Fixing the Sound Barrier

Three Generations of U.S. Research into Sonic Boom Reduction

... and what it means to the future

Presented in Conjunction with the University of California Davis Air Quality Research Center Revolution in Aviation Symposium
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Outline

• Perspective
  – Concorde & The U.S. SST
  – Recent interest in supersonic civil aircraft
• Sonic Boom Basics
• Progress in Sonic Boom Minimization
• What’s happening now
• Looking forward
Perspective

Concorde

Cruise Speed: Mach 2
Takeoff Weight: 400,000 lbs
Payload: 100 passengers
First Flight: 1969
Commercial Service: 1976-2004

U.S. SST

Cruise Speed: Mach 2.7
Takeoff Weight: 675,000 lbs
Payload: 274 passengers
Program Start: 1965
Program Cancelled: 1971
Perspective

Concorde, U.S. SST faced many challenges

One of the largest was… SONIC BOOM!

…Leading to the FAR prohibiting supersonic commercial flight over U.S.
Interest in Supersonic Flight has not Diminished

Supersonic cruise aircraft offer significant mobility improvements in the NextGen System

Supersonic flight over land will enable a revolution in transportation …

… up to 50% reduction in cross country travel time

… improving personal productivity and well-being

… moving time-critical cargo, including life-saving medical supplies

… enhancing homeland security through rapid transportation of critical responder teams

Supersonic Civil Aircraft with increasing capability will be enabled if technology and environmental barriers can be overcome
Sonic Boom Basics

Sonic Boom is NOT the sound of an aircraft “breaking the sound barrier”

Sonic Boom is created as long as the aircraft is flying faster than Mach 1.0

Speed < Speed of Sound (< Mach 1)
Pressure Disturbance (sound) precedes aircraft

Speed = Speed of Sound (Mach 1)
Aircraft Speed = Speed of Pressure Disturbance

Speed > Speed of Sound (> Mach 1)
Aircraft precedes pressure disturbance,
All disturbance reaches an observer instantaneously
Sonic Boom Basics

- Sonic Boom is 3-Dimensional
- Large “Carpet” of Ground is exposed as aircraft flies
- Noise is reduced at the edge of the carpet

Multiple disturbances (“shock waves”) near aircraft

- Disturbances Merge
- Signal lengthens
- Noise attenuates

- Two disturbances remain
- Signal has a characteristic “N” shape
- Called an “N wave” boom “signature”
Sonic Boom Basics: The N-Wave

Measured Sonic Boom

Measured Subsonic Takeoff Flyover
Sonic Boom Basics: The N-Wave

.. To the same scale
Sonic Boom Basics: The N-Wave

Factors in N wave annoyance

Overpressure $\Delta p$

Duration

Rise Time

Measured Sonic Boom

Time, s

$\Delta P$

0

-2

-1

0

1

2

0 0.1 0.2 0.3 0.4

0

-1

-2

-2
Practical Approaches to Sonic Boom Reduction

If Aircraft ground speed < Speed of Sound at the ground (~660 kts)…

Boom can “refract” and not reach the ground

Boom Region

“Caustic Line”

Rumble sound, rapidly decaying

Ground

Mach cutoff

NO BOOMS OBSERVED

BOOMS OBSERVED

ALTITUDE, KFT

MACH

0 1.0 1.1 1.2 1.3 1.4
Sonic Boom Minimization Through Aircraft Shaping

Shocks Coalesce into “N-wave”

Disturbances do not Fully Merge

Control Strength and Position of Disturbances

Minimum Overpressure

Minimum Initial Shock

Shaped Boom at the Ground
Low Boom signatures are achieved by applying shaping to smaller aircraft

Potentially more than 35 dB(a) of Reduction!
**Sonic Boom Research in Supersonic R&D Programs**

### 1st Generation

**60’s-70’s Concorde U.S. SST**
- Mach: 2.0 - 2.7
- TOGW 400,000 - 675,000 lbs
- Payload: 100 - 234 Passengers
- Sonic Boom Basics
- Community Impact
- Shaping Concepts

### 2nd Generation

**80-90’s High-Speed Research**
- Mach: 2.4
- TOGW 750,000 lbs
- Payload: 300 Passengers
- Shaping Benefit
- Low Boom Design
- Community & Wildlife Impact

### 3rd Generation

**Current Efforts NASA, FAA & Industry**
- Mach: 1.2-2.0
- TOGW 100,000-300,000 lbs
- Payload: 8-100 Passengers
- Integration of Low Boom Design
- Indoor Noise Impact
- Atmosphere Effects

**DARPA Quiet Supersonic Platform**
- Mach: 2.4
- TOGW 100,000 lbs
- Payload: 20,000 lbs
- Benefit of Small Size
- Low Boom Design
- Flight Validation of Boom Shaping

**We are doing something!**

**Can we do something?**

**Can we live with it?**
Research on Low Boom Design
Research on Boom Acceptability
Summary of Sonic Boom Research

• Basics of Sonic Boom creation, propagation and impact are well understood
  – Includes structural damage, avalanches, animal life

• Several practical reduction approaches have been identified
  – Flight below the cutoff Mach number
  – Shaped booms

• Theory, design approaches and benefits have been validated
  – Analysis, ground experiments, simulation, flight tests
Current Research Focus

• Understanding impact of booms heard by people indoors
  – Transmission of the boom sound into a house/building
  – Effects of rattle and startle
• Understanding effect of atmospheric turbulence
• Full integration of boom reduction into aircraft design
  – Shaping the aft portion of the signature
  – Engine exhaust jet effects
  – Simultaneous design for low boom, high efficiency, light weight, etc.
Future Vision

Efficient, Affordable Supersonic Flight.....

Thank you for your attention!

... with little or no sonic boom noise