

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..

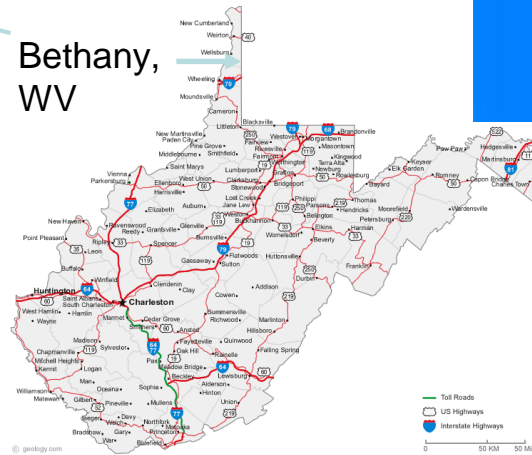


Gambia

Nigeria



Bethany,
WV



USAFA



Early Air Force Career



- T-37 IP at Williams AFB



U-2 Pilot



Air Force Flight Test



Air Force Exchange Instructor 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



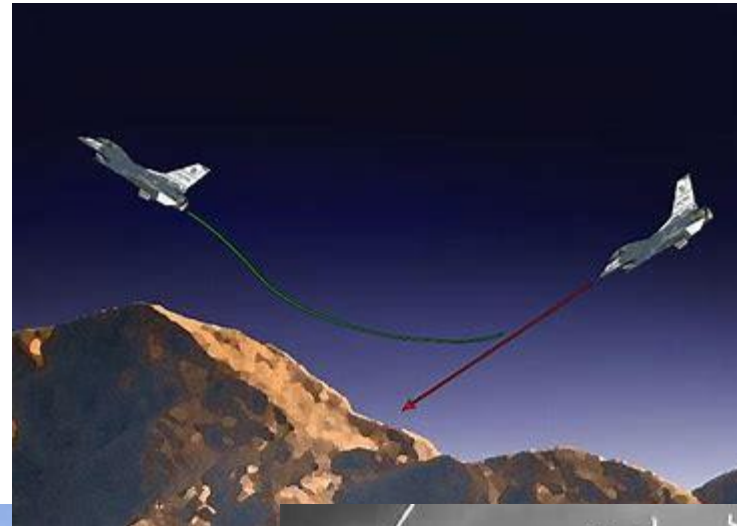
- Space Launch System (SLS) Control Tests



NASA Collision Avoidance Test



- F-16 Ground Collision Avoidance Tests



Science and Flight Test Work



DC-8



ER-2



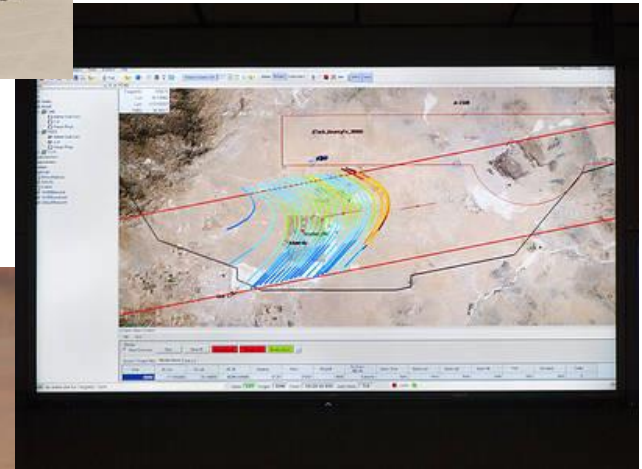
Supersonics work - External Wind Tunnel



Supersonics – Boom modeling



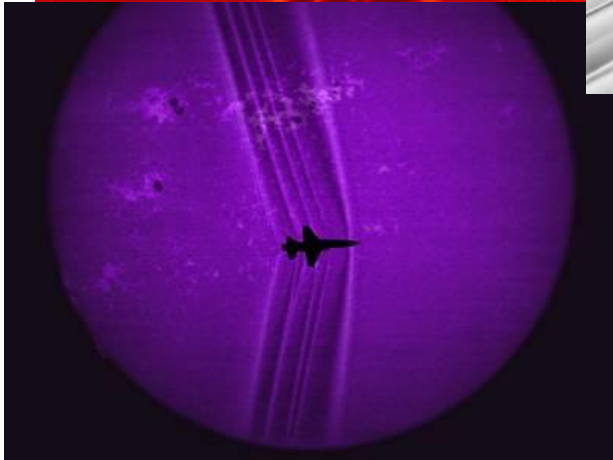
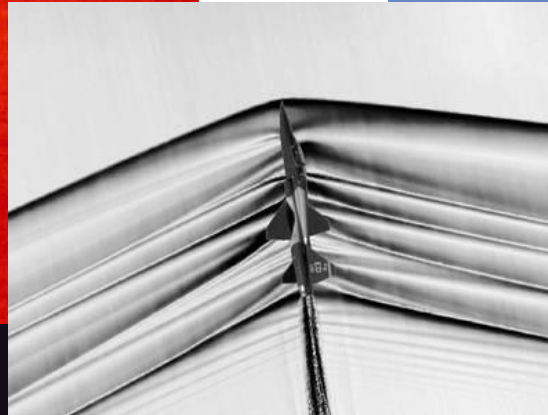
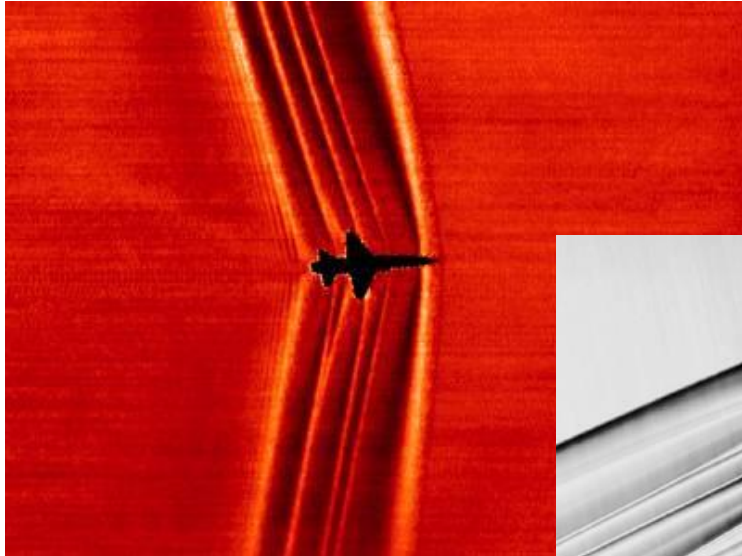
- Measuring the Boom
- Modeling the Boom
- Predicting the Boom



Supersonics – Shockwave



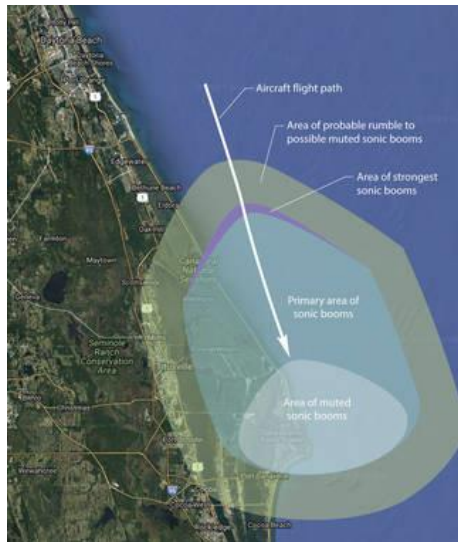
- Measuring the Shockwave



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





Low-Boom Flight Demonstration



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**



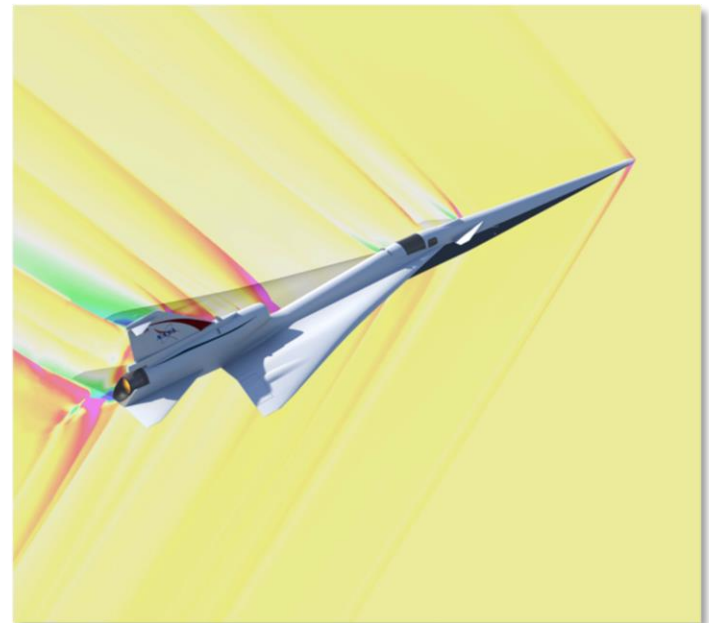
Background and Overview



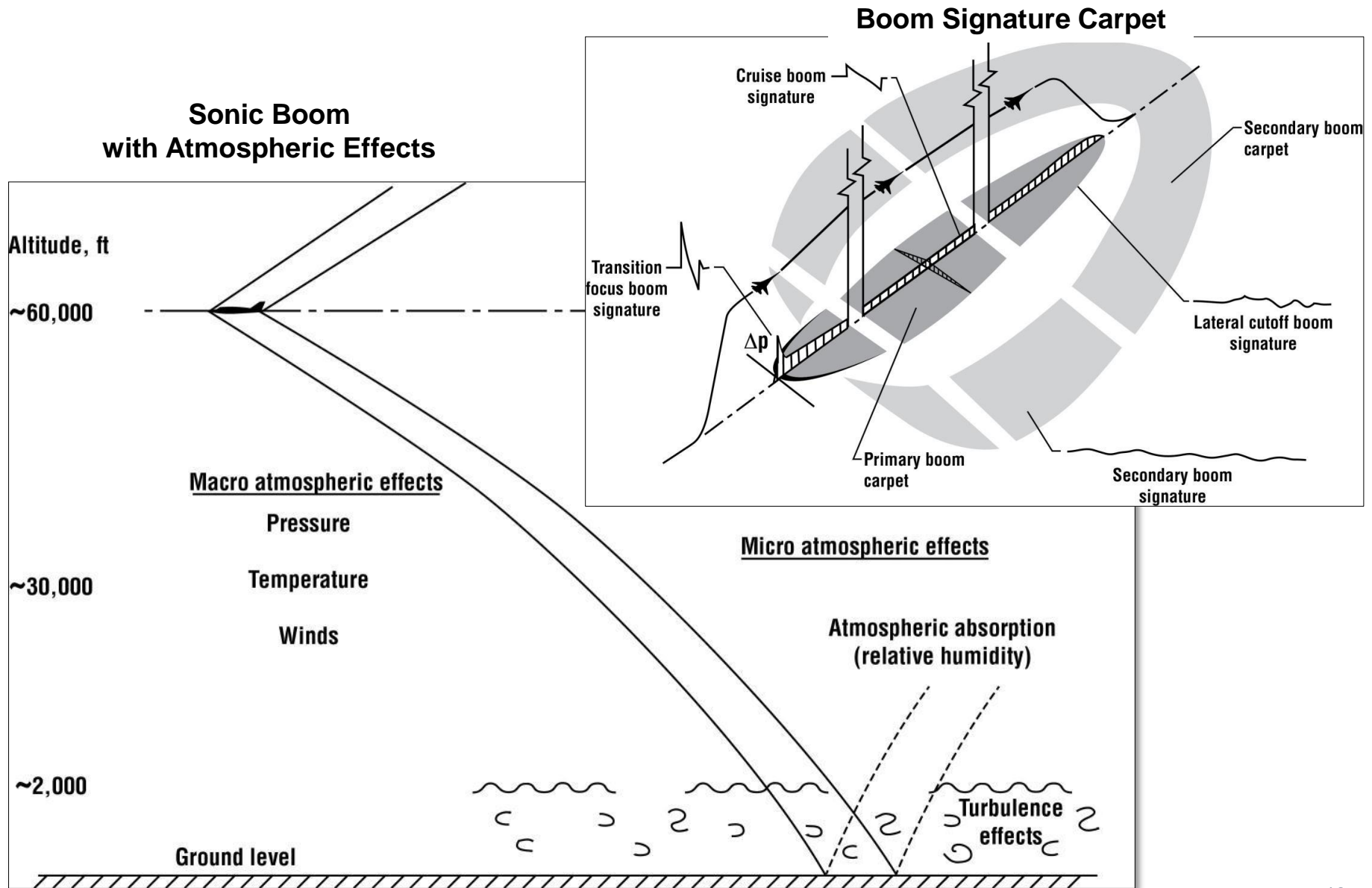
Overcome the sonic boom barrier and open the door for development of a new generation of environment-friendly supersonic civil transport aircraft

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 Basics: N Wave Sonic Boom



Image of pressure distribution immediately below a supersonic aircraft

By the time the shocks have propagated only a few hundred feet, they have begun to merge.

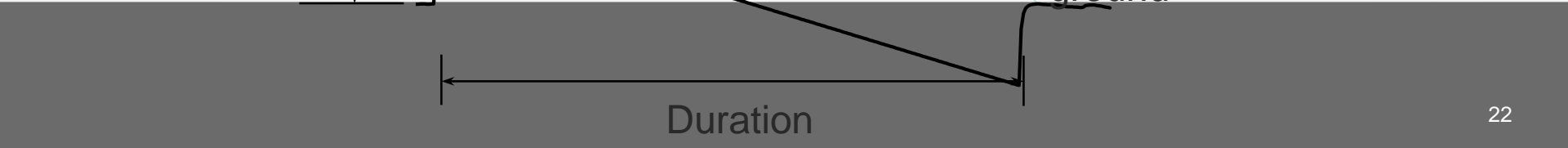
Within a few thousand feet, the shocks have completely merged into an "N wave" and retain that shape as it travels toward the ground ...

... resulting in a loud Sonic Boom at the ground

Rise Time

Duration

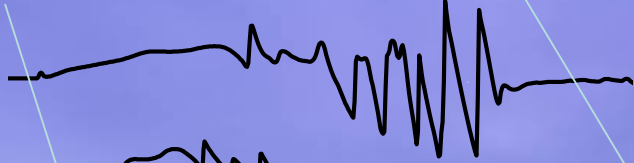
Pressure Rise



Sonic Boom Basics: Shaped Pressure Signal



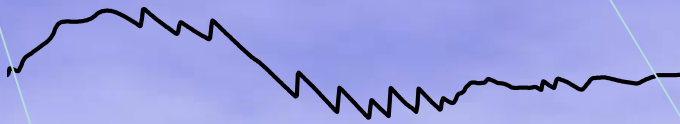
Image of pressure distribution of quiet supersonic aircraft



Very little shock merging after a few thousand feet



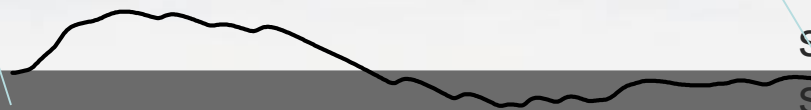
Signature retains its shape all the way to the ground ...



...and reduces in strength ...



... resulting in a significantly quieter sound at the ground



From Boom to Thump: Quiet Supersonic Design Technical Challenge

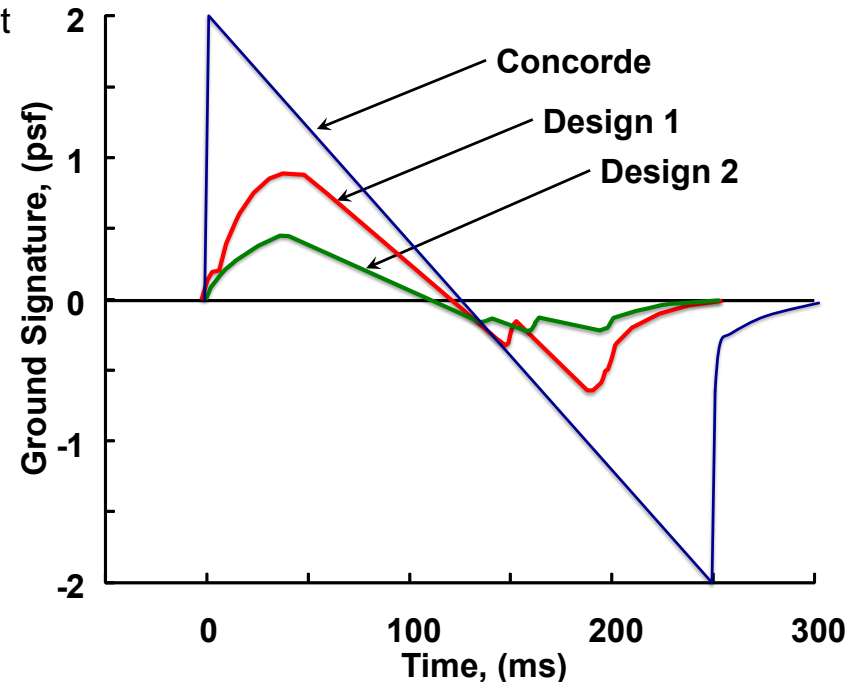


Objective

- 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

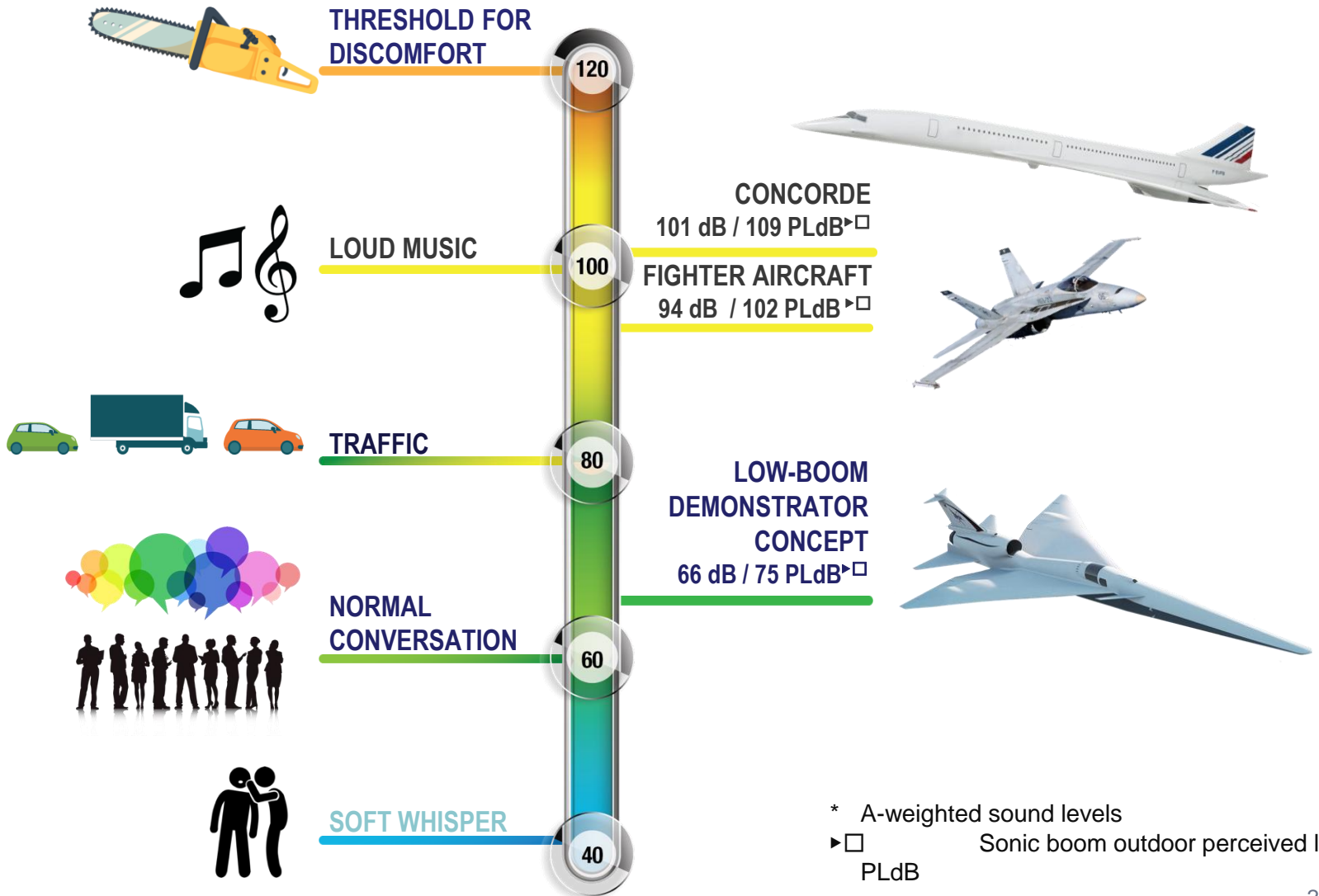
- Build on 40+ years of research in sonic boom minimization
- Improve usability, accuracy and speed of high fidelity analysis tools for inclusion in the design process
- Develop new near-field & ground signature design targets that produce less noise, and allow more flexibility in the design process
- 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*)



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 26

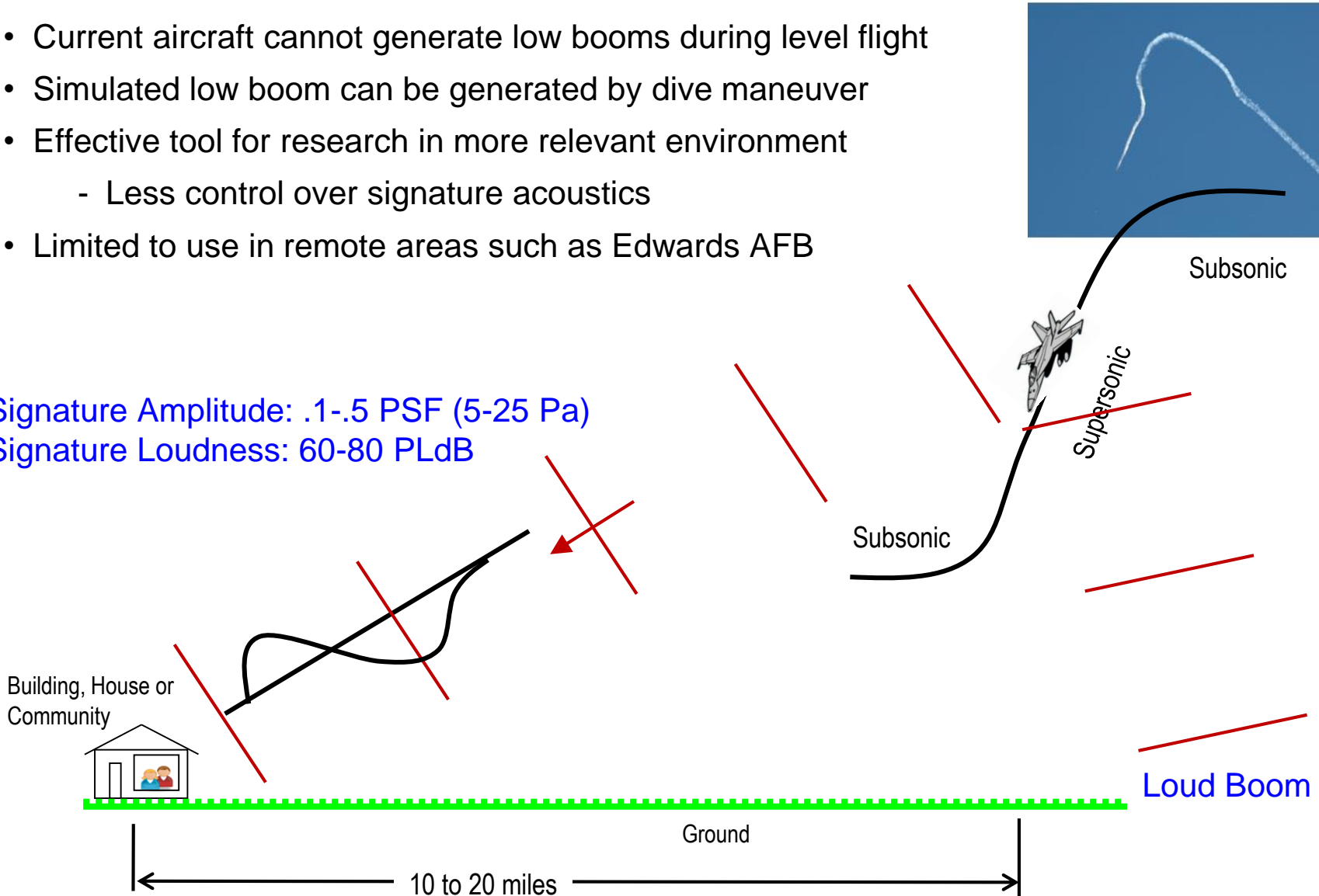


What is a Quiet Supersonic Flight and How do We Measure Response? 2 – Flight Research with Specialized Aircraft Maneuver

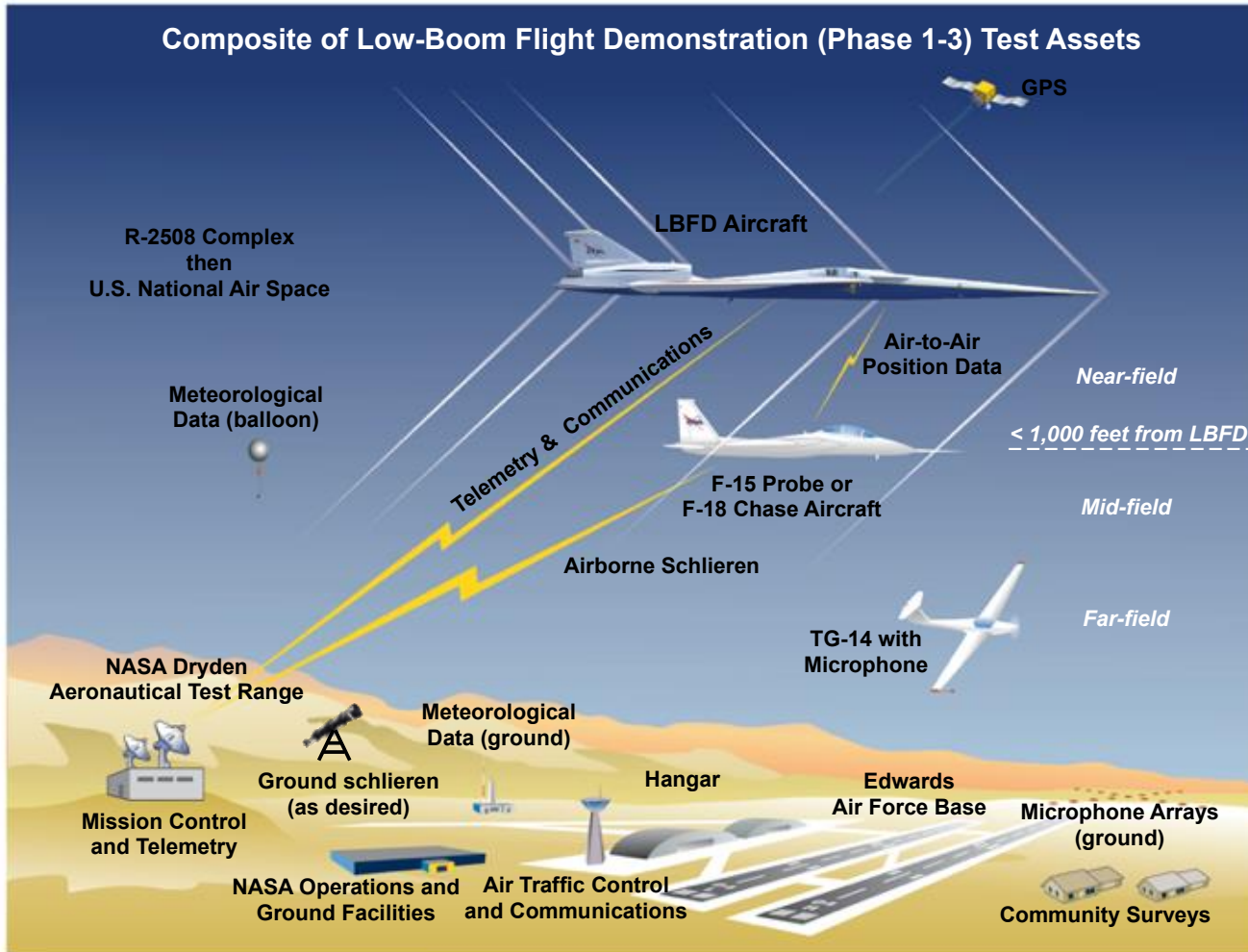
- Current aircraft cannot generate low booms during level flight
- Simulated low boom can be generated by dive maneuver
- Effective tool for research in more relevant environment
 - Less control over signature acoustics
- Limited to use in remote areas such as Edwards AFB



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

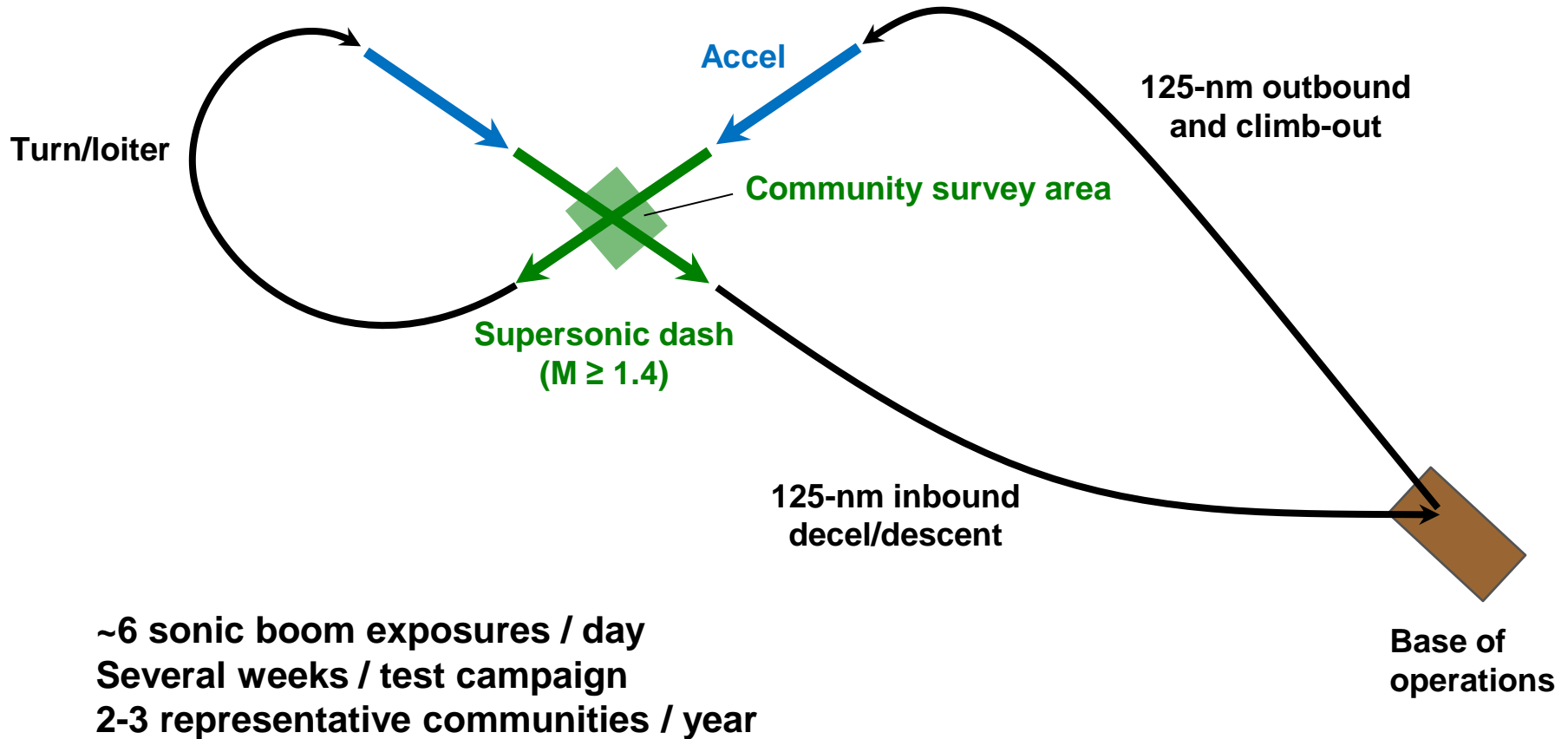
Phase 3 - Community Response

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

Typical Phase 3 Flight Operation



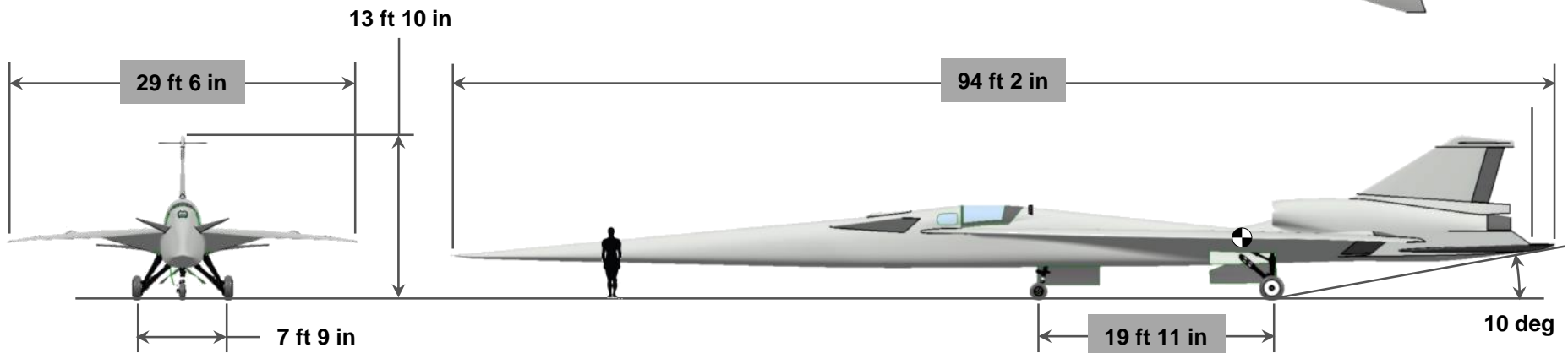
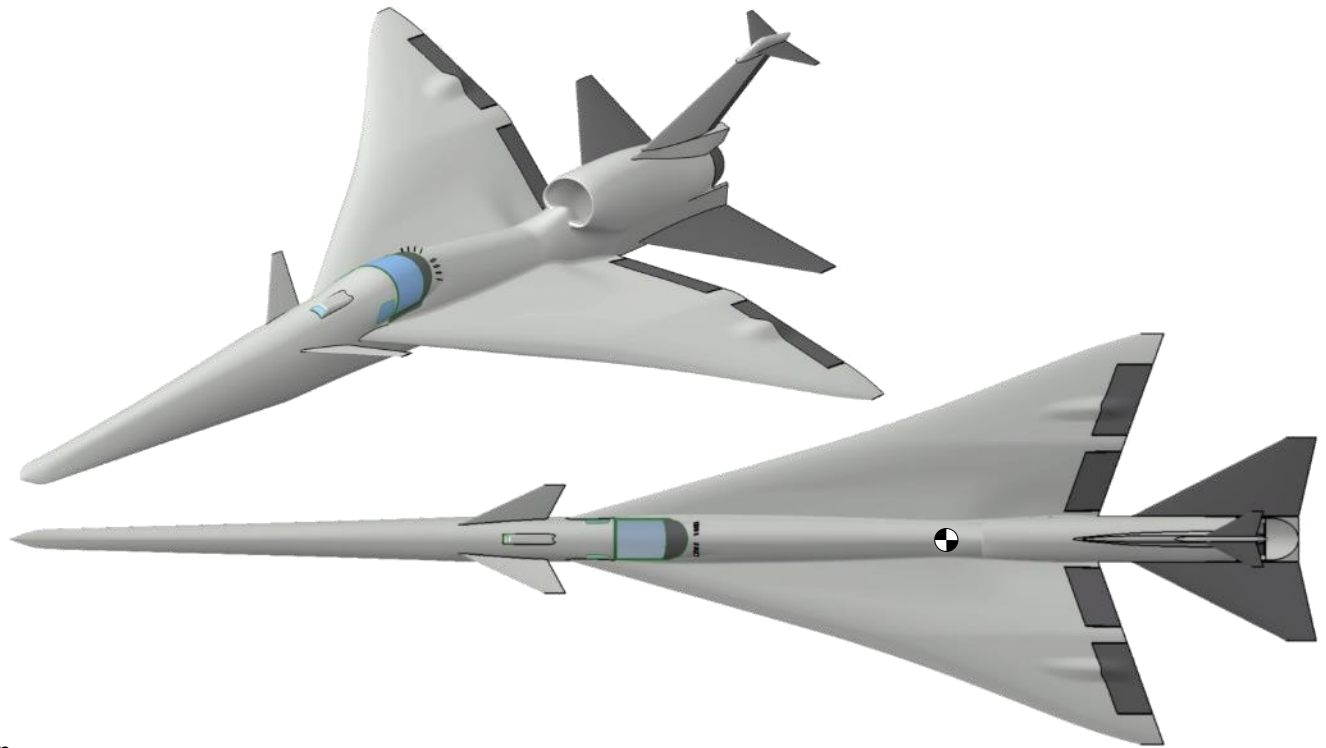
Baseline Mission – Figure 8



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



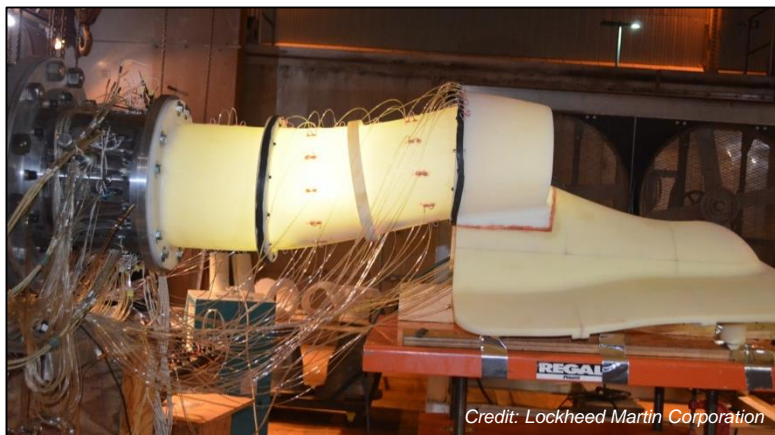
X-59 QueSST Preliminary Design Overview



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



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

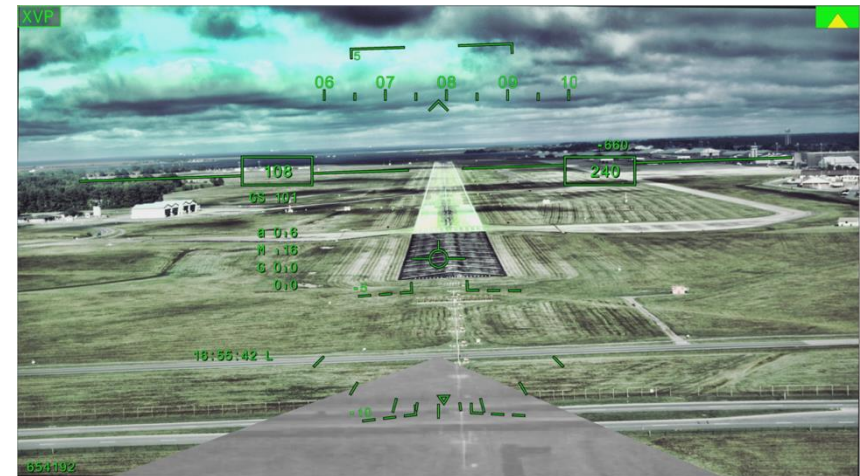
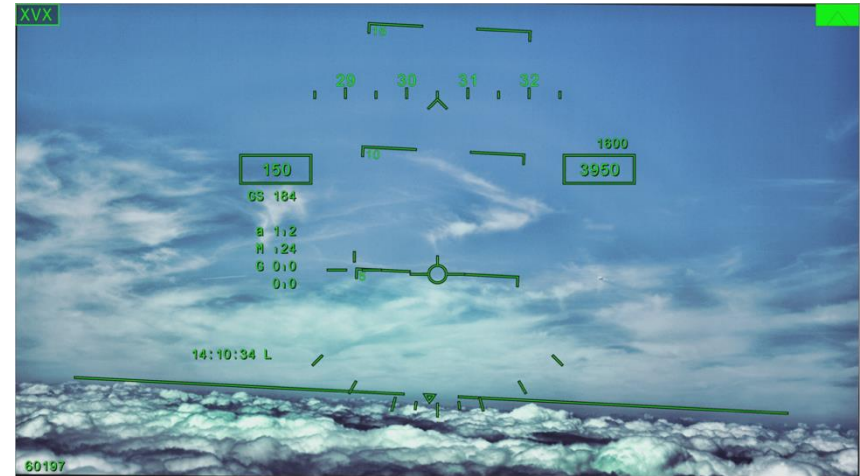
Fast Approach Speed / Center of Rotation probably ahead of pilot...
Open loop landing technique

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)

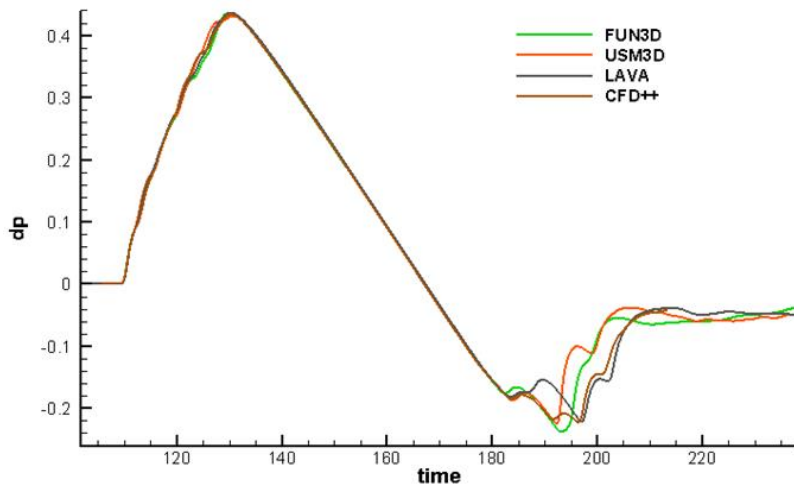
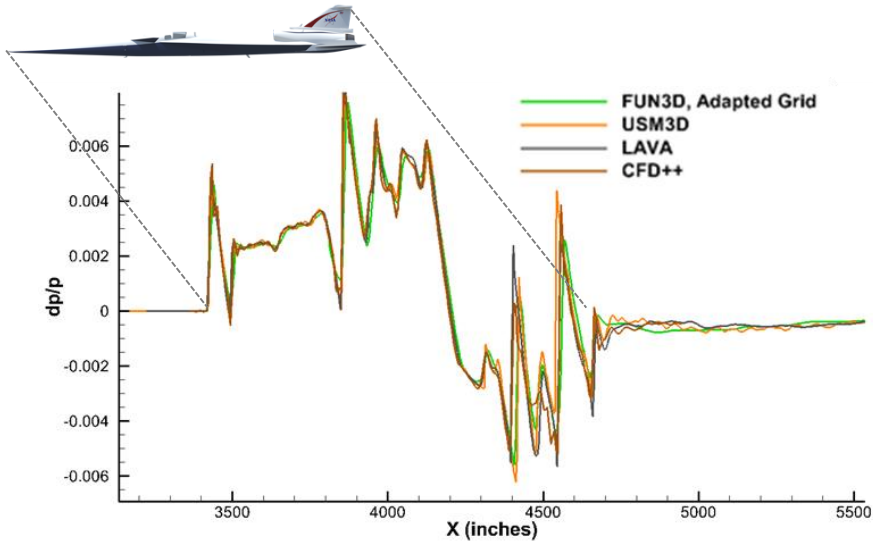
Low/no-focus supersonic acceleration/climb performance

Mission performance (hot day)

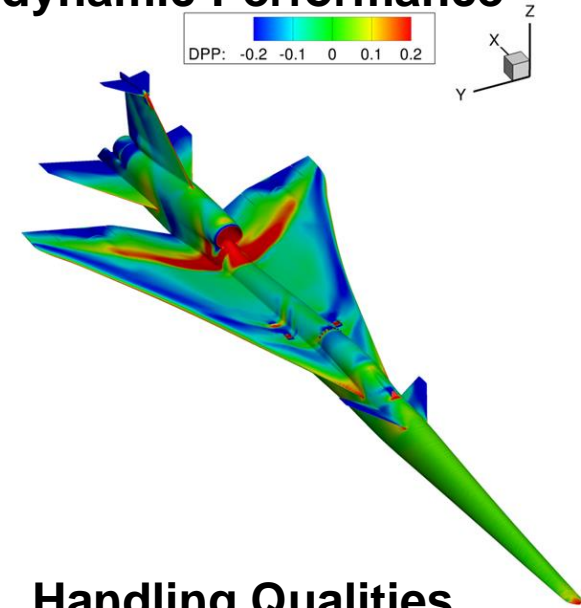
Concept Assessments



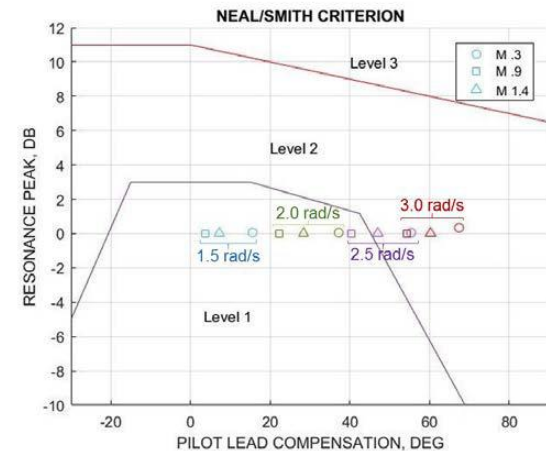
Sonic Boom



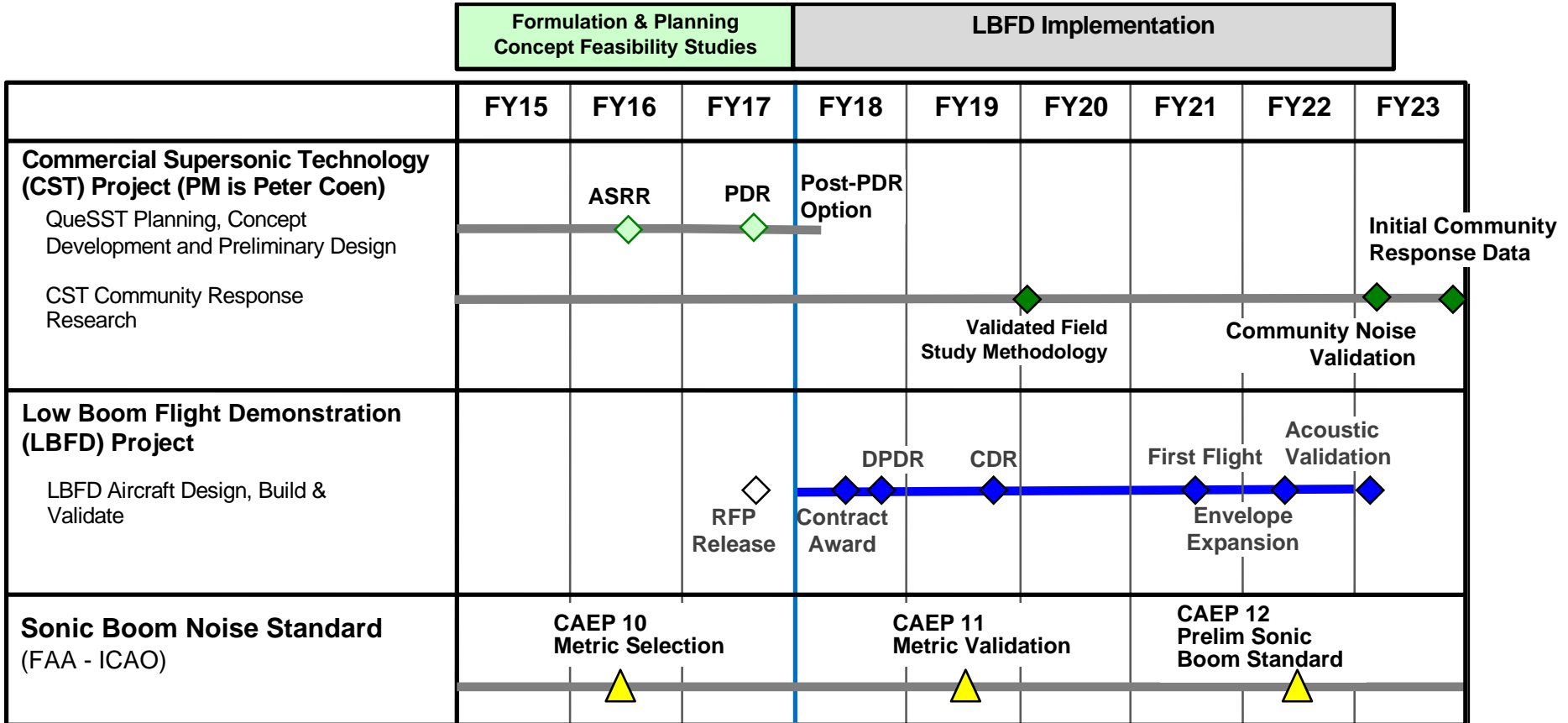
Aerodynamic Performance



Handling Qualities



LBFD – Future Plans



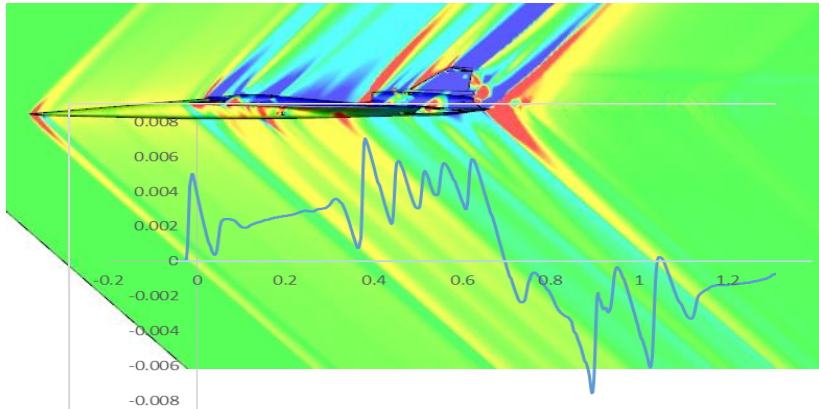
◆ CST Milestones
 ◆ LBFD Milestones
 ◆ NASA Input to CAEP

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

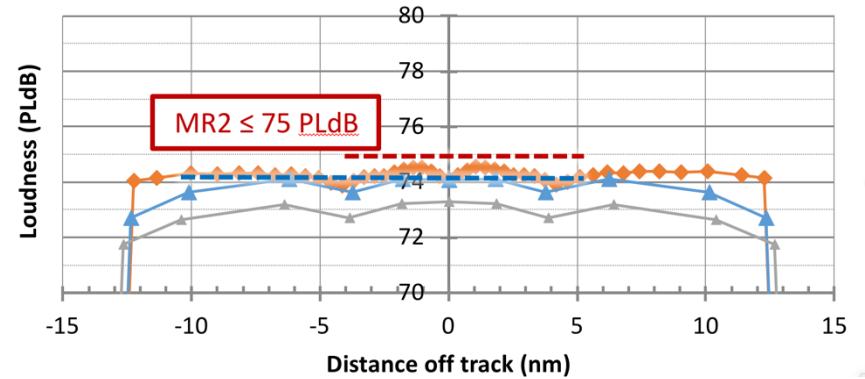
Quieting the Boom



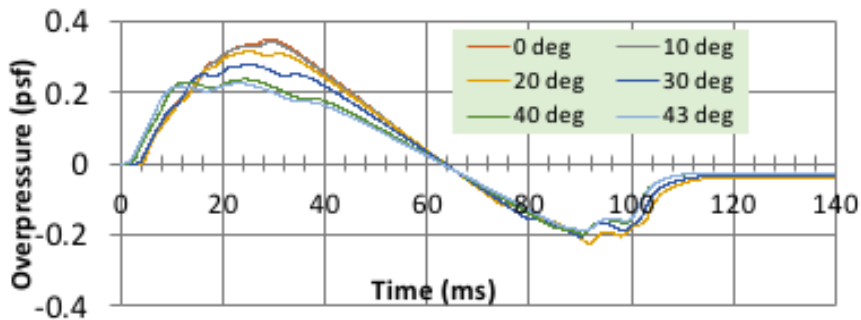
Low-Boom Design Tools



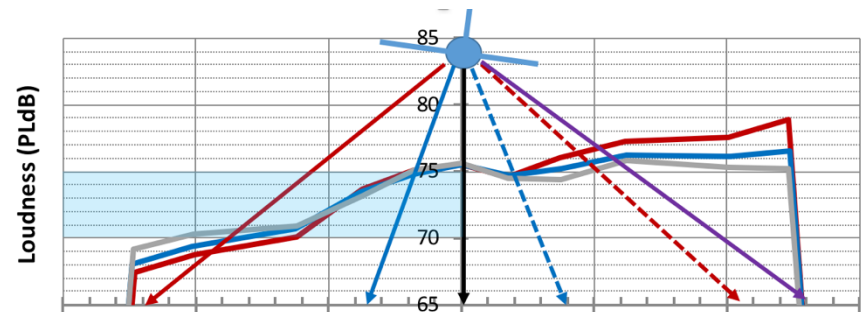
Cruise Boom – Level Flight



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



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

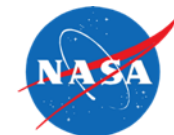


Assured Autonomy for Aviation Transformation

Develop high impact aviation autonomy applications

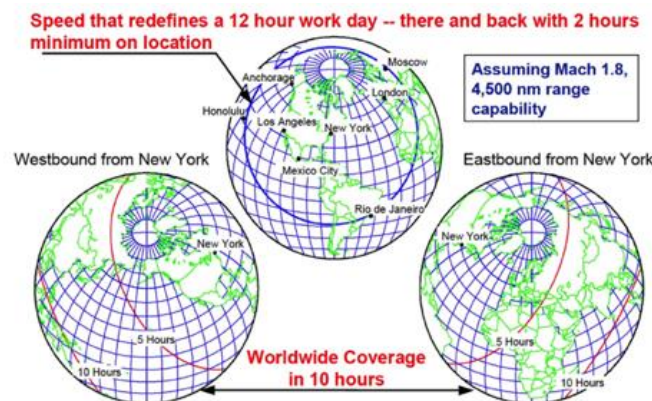
U.S. leadership for a new era of flight

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



- 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

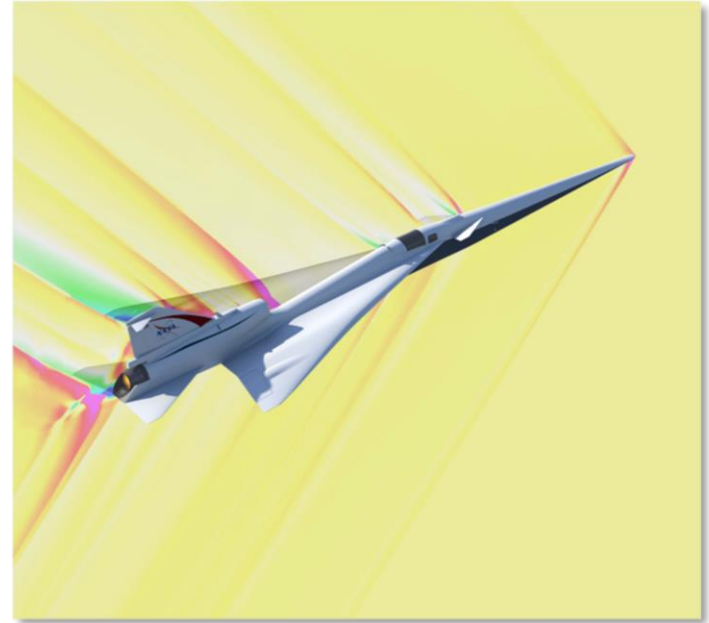
Background and Overview



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

Armstrong Flight Research Center

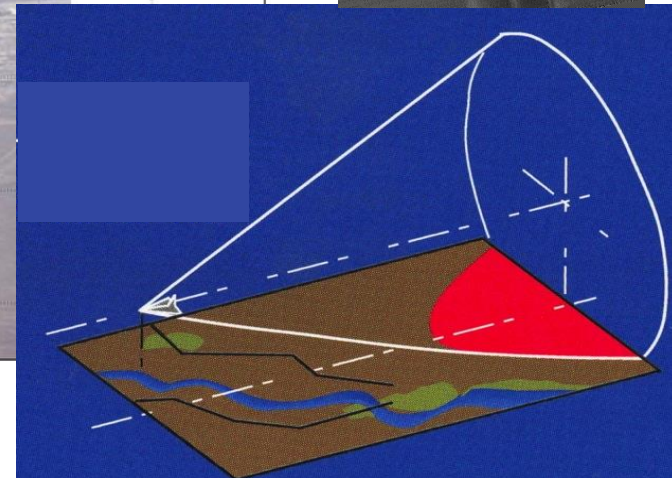
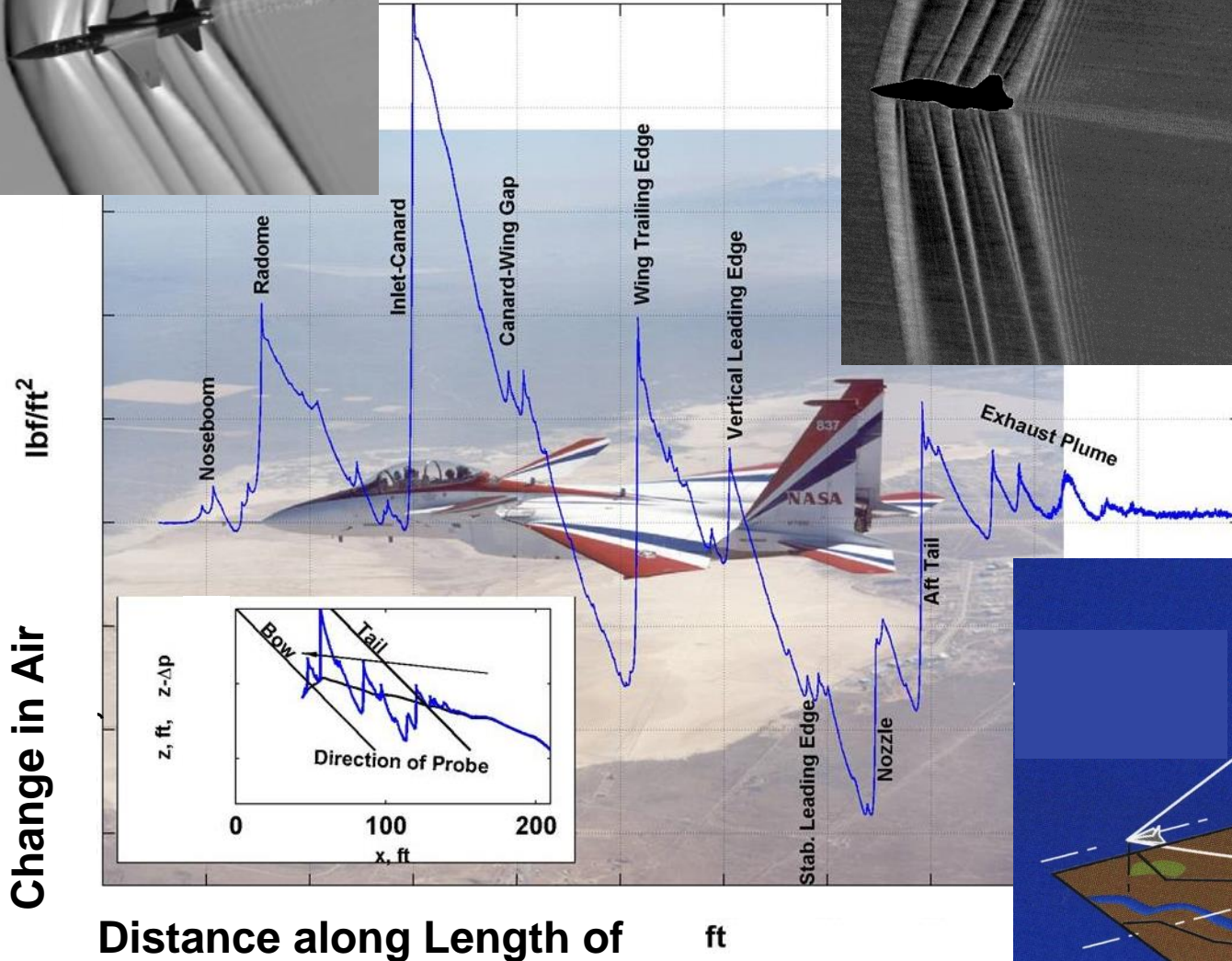
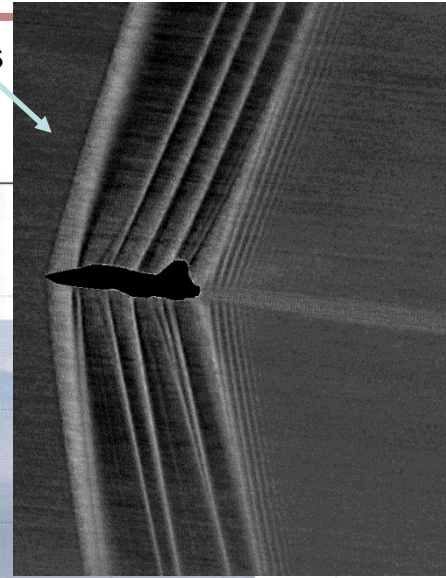
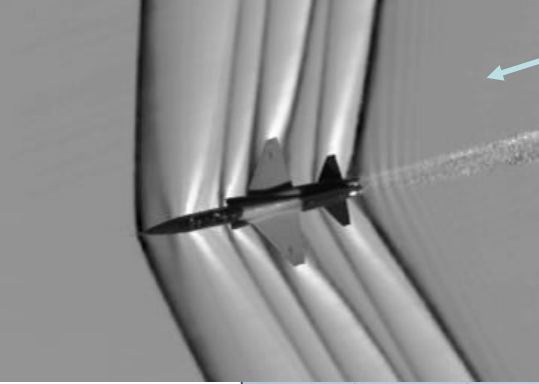


Edwards AFB, California, main campus:

- 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

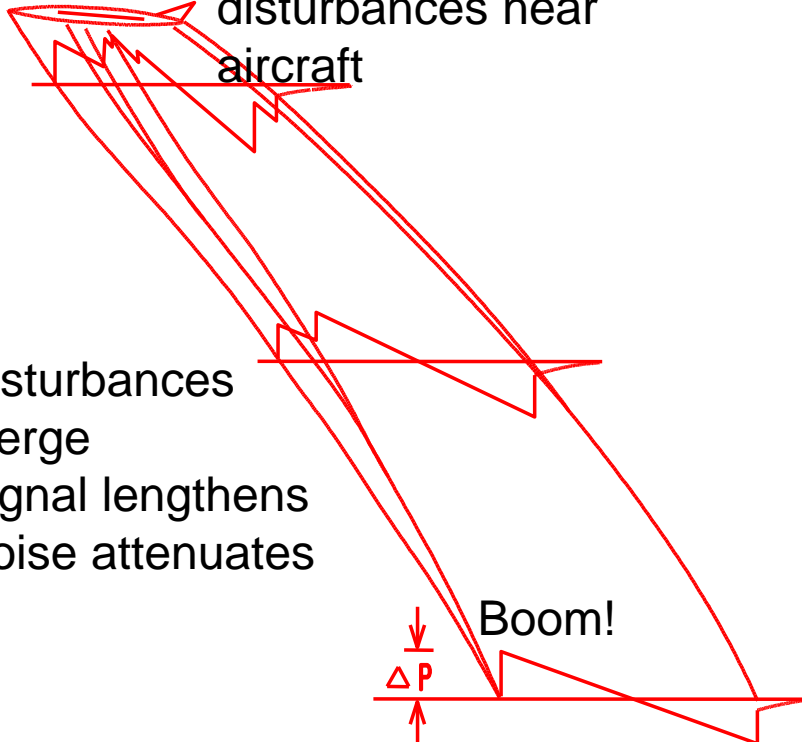
T-38 Shockwave images



Sonic Boom Reduction by Aircraft Shaping



Multiple disturbances near aircraft



- Disturbances merge
- Signal lengthens
- Noise attenuates

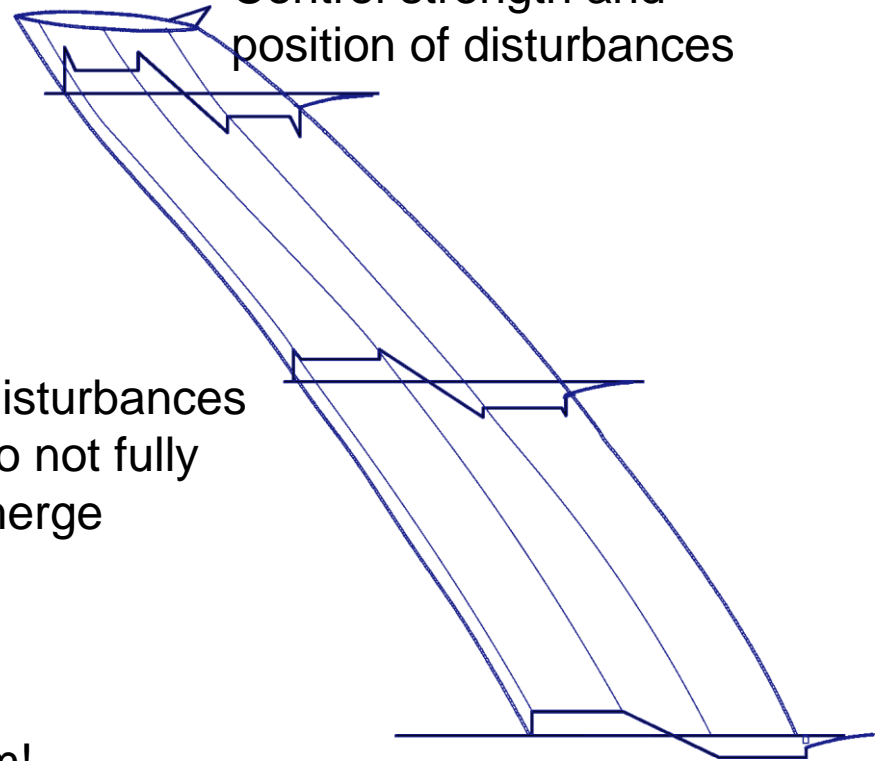
Boom!

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 FedBizOpps
Aug 2017	LBFD DBT RFP release anticipated
1 st qtr CY 18	LBFD DBT contract award
3 rd qtr CY 19	Critical Design Review
1 st qtr CY 21	First flight
4 th qtr CY 21	Envelope Expansion complete
3 rd qtr CY 22	Low boom acoustic signature validation complete
1 st qtr CY 23	Initial community response test (based at NASA AFRC)
2023 - 2025	Community response tests in US (remote based)

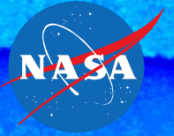
Dates in blue text are estimated and dependent on approval and funding

Density Changes



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

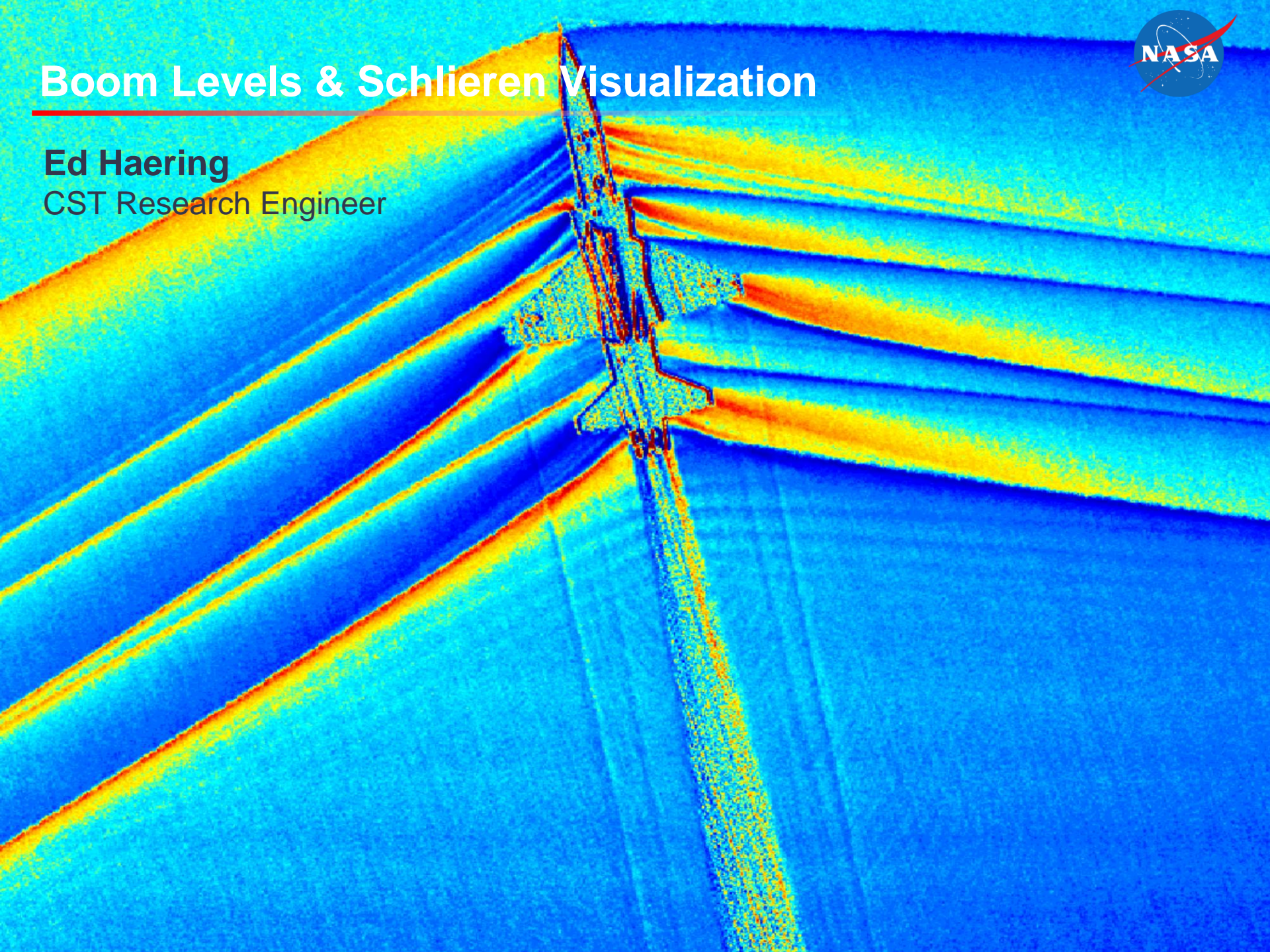




Boom Levels & Schlieren Visualization

Ed Haering

CST Research Engineer





PILOTS

Generally best kept on a short leash.