Shaped Sonic Boom Demonstration / Experiment
Airborne Data
SSBD Final Review

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Outline

F-5E Shaped Sonic Boom Experiment

• Past airborne shock measurement efforts
  – SR-71 Sonic Boom Propagation Experiment
  – F-5E Inlet Spillage Shock Measurement
• Flight test approach
• GPS data
• SSBD Mach calibration
• Super Blanik L-23 sailplane
• Near-field probing
  – Maneuvers
  – Control Room Displays
  – Pressure Instrumentation
  – Signatures
• Summary
• CFD comparison to flight data, Keith Meredith, Northrop-Grumman Corp.
SR-71 Sonic Boom Propagation Experiment

Near-Field
Mid-Field
Far-Field
Atmospheric Boundary Layer
Ground Array
YO-3A
F-16XL Probing Aircraft
Non-N-wave
N-wave
SR-71 Sonic Boom Propagation Experiment
Experiment
SR-71
F-16XL Probing Aircraft
Non-N-wave
N-wave
BOOM! BOOM!
Bow Shock
Tail Shock
BOOM! BOOM!
YO-3A
Bow Shock
Tail Shock
Inlet Spillage Shock Measurement - Feb. ‘02

DFRC Facilities and Expertise used to Accurately Record Inlet Shock Strength in Flight...

... Resulting in Modification to Design Process
Airborne Data Flight Test Approach

F-5E Shaped Sonic Boom Experiment

- NASA Dryden F-15B probes below and to side of F-5E, 60 to 720 ft flightpath separation, F-15B nose always behind SSBD tail for supersonic probing
- F-15B noseboom pressures measures shock strengths
- GPS on both aircraft measures relative position
- GPS basestation (Palmdale & Edwards) for postflight carrier-phase differential corrections
- USAF TPS Super Blanik L-23 flies at 6,000 to 8,000 ft over North Base ground array, records sonic boom on wingtip microphone, GPS also
GPS Data Processing

F-5E Shaped Sonic Boom Experiment

- SSBD, F-5E, F-15B, and L-23 all had carrier-phase differential GPS
- GPS basestations at Palmdale and NASA Dryden
- Ashtech’s PNAV program used for post-flight time-based position, velocity for each aircraft
- Integer ambiguity resolution set to "float" as GPS satellite lock lost at times during flight, "fixed" used for some probing flights
- Raw GPS data lost on six flights, suspect incorrect downloading program used
- Realtime GPS data (NMEA messages) received from SSBD and baseline F-5E on most flights on field-deployed laptop computer. Was able to calibrate NMEA to PNAV differences and recover four flights
- GPS data lost
  - Flt 14 supersonic pass
  - Flt 15 entire flight
**GPS Realtime vs. Postflight Data**

**F-5E Shaped Sonic Boom Experiment**

- Lateral shift small, ignored, raw GPS data not lost for probing flights
- Altitude shift of NMEA due to realtime ionospheric modeling off
- Relative error of velocity components as a linear function of altitude on SSBD and baseline F-5E, not on F-15B, suspect incorrect GPS setup program
• Position data from GPS antennae translated to SSBD nose (w/o noseboom) as origin, F-15B pressure ports based on:
  – 0° roll angle
  – GPS flight path angle plus assumed AOA for pitch angle
  – 1° AOA for F-15B, 1.75° AOA for SSBD (neither aircraft had test AOA sensor)
  – GPS flight path heading of each vehicle (F-15B Euler angles not instrumented, SSBD Euler angles not believable)
• Translated latitude, longitude, altitude differenced to give North, East, Down separation components
• Relative position components rotated to SSBD stability axes using GPS velocity and atmospheric reference lateral winds to give airmass relative positions.
• Carrier-phase differential GPS solutions investigated:
  – PNAV “Float” (baseline) and “fixed” (best for now) ambiguities with Palmdale basestation for SSBD
  – PNAV “Float” and “fixed” ambiguities with Edwards basestation for SSBD
  – GrafMov software (gives carrier-phase relative position without basestations)
• All solutions within +/- 2 ft of baseline in each component
• NASA’s Autonomous Aerial Refueling project gives optical relative position good to inches to determine best GPS processing
GPS Relative Position Differences

F-5E Shaped Sonic Boom Experiment

- Little to no variation during signature
- Other signatures give different biases

Images of graphs showing GPS relative position differences.
Mach Calibration Method

F-5E Shaped Sonic Boom Experiment

• Assume zero error in total pressure
• Indicated Mach, $M_i$, is a function of indicated total and static pressure only
• GPS data and geodetic separation model gives geometric altitude above mean sea level, $Z$
• GPSsonde and atmospheric analysis gives pressure altitude, $H_p$, and lateral pressure gradient as a function of $Z$
• Some GPSsonde data were off in excess of 300 ft
  – DC shifts in altitude after data dropouts
  – Some late balloon launches did not have proper initial pressure set
  – Sometimes balloon package is just “bad”
• Combine GPS derived $Z$ with atmospheric $Z$-$H_p$ to give true $H_p$ for all aircraft data points
• Aircraft total pressure with true $H_p$ gives true Mach, $M_{inf}$
• Mach correction, $M_{inf} - M_i = f(M_i)$ during stable flight
• Stable Data: GPS $|V_d|<10$ fps, $|\phi|<10^\circ$, GPS error < 10 ft
Mach Calibration

F-5E Shaped Sonic Boom Experiment

- Large hysteresis loop during climbs and descents due to pneumatic lag
Mach Calibration, Stable Supersonic

F-5E Shaped Sonic Boom Experiment

- 1-σ Mach error 0.00084 or 20 ft altitude error
- GPSsonde error of 300 ft would cause 0.013 Mach error
Flight Region

F-5E Shaped Sonic Boom Experiment

- F-15B probing at SSBD stable points, Hwy 395 to North Base, and reverse track
- Sailplane over ground array
YO-3A Instrumentation

- Microphones on wingtips and vertical tail
- Microphones, airdata, time, and voice on FM recorder
- Handheld GPS for position fix when boomed
• Sailplane with sonic boom microphone on wingtip at 6,000 to 8,000 ft over ground array
• Same boom recording design philosophy of YO-3A, with better microphone, recorder
• USAF TPS under contract to NASA Dryden for effort, TPS has all aircraft operation and safety of flight
L-23 Sonic Boom Instrumentation

F-5E Shaped Sonic Boom Experiment
L-23 Pressure & Microphone Data

F-5E Shaped Sonic Boom Experiment

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SSBD & Baseline Booms on Glider

F-5E Shaped Sonic Boom Experiment

![Graph showing overpressure vs time for Baseline F-5E and SSBD configurations.](image-url)
Incident and Reflected Booms

F-5E Shaped Sonic Boom Experiment

USAFTPS Blanik L-23 Glider Data 1/15/04 PRELIMINARY

- Overpressure, psf

- Baseline F-5E
- SSBD
- Baseline F-5E reflected
- SSBD reflected
Shock Probing Back to Front

F-5E Shaped Sonic Boom Experiment
Shock Probing Front to Back

F-5E Shaped Sonic Boom Experiment

SSBE Flt 30 Sig 6 Time = 55198.09 sec

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Probing Separations

F-5E Shaped Sonic Boom Experiment

SSBD Probing Conditions, partials and abs(phi)>30 eliminated

- Probing Separations
- F-5E Shaped Sonic Boom Experiment

Graph showing probing conditions with separation and Mach number axes.
Control Room Sonic Boom Position Display

F-5E Shaped Sonic Boom Experiment

- For indication purposes, located in control room
- Mission controller can suggest fine position and rate adjustments
- Enhances test point efficiency and quality, not required for flight

Example Data from SR-71 / F-16XL
Control Room Sonic Boom Display

F-5E Shaped Sonic Boom Experiment

- Direct indication of measured shock waves
- Mission controller can advise if ahead or behind shock waves
- Enhances test point efficiency, not required for flight

Example Data from SR-71 / F-16XL
Remote Flight Monitoring

F-5E Shaped Sonic Boom Experiment

• Realtime GPS data received in field via Pacific Crest UHF radio modem
• Matlab program displays flight conditions, plots flight path on map
• Realtime data recorded, saved four flights of GPS data
Sonic Boom Probing Noseboom

F-5E Shaped Sonic Boom Experiment

100 IN^3 TANK

TOTAL PRESSURE PORT

F-5E Shaped Sonic Boom Experiment

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F-15B Pressure Measurements

F-5E Shaped Sonic Boom Experiment

• August 2003 SSBD flights
  – 252 in³ lag tank selected based on pneumatic simulation
  – Druck differential pressure transducer output had long run to PCM system: noisy data due to EMI
  – Dive into test point with large tank caused Drucks to be overranged for almost all probing data
  – Lag tank absolute transducer showed SSBD shock waves: inconceivable
  – 17 sps Sonix static pressure transducer on F-15B used for overpressures

• January 2004 SSBE flights
  – August 2003 flight data used to adjust pneumatic simulation, 100 in³ tank fabricated
  – 7 grams of attic insulation used in tank to prevent “ringing”
  – Druck’s output sent to TTC multiplexer recorder
    • 1000 sps
    • shorter run
    • lower noise
  – Excellent differential pressure data
  – Absolute pressure transducer on tank showed up to 10 psf shifts when F-15B microphone keyed, easy to remove shifts
  – Lag tank absolute transducer showed no SSBD shock waves as expected
Pressure Overshoot Premonition

F-5E Shaped Sonic Boom Experiment

- Measured pressure overshoots BEFORE shock wave, reason unknown
Near-Field Probing Shock Features

SSBD Flt 30 / F-15B Flt 251 1/21/04 Signature #5

Overpressure, psf

Distance from SSBD Nose - SSBD Nose to Calculated Bow Mach Cone, ft
Near-Field Probing Directly Under

F-5E Shaped Sonic Boom Experiment

![Graph showing near-field probing results](image-url)
Near-Field Probing to Side

F-5E Shaped Sonic Boom Experiment

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Flt 8 Signature 2 Animation

F-5E Shaped Sonic Boom Experiment

SSBD Flt 8 Sig 2 Time =65968.16 sec
Flt 30 Signature 6

F-5E Shaped Sonic Boom Experiment

Diagram showing overpressure and distance from SBD nose to SBD nose.
F-5E Shaped Sonic Boom Experiment

Flt 30 Signature 9

Overpressure, psi

Distance from SSBD Nose - SSBD Nose to Calculated Bow Mach Cone, ft

Distance downstream, ft

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Flt 31 Signature 2

F-5E Shaped Sonic Boom Experiment

Graph showing data with axes labeled:
- Distance from SSBD Nose - SSBD Nose to Calculated Bow Mach Cone, ft
- Overpressure, psf

Inset graph showing:
- Distance back from SSBD nose, ft
- Distance down, ft
Flt 31 Signature 2 Animation

F-5E Shaped Sonic Boom Experiment

SSBE Flt 31 Sig 2 Time = 70910.06 sec
Flt 32 Signature 17 Animation

F-5E Shaped Sonic Boom Experiment

SSBE Flt 32 Sig 17 Time = 79432.02 sec
SSBD/E Airborne Data Summary

F-5E Shaped Sonic Boom Experiment

- **Airborne Data Gathered**
  - SSBD Airdata, GPS, Inertial package on 28 flights
  - Baseline F-5E GPS on 11 flights
  - F-15B shock pressures, GPS on 6 flights, 69 probings measured
  - L-23 glider measured pressures, GPS on 13 flights, 29 booms recorded
  - GPSsonde weather balloon data

- **Ready for comparison to CFD, propagation to ground**

- **Further effort**
  - Refine relative position data (~ several ft) using optical method from Autonomous Aerial Refueling program
  - AIAA papers at Reno, January 2005
  - Refine pneumatic lag simulation
  - Investigate “ringing” in large tank
  - Investigate pressure overshoot premonition
  - Investigate realtime GPS velocity errors on SSBD, F-5E GPS units