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..
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.)
Low-Boom Flight Demonstration

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

Altitude, ft

~60,000

~30,000

~2,000

Ground level

Macro atmospheric effects

Pressure

Temperature

Winds

Micro atmospheric effects

Atmospheric absorption (relative humidity)

Turbulence effects

Boom Signature Carpet

Cruise boom signature

Primary boom carpet

Secondary boom carpet

Lateral cutoff boom signature

Δp

Transition focus boom signature

NASA
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.
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*)

Threshold for Discomfort: 120 dB

Concorde: 101 dB / 109 PLdB

Fighter Aircraft: 94 dB / 102 PLdB

Traffic: 80 dB

Low-Boom Demonstrator Concept: 66 dB / 75 PLdB

Normal Conversation: 60 dB

Soft Whisper: 40 dB

* A-weighted sound levels

PldB: Sonic boom outdoor perceived levels,
What is a Quiet Supersonic Flight and How do We Measure Response? 1 – Boom Simulators

- 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
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

Building, House or Community

10 to 20 miles

Ground
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

- Turn/loiter
- Supersonic dash \((M \geq 1.4)\)
- Community survey area
- 125-nm outbound and climb-out
- 125-nm inbound decel/descent
- Base of operations

~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/ft²
- **T/W**: 0.60
- **Engine**: 1xGE F414
- **Design Mach**: 1.42
- **Loudness**: <75 PLdB

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**X-59 QueSST Preliminary Design Overview**

- **COTS engine**
  - Provides desired combination of performance and reliability, stock nozzle reduces complexity and cost

- **Wing Shielding to reduce impact of inlet spillage on sonic boom**

- **Canopy, Seat, and Crew Escape Systems**
  - Workable moldline and minimizes qualification costs

- **Extended Nose with area shaping to reduce forward shock**

- **T-tail to minimize and tailor aft shock**

- **Conventional Tail Arrangement simplifies stability and control challenges**

- **Fixed Canard provides nose-up trim**

- **F-16 Block 25 Landing Gear & Flight Systems**

- **eXternal Vision System (XVS)**
  - Ultra-High Definition video display and symbology system to replace forward vision for the pilot

- **Extended Nose with area shaping to reduce forward shock**

- **Design provides a cost-effective solution to meet the low-boom design requirements, NASA-Provided Flight Systems and GFE are leveraged to enhance aircraft capabilities and provide key value added opportunities**
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
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
Backup Slides
## Mission Requirements

### Key Mission Requirements

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

Sonic Boom

Aerodynamic Performance

Handling Qualities
**LBFD – Future Plans**

<table>
<thead>
<tr>
<th>FY15</th>
<th>FY16</th>
<th>FY17</th>
<th>FY18</th>
<th>FY19</th>
<th>FY20</th>
<th>FY21</th>
<th>FY22</th>
<th>FY23</th>
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</thead>
<tbody>
<tr>
<td><strong>Commercial Supersonic Technology (CST) Project (PM is Peter Coen)</strong></td>
<td></td>
<td></td>
<td>ASRR</td>
<td>PDR</td>
<td>Post-PDR Option</td>
<td></td>
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<td>Initial Community Response Data</td>
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<tr>
<td>QueSST Planning, Concept Development and Preliminary Design</td>
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<td></td>
<td></td>
<td></td>
<td>Validated Field Study Methodology</td>
<td>Community Noise Validation</td>
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<tr>
<td>CST Community Response Research</td>
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<tr>
<td><strong>Low Boom Flight Demonstration (LBFD) Project</strong></td>
<td></td>
<td></td>
<td>DPDR</td>
<td>CDR</td>
<td>First Flight</td>
<td>Acoustic Validation</td>
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<tr>
<td>LBFD Aircraft Design, Build &amp; Validate</td>
<td></td>
<td></td>
<td>RFP Release</td>
<td>Contract Award</td>
<td>Envelope Expansion</td>
<td></td>
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<tr>
<td><strong>Sonic Boom Noise Standard (FAA - ICAO)</strong></td>
<td></td>
<td></td>
<td>CAEP 10 Metric Selection</td>
<td>CAEP 11 Metric Validation</td>
<td>CAEP 12 Prelim Sonic Boom Standard</td>
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</tbody>
</table>

- CST Milestones
- LBFD Milestones
- NASA Input to CAEP

**Notes:**
- 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

MR2 ≤ 75 PLdB
NASA Aeronautics Strategic Vision

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
• 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
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

Change in Air Pressure, Distance along Length of Aircraft.

T-38 Shockwave images

EAA AirVenture – T. Jones – 7/28/17
Sonic Boom Reduction by Aircraft Shaping

- Multiple disturbances near aircraft
- Disturbances merge
- Signal lengthens
- Noise attenuates

Boom!

- 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
## LBFD Timeline

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Description</th>
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<tbody>
<tr>
<td>2013 - 2014</td>
<td><strong>Concept Exploration Studies</strong></td>
</tr>
<tr>
<td>2014 - 2015</td>
<td><strong>Concept Refinement Studies</strong></td>
</tr>
<tr>
<td>Feb 2016</td>
<td>QueSST Preliminary Design contract awarded to Lockheed-Martin as part of NASA’s New Aviation Horizons Initiative</td>
</tr>
<tr>
<td>Feb 2017</td>
<td>Sources Sought Notice Posted on FedBizOpps (<a href="https://www.fbo.gov/">https://www.fbo.gov/</a>)</td>
</tr>
<tr>
<td>Jun 2017</td>
<td>Preliminary Design Review</td>
</tr>
<tr>
<td>Jun 2017</td>
<td>LBFD Design/Build/Test (DBT) Draft Request For Proposal (RFP) released on FebBizOpps</td>
</tr>
<tr>
<td>Aug 2017</td>
<td>LBFD DBT RFP release anticipated</td>
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<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; qtr CY 18</td>
<td>LBFD DBT contract award</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; qtr CY 19</td>
<td>Critical Design Review</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; qtr CY 21</td>
<td>First flight</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; qtr CY 21</td>
<td>Envelope Expansion complete</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; qtr CY 22</td>
<td>Low boom acoustic signature validation complete</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; qtr CY 23</td>
<td>Initial community response test (based at NASA AFRC)</td>
</tr>
<tr>
<td>2023 - 2025</td>
<td>Community response tests in US (remote based)</td>
</tr>
</tbody>
</table>

*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
PILOTS
Generally best kept on a short leash.