Sonic Boom Awareness in the Civil Supersonic Cockpit

Presented to: Flight Test Safety Workshop
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Date: April 23-25, 2013
Topics

- Regulations
- Sonic Boom Hazards / Annoyances
- Business Case for Civil Supersonic Aircraft
- Sonic Boom Basics
- Cockpit Display
- Predictive Display Capability
- Flightdeck Integration
14CFR §91.817-Civil aircraft sonic boom

(a) No person may operate a civil aircraft in the United States at a true flight Mach number greater than 1 except in compliance with conditions and limitations in an authorization to exceed Mach 1 issued to the operator under appendix B of this part.

(b) In addition, no person may operate a civil aircraft for which the maximum operating limit speed exceeds a Mach number of 1, to or from an airport in the United States, unless--

(1) Information available to the flight crew includes flight limitations that ensure that flights entering or leaving the United States will not cause a sonic boom to reach the surface within the United States; and

(2) The operator complies with the flight limitations prescribed in paragraph (b)(1) of this section or complies with conditions and limitations in an authorization to exceed Mach 1 issued under appendix B of this part.
(a) General. For the Concorde airplane, compliance with this subpart must be shown with noise levels measured and evaluated as prescribed in subpart B of this part, and demonstrated at the measuring points prescribed in appendix B of this part.

(b) Noise limits. It must be shown, in accordance with the provisions of this part in effect on October 13, 1977, that the noise levels of the airplane are reduced to the lowest levels that are economically reasonable, technologically practicable, and appropriate for the Concorde type design.
FAA Policy Statement

Federal Aviation Administration
14 CFR Parts 36 and 91

• Civil Supersonic Airplane Noise Type Certification Standards and Operating Rules
• AGENCY: Federal Aviation Administration (FAA), DOT.
• ACTION: Statement of policy.
• SUMMARY: This action updates the Federal Aviation Administration’s (FAA) policy on noise limits for future civil supersonic aircraft to reflect current U.S. noise regulations. This action is intended to provide guidance on noise limits to manufacturers that are considering designs for supersonic aircraft. Noise standards for supersonic operation will be developed as the unique operational flight characteristics of supersonic designs become known and the noise impacts of supersonic flight are shown to be acceptable.

Issued in Washington DC on October 16, 2008. Carl Burleson

Ref: http://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/supersonic_aircraft_noise/media/noise_policy_on_supersonics.pdf
### ICAO Regulations

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<tr>
<td>Noise certification</td>
<td>Surrounding Airport community noise impact</td>
<td>Agree Terms of Reference &amp; possible timeline for rule development</td>
<td>Consider Adoption of Current Subsonic Noise Rule for Supersonic Airplanes</td>
<td>If required, Propose Modification to Current Supersonic Noise rule for Supersonic Airplanes</td>
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<tr>
<td>Emissions</td>
<td>Local Air Quality control</td>
<td>Agree Terms of Reference &amp; possible timeline for rule development</td>
<td>Consider Adoption of revised Emissions Rules for Supersonic Airplanes</td>
<td>If required, if no action taken at CAEP/8 consider adoption of revised Emissions rules for Supersonic Airplanes</td>
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<tr>
<td>Cruise Emissions</td>
<td>Global Atmospheric Impacts (e.g. climate change, ozone)</td>
<td>Consider existing global emissions assessments and promote new assessments.</td>
<td>Report status on new cruise emission assessments</td>
<td>Propose guidance on importance of cruise emissions with link to type of fleet (SSBJ and HSCT may be different)</td>
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ICAO supersonic regulatory goals and timelines. Adapted from International Civil Aviation Organization (2006). Review of Supersonic Standards-CAEP/7-WP-10. Montreal, Canada: Author

Now CAEP 11 (2019)?
Sonic Boom Hazards / Annoyance
Factors and Relationships for Sonic Boom Regulations

Sonic Boom
- Overpressure (psf)
- Perceived Level in Decibels (PLdB)

Other Noise
- Effective Perceived Noise Level (EPNL)
- Other noise metrics

Sonic Boom Hazards
Mitigation with Cockpit Display

• Restrictions of sonic boom intensity and locations are likely
• Sonic booms are affected by aircraft trajectory and changing atmospheric conditions, which are very difficult for pilots to judge unaided
• A real-time display of sonic boom prediction would allow pilots to make in-flight adjustments that allow them to comply with restrictions and mitigate the annoyance from sonic booms

Business Case for Civil Supersonic Aircraft

Business Case for Civil Supersonic Aircraft

Business Case for Civil Supersonic Aircraft

Percentage of cost (relative value) increase with percent of trip flown at subsonic speeds. Adapted from “The Investigation of Supersonic Commercial Transport Performance Issues Using Multivariate Optimization” by Lee and Nicholls, 1997, AIAA 97-5569.
Sonic Boom Basics
Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground

Sonic Boom Basics

Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground

M = 1.015

Sonic Boom Basics
Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground


M=1.10
Sonic Boom Basics
Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground.

M = 1.20

Sonic Boom Basics
Mach Cone and Ray Cone

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Sonic Boom Basics

Mach Cone and Ray Cone

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M = 1.50

Sonic Boom Basics
Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground

M = 1.60

Sonic Boom Basics
Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground

Sonic Boom Basics
Mach Cone and Ray Cone

- Shock waves, which are generated at the aircraft, can take several minutes to propagate forward on the ray cone to the ground

M=1.80

Sonic Boom Basics

N-Wave

• Much as a motorboat makes a 2-D “V” shaped wake on the water, a supersonic aircraft makes a 3-D cone-shaped shock wave pattern through the sky

Sonic Boom Carpet

- 50K ft altitude, Carpet is 50 miles wide
Sonic Boom Basics

Components of Boom

Sonic Boom Basics
Mach Cut-Off

• If the Mach number remains below about ~1.1–1.3, the refraction may prevent the boom from reaching the ground – this is called Mach Cutoff

• In a Mach Cutoff condition, the only noise heard may be a rumble, like distant thunder, or engine noise, or nothing at all

Sonic Boom Basics

Caustic Focus

- Sonic boom focusing occurs along the caustic, either from maneuvering or acceleration
- Focused sonic booms can have overpressures of 3 to 10 times normal booms

Sonic Boom Basics
Components of Boom

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**Sonic Boom Basics**

**Variables**

- Aircraft/Engine Configuration - Shaping
- Aircraft Weight
- Atmospherics-Temperature/Wind/Humidity
- Aircraft Trajectory-Speed/Altitude/Dive Angle
- Terrain/Topography

**Annoyance Levels**

- Concorde >2 psf
- 1.5 psf yields ~10-35%
- 0.3-0.5 psf yields ~ 1-5%
- Low Boom Aircraft may be even lower

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**Notional Low Boom Acceptability Criteria**

- Population
- Average
- Noise Sensitive
- Individuals

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*Image description:* The diagram illustrates the relationship between sonic boom levels and acceptability criteria, showing how varying factors affect the percentage of individuals who accept or are disturbed by the noise. The x-axis represents the level of sonic boom (from quieter to louder) in terms of psf, while the y-axis shows the percentage of acceptable individuals. The graph highlights different population segments such as noise-sensitive individuals and the average population, illustrating the threshold at which sonic booms are considered acceptable or unacceptable.
"Cockpit" Display of Boom

Positional Awareness Map 3 Dimensional
PAM3D
Cockpit Display
“GoogleEarth”

- Translation of data to display in GoogleEarth
- White line show trajectory of aircraft
- Sonic boom impact areas are color-coded to reflect pressure values

Predictive Display Capability

– Analyze planned trajectory and/or weather data to determine sonic boom impact locations and intensities, which will enable flights to be planned effectively

– Determine appropriate trajectory based on desired sonic boom footprint

– Provide in-flight cues to pilots, enabling them to achieve desired trajectory

– Provide system that allows air traffic controllers to analyze flight plans for approval, monitor aircraft in flight, and review flight data to enforce regulations

Flight Demonstrations

– NASA about to start F-18 flights with display in the cockpit

– We welcome input to improve the display symbology and usability

– Integration with future low boom demonstrator aircraft simulator, and then the actual vehicle
Flightdeck Integration

Isopemps Using Surface Pressure Symbology

OverPressure Contours Using Windshear Symbology

No Boom Regions Using Temporary Flight Restrictions Symbology

Concluding Remarks

• **Sonic Boom Propagation not intuitive:**
  – Atmospheric effects
  – Aircraft trajectory
  – Intensity

• **Display beneficial for:**
  – Development of supersonic rule change
  – Operational use

• **Flight demonstrations upcoming**
  – Development of display symbology and usability
Community Response to Sonic Boom: Notional Roadmap for Research to Support Standards Development

- **Past**
  - SSTG, WG1 & CAEP
    - Develop and approve methodologies, protocols standards and criteria

- **Now**
  - Research Community
    - Develop initial metrics, revise and improve based on test results
    - Develop models for atmospheric effects and flight operations, validate with flight

- **CAEP/11? CAEP/12?**
  - Draft Boom Standards
  - Draft Certification Criteria
  - Metric for Draft Standards
  - Models for Draft Cert. Criteria

**Standards Development**
- SSTG, WG1 & CAEP
  - Develop and approve methodologies, protocols standards and criteria

**Metric Development & Validation**
- Research Community
  - Develop initial metrics, revise and improve based on test results

**Effects of the Atmosphere & Flight Operations**
- Research Community
  - Develop models for atmospheric effects and flight operations, validate with flight

**Research Aircraft Development**
- Industry, Government Agencies?
  - Design and build low boom testbed, validate signature and flight performance

**Community Exposure Tests**
- Research Community, Industry, Government Agencies
  - Develop protocols for community testing, conduct pilot tests
  - Conduct initial community overflight experiments

**Statistical Extrapolation to General Population Exposure**
- Research Community, Government Agencies
  - Develop model for reaction vs. exposure (single, multiple events, route exposure)
  - Conduct initial community response assessments

- Aircraft Cleared for Flight
- Initial Community Test Complete
- Correlation & Assessment of Model for Draft Standards
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FAA Regulations

Ref: http://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/supersonic_aircraft_noise/
FAA Regulations

- 14CFR §91.821-Civil supersonic airplanes: Noise limits.

Except for Concorde airplanes having flight time before January 1, 1980, no person may operate in the United States, a civil supersonic airplane that does not comply with Stage 2 noise limits of part 36 in effect on October 13, 1977, using applicable trade-off provisions.
FAA Regulations

- **14CFR § 91.819-Civil supersonic airplanes that do not comply with part 36.**

(a) **Applicability.** This section applies to civil supersonic airplanes that have not been shown to comply with the Stage 2 noise limits of part 36 in effect on October 13, 1977, using applicable trade-off provisions, and that are operated in the United States, after July 31, 1978.

(b) **Airport use.** Except in an emergency, the following apply to each person who operates a civil supersonic airplane to or from an airport in the United States:

1. Regardless of whether a type design change approval is applied for under part 21 of this chapter, no person may land or take off an airplane covered by this section for which the type design is changed, after July 31, 1978, in a manner constituting an "acoustical change" under Sec. 21.93 unless the acoustical change requirements of part 36 are complied with.

2. No flight may be scheduled, or otherwise planned, for takeoff or landing after 10 p.m. and before 7 a.m. local time.
FAA Regulations

- Appendix B--Authorizations to Exceed Mach 1 (§91.817) § B91.1-Section 1. Application.

- (a) An applicant for an authorization to exceed Mach 1 must apply in a form and manner prescribed by the Administrator and must comply with this appendix.
- (b) In addition, each application for an authorization to exceed Mach 1 covered by section 2(a) of this appendix must contain all information requested by the Administrator necessary to assist him in determining whether the designation of a particular test area or issuance of a particular authorization is a "major Federal action significantly affecting the quality of the human environment" within the meaning of the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.), and to assist him in complying with that act and with related Executive Orders, guidelines, and orders prior to such action.
- (c) In addition, each application for an authorization to exceed Mach 1 covered by section 2(a) of this appendix must contain--
  - (1) Information showing that operation at a speed greater than Mach 1 is necessary to accomplish one or more of the purposes specified in section 2(a) of this appendix, including a showing that the purpose of the test cannot be safely or properly accomplished by overocean testing;
  - (2) A description of the test area proposed by the applicant, including an environmental analysis of that area meeting the requirements of paragraph (b) of this section; and
  - (3) Conditions and limitations that will ensure that no measurable sonic boom overpressure will reach the surface outside of the designated test area.
- (d) An application is denied if the Administrator finds that such action is necessary to protect or enhance the environment.
FAA Regulations

• Appendix B--Authorizations to Exceed Mach 1 (Sec. 91.817) Sec. B91.2-Section 2. Issuance.

• (a) For a flight in a designated test area, an authorization to exceed Mach 1 may be issued when the Administrator has taken the environmental protective actions specified in section 1(b) of this appendix and the applicant shows one or more of the following:
  • (1) The flight is necessary to show compliance with airworthiness requirements.
  • (2) The flight is necessary to determine the sonic boom characteristics of the airplane or to establish means of reducing or eliminating the effects of sonic boom.
  • (3) The flight is necessary to demonstrate the conditions and limitations under which speeds greater than a true flight Mach number of 1 will not cause a measurable sonic boom overpressure to reach the surface.
• (b) For a flight outside of a designated test area, an authorization to exceed Mach 1 may be issued if the applicant shows conservatively under paragraph (a)(3) of this section that--
  • (1) The flight will not cause a measurable sonic boom overpressure to reach the surface when the aircraft is operated under conditions and limitations demonstrated under paragraph (a)(3) of this section; and
  • (2) Those conditions and limitations represent all foreseeable operating conditions
Sonic Boom NASA Research

- N+2 Design Studies
- Cruise Boom Signature
- Transition Focus Boom Signature
- Primary Boom Carpet
- Secondary Boom Carpet
- Secondary Boom Signature
- Lateral Cutoff Boom Signature
- • FaINT Project
- • Structural Response
- • Indoor Human Response
- • WSPR Project
- • OTTR Project

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Mach Jump

- Airdata systems can show a jump of hundreds of feet of altitude when going through Mach 1.0 while the aircraft is level.
- Need to filter altitude data before transmission to ATC and/or educate controllers of problem.
The sonic boom prediction tool merges it with real-time aircraft data feeding a local area moving map display.

The current sonic boom footprint is displayed on the map.

For certain lower Mach and higher altitude flight conditions, the shock waves refract upward and never reach the ground (i.e., Mach cutoff condition).

The display would show the maximum Mach number and/or minimum altitude to prevent shock waves from reaching the ground.

Predictive Display Capability

- Pilot selectable menu of preprogrammed maneuvers, such as accelerations, turns, or push overs.
- Selected maneuver’s sonic boom footprint shown on map, for pilot to accept or modify parameters of that maneuver to place the footprint in the desired location.
- Certain locations may be "No Boom" zones, while other locations may be an insensitive place to put inevitable acceleration or focus booms, or of military interest for loud booms.
- After the pilot has accepted a future maneuver, guidance information is given to the pilot to execute that maneuver.

Contact Information

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