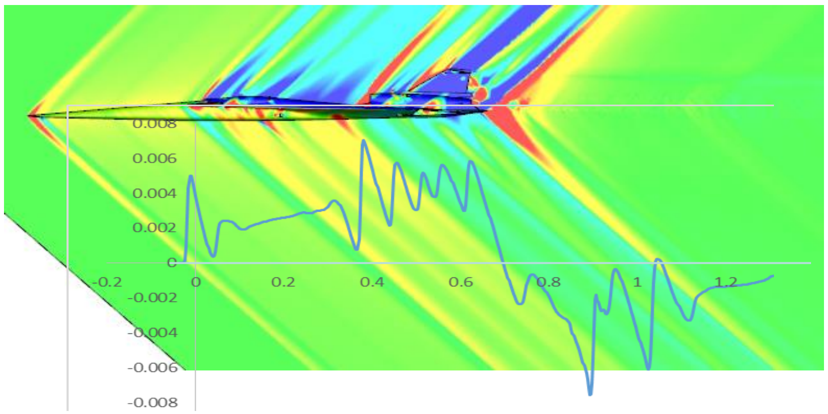
LBFD – Future Plans



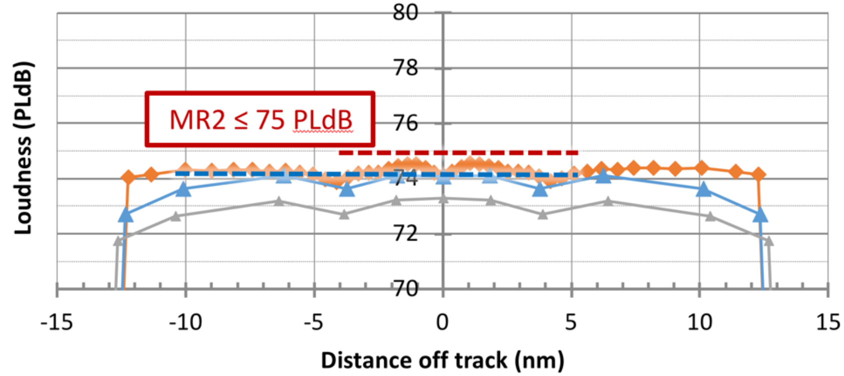
CAEP – Committee on Aviation and Environmental Protection
ICAO – International Civil Aviation Organization
ASRR – Aircraft Systems Requirement Review

Quieting the Boom

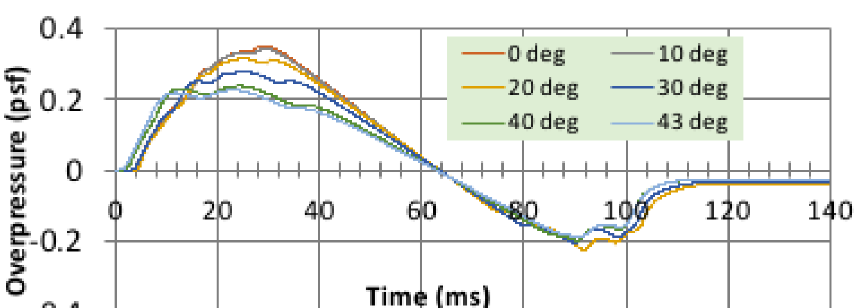
Low-Boom Design Tools



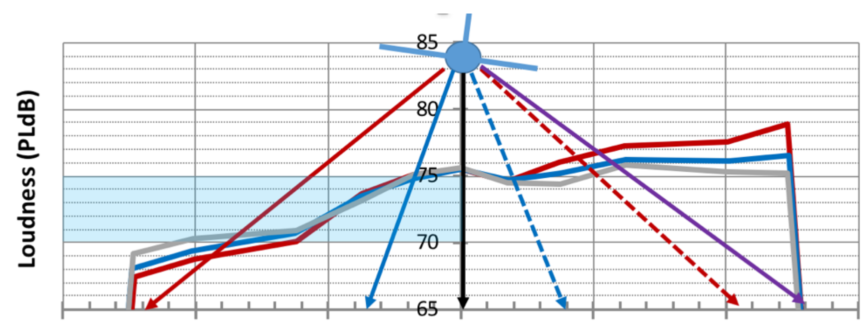
Cruise Boom – Level Flight



Sonic Boom Signatures (level flight)



Cruise Boom – Steady Turn



NASA Aeronautics Strategic Vision

3 Mega-Drivers

6 Strategic Thrusts

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

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

Innovation in Commercial Supersonic Aircraft
Achieve a low-boom standard

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

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

Assured Autonomy for Aviation Transformation
Develop high impact aviation autonomy applications

U.S. leadership for a new era of flight

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 will be excellent export products that can be capitalized on by the US to support a positive balance of trade

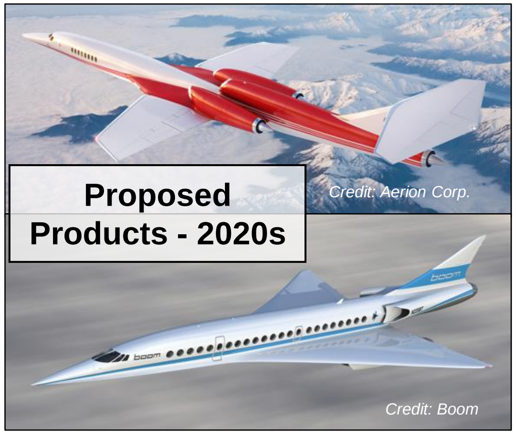
- New supersonic products lead to more high-quality jobs in the US
  - Large potential market predicted: - business aircraft followed by larger commercial aircraft
  - Technology leadership established through initial products will lead to development of larger, more capable airliners

- The government plays a central role in developing the data needed for regulation change that is essential to enabling this new capability

Barriers to Commercial Supersonic Flight: Sonic Boom Noise and Overland Flight Prohibitions

- Planned introduction of supersonic commercial transports in 1970's brought the problem of sonic boom noise to public attention
- Community overflight tests in the US and elsewhere showed sonic boom noise to be unacceptable
- Supersonic overflight restrictions followed
  - US: FAA Regulation (FAR) prohibits supersonic flight over US
  - Worldwide: ICAO Assembly Resolution – "No unacceptable situation for the public due to sonic boom"
- Restriction dramatically limited market potential for supersonic commercial aircraft

Credit: Concorde G-BOAC by Eduard Marmet https://en.wikipedia.org/wiki/Concorde_aircraft_histories#/, license https://creativecommons.org/licenses/by-sa/3.0/legalcode



- 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 must be able to fly overland without creating an "unacceptable situation" and compared to Concorde, be efficient & green
- The creation of overland certification requirements based on acceptable noise levels will enable this vision

Background and Overview

Overcome the sonic boom barrier and open the door for development of a new generation of environment-friendly supersonic civil transport aircraft

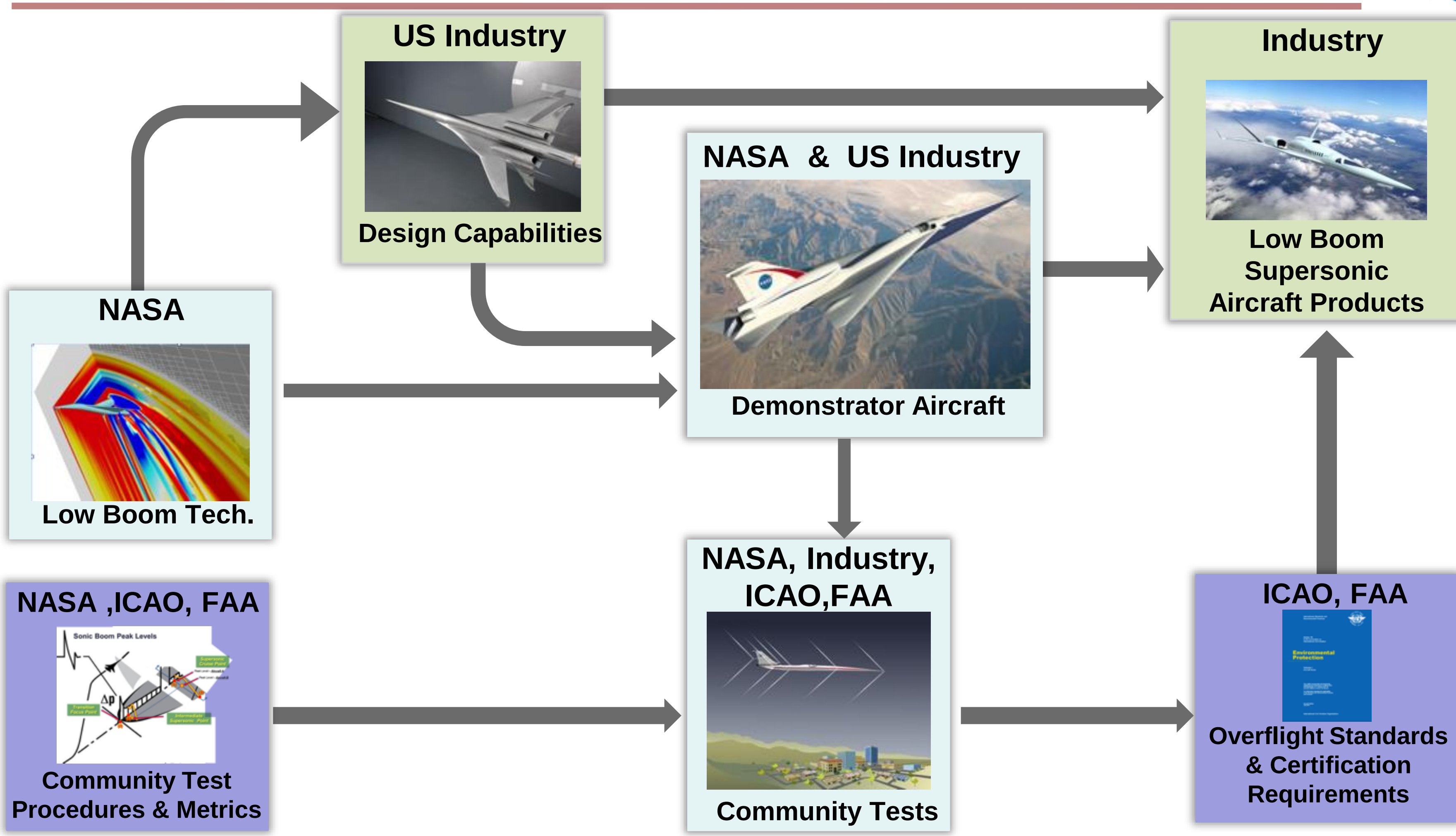
Overall Requirement

- Demonstrate that noise from sonic booms can be reduced to a level acceptable to the population residing under future supersonic flight paths
- Create a community response database that supports an International effort to develop a noise based rule for supersonic overflight

Approach

- Partner with regulatory agencies and communities to create a roadmap for community response study and rule development – with Commercial Supersonic Technology (CST) Project in Phase 2 and 3
- Revitalize the excitement of manned X-Planes using a focused and cost-effective approach to design and operate a low boom research aircraft
- Partner with industry and OGAs to formulate, obtain approval and execute

Roles - Supersonic Overland Flight



- NASA has invested in supersonic tools and technologies in partnership with US industry
- Unique NASA role in development of demonstrator
- NASA leadership provides the key data required to determine certification standards for supersonic overland flight

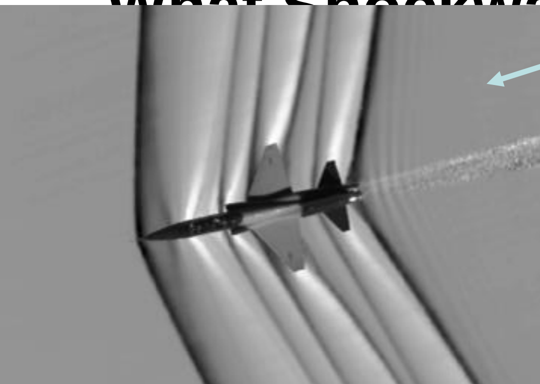
Armstrong Flight Research Center

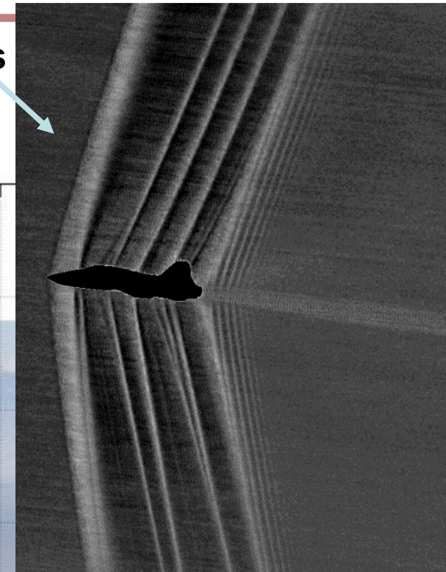
Edwards AFB, California, main campus:

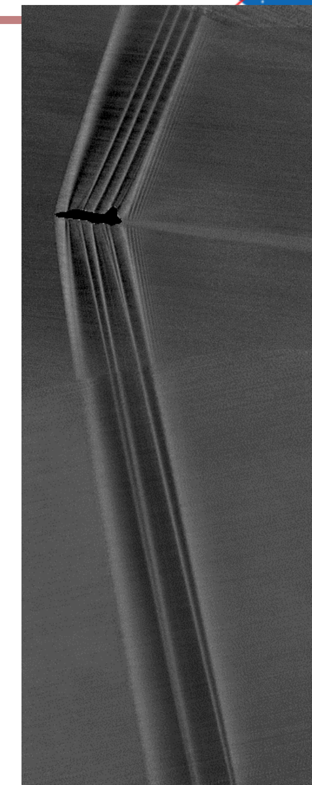
- Year-round flying weather
- 350 testable days per year
- 68 miles of lakebed runways
- 29,000 feet of concrete runways
- 301,000 acres remote area
- Extensive range airspace
- Supersonic corridors

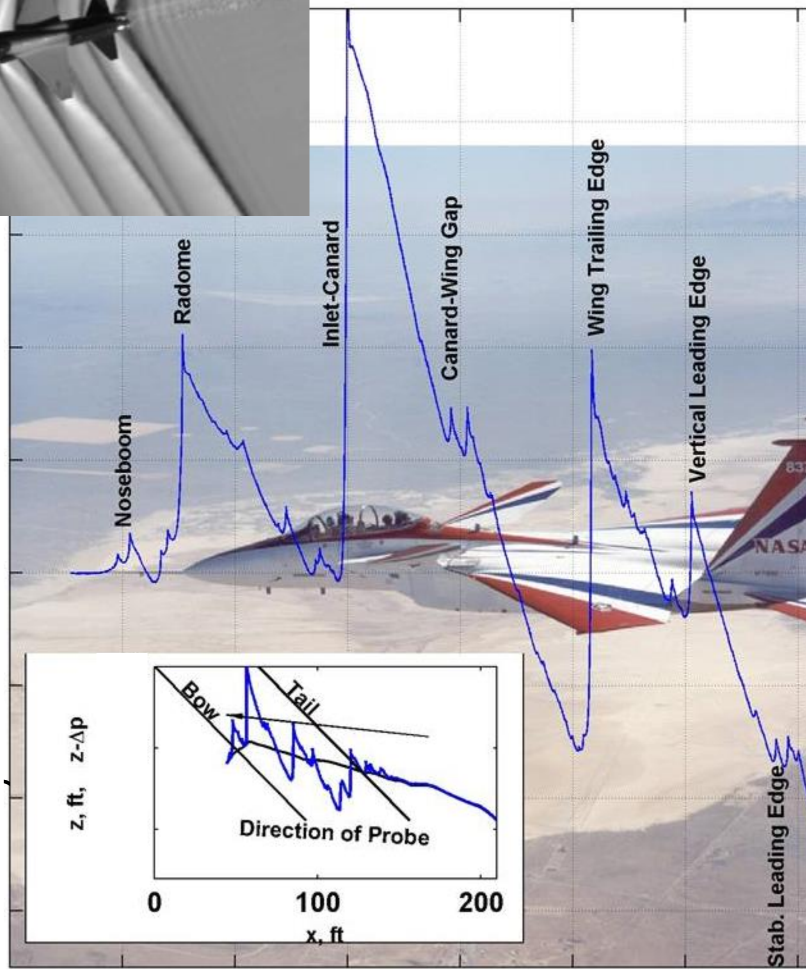
What Shockwaves Look Like

T-38 Shockwave images



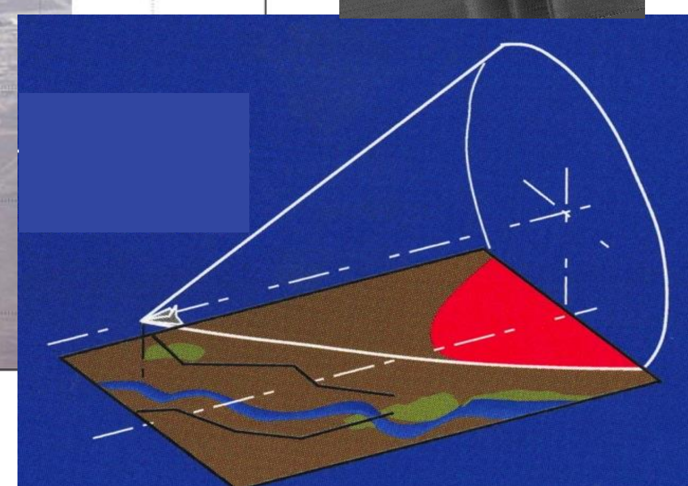






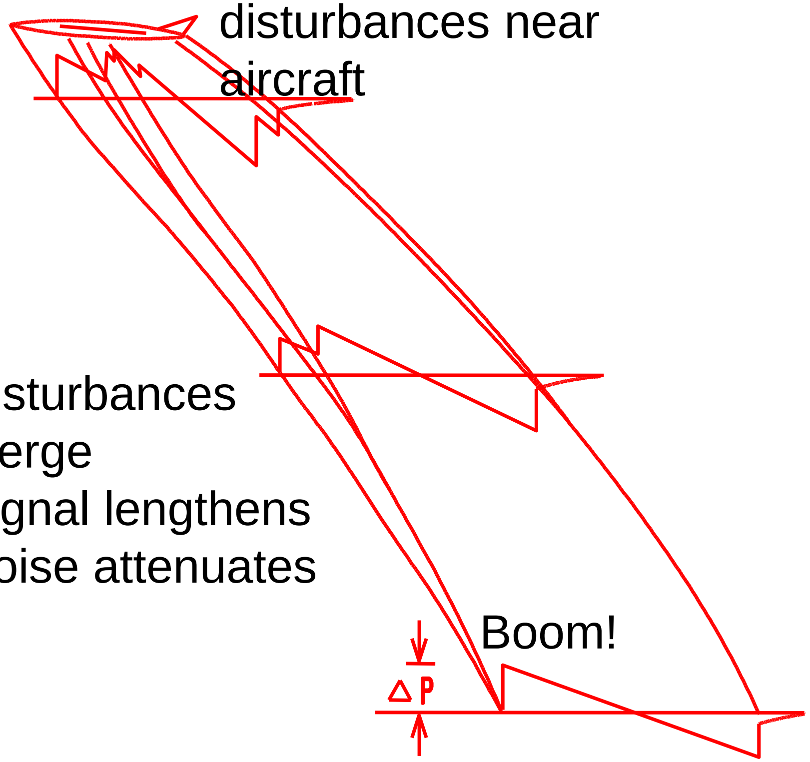
Change in Air lbf/ft^2

Distance along Length of Aircraft, ft



Sonic Boom Reduction by Aircraft Shaping

Multiple disturbances near aircraft



- Disturbances merge
- Signal lengthens
- Noise attenuates

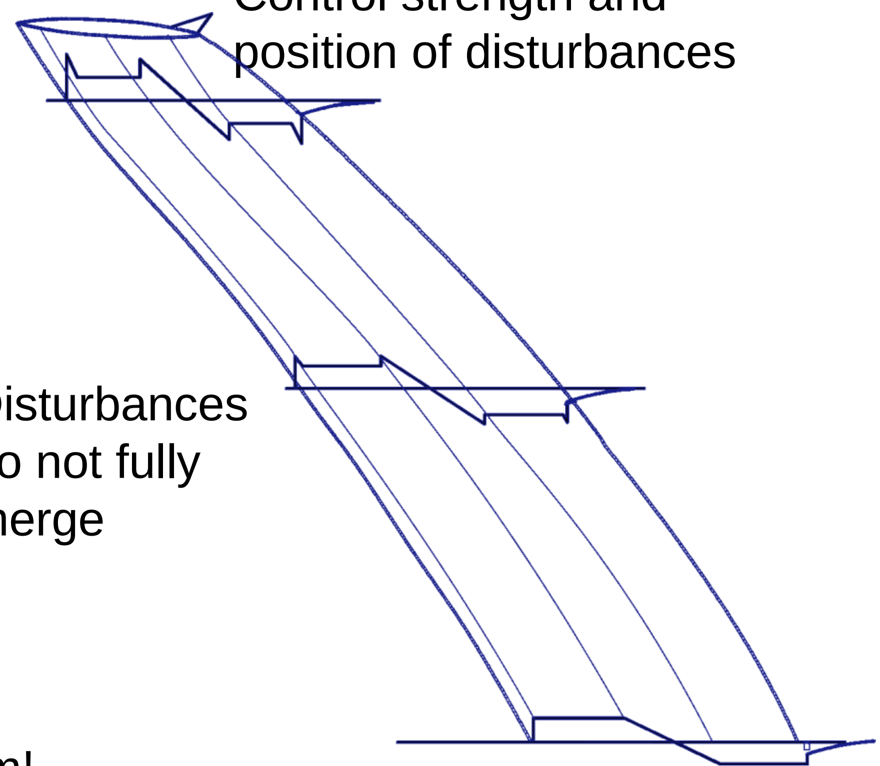
Boom!

Boom!

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

Typical Supersonic Design

Control strength and position of disturbances



Disturbances do not fully merge

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

Specially Shaped Boom Design

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
1st qtr CY 18	LBFD DBT contract award
3rd qtr CY 19	Critical Design Review
1st qtr CY 21	First flight
4th qtr CY 21	Envelope Expansion complete
3rd qtr CY 22	Low boom acoustic signature validation complete
1st qtr CY 23	Initial community response test (based at NASA AFRC)
2023 - 2025	Community response tests in US (remote based)

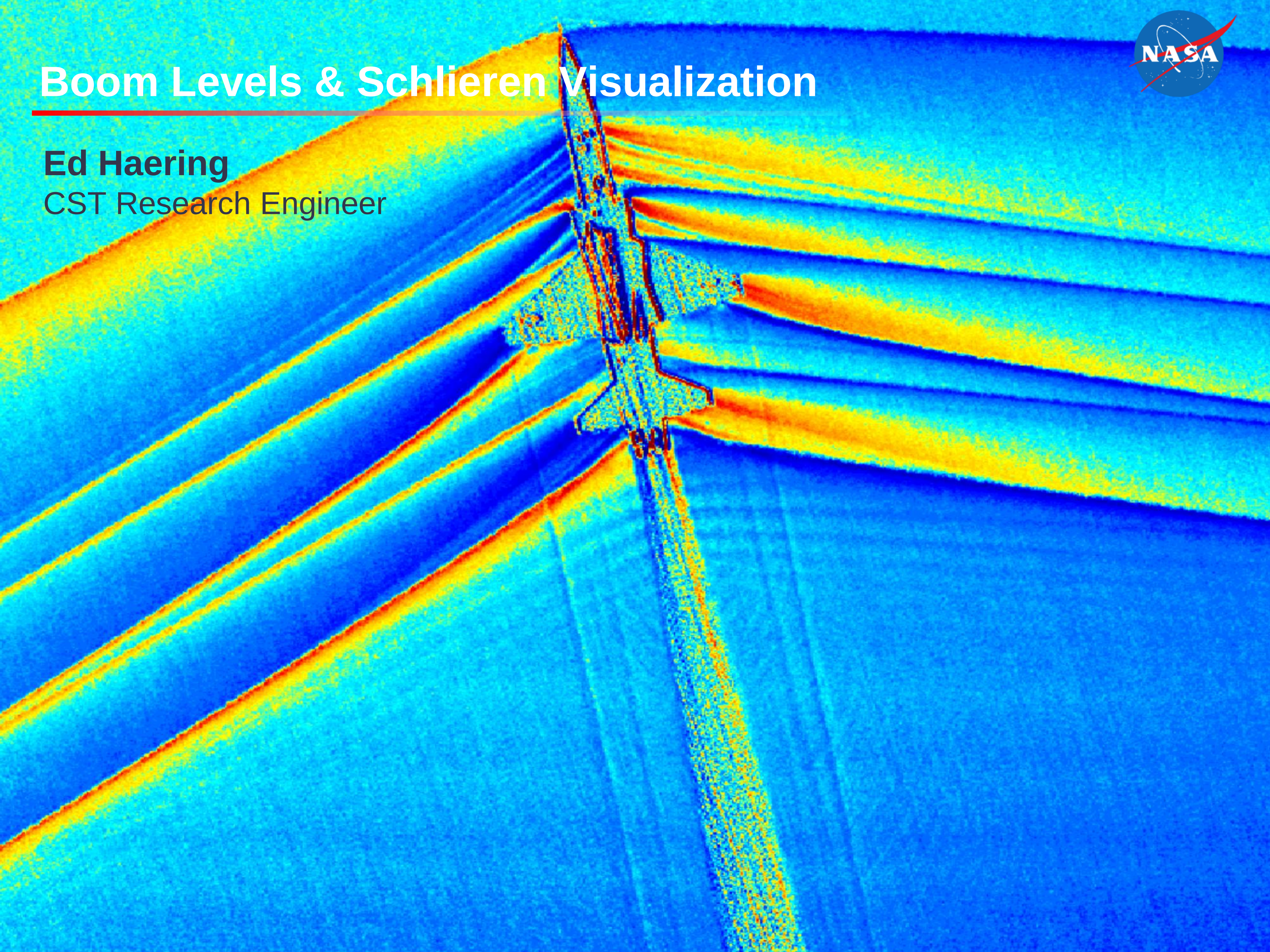
Dates in blue test are estimated and dependent on approval and funding

Density Changes

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

Boom Levels & Schlieren Visualization

Ed Haering
CST Research Engineer




PILOTS
Generally best kept on a short leash.