Fixing the Sound Barrier

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

… and what it means to the future

Presented at the
FAA Public Meeting on Sonic Boom

July 14, 2011

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

…Leading to the FAR prohibiting supersonic commercial flight over U.S.

One of the largest was… SONIC BOOM!

Interest in Supersonic Flight has not Diminished

Supersonic cruise aircraft offer significant mobility improvements in the Future Air Transportation System

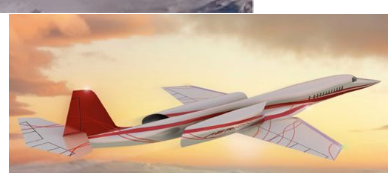
Supersonic flight over land will enable a revolution in transportation …

… up to 50% reduction in cross country travel time

… improving personal productivity and well-being

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

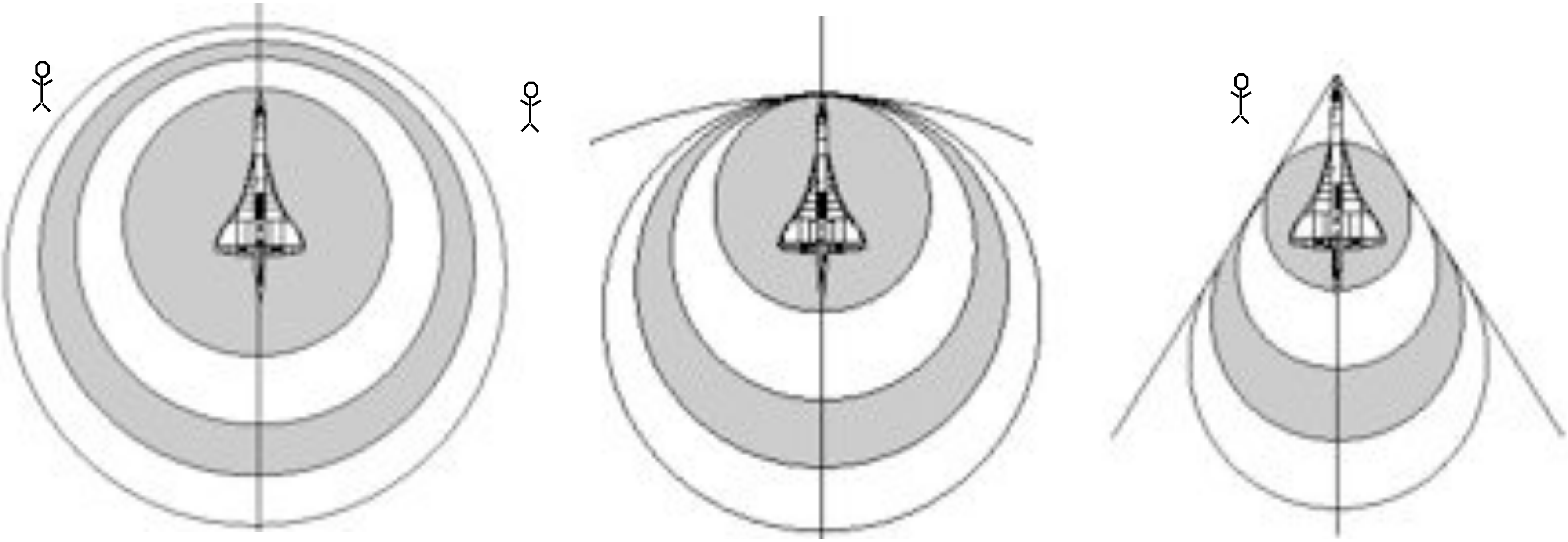
… enhancing homeland security through rapid transportation of critical responder teams



2010 **2020** **2030**

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

Sonic Boom Basics



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

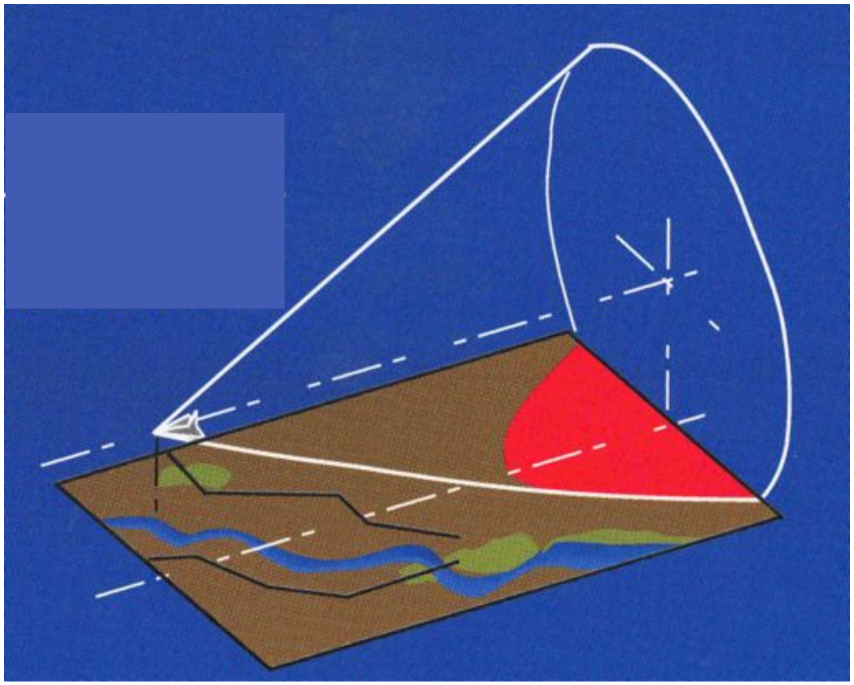
- Speed = Speed of Sound
  = Mach 1
- Aircraft Speed = Speed of Pressure Disturbance

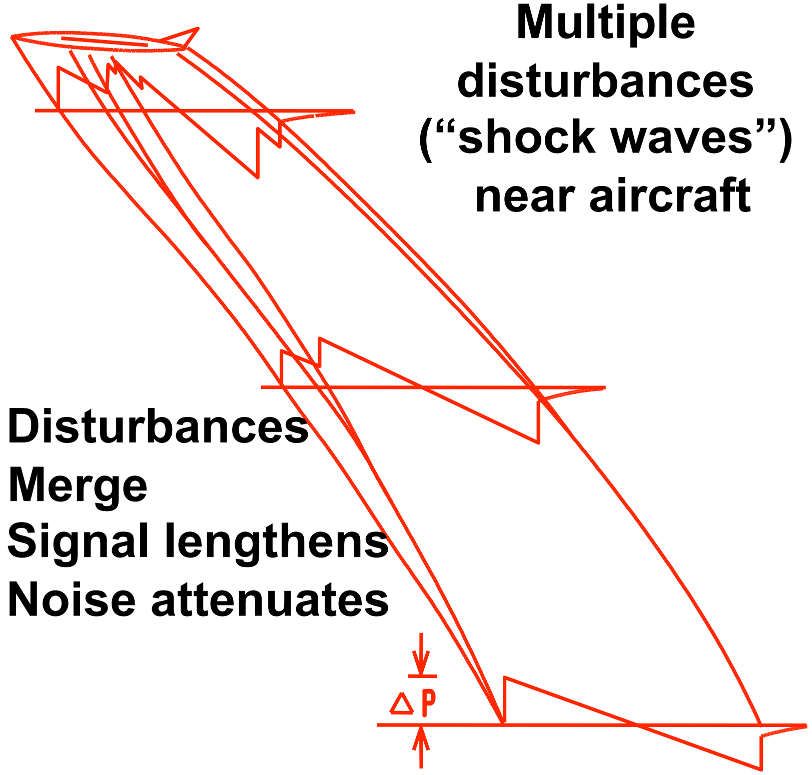
- Speed > Speed of Sound
  > Mach 1
- Aircraft precedes pressure disturbance
- All disturbance reaches an observer instantaneously

Sonic Boom 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

Sonic Boom Basics





Multiple disturbances ("shock waves") near aircraft

- Disturbances Merge
- Signal lengthens
- Noise attenuates

- Sonic Boom is 3-Dimensional
- Large "Carpet" of ground is exposed as aircraft flies
- Noise is reduced at the edge of the carpet

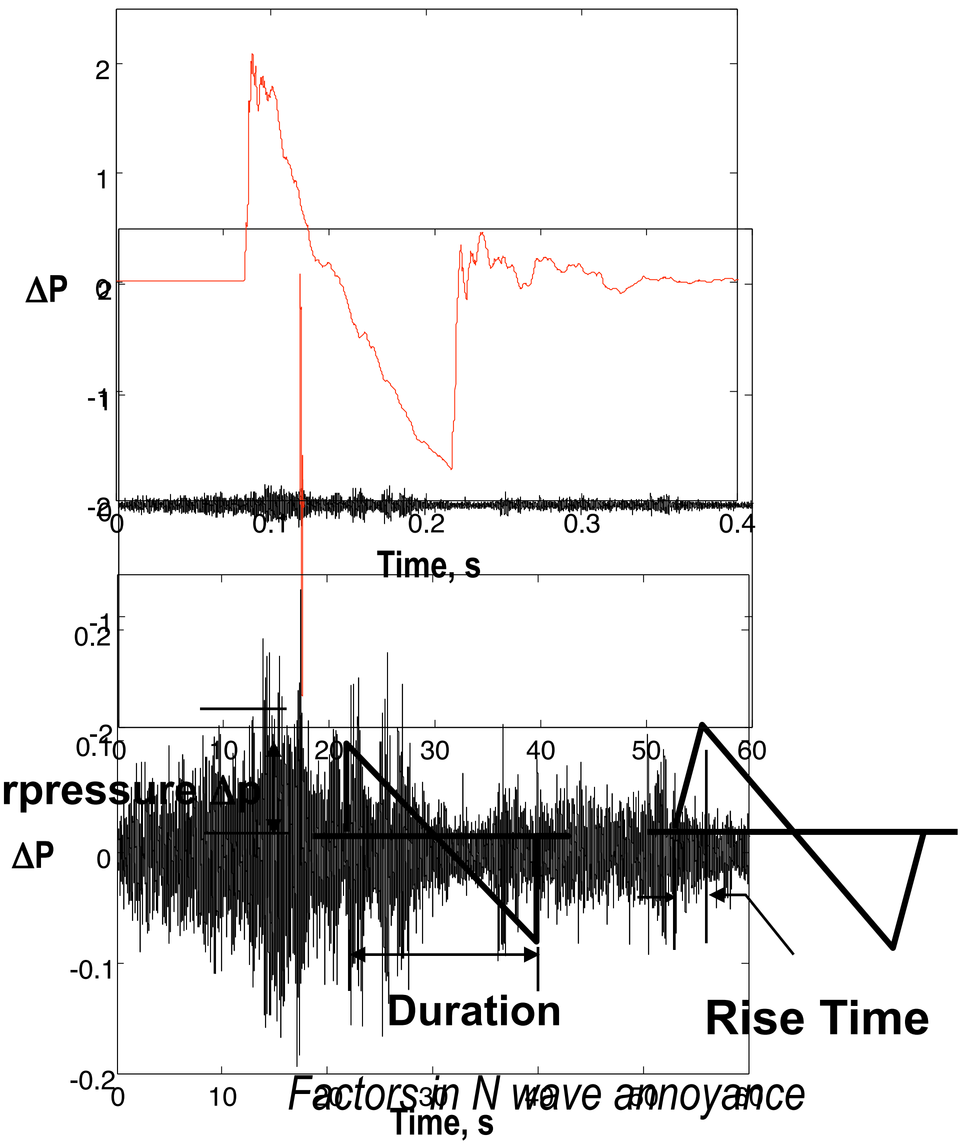
- Two disturbances remain
- Signal has a characteristic "N" shape
- Called an "N wave" boom "signature"

Sonic Boom Basics: The N-Wave

Measured Sonic Boom

.. To the same scale

Measured Subsonic Takeoff Flyover



Sonic Boom Research in Supersonic R&D Programs

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!

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***

Can we do something?

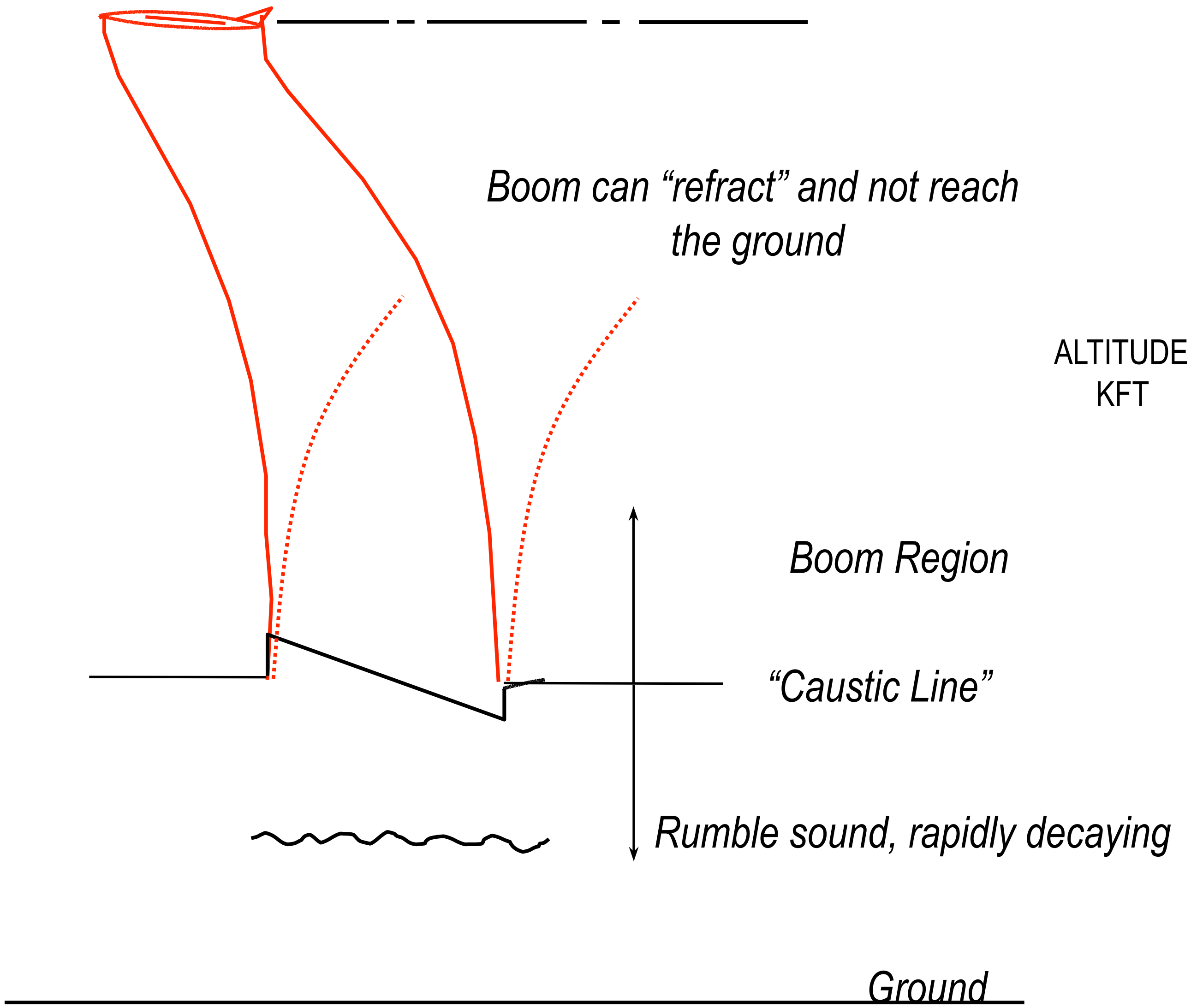
1st Generation

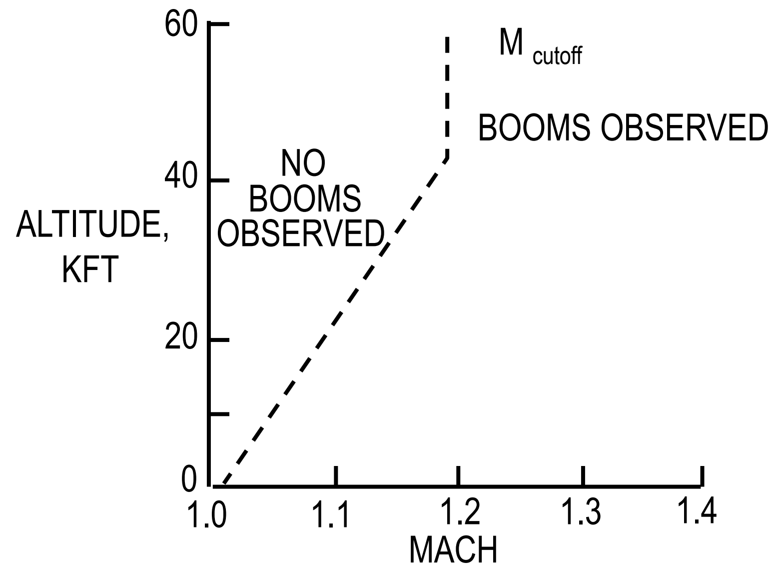
60's-70's Concorde U.S. SST	*Mach: 2.0 -2.7* *TOGW 400,000 - 675,000 lbs* *Payload: 100 -234 Passengers*	***Sonic Boom Basics*** ***Community Impact*** ***Shaping Concepts***

Can we live with it?

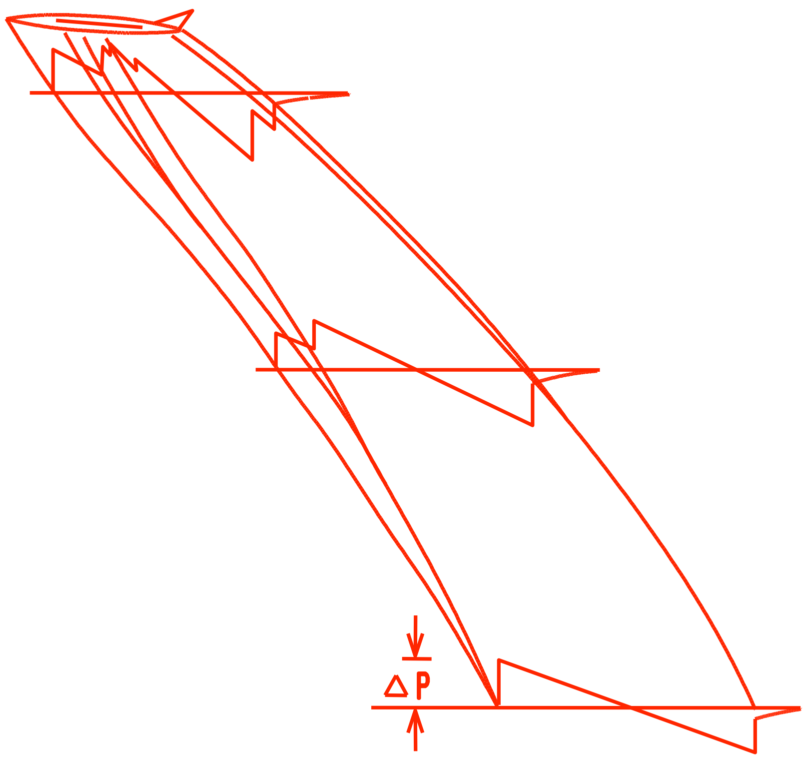
Practical Approaches to Sonic Boom Reduction -1 "Boomless" Flight

If Aircraft ground speed < Speed of Sound at the ground (~760 mph)…





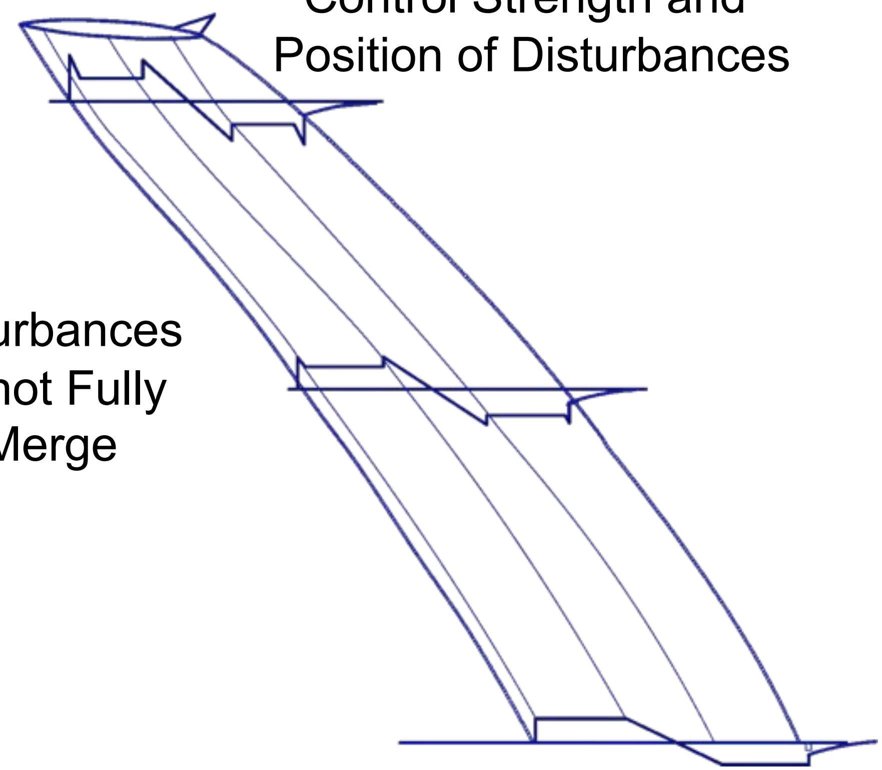
Practical Approaches to Sonic Boom Reduction -2
Minimization Through Aircraft Shaping



Shocks Coalesce into “N-wave”

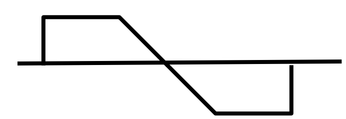
Control Strength and Position of Disturbances

Disturbances do not Fully Merge

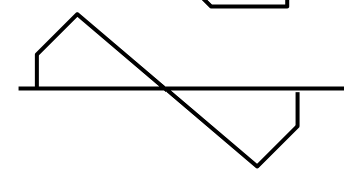


Shaped Boom at the Ground

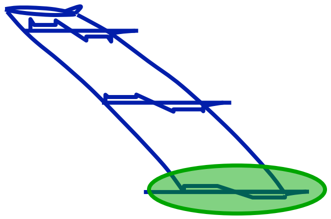
Minimum Overpressure



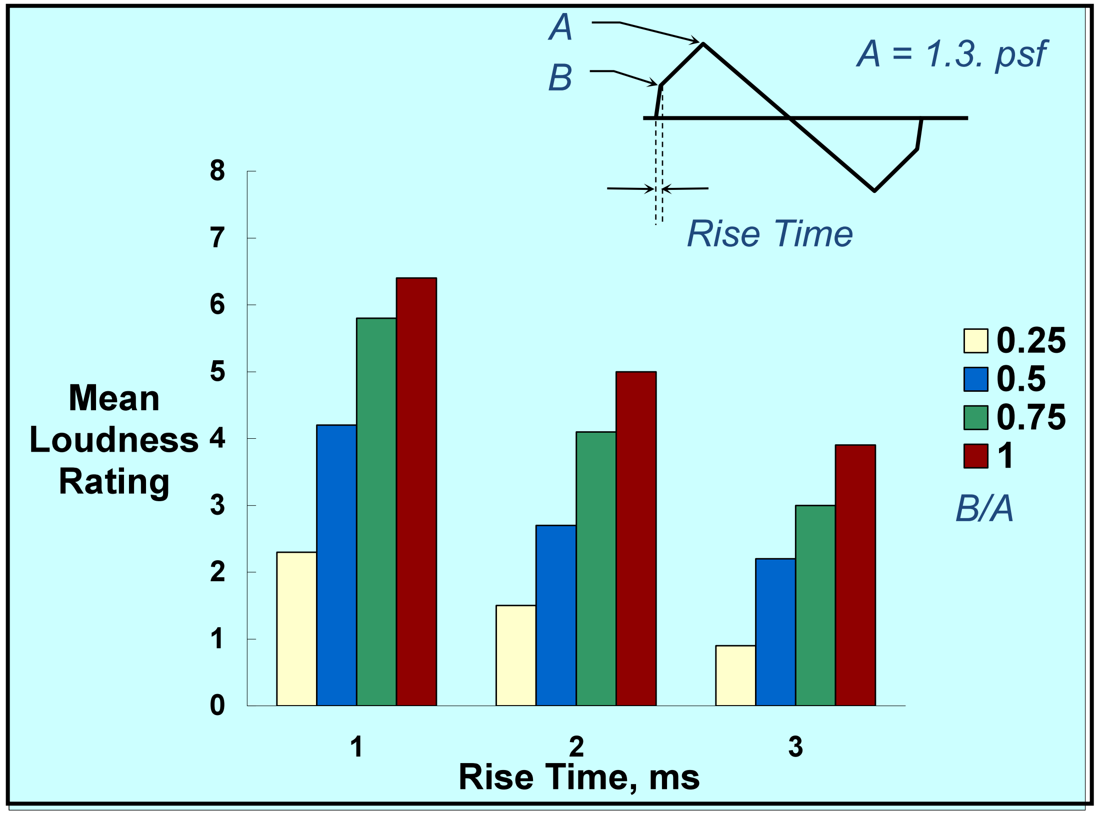
Minimum Initial Shock



Noise Reduction from Sonic Boom Shaping

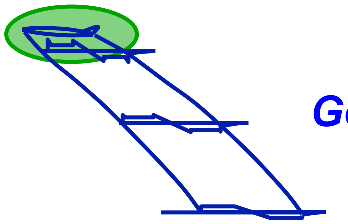


Sonic boom simulator

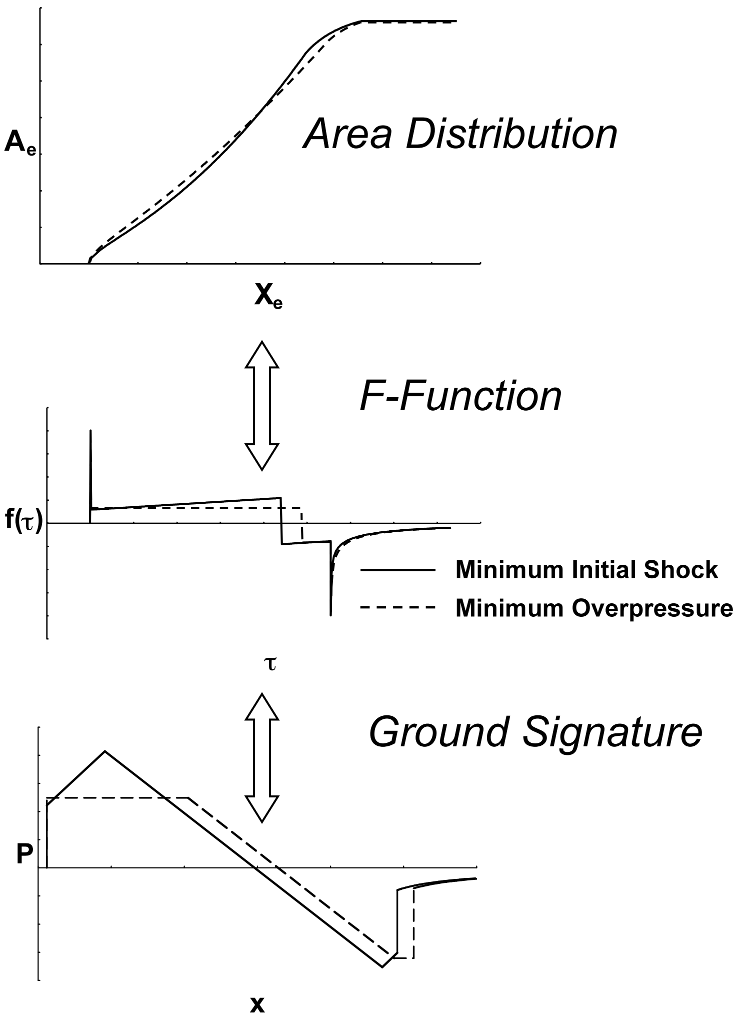


Sullivan 1990

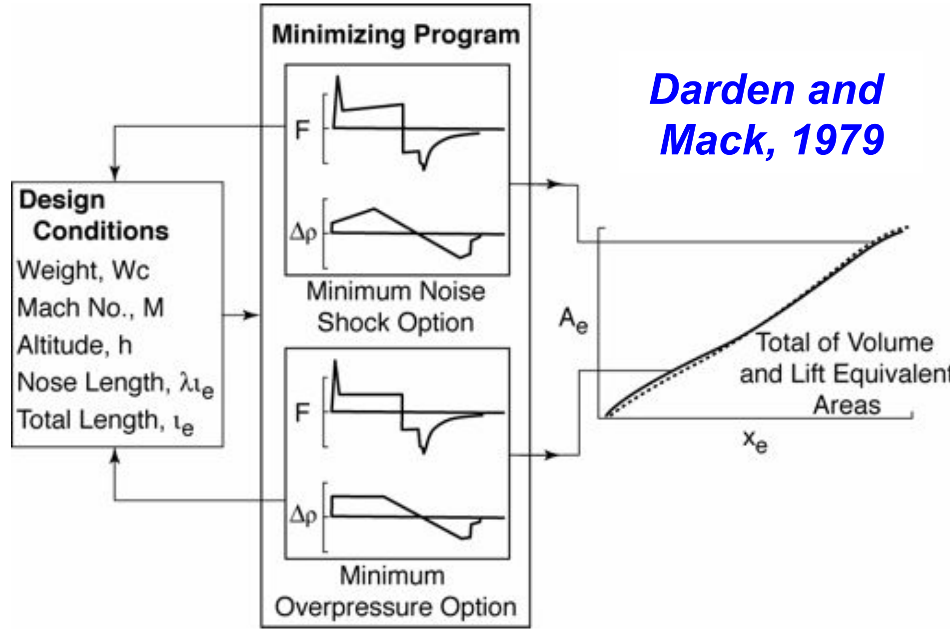
Practical Application of Boom Shaping Concept

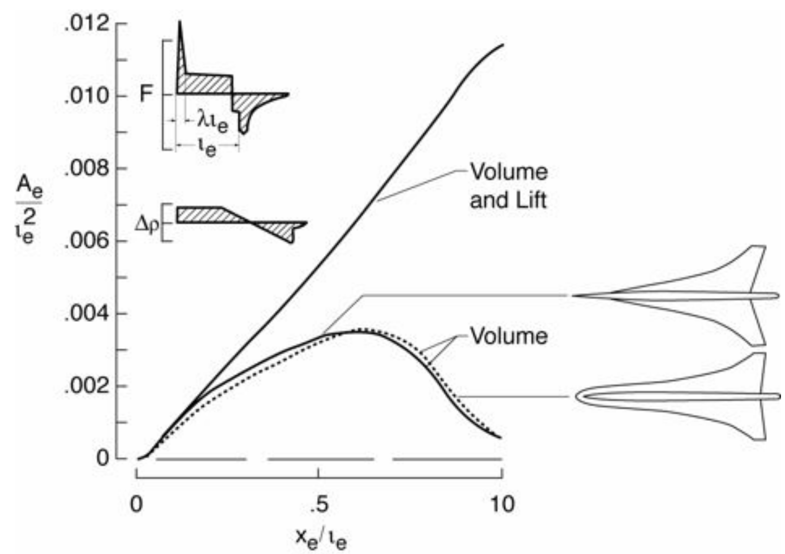


George & Seebass 1969



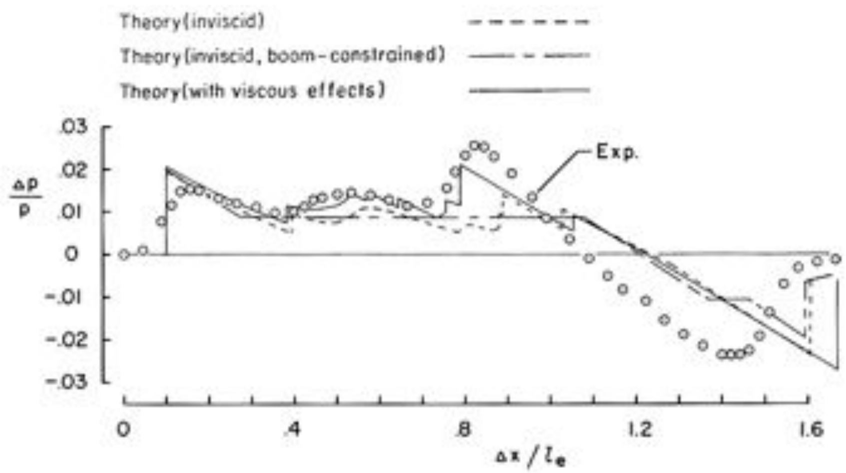
Darden and Mack, 1979

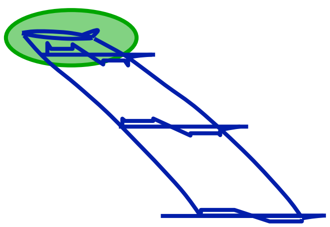


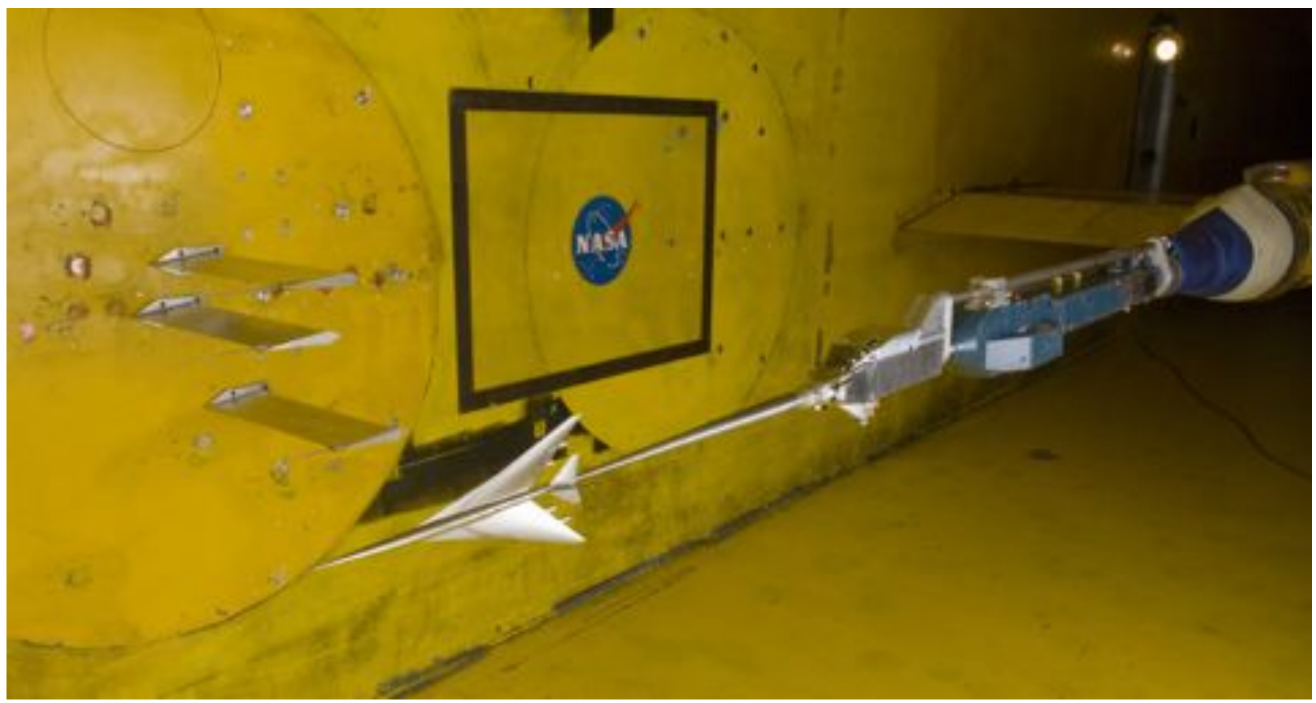


Experimental Validation of Boom Reduction Concepts

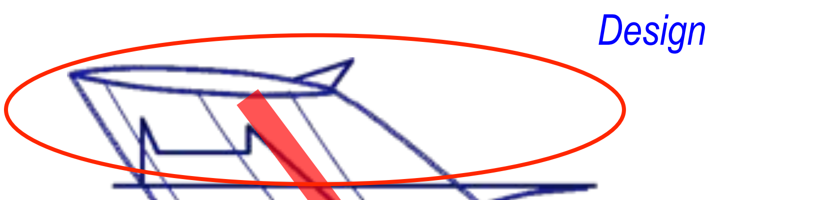
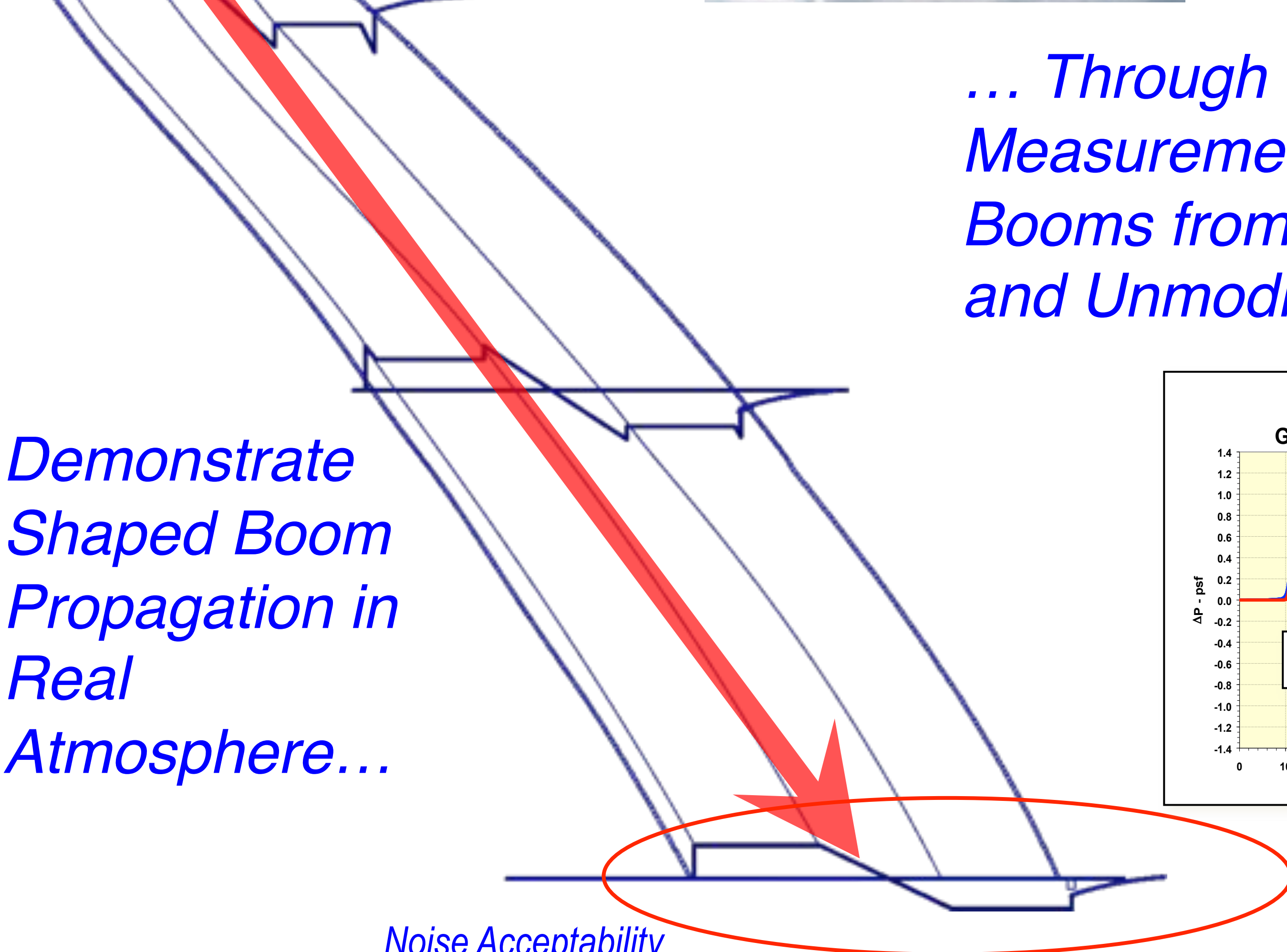
- Scale model tests in supersonic wind tunnels





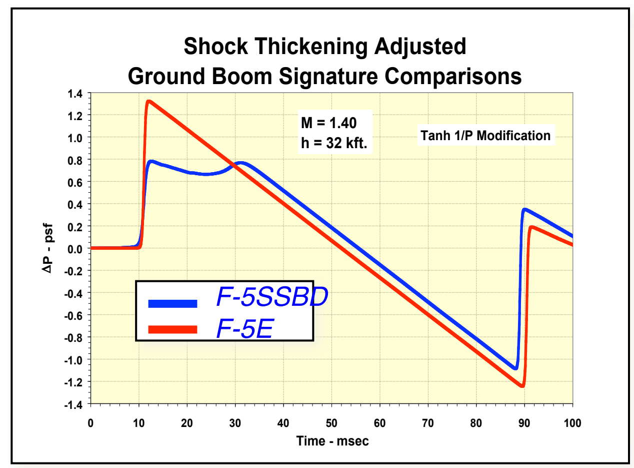


Key Step in Validation of Theory

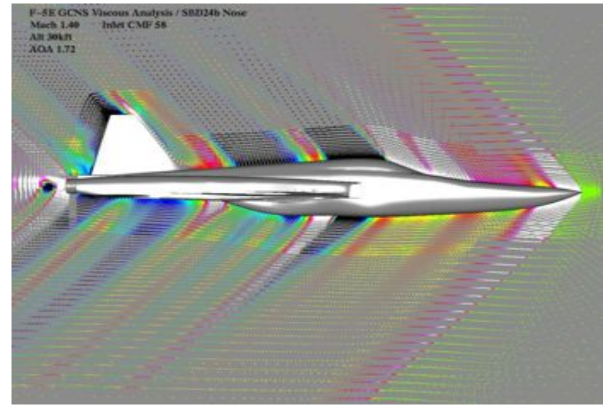
… Through Ground Measurement of Booms from Modified and Unmodified F-5Es

Demonstrate Shaped Boom Propagation in Real Atmosphere…

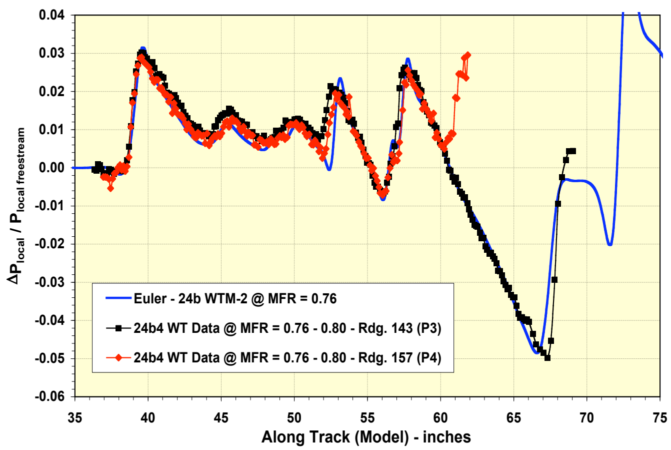


Shaped Sonic Boom Demonstrator (SSBD)

F5-E loaned by US Navy



Extensive design effort using most up to date computational methods



Wind tunnel validation of design

Engineering, fabrication & flight clearance for research aircraft

NORTHROP GRUMMAN Integrated Systems

DARPA

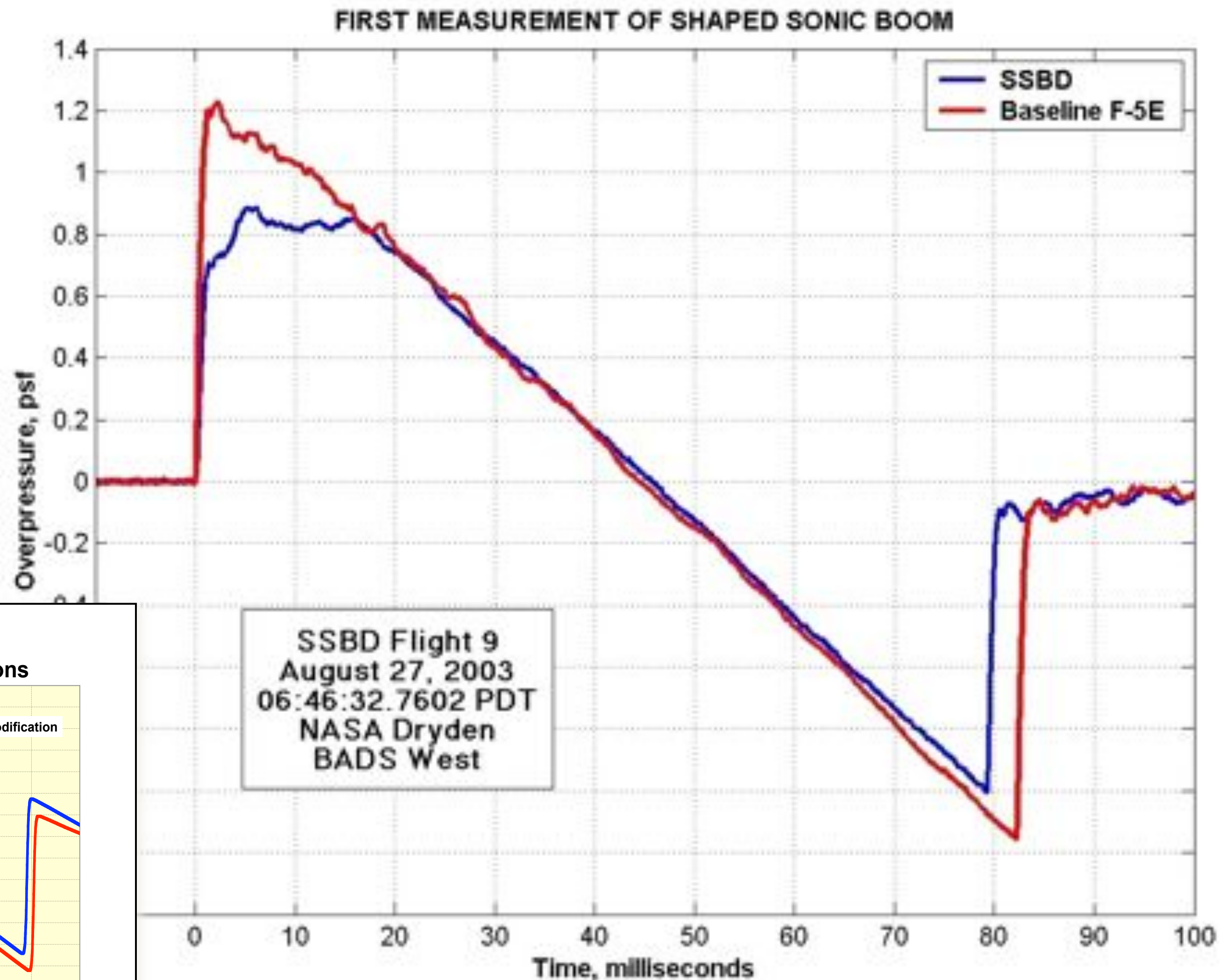
NAVAIR

Theory Validated!

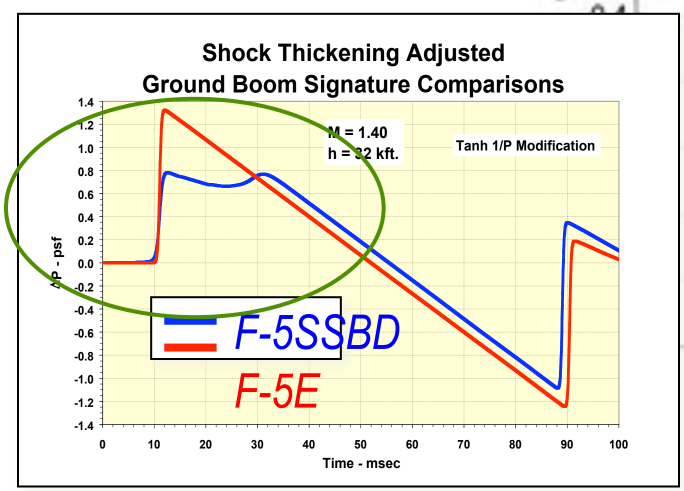
First-Ever Shaped Sonic Boom Recorded 27 August 2003

Signatures recorded during SSBD back-to-back data flights in the Edwards AFB supersonic flight corridor early morning

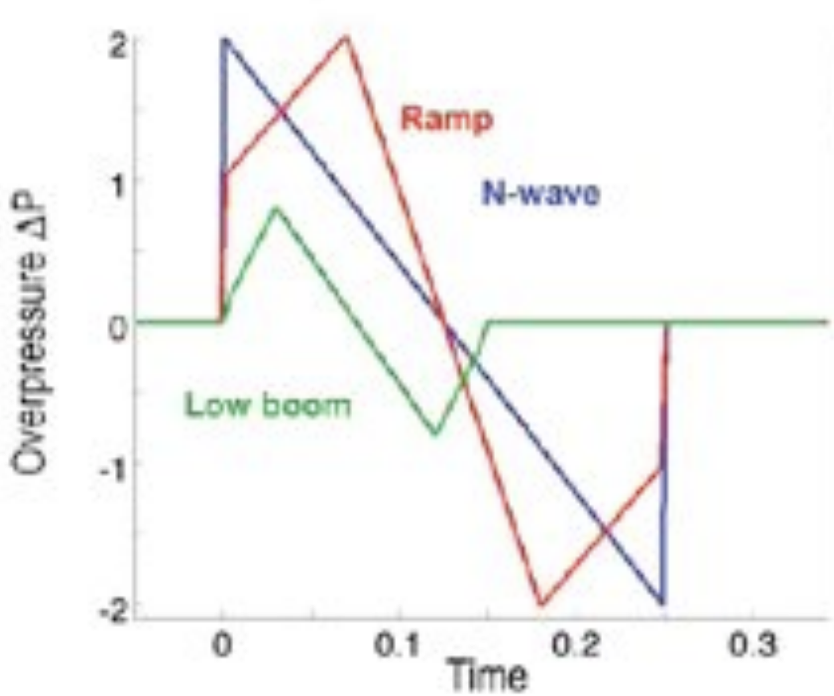
Flight conditions:
Mach 1.36+,
Altitude 32,000 ft

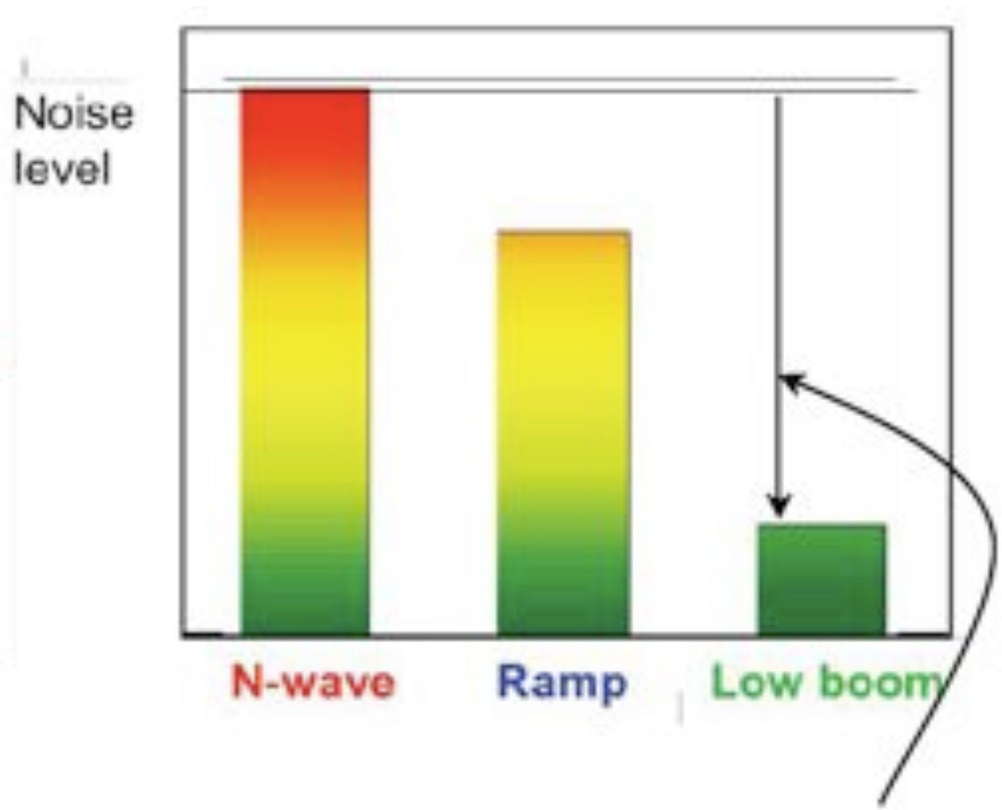


Design Mach: 1.4



Impact of Boom Shaping on Noise





Low Boom signatures are achieved by applying shaping to smaller aircraft

Potentially more than 35 dB(a) of Reduction!
~2000x less sound intensity

Research on Boom Acceptability
How do We Determine What is Low Enough?





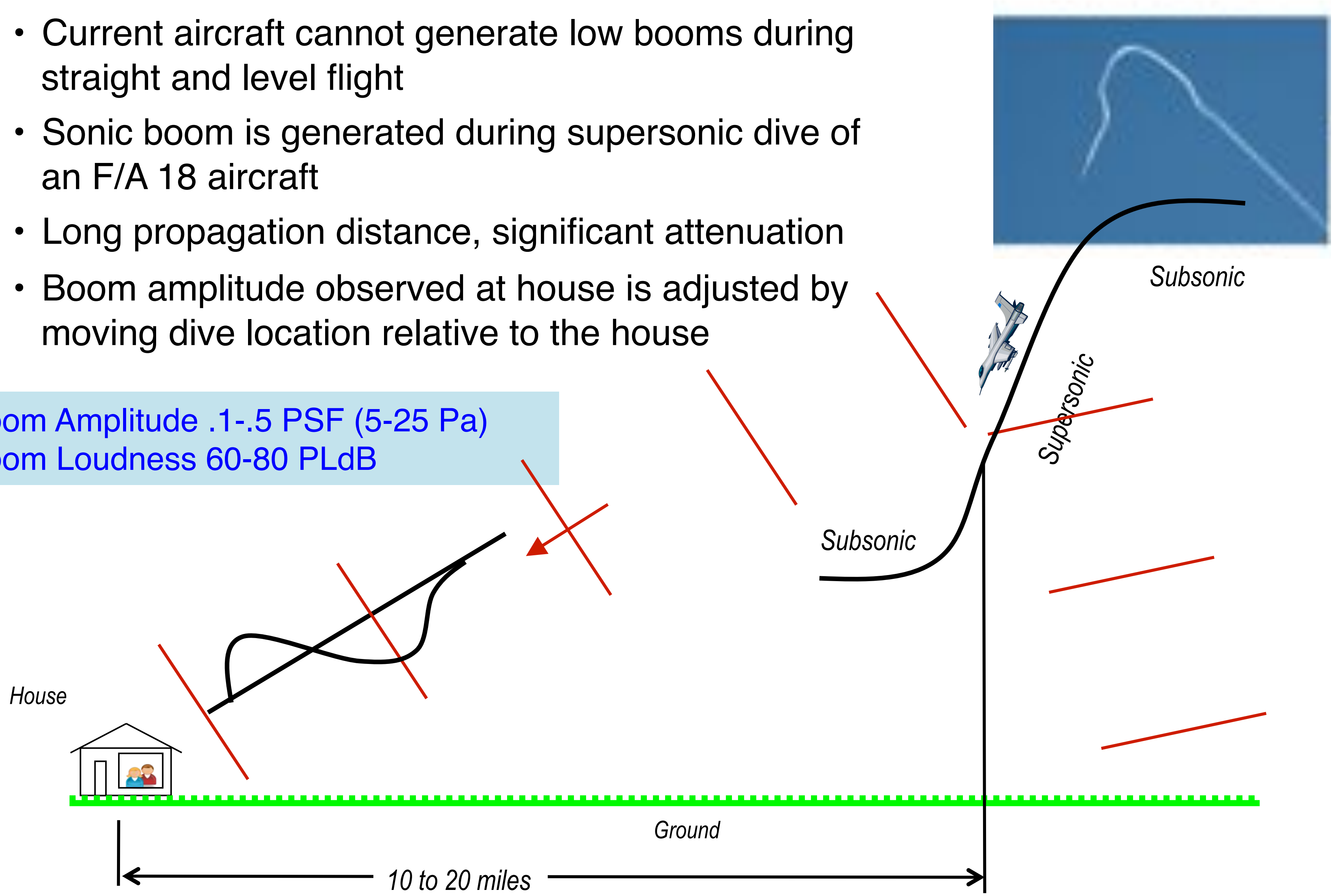
Gulfstream
A GENERAL DYNAMICS COMPANY

- Sophisticated boom simulators
- Greatly improved reproduction of sonic boom noise
  - Consistent, repeatable test conditions
- Study elements of boom that create annoyance
  - Goal: Understand how annoyance is related to spectrum, level, rattle, vibration

How do We Study Low Sonic Boom?

- Current aircraft cannot generate low booms during straight and level flight
- Sonic boom is generated during supersonic dive of an F/A 18 aircraft
- Long propagation distance, significant attenuation
- Boom amplitude observed at house is adjusted by moving dive location relative to the house

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



Research in Realistic Environments



Structural & Acoustic Response

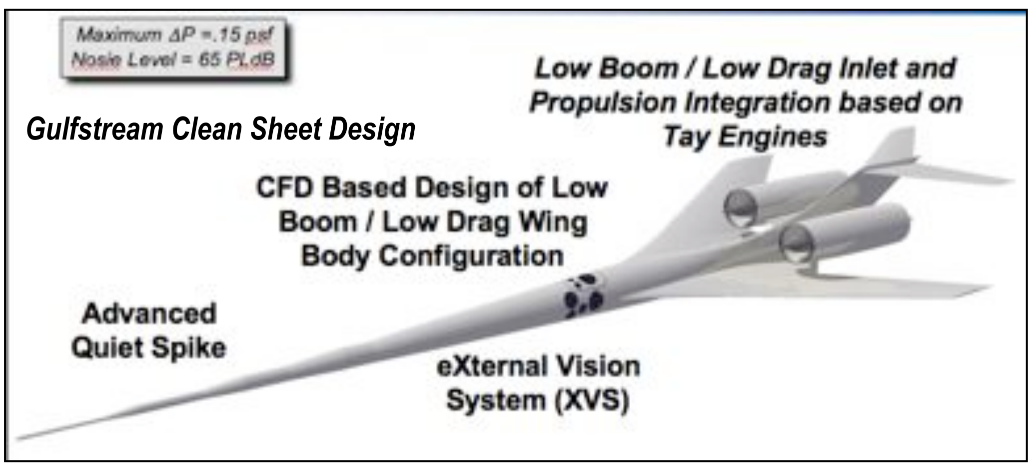

Subjective Reaction

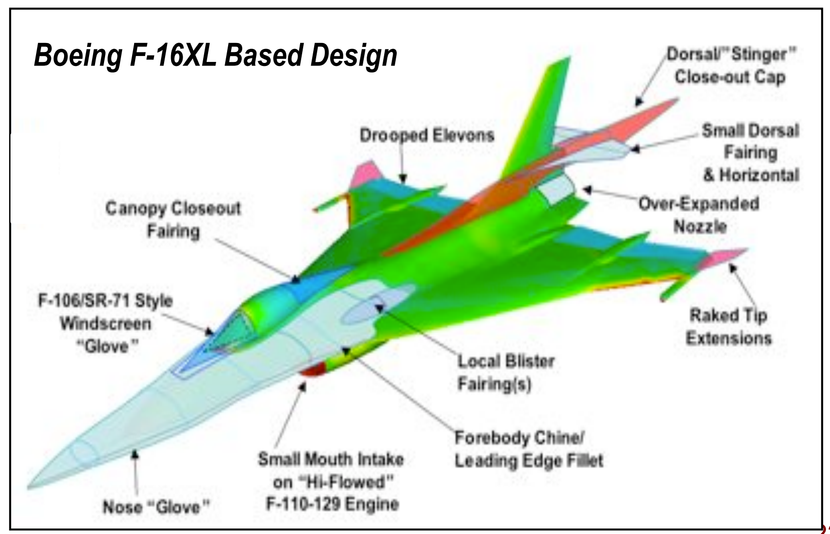
- Dive maneuver creates new research opportunities
- Realistic, varied structures and environments
  - Living & working conditions
- Test conducted in approved supersonic flight corridors


Small & Large Structures

Flight Validation is a Critical Next Step

- Full scale, complete validation of design tools & techniques
- Develop understanding of the full spectrum of atmospheric effects
- Validate acceptability measures in realistic situations
- Gather data on public reaction to low noise sonic boom
  - Communities without prior experience of sonic boom exposure





Summary of Sonic Boom Research

Past Research

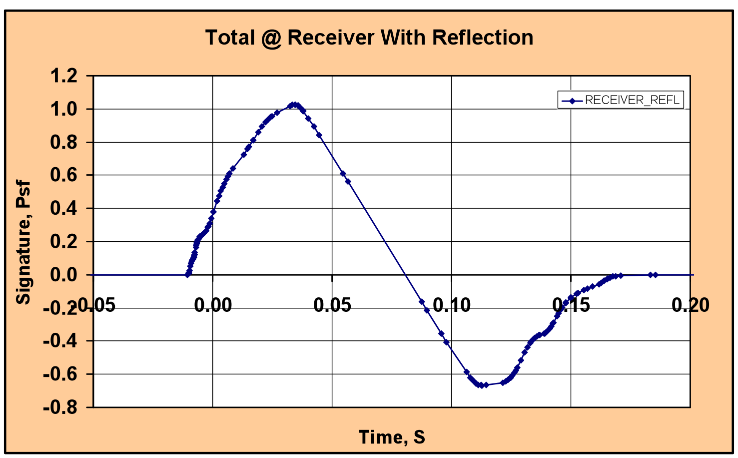
- Basics of sonic boom creation, propagation and impact are well understood
  - Effects on structures, terrain and animal life are minimal
  - Human response is primary consideration
- Several practical reduction approaches have been identified
  - Flight below the cutoff Mach number
  - Shaped booms
- Theory, design approaches and benefits have been validated
  - Analysis, ground experiments, simulation, flight tests

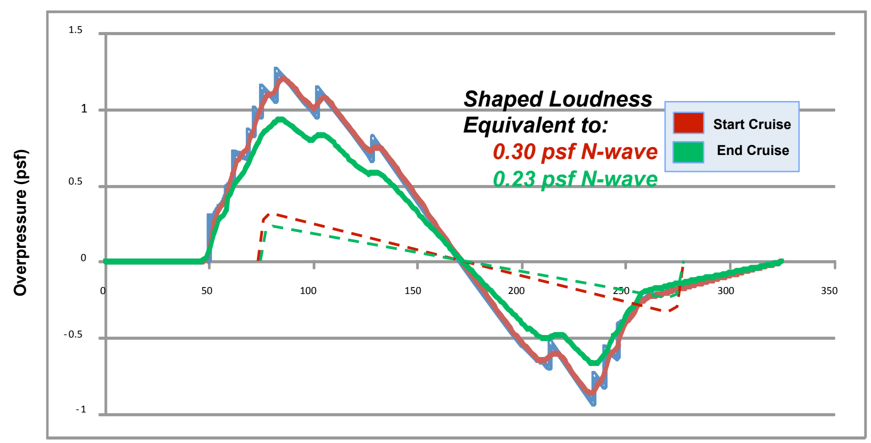
Current Research Focus

- 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 atmosphere, operations & realistic ground environments
- 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

Expanding Design Knowledge

- New target signatures
- More sophisticated analytical and design tools
- Multiple disciplines considered simultaneously
  - Boom, efficiency, takeoff and landing noise, etc.





Future Vision

Efficient, Affordable Supersonic Flight…..

… with little or no sonic boom noise