Recent Supersonic Vehicle Studies At Gulfstream Aerospace

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Gulfstream has long been interested in supersonic concepts.
All Supersonic Studies are Not the Same

NASA’s High Speed Civil Transport (HSCT) program, initiated in the late 1980s and terminated in 1999, differs greatly from the envisioned Quiet Supersonic Jet (QSJ)

- **Design Requirements**
  - HSCT... a 300 pax, Mach 2.4, 600k lb airliner
  - QSJ... a relatively small 100k to 150k lb, Mach 1.8 transport

- **Study Focus**
  - HSCT... not intended to fly supersonic over land
  - QSJ... requires supersonic over land flight for success

*Focused efforts to design a small, low boom configuration, if successful, may pave the way forward for future high speed vehicles.*
QSJ Initial Design Goals

How Far ➔ NBAA IFR Range ➔ 4,800 NM
How Fast ➔ Cruise Mach ➔ 1.6 - 2.0
How Much ➔ Max Ramp Weight ➔ 100,000 Lb
  ➔ Design Payload ➔ 1,600 Lb
  ➔ Cabin Size ➔ 1,300 Cu Ft (GII Size)
From Where ➔ Takeoff Field Length - SL;ISA+20C ➔ 6,500 Ft
  ➔ ACN, Approach Category, and Design Group ➔ <30 / C / III
Safely ➔ Civil Certification ➔ FAA FAR 25 or Similar Standard

Responsibly ➔ Environmental Issues
  ➔ Boom Overpressure ➔ Acceptable for Overland SS Flight
  ➔ Takeoff Emissions ➔ ICAO with Margin
  ➔ Cruise Emissions ➔ Minimum Impact
  ➔ Airport Noise ➔ Stage 4 with 10dB Margin

Reliably ➔ Mission Readiness ➔ > 0.99
Cost ➔ Engine Life (STBO) ➔ >= 2,000 Hr
Effectively ➔ Civil Market Price ➔ $ 70 - 100 M
### A Baseline QSJ Configuration

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Overall Length</td>
<td>140 Ft</td>
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<tr>
<td>Maximum Height</td>
<td>25 Ft</td>
</tr>
<tr>
<td>Span Wings Forward</td>
<td>100 Ft</td>
</tr>
<tr>
<td>Span Wing Aft</td>
<td>60 Ft</td>
</tr>
<tr>
<td>Wing Area</td>
<td>1,600 Sq Ft</td>
</tr>
<tr>
<td>Takeoff Weight</td>
<td>100,000 Lb</td>
</tr>
<tr>
<td>Takeoff Thrust</td>
<td>38,000 Lb</td>
</tr>
<tr>
<td>Transonic Accel Thrust</td>
<td>18,000 Lb</td>
</tr>
<tr>
<td>Mach 1.8 Cruise Thrust</td>
<td>12,500 Lb</td>
</tr>
</tbody>
</table>

Variable geometry provides... improved airport performance, lower noise, and improved subsonic range at the expense of... increased complexity, more difficult certification, and weight.
QSJ Technical Challenges

Propulsion Integration
• Engine Fuel Efficiency
• Engine Life
• High Inlet Performance
• Low Inlet Distortion
• Rotor Burst Protection

Pilot View
• Video Vision
• Conformal Vision
• Enhanced Vision
• Synthetic Vision

Environmental Issues
• Sonic Boom Suppression
• Engine Exhaust Emissions
• Community Noise

Advanced Systems
• FBW / FBL / PBW
• Variable Geometry Systems
• CG Management

Structural Arrangement
• Structural Stiffness
• Thermal Management
• Advanced Materials
• Low Weight / Flutter Resistant Concepts

Operational and Regulatory Issues
• Supersonic Over Land Flight Prohibition
• Certification and Safety Standards
• ATC Integration
• High Altitude Operations

Aerodynamic Performance
• High Supersonic L/D
• High CLmax
• Handling Qualities
Impulsive “Boom” noise is caused by initial and final abrupt pressure rises.

Low frequency “inaudible” content.
Sonic Boom Shaping Strategy

N-Wave Sonic Boom Signature

- Re-shape initial and final pressure rises to “inaudible” frequency level
- Low frequency “inaudible” content

Delta P (psf) vs Time (msec)
Sonic Boom Suppression - Approach

- **Boom Strength ~ Vehicle Weight**
  - QSJ Size An Advantage
  - Minimize Weight

- **Aerodynamic Shaping**
  - Vehicle Configuration
  - Engine Placement
  - Boom Reduction Concept Development
  - Wind Tunnel Testing (Concept Validation)

- **Define Acceptable Boom Characteristics/Signature**
  - Human Ear Response
  - Building Structures Response
  - Sonic Boom Simulation
    - Gulfstream Boom Lab
    - NASA LaRC Boom Lab

- **Develop/Test Technology Demonstrator Vehicle**
Progress on Sonic Boom Reduction

Initial Cruise Sonic Boom Strength

- Concorde
- HSCT
- SBJ
- QSJ Shaped
- QSJ Advanced Concepts
- DARPA QSP Goal
- HSCT/2.4M/57K/190
- Concorde/2.0M/49K/243
- SBJ/1.8M/55K/333
- QSJ/1.8M/55K/333
- QSJ++/1.8M/55K/333

Lighter weight vehicles have weaker sonic boom signatures.

Special shaping further reduces the sonic boom signature.

Vehicle size, shaping, and advanced concepts dramatically reduce the sonic boom signature.
Advanced Boom Reduction Concept Testing

DARPA Initial Overpressure Goal

Wind Tunnel Test Data - Symbols

CFD Calculation - Lines

Low Boom Config 1

Low Boom Config 2

Excellent Correlation & Validation of Boom Suppression Concepts

Gulfstream Wind Tunnel Models in NASA Langley UPWT

Gulfstream
Cruise Acoustic Signature Levels

QSJ Advanced+ >35dB Quieter Than Concorde

- Configuration
- PLdB
- dB(A)

>35dB Reduction

<table>
<thead>
<tr>
<th>dB</th>
<th>HSCT</th>
<th>Concorde</th>
<th>SBJ</th>
<th>QSJ shaped</th>
<th>QSJ advanced</th>
<th>QSJ advanced+</th>
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<tbody>
<tr>
<td>PLdB</td>
<td>110</td>
<td>110</td>
<td>100</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>dB(A)</td>
<td>100</td>
<td>100</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
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10/27/03

Gulfstream
Engine Exhaust Emissions

Airport Environment, Requirements Based on ICAO Regulations and Demonstrated Engine Performance

- Oxides of Nitrogen <60 g/kN
- Unburned Hydrocarbons <4 g/kN
- Carbon Monoxide <40 g/kN
- Characteristic Smoke Number <10

Considered Technically Feasible

Cruise Emissions -- No Regulations for NO\textsubscript{X}, Ozone Depletion, H\textsubscript{2}O, CO\textsubscript{2}

- Gulfstream Atmospheric Modeling Study -- Favorable Results for QSJ NOX/Ozone Impact
- H\textsubscript{2}O, CO\textsubscript{2} -- Design for Min Fuel Burn -- Minimize SFC and Zero Fuel Weight, and Maximize L/D

“Green” aircraft solutions are driven by aeronautical fundamentals.
Estimated Certification Noise Levels

-25 -20 -15 -10 -5 0

Sideline Fly Over Approach Cumulative

Margin to Stage 3 Noise Limit (dB)

QSJ Requirement = Stage 4 -10dB

• Future designs should not be any noisier than today’s product standard.
• Initial estimates indicate Stage 4 -10dB is achievable.
Progress Being Made

• Smaller supersonic configurations designed to cruise below Mach 2.0 are viewed as a logical first step toward next generation supersonic transports.

• Configurations with shaped, low boom signatures are considered feasible.

• Boom suppression technology demonstrator is needed.

• Certification standards and criteria for acceptable supersonic over land flight need to be developed.

Progress toward a viable supersonic business jet requires elimination of the prohibition of supersonic over land flight.