Sonic Boom Awareness in the Civil Supersonic Cockpit

Presented to: Flight Test Safety Workshop

By: Robert “Buck” Joslin (FAA) and Ed Haering Jr (NASA-Dryden)

Date: April 23-25, 2013

FLIGHT TEST SAFETY COMMITTEE

Topics

- Regulations
- Sonic Boom Hazards / Annoyances
- Business Case for Civil Supersonic Aircraft
- Sonic Boom Basics
- Cockpit Display
- Predictive Display Capability
- Flightdeck Integration

FAA Regulations

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.

FAA Regulations

14CFR §36.301- Noise limits: Concorde

Part 36 NOISE STANDARDS: AIRCRAFT TYPE AND AIRWORTHINESS CERTIFICATION

Subpart D--Noise Limits for Supersonic Transport Category Airplanes

(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

Noise

Sonic Boom

Emissions

Certification Condition	Environmental Protection Area	CAEP 7 Mtg (2007)	CAEP 8 Mtg (2010)	CAEP 9 Mtg (2013)
Noise certification	Surrounding Airport community noise impact	Agree Terms of Reference & Possible timeline for rule development	Consider Adoption of Current Subsonic Noise Rule for Supersonic Airplanes	If required, Propose Modification to Current Supersonic Noise rule for Supersonic Airplanes
Sonic Boom	En-route Sonic Boom control	Agree Terms of Reference & possible timeline for rule development	Report status on Acceptable metric and on Animal and Human Response Assessments Reassess terms of Reference	Propose Supersonic Rule with: 1) Acceptable metric 2) Acceptable limits 3) Demonstration method
LTO Emissions	Local Air Quality control	Agree Terms of Reference & possible timeline for rule development	Consider Adoption of revised Emissions Rules for Supersonic Airplanes	If required, (if no action taken at CAEP/8) consider adoption of revised Emissions rules for Supersonic Airplanes
Cruise Emissions	Global Atmospheric Impacts (e.g. climate change, ozone)	Consider existing global emissions assessments and promote new assessments.	Report status on new cruise emission assessments	Propose guidance on importance of cruise emissions with link to type of fleet (SSBJ and HSCT may be different)

Now CAEP 11 (2019) ?

ICAO supersonic regulatory goals and timelines. Adapted from International Civil Aviation Organization (2006). Review of Supersonic Standards-CAEP/7-WP-10. Montreal, Canada: Author

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

Hazard / Annoyance

- Research and standard required
- Impact assessment and public education/awareness required
- Not an issue

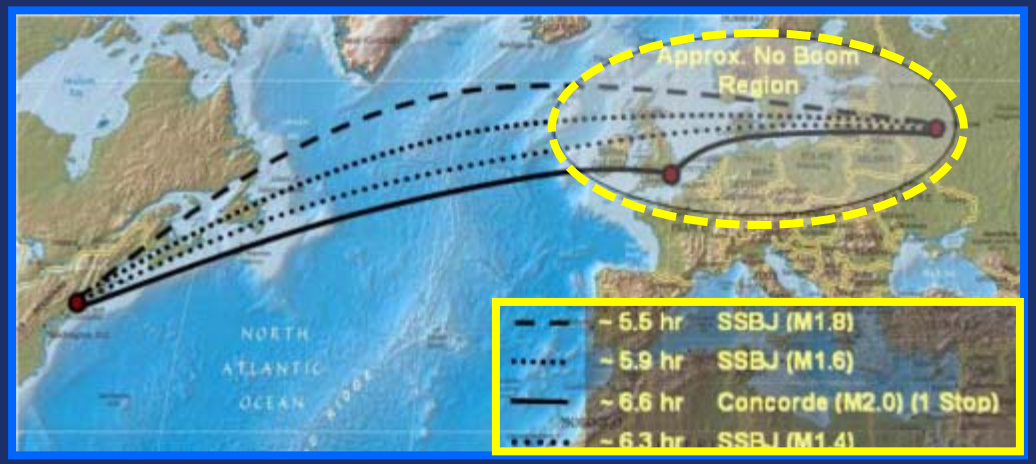
Ref: Joslin, R. E.,(2011). A case for federal aviation regulations to develop civil supersonic transport aircraft. *International Journal of Applied Aviation Studies*, 11(2), 13-36.

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**

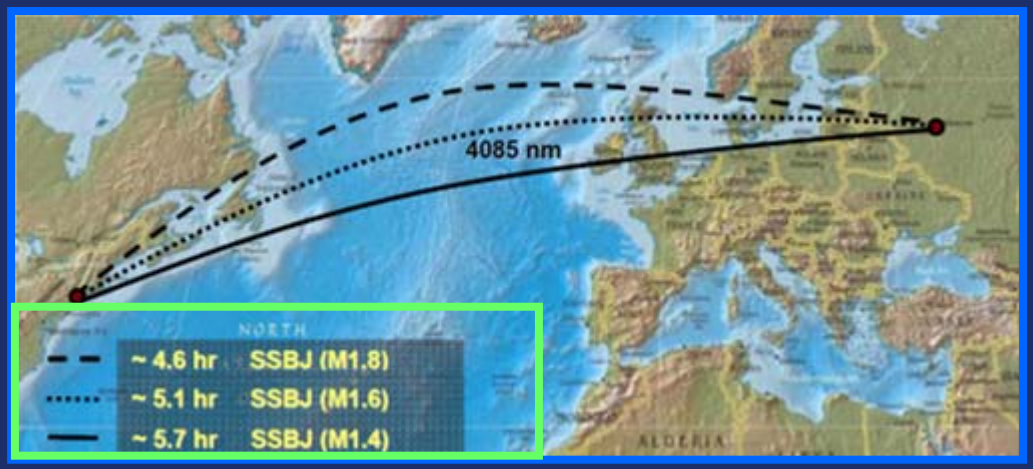
Ref: Adapted from Haering, E. (2010). Real-Time sonic boom display, *NASA Dryden Flight Research Center* [PowerPoint Slides]. Edwards AFB, CA.

Business Case for Civil Supersonic Aircraft



With Overland Sonic Boom Restriction

Without Overland Sonic Boom Restriction



Ref: Chudoba, B., Oza, A., Robert, K., Mixon, B., Colema n, G., & Czysz, P. (2007, January). Whatprice supersonic speed? An applied market research case study-part 2. *45th AIAA Aerospace Sciences Meeting and Exhibit*. Reno, NV.

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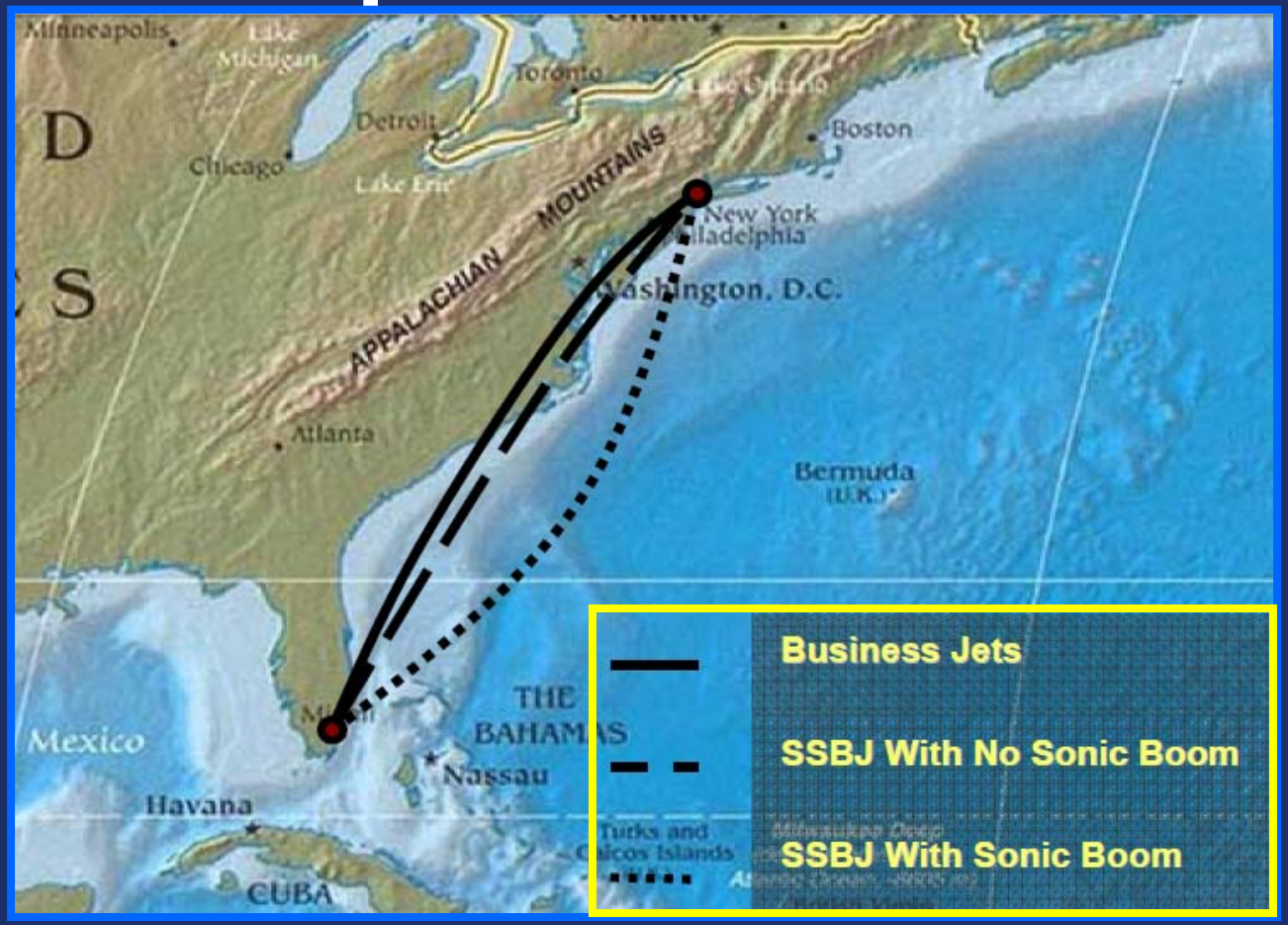

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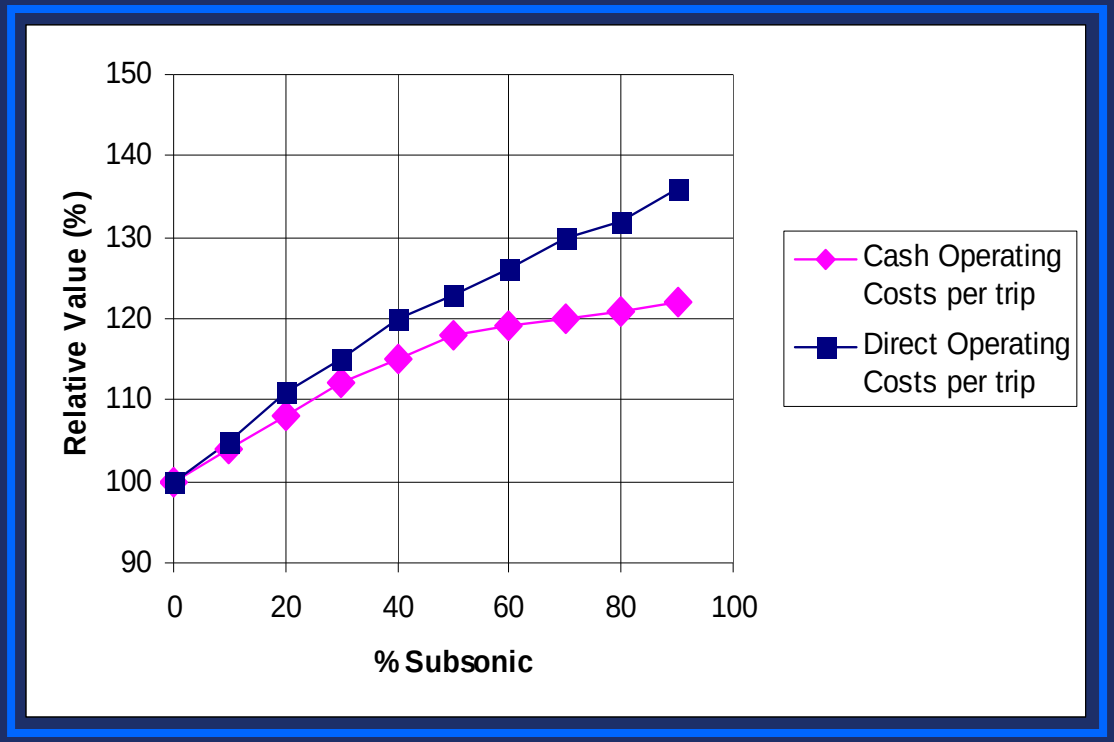
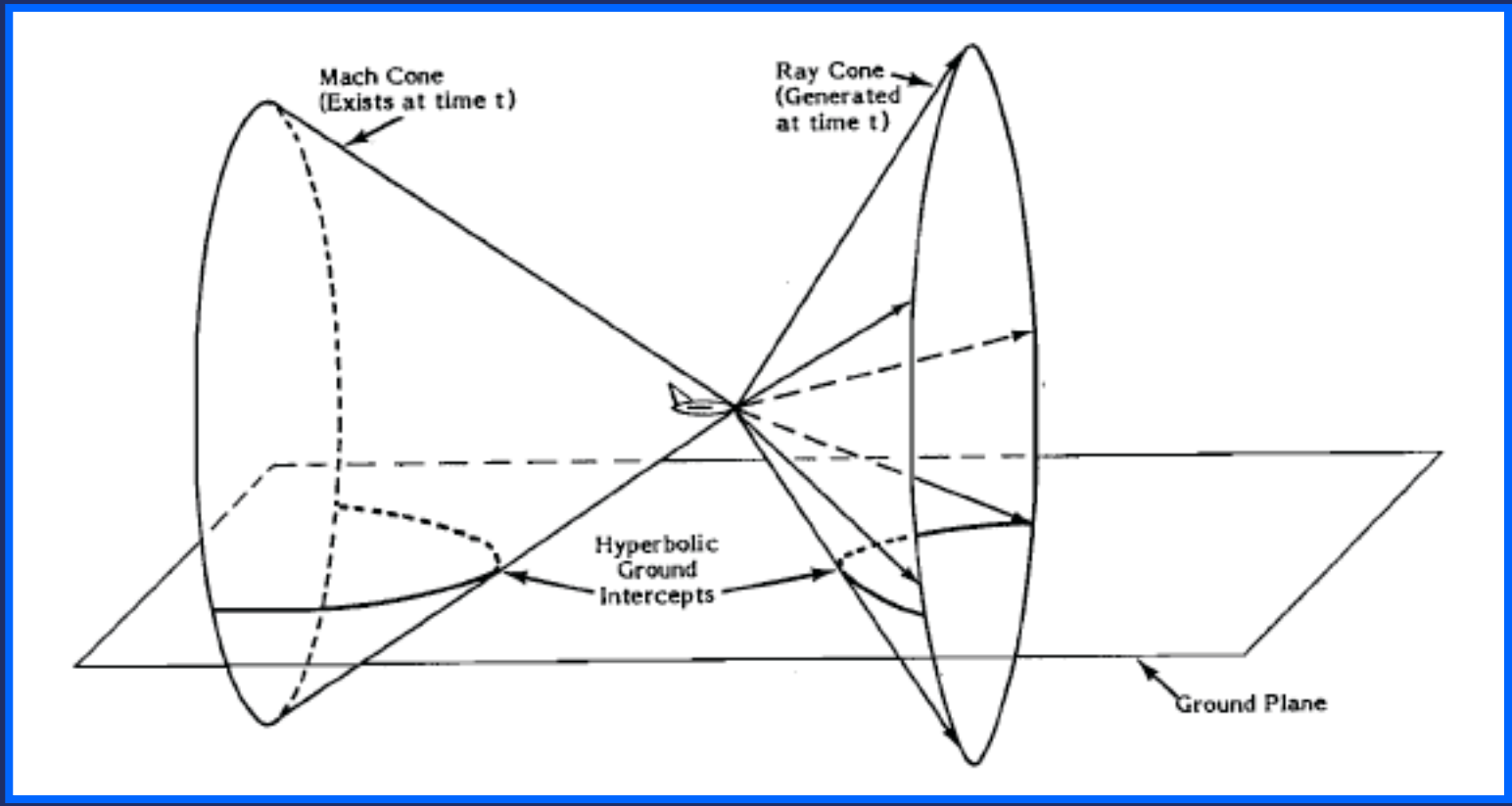


Percentage of cost (relative value) increase with percent of trip flown at subsonic speeds. Adapted from "The Investigation of Supersonic Commercial Transport Performance Issues Using Multivariate Optimization" by Lee and Nicholls,1997, *AIAA 97-5569.*

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**



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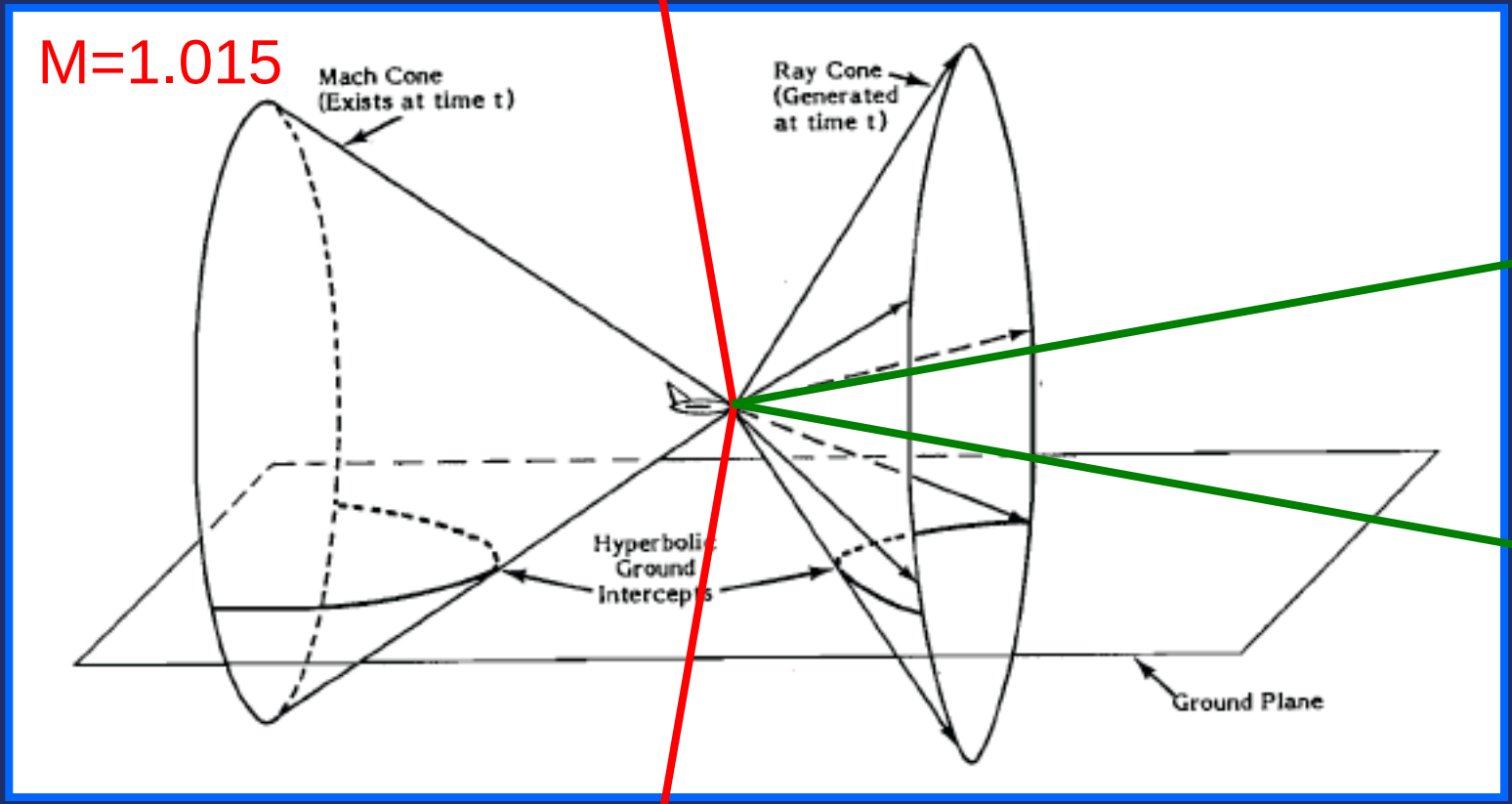

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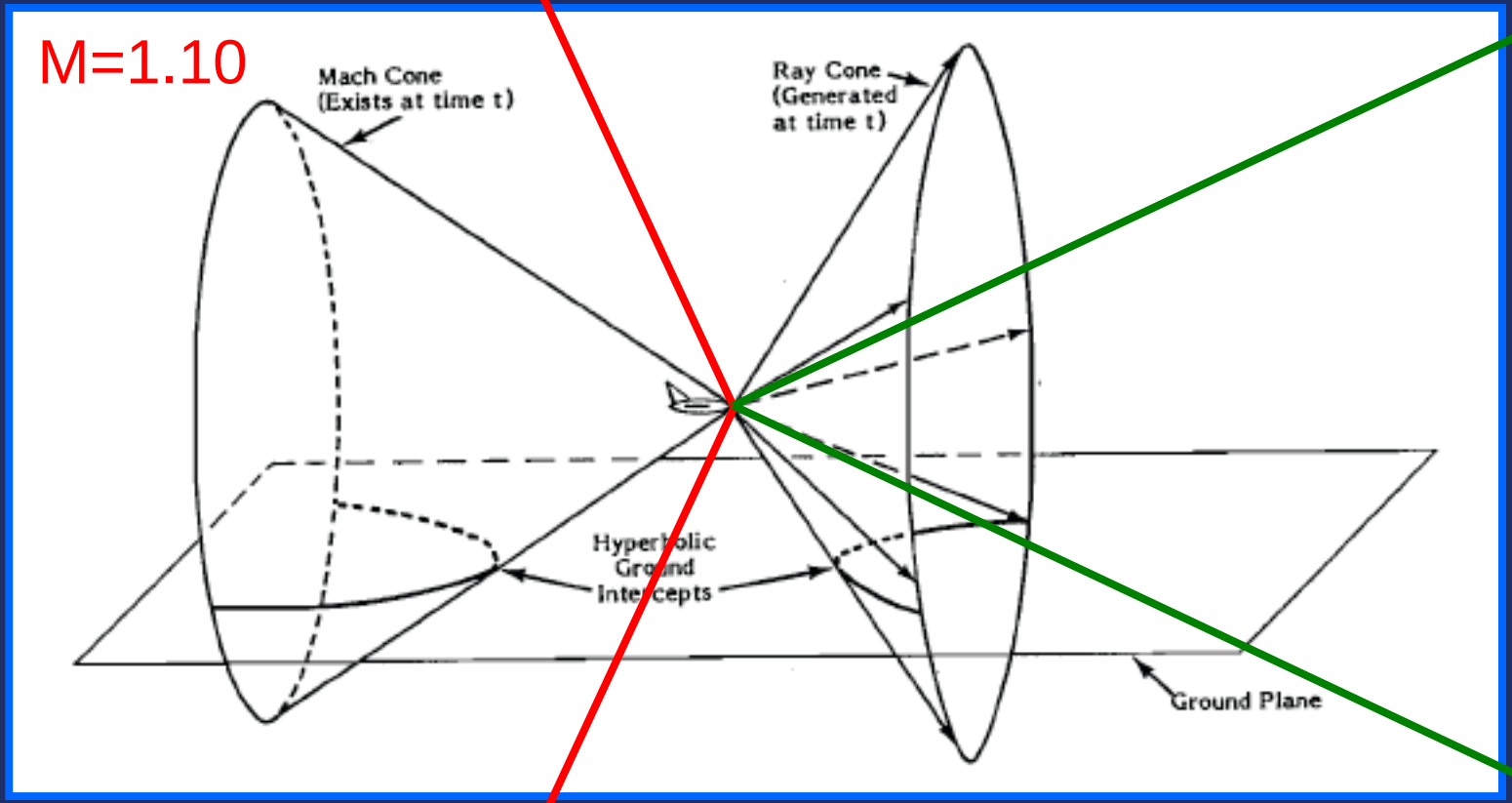

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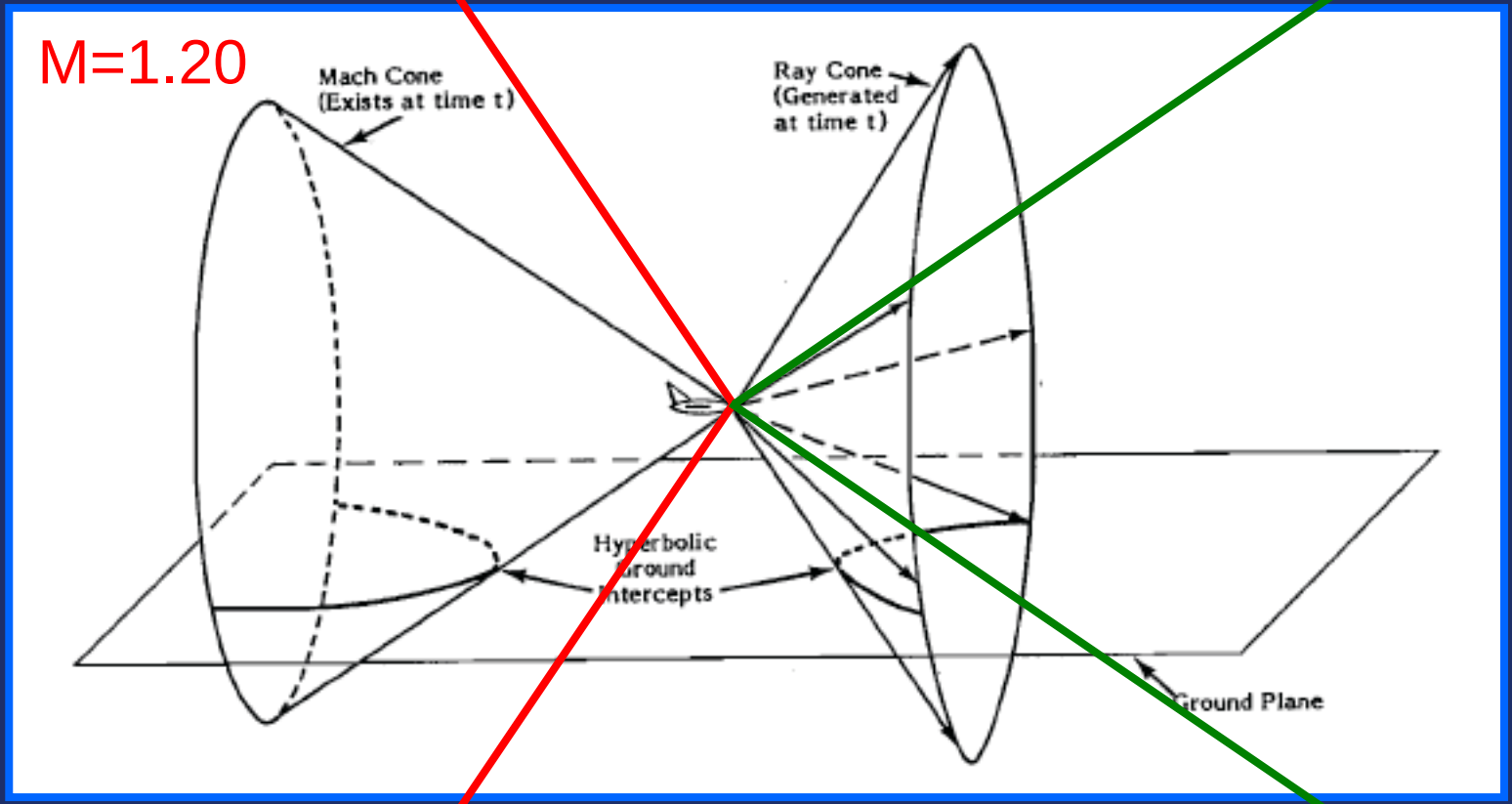

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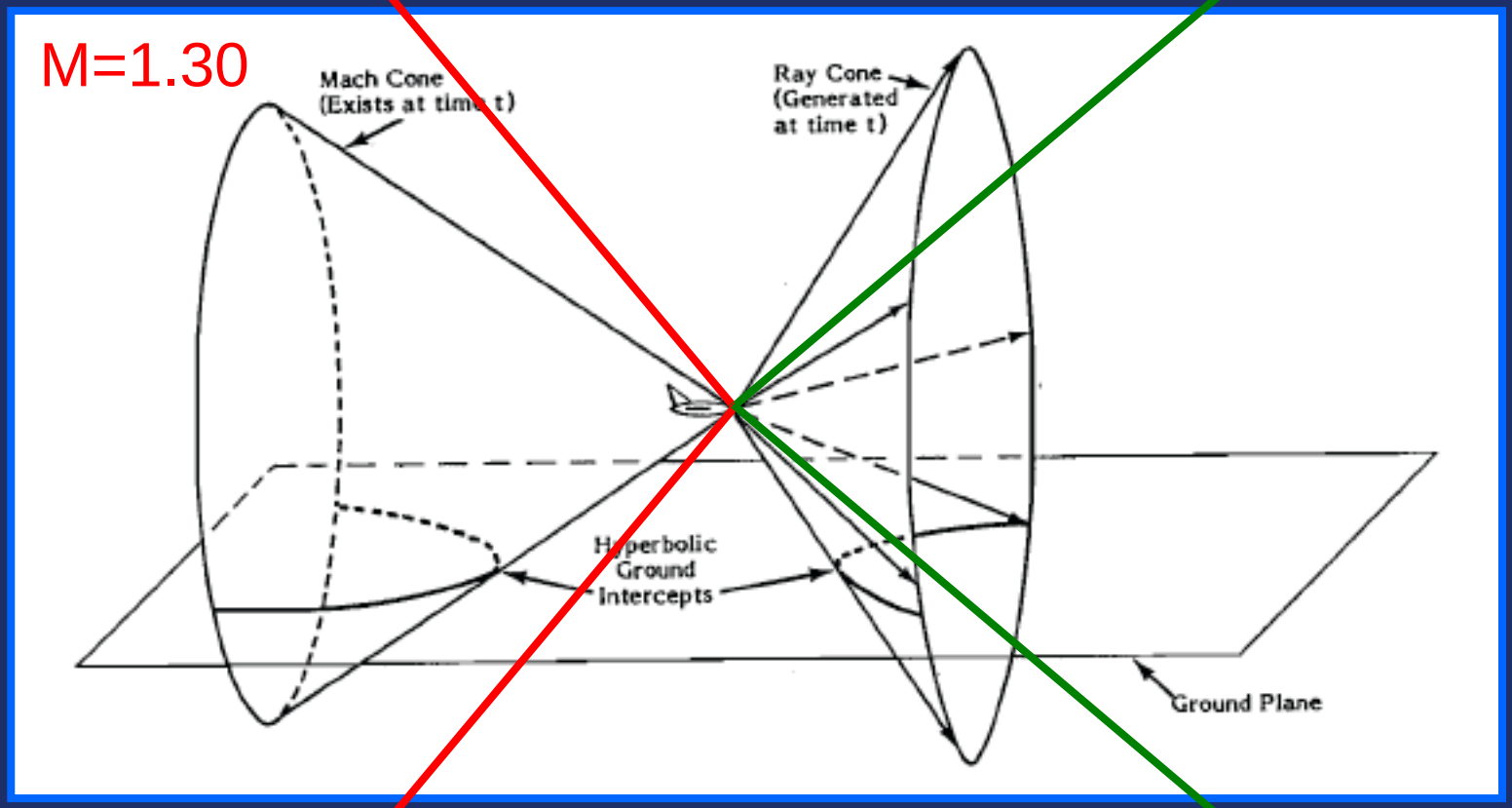

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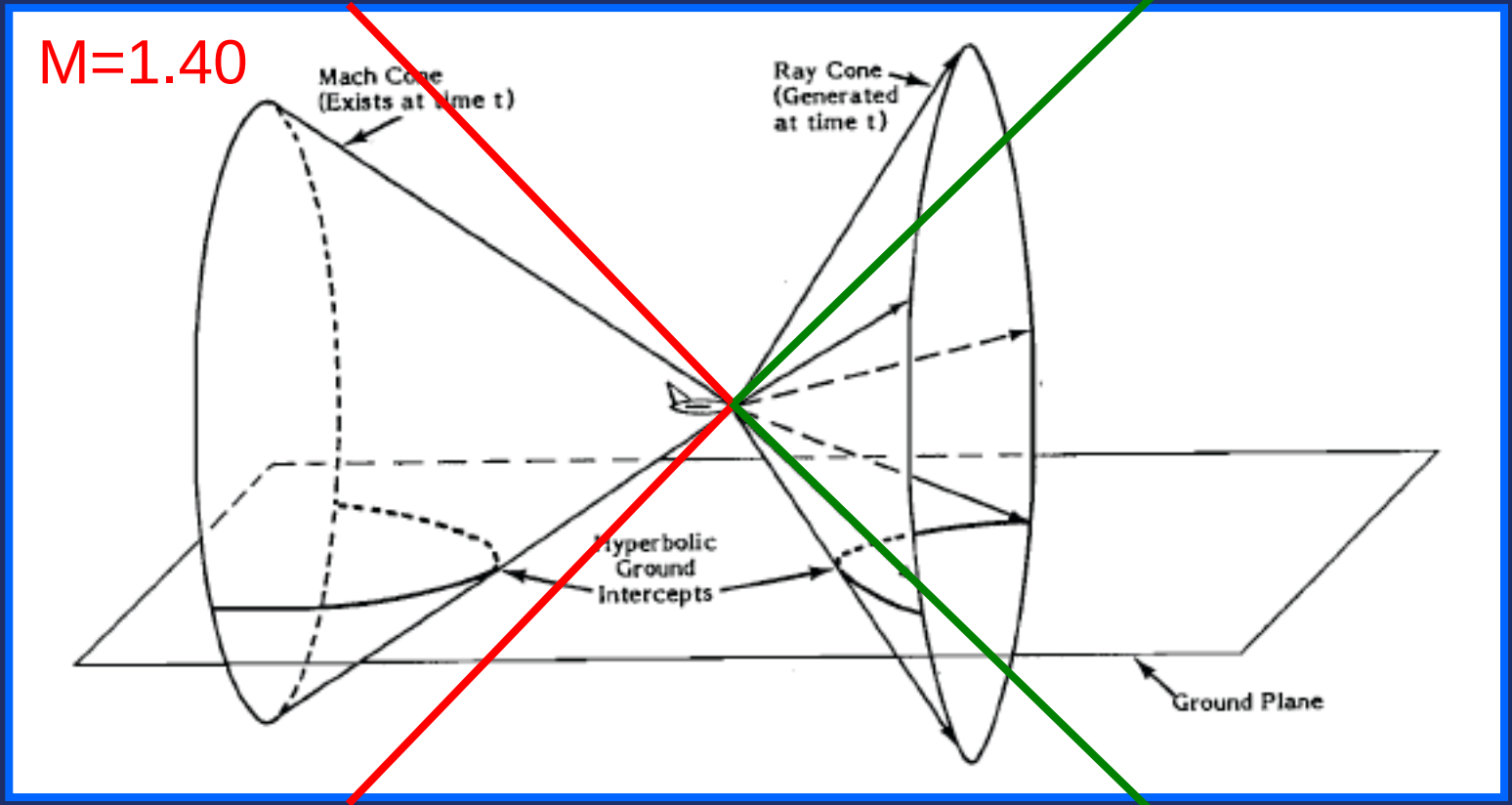

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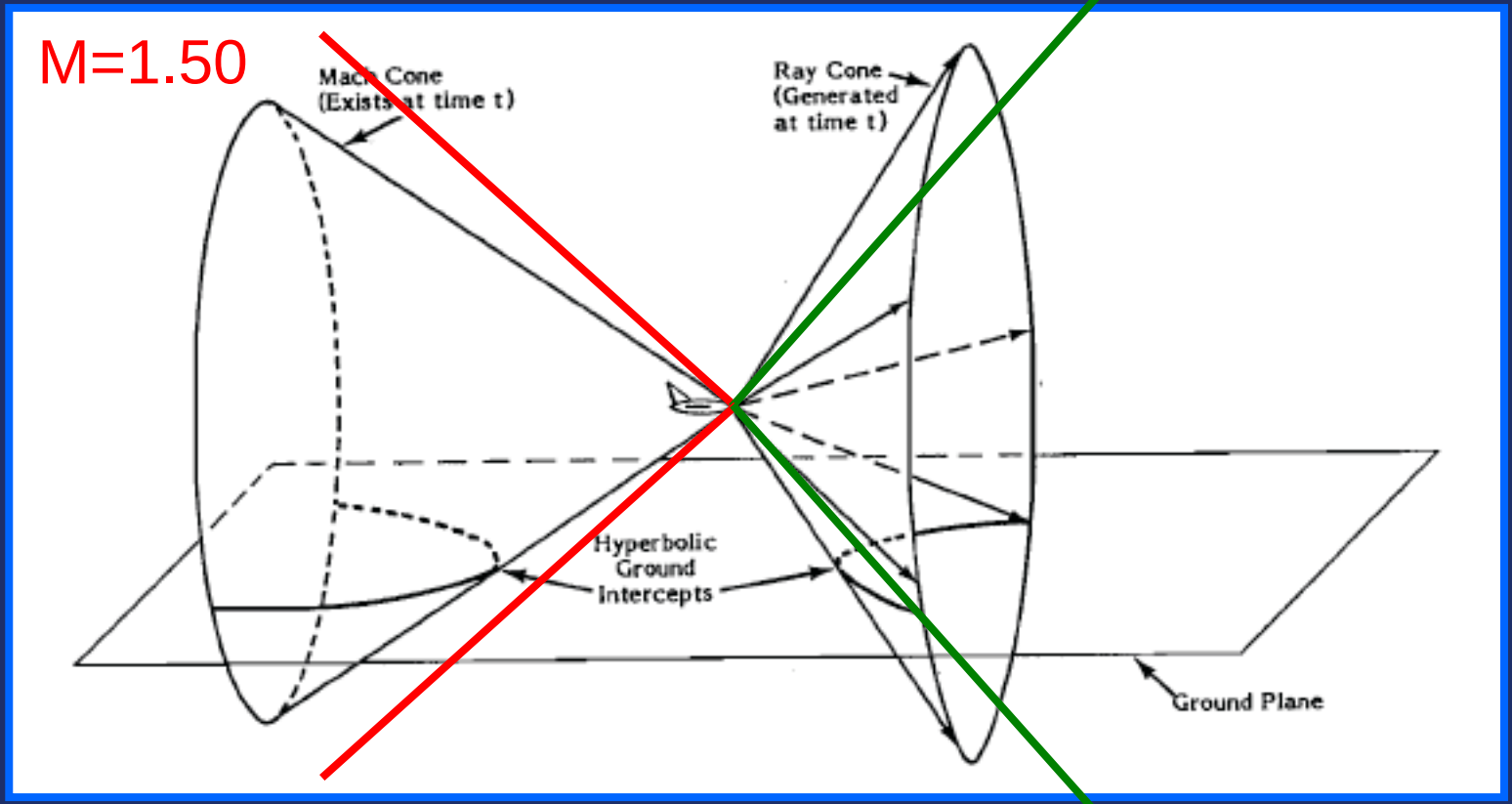

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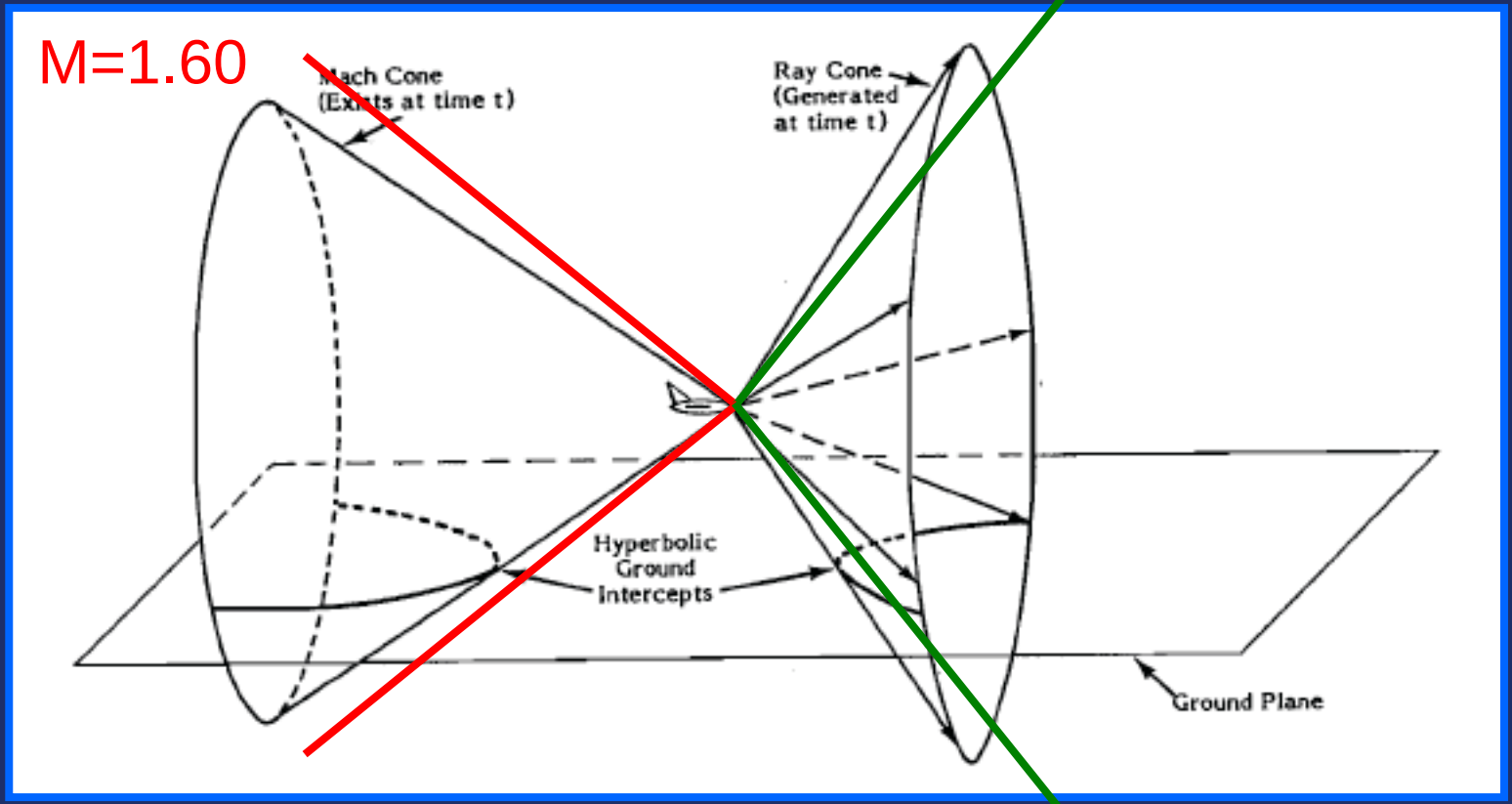

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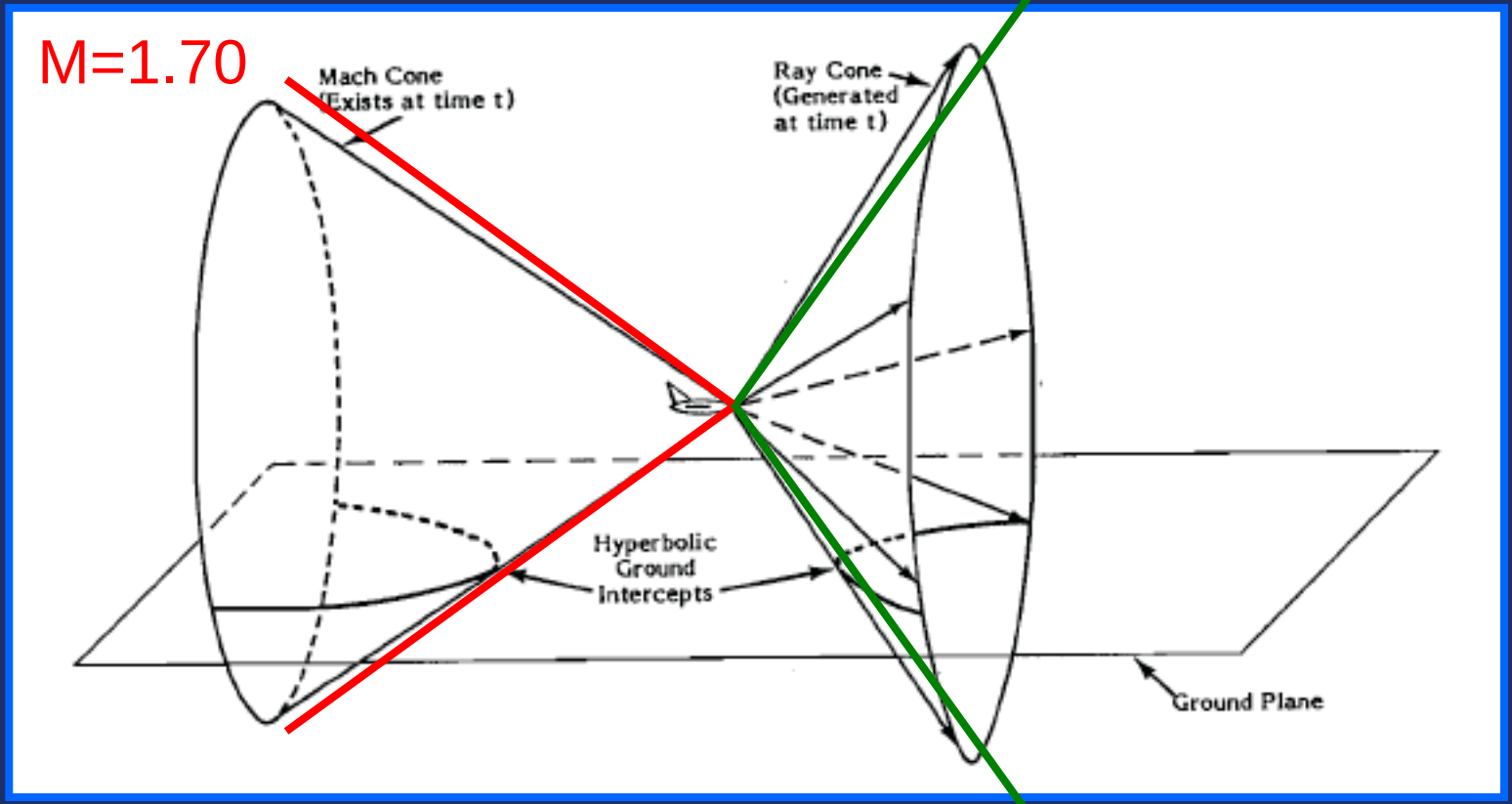

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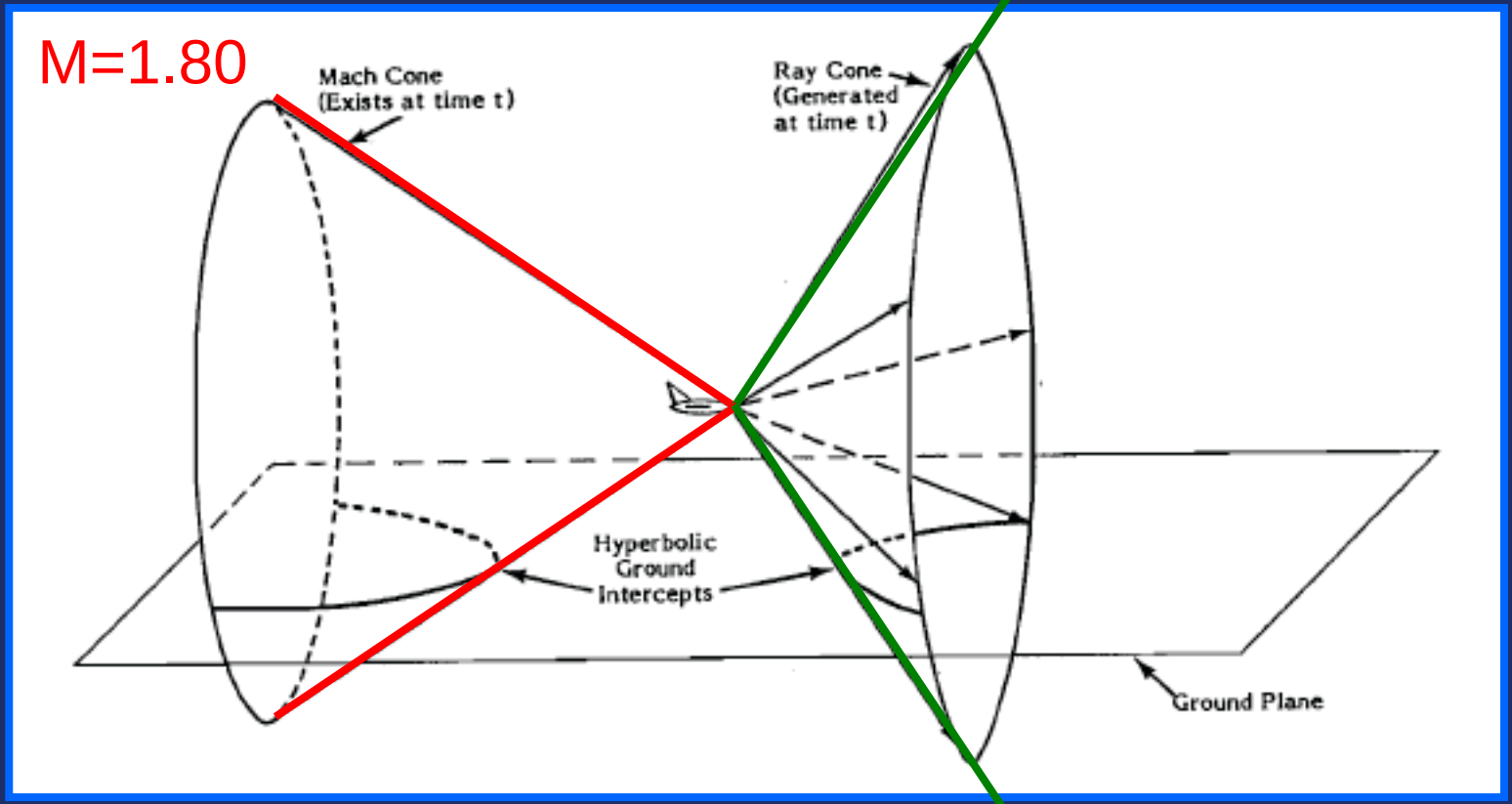

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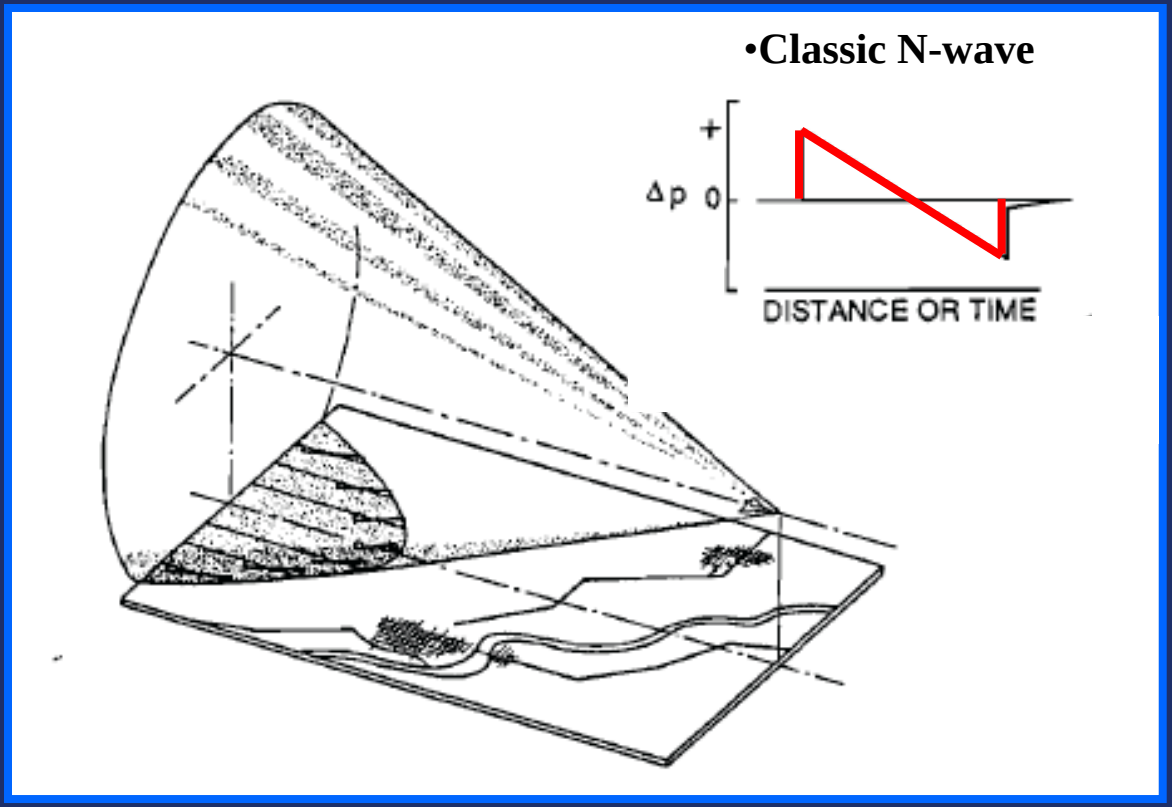
Sonic Boom Basics

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**



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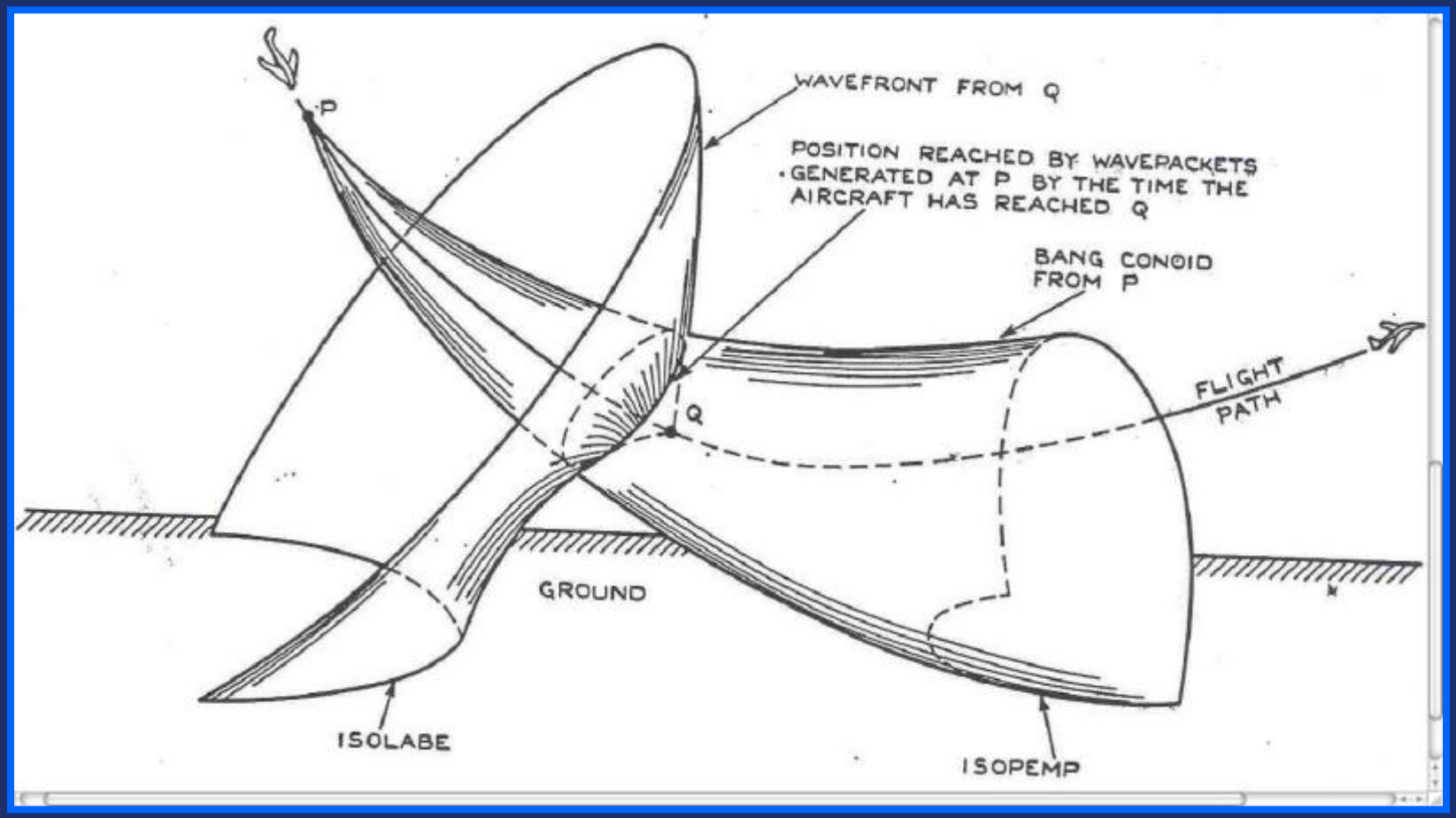
Sonic Boom Carpet

- **50K ft altitude, Carpet is 50 miles wide**

Sonic Boom Basics

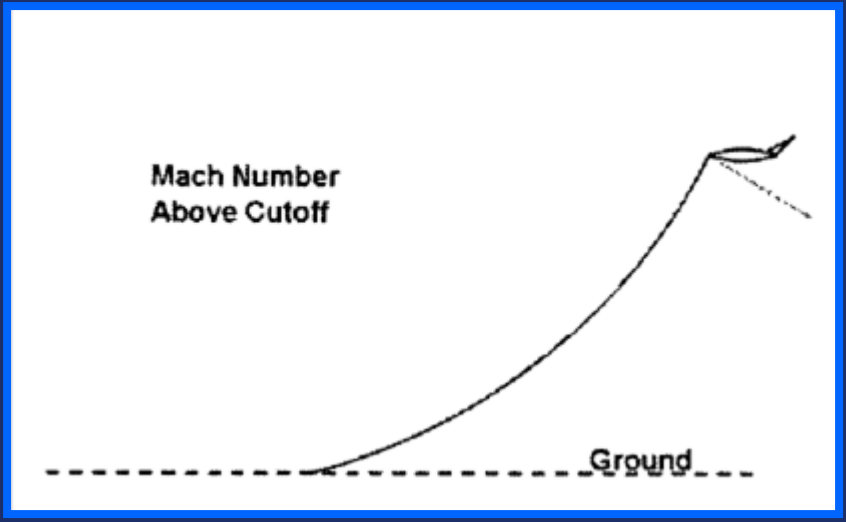
Components of Boom

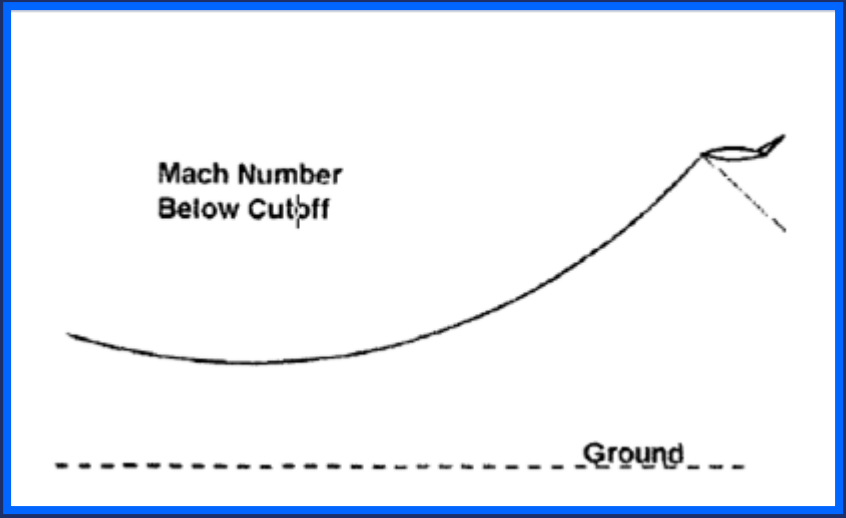


Ref: Adapted from Warren, C. H. E. (1964). The Propagation of Sonic Bangs in a Nonhomogeneous Still Atmosphere. *AIAA Preprint*, (64-547).

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





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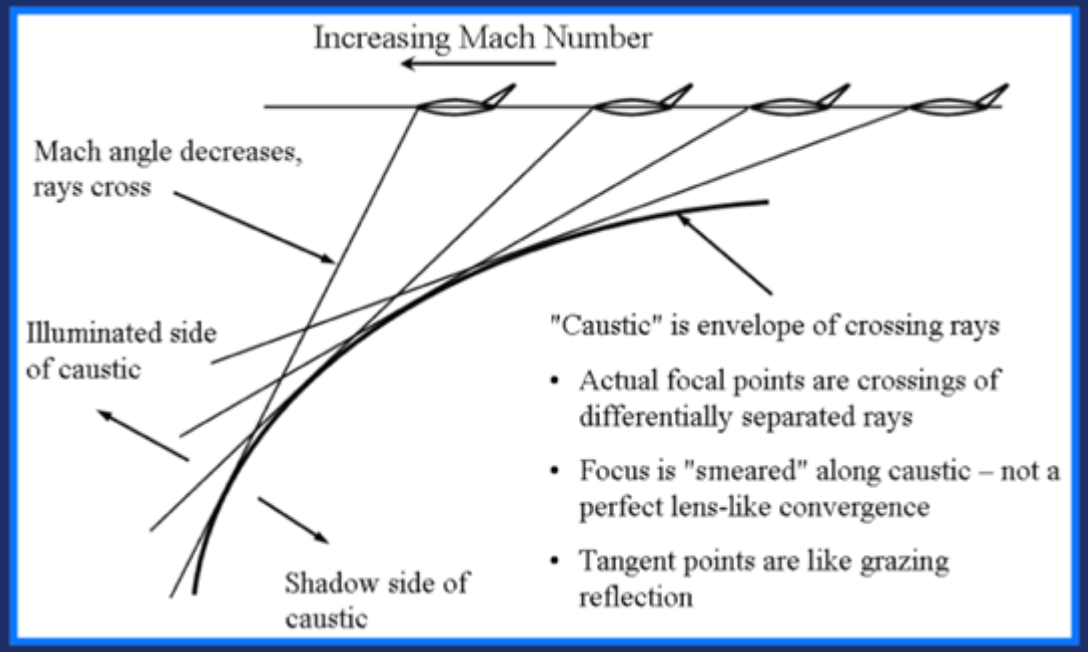
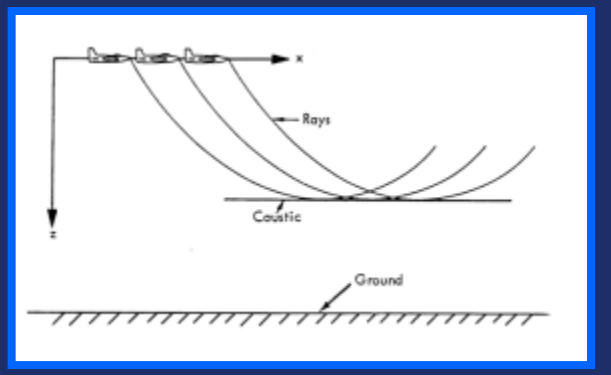
Sonic Boom Basics

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**





Caustic at Mach Cut-off

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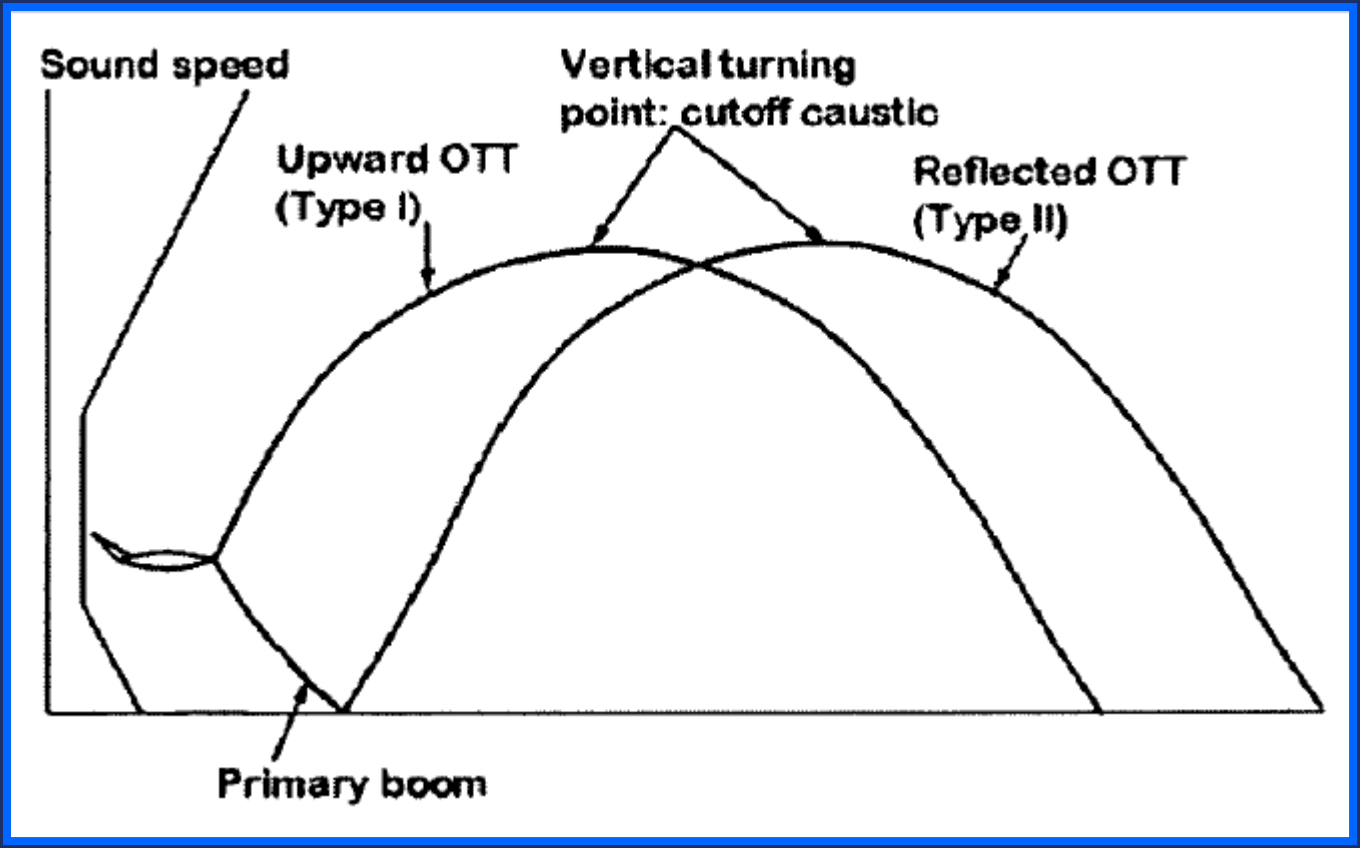
Sonic Boom Basics

Components of Boom



Ref: Haering, E. (2010). Real-Time sonic boom display, *NASA Dryden Flight Research Center* [PowerPoint Slides]. Edwards AFB, CA.

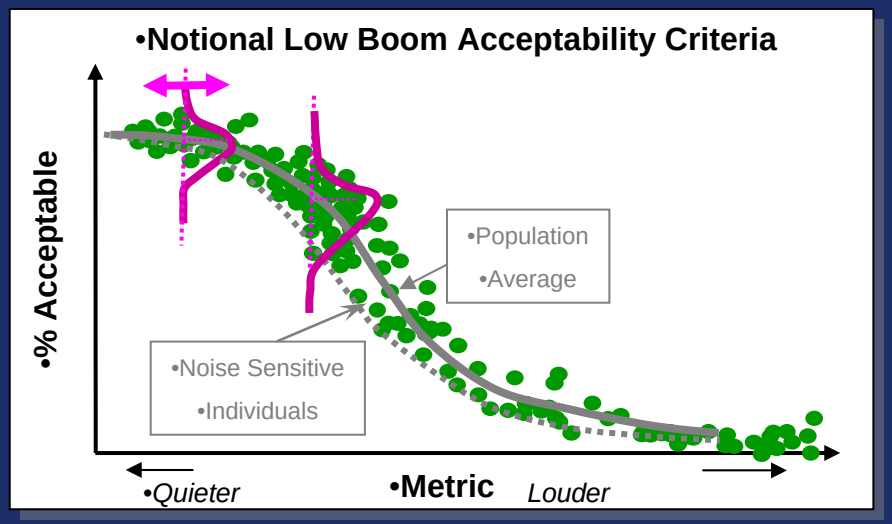
Sonic Boom Basics

Variables

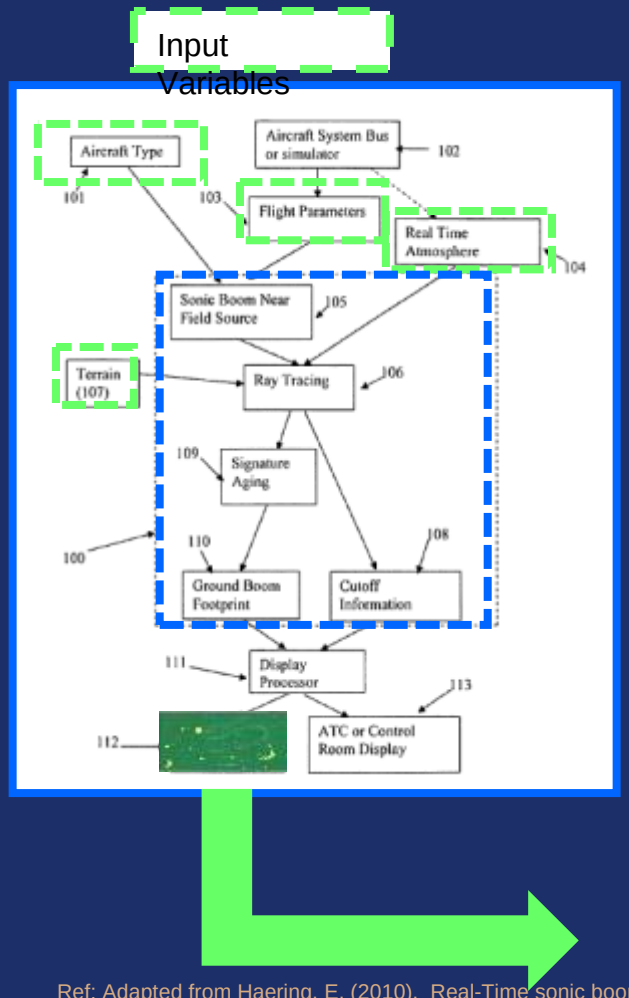
- Aircraft/Engine Configuration - Shaping
- Aircraft Weight
- Atmospherics-Temperature/Wind/Humidity
- Aircraft Trajectory-Speed/Altitude/Dive Angle
- Terrain/Topography

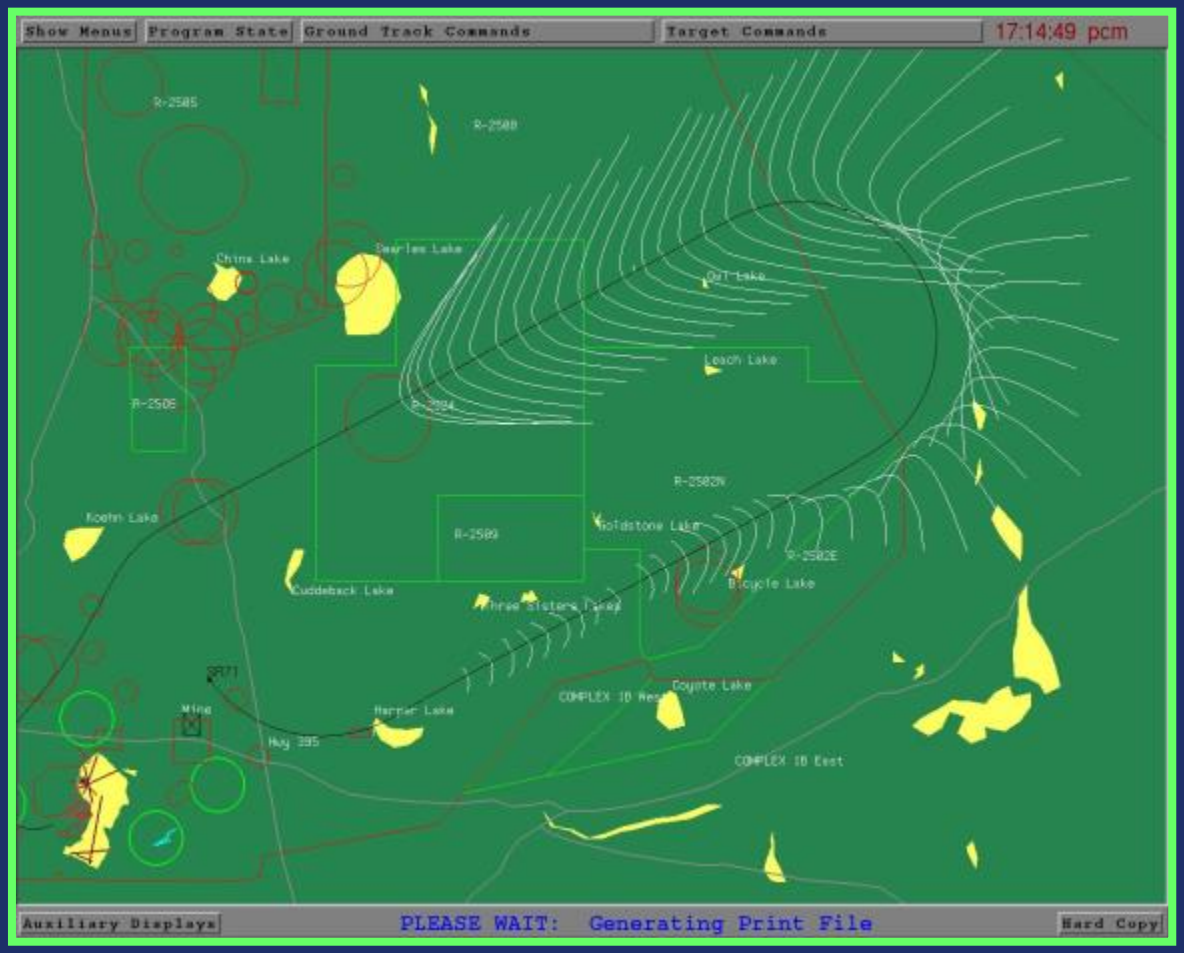
Annoyance Levels

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



“Cockpit” Display of Boom





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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**

Ref: Haering, E. (2010). Real-Time sonic boom display, *NASA Dryden Flight Research Center* [PowerPoint Slides]. Edwards AFB, CA.

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 then 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

Ref: Adapted from Haering, E. (2010). Real-Time sonic boom display, *NASA Dryden Flight Research Center* [PowerPoint Slides]. Edwards AFB, CA.

Flight Demonstrations

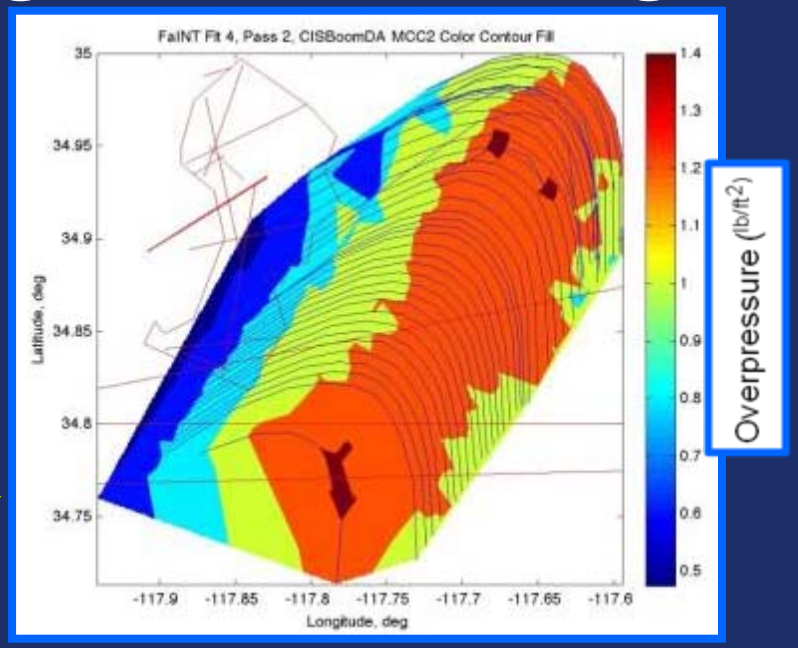
- NASA about to start F-18 flights with display in the cockpit
- We welcome input to improve the display symbology and usability
- Integration with future low boom demonstrator aircraft simulator, and then the actual vehicle

Flightdeck Integration

TCAS

Weather

EGPWS



HUD

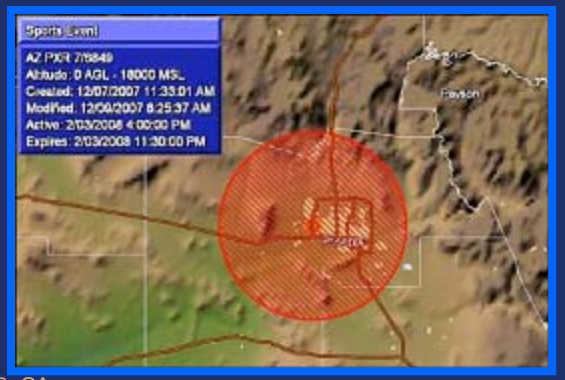
Synthetic Vision

FMS

Isopemps Using
Surface Pressure Symbology

OverPressure Contours Using
Windshear Symbology

No Boom Regions Using
Temporary Flight Restrictions Symbology



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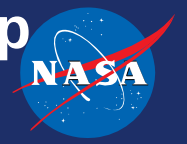
Concluding Remarks

- **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

Backup Slides

Community Response to Sonic Boom: Notional Roadmap for Research to Support Standards Development



•PAST •NOW •CAEP/11? CAEP/12?

Standards Development

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

• Draft Boom Standards

• Draft Certification Criteria

Metric Development & Validation

- •Research Community
- Develop initial metrics, revise and improve based on test results

• Metric for Draft Standards

Effects of the Atmosphere & Flight Operations

- •Research Community
- Develop models for atmospheric effects and flight operations, validate with flight

• Models for Draft Cert. Criteria

Research Aircraft Development

- •Industry, Government Agencies?
- •Design and build low boom testbed, validate signature and flight performance

• Aircraft Cleared for Flight

•Community Exposure Tests

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

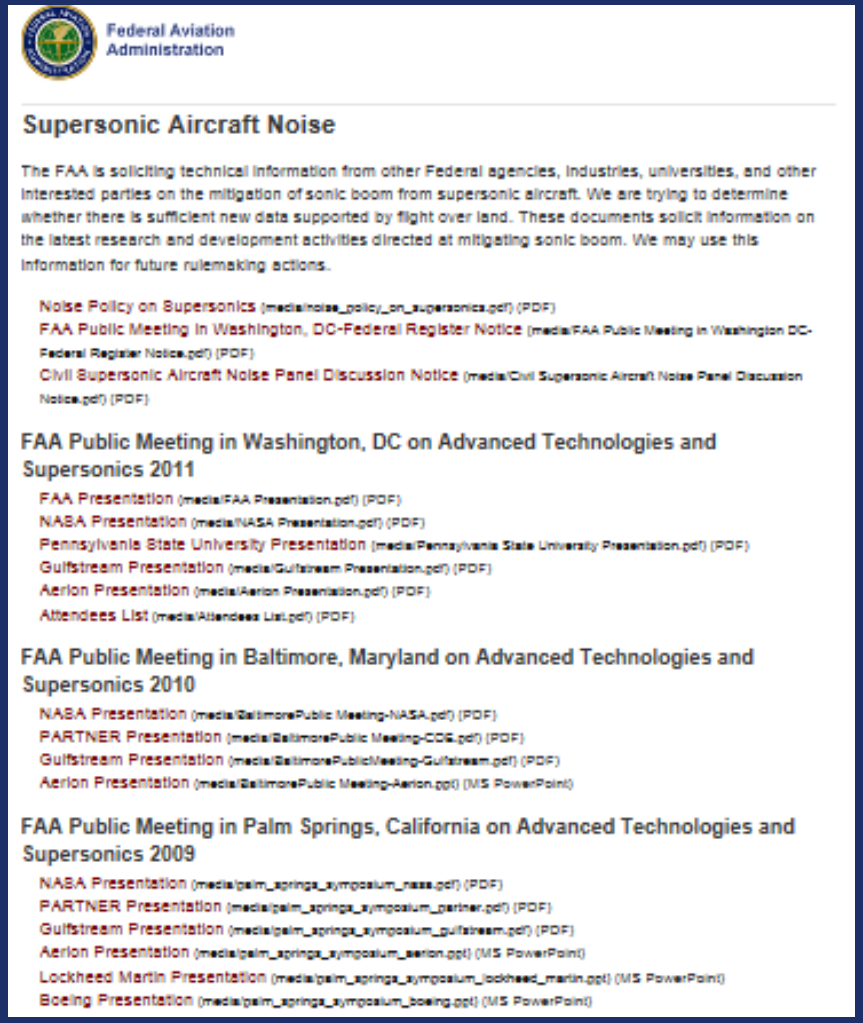
• Initial Community Test Complete

•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

•Correlation & Assessment of Model for Draft Standards

FAA Regulations



Federal Aviation Administration

Supersonic Aircraft Noise

The FAA is soliciting technical information from other Federal agencies, industries, universities, and other interested parties on the mitigation of sonic boom from supersonic aircraft. We are trying to determine whether there is sufficient new data supported by flight over land. These documents solicit information on the latest research and development activities directed at mitigating sonic boom. We may use this information for future rulemaking actions.

Noise Policy on Supersonics (media/noise_policy_on_supersonics.pdf) (PDF)
FAA Public Meeting in Washington, DC-Federal Register Notice (media/FAA Public Meeting in Washington DC-Federal Register Notice.pdf) (PDF)
Civil Supersonic Aircraft Noise Panel Discussion Notice (media/Civil Supersonic Aircraft Noise Panel Discussion Notice.pdf) (PDF)

FAA Public Meeting in Washington, DC on Advanced Technologies and Supersonics 2011

FAA Presentation (media/FAA Presentation.pdf) (PDF)
NASA Presentation (media/NASA Presentation.pdf) (PDF)
Pennsylvania State University Presentation (media/Pennsylvania State University Presentation.pdf) (PDF)
Gulfstream Presentation (media/Gulfstream Presentation.pdf) (PDF)
Aerion Presentation (media/Aerion Presentation.pdf) (PDF)
Attendees List (media/Attendees List.pdf) (PDF)

FAA Public Meeting in Baltimore, Maryland on Advanced Technologies and Supersonics 2010

NASA Presentation (media/BaltimorePublic Meeting-NASA.pdf) (PDF)
PARTNER Presentation (media/BaltimorePublic Meeting-COE.pdf) (PDF)
Gulfstream Presentation (media/BaltimorePublicMeeting-Gulfstream.pdf) (PDF)
Aerion Presentation (media/BaltimorePublic Meeting-Aerion.ppt) (MS PowerPoint)

FAA Public Meeting in Palm Springs, California on Advanced Technologies and Supersonics 2009

NASA Presentation (media/palm_springs_symposium_nasa.pdf) (PDF)
PARTNER Presentation (media/palm_springs_symposium_partner.pdf) (PDF)
Gulfstream Presentation (media/palm_springs_symposium_gulfstream.pdf) (PDF)
Aerion Presentation (media/palm_springs_symposium_aerion.ppt) (MS PowerPoint)
Lockheed Martin Presentation (media/palm_springs_symposium_lockheed_martin.ppt) (MS PowerPoint)
Boeing Presentation (media/palm_springs_symposium_boeing.ppt) (MS PowerPoint)

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.**

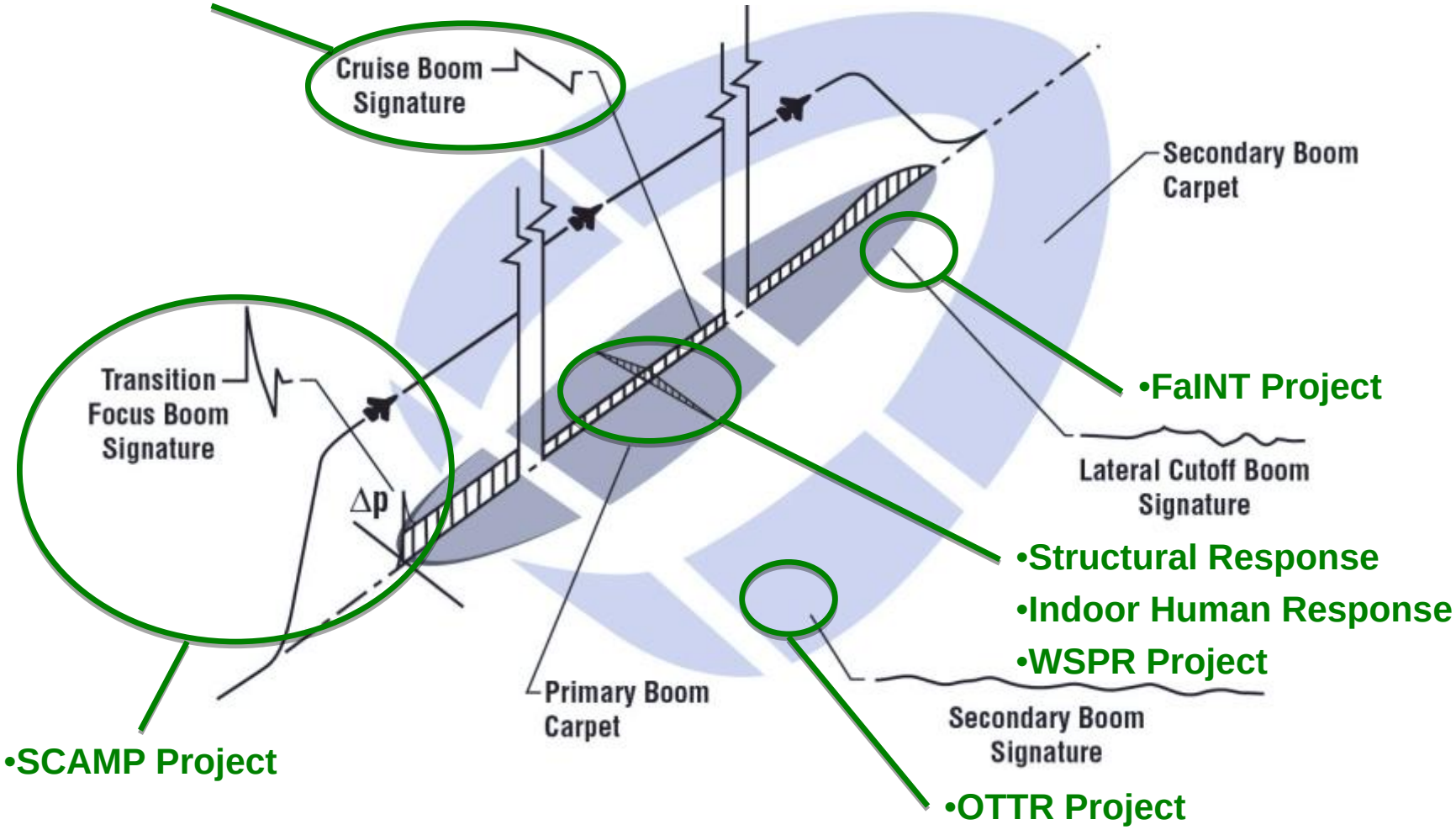
- **(a) An applicant for an authorization to exceed Mach 1 must apply in a form and manner prescribed by the Administrator and must comply with this appendix.**
- **(b) In addition, each application for an authorization to exceed Mach 1 covered by section 2(a) of this appendix must contain all information 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**

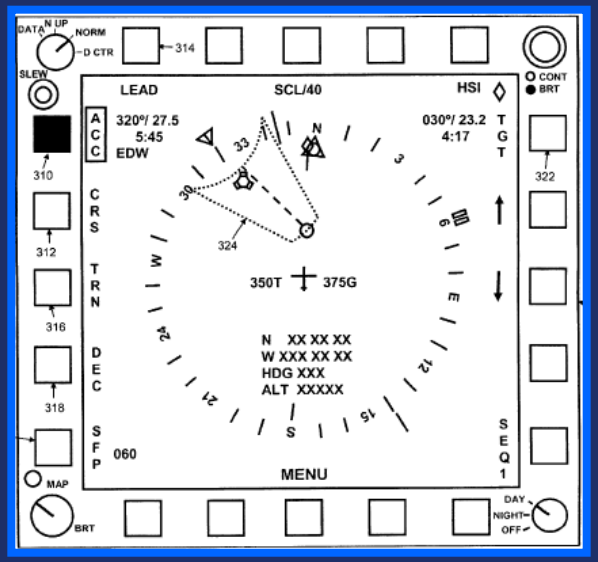
Sonic Boom NASA Research

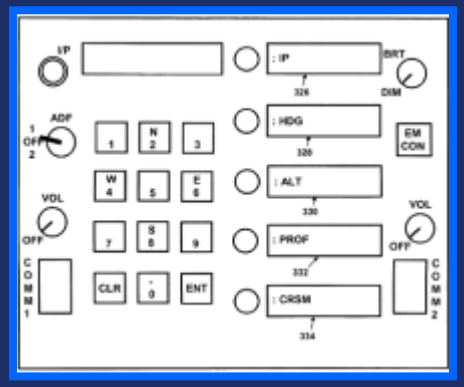


Mach Jump

- 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

Predictive Display Capability

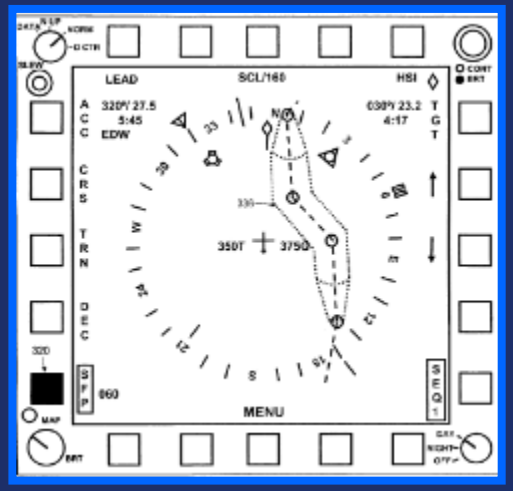




- The sonic boom prediction tool merges it with to real-time aircraft data feeding a local area moving map display.
- The current sonic boom footprint is displayed on the map.
- For certain lower Mach and higher altitude flight conditions, the shock waves refract upward and never reach the ground (i.e. Mach cutoff condition).
- The display would show the maximum Mach number and/or minimum altitude to prevent shock waves from reaching the ground.

Ref: Adapted from Haering, Jr. et al. (2012). U.S. Patent No. 8,145,366 B1 Washington, DC: U.S. Patent and Trademark Office.

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.

Ref: Adapted from Haering, Jr. et al. (2012). U.S. Patent No. 8,145,366 B1 Washington, DC: U.S. Patent and Trademark Office.

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