Why Are We Looking At An HSCT Now?

- The forecast for long range scheduled international traffic is sufficiently large in the post year-2005 time period to support a fleet of HSCT's.

- Technologies are projected to be available to create an HSCT that will have the required performance and operating economics, and which can be sold at a price that will provide a reasonable return to Boeing and the airlines.

- With relatively modest surcharges over competing subsonic fares, it is expected that an HSCT providing roughly a 50% time savings would capture a significant market share.

  • Passengers appear to be willing to pay...but how much?

  • Potential for stimulation of travel.

- Boeing cannot afford to pass on this potential market opportunity...we must continue to do our homework.
World Air Travel Forecast Through 2005

Historic: 7.5% per year
Forecast: 5.9% per year and 4.8% per year

Revenue passenger miles, billions

Year

1970 75 80 85 90 95 2000 05

Note: Excludes U.S.S.R.
World Traffic Demand Forecast

Year 2000

4.8 million passengers per day

Domestic 71%

Scheduled international 23%

Chartered international 6%
HSCT Study Markets

Year 2000
1.09 million passengers per day

- Predominantly overland
- North America to Europe
- North America to Asia
- Europe to Asia
- Other

HSCT segment: 315,000 passengers per day
Less than 2,500 nmi

Year 2015
1.90 million passengers per day

- Predominantly overland
- North America to Europe
- North America to Asia
- Europe to Asia
- Other

HSCT segment: 607,000 passengers per day
Less than 2,500 nmi
Cities Used in the Study Route System
HSCT MARKET ESTIMATE

TOTAL POTENTIAL MARKET

UNITs

YEAR

- MACH 2.4
- 300 PAX TRI CLASS
- 5000 NMI RANGE

TOTAL POTENTIAL MARKET

4.0%/YR
5.7%/YR
Market Requirements

- **Speed**
  - Mach 2.4 provides a good balance in trip time benefit, technology risk, reducing environmental impact, and overall system scheduling efficiency.

- **Design range**
  - The initial range capability of 5000 nmi would provide non-stop service for city-pairs comprising approximately 80% of the forecast long range international scheduled passengers flown.

  - The airplane is projected to grow to 6,500 nmi range capability, expanding non-stop capabilities.

- **Seat-size**
  - The airplane is nominally 300 seats tri-class. This capacity provides a balance between reduced seat-mile costs and a size that is consistent with the increased frequencies of the HSCT.
HSCT Flexibility

* For equivalent subsonic trip time
Viable High Speed Civil Transport

Elements of success:

- Environmental acceptability
- Technical feasibility
- Economic viability
Environmental Goals

- Emissions:
  - No significant ozone depletion

- Airport noise:
  - As quiet as Stage III subsonic airplanes

- Sonic boom:
  - No perceptible boom over populated areas
Economic Measures of Success for the HSCT

- The cost-price-market loop must close

- Sufficient program (total units) to allow airframe and engine manufacturers to build and sell with a reasonable return on investment

- Overall economics (operating plus ownership costs) that permit a reasonable return to the airline

- Passengers appear to be willing to pay relatively modest surcharges over competing subsonic fares for roughly a 50% time savings

- Surcharge target is in the +10 to +20% range

- Current indications are that technologies could be available to achieve the target surcharge level
Making the World Smaller
With High Speed Civil Transport
Economically and with positive environmental impact

<table>
<thead>
<tr>
<th></th>
<th>New York</th>
<th>Paris</th>
<th>Typical fares (1990 dollars)</th>
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<tbody>
<tr>
<td>Piston engine</td>
<td>1955</td>
<td>11 hours</td>
<td>Full economy: $1,800</td>
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<tr>
<td></td>
<td>M = 0.45</td>
<td></td>
<td>Discount: --</td>
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<tr>
<td>Subsonic</td>
<td>1990</td>
<td>7 hours</td>
<td>Average: --</td>
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<tr>
<td></td>
<td>M = 0.82</td>
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<tr>
<td>Concorde</td>
<td>1990</td>
<td>3 1/2 hours</td>
<td>$857</td>
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<tr>
<td></td>
<td>M = 2.0</td>
<td></td>
<td>$250</td>
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<td></td>
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<td>$500</td>
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<tr>
<td>HSCT</td>
<td>2000+</td>
<td>3 hours</td>
<td>$2,700</td>
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<tr>
<td></td>
<td>M = 2.4</td>
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<td>$2,700</td>
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<td>$2,700</td>
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</table>

$950 $290 $550
Effect of Cruise Mach Number on Maximum Takeoff Weight

- 5,000 nmi
- 290 passengers

Possible weight limit

Optimum for HSCT

Cruise Mach number
High Speed Civil Transport

• Boeing has a significant study effort directed at development of a viable High Speed (Supersonic) Civil Transport for introduction into service early in the next century

• The program integrates technology development, aircraft design, manufacturing research, and airline requirements

• While the results of studies to date are encouraging, it is also clear that early, focused technology development is vital to the timing and ultimate success of the HSCT
HSCT Planning Schedule

- Feasibility
- PD and trades
- Technology development
- Production program


Key Dates:
- Preliminary concept defined
- Critical technology selection
- Go-ahead
- Certification
1991 HSCT Budget Breakdown

Technology and test 67%
Design/dev 22%
MR&D 11%

Aerodynamics
Noise
Structures
Supporting
Propulsion

Total ~150 engineers

Facilities equipment development

Alternatives and major trades
Baseline trades

MR&D 11%

Producibility assessments
HSCT TECHNOLOGY PROJECTIONS AND PROGRESS

PERFORMANCE AND ECONOMICS DRIVERS

APPROPRIATE TECHNOLOGIES

- PROJECTIONS
- DEVELOPMENTS
- DATABASE

DESIGN REQUIREMENTS
& OBJECTIVES

- CERTIFICATION
- ENVIRONMENTAL
- MARKET

HSCT DESIGN ACTIVITIES

- CONFIGURATIONS
- COMPONENTS

PERFORMANCE & ECONOMICS

MSG: HSCT PERFORMANCE & ECONOMICS ARE DEPENDENT ON ACHIEVING HIGH CONFIDENCE LEVEL IN KEY PROJECTED TECHNOLOGIES BY GO AHEAD.
HSCT TECHNOLOGY PROJECTIONS AND PROGRESS

TECHNOLOGY PROJECTION AND DEVELOPMENT PROCESS

- CANDIDATE TECHNOLOGIES
- RISK ASSESSMENT
- BASELINE TECHNOLOGIES
- ALTERNATE TECHNOLOGIES
- TECHNOLOGY DEVELOPMENT PLAN
- HSCT TECHNOLOGY DEVELOPMENT PROGRAM
  - NASA
  - INDUSTRY
- HSCT TECHNOLOGY DATABASE
  - HSCT TECH DEV PROGRAMS
  - APPLICABLE SUBSONIC
  - US SST PROGRAM
  - MILITARY
- ALTERNATIVE CONFIGURATION DESIGNS
HSCT Blended Configuration Design Concerns

- Balance and loadability
- Landing gear configuration and integration
- Propulsion installation concerns
- Interior volume
- Evacuation
- Cabin-floor angles
- Tail heating
Unblended Configuration

- Increased passenger count
- Improved balance, loadability, tail-sizing
- Outboard shift of engines
- Increased-sweep outboard wing
- Three-post main gear
- Floor-level emergency exits
- Increased nose gear load (improved steering)
- Water ballast deleted
- Increased body fuel volume (fore and aft)
- Increased wing incidence, straight floor (lower floor angles)
High Speed Civil Transport

Baseline Configuration

Range  5,000 nmi
Payload 302 passengers tri-class
MGW  705,000 lbs
OEW  275,000 lbs
Noise  FAR 36 stage III
Wing area  7,100 ft²
High Speed Civil Transport

Baseline Features

Suppressed turbojet propulsion system
3-post 6-wheel steerable MLG

28 first class
38 in pitch

60 business class
36 in pitch

214 tourist class
33/34 in pitch

302 passengers

Interior arrangement
## Baseline Engine Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Turbine bypass turbojet</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Internally ventilated noise suppressor</td>
</tr>
<tr>
<td>Inlet</td>
<td>Axisymmetric mixed-compression with translating centerbody</td>
</tr>
<tr>
<td>Combustor</td>
<td>Low emissions (5 to 8 lb NO_x/1,000 lb fuel)</td>
</tr>
<tr>
<td>Engine maximum airflow</td>
<td>460 lb/s</td>
</tr>
<tr>
<td>Takeoff thrust</td>
<td>62,200 lbs at M = 0.2</td>
</tr>
<tr>
<td>Pod length</td>
<td>345 in</td>
</tr>
<tr>
<td>Pod inlet diameter</td>
<td>53.9 in</td>
</tr>
<tr>
<td>Pod maximum diameter</td>
<td>73.8 in</td>
</tr>
<tr>
<td>Pod weight</td>
<td>14,100 lb</td>
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</tbody>
</table>
HIGH SPEED CIVIL TRANSPORT

BRITISH AIRWAYS REVIEW

PURPOSE

"BEGIN A PROCESS THAT WILL LEAD TO AIRLINE PARTICIPATION IN
THE ASSESSMENT AND DESIGN OF AN ECONOMICALLY VIABLE HSCT."

TODAY'S MEETING

- SHARE WITH BRITISH AIRWAYS OUR ASSUMPTIONS AND STUDY RESULTS.
- LISTEN TO YOUR FEEDBACK.
- BEGIN TO PLAN FUTURE HSCT ACTIVITY WITH BRITISH AIRWAYS.
HIGH SPEED CIVIL TRANSPORT

INTERIORS

- DESIGN REQUIREMENTS & OBJECTIVES
- INTERIOR ARRANGEMENT
- CROSS-SECTIONS
- CARGO STUDIES
- EVACUATION ISSUES
- TEAGUE'S INTERIOR CONCEPTS
HIGH SPEED CIVIL TRANSPORT

AIRPORT ISSUES

• DESIGN REQUIREMENTS & OBJECTIVES
• AIRPORT PARKING
• RUNWAY LOADING
• TAXIWAY TURNING
• TURN-AROUND
• GROUND HANDLING
• FLIGHT DECK OVERHANG
Preferred Airline Configuration
"Nonproblems"

- Field length requirements - same as large subsonic aircraft
- Runway separation - no more critical than large subsonic aircraft
- Turbulence impact on operations - less critical than large subsonic aircraft
- Fuels - jet A is satisfactory
HIGH SPEED CIVIL TRANSPORT

KEY PROGRAM ISSUES

TECHNICAL

AIRFRAME

• HIGH TEMPERATURE COMPOSITE STRUCTURE
• JET NOISE SUPPRESSORS
• ENGINE INLET
• AERODYMANICS AND CONTROLS

ENGINE

• LOW EMISSIONS BURNERS
• VARIABLE CYCLE ENGINE CORE
Low NO$_x$ Combustor Concept

Fuel → Fuel-rich combustor → Intermediate quench zone → Fuel-lean combustor

Primary airflow

Fuel preparation

NO$_x$ index

Lean

Rich

Fuel-air equivalence ratio

50

40

30

20

10

0
Engine Developments

- Single spool
- Simple concept
- High-temperature materials
- Noise-suppression nozzle
- Low-emission combustor

- Dual spool
- Variable geometry
- High-temperature materials
- Low-emission combustors
- Noise-suppression nozzle

- Dual spool
- Big valve
- Heavier
- Longer
- Conceptual design
1989 NACA Nozzle Concept

- Plug doors (open)
- Ejector air on (turbine bypass)
- Secondary air doors (open)

Coannular exhaust
NACA Nozzle Results

- Low-frequency jet noise reduced
- Low thrust loss
- Mixing noise remained high
- Concept fell short of expectations
Internally Mixed Ejector - Suppressor Nozzle Concept

Secondary air

Sound attenuation lining

Mixing region

Engine exhaust

Low-noise mixed-velocity stream
Proposed Usage of Materials for the HSCT

- Composite honeycomb skin panels with composite substructure
- Titanium honeycomb skin panels with composite substructure
- Full-depth composite honeycomb panels
Materials Technology Development Tasks

- Structural materials
- Composites
- Metals
- Adhesives
- High-temperature sealants
- Finishes
- Lubricants
<table>
<thead>
<tr>
<th>Scheduled</th>
<th>Thermoplastics</th>
<th>Thermosets</th>
<th>Open-hole compression</th>
<th>Open-hole tension</th>
<th>Uni compression</th>
<th>Uni tension</th>
<th>CAI</th>
<th>GIC</th>
<th>GIIC</th>
<th>Fluid sensitivity</th>
<th>Compressive interlaminar shear</th>
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<tr>
<td>In testing</td>
<td>1 2 3 4 5 6 7 8 9 10 11</td>
<td>1 2 3 4 5 6 7 8 9 10 11</td>
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Damage Tolerance Versus Compression Strength

Compression after impact, ksi (1500 in-lb impact)

Open-hole compression, ksi (350°F hot-wet)
Manufacturing Research and Development

3- by 5-ft Body Panels

Honeycomb panel

Skin stringer panel

Producibility issues
- Cure cycle optimization
- Layup properties
- Titanium-core bonding
- Laminate thickness over core
- Bagging requirements
Composite Structure Development

Structural design concepts
- Weight
- Durability
- Cost

Materials development
- Properties
- Temperature capability
- Durability
- Cost

Manufacturing development
- Producibility
- Tooling and capital
- Quality
- Cost
High-Speed Aero Optimization

- Transonic flap deflections
- Wing-body tailoring
- Leading-edge design
- Nacelle concepts
- Wingtip variations
Aerodynamic Efficiency Improvement Projections

- Supersonic Cruise Research
- Detailed design integration
- Recent HSCT designs
- Optimization methods
- Riblets
- HLFC
Vortex Fence

Effect of Vortex Fence in Ground Effect

High-lift Vortex Amplification

\[ C_L \]

\[ \alpha \]
High-Speed Aerodynamics

Flow quality
Parabolized Navier-Stokes
(Total pressure)

Boeing supersonic wind tunnel

Drag prediction
Euler
Full potential (Tranair)
Linear potential

Test versus theory comparison
High-Lift System Concepts

- Vortex suppression
- Trapped vortex
- Vortex control
- Vortex separation
- Suction
- Blowing
- Boundary layer control
- Spanwise blowing
- Vortex control
Vortex Krueger Flaps

Vortex Krueger Trapped Vortex

Climbout With Programmed Flaps - Plain and Vortex Krueger Leading-Edge Flaps

L/D Trim

12

0

High L/D - Attached Flow
Wing Planform Evolution

- Model 833
  - 1987 baseline
  - SCR double delta

- Model 854
  - Performance
  - Fuel volume

- Model 870
  - Increased span
  - Noise

- Model 873
  - Strake extension
  - Fuel volume

- Model 871
  - Increased span
  - Noise

- Model 890
  - Swept tip
  - Performance
Variable Geometry Inlet Concept

Centerbody extended at low speed to increase throat area

Centerbody retracted at supersonic cruise to reduce throat area
CFD Representation of the Inlet Operating at Mach 2.4
Passenger Willingness to Pay a Fare Premium

![Diagram showing the range of survey responses for passenger willingness to pay a fare premium. The x-axis represents market share in percentage, ranging from 0% to 100%, and the y-axis represents fare premium in percentage, ranging from 0% to 60%. The graph includes data points at 25%, 50%, 65%, and 85% market share, illustrating the varying willingness to pay at different market share levels.](image-url)
HSCT MARKET ESTIMATE

BASELINE HSCT MARKET PENETRATION

UNITS
2,500
2,000
1,500
1,000
500
0
2,000 2,005 2,010 2,015 2,020 2,025 2,030 2,035 2,040
YEAR

TOTAL POTENTIAL MARKET
- MACH 2.4
- 300 PAX TRI CLASS
- 5000 NMI RANGE

OPTIMISTIC

- BASELINE A/P PENETRATION

PESSIMISTIC

TWO PROGRAMS

SINGLE PROGRAM
HSCT Laminar Flow Control Studies

Airfoil section showing laminar flow control details

HSCT laminar flow control concept
Low-Sonic-Boom Design Results

High-sweep root to tip long-lifting length

Staggered nacelles

Swept tail

Longer, bulged-nose, delayed-ramp, wave form

Body contouring aft shock shaping

Results:
Boom over pressure - 0.75 psf (base is 2.5 psf)
Boom loudness - 71 dBA (base is 88 dBA)
Gross weight penalty - +2%
Payload penalty - -42 passenger (-15%)
HSCT Planning Schedule

- Feasibility
- PD and trades
- Technology development
- Production program


Preliminary concept defined
Critical technology selection
Go-ahead
Certification
HSCT TECHNOLOGY DEVELOPMENT PLAN
TECHNOLOGY AND CONFIGURATION DEVELOPMENT MILESTONES

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<tr>
<td>AIRFRAME</td>
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<tr>
<td>TECHNOLOGY &amp; CONCEPT DEVELOPMENT</td>
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<td>PRELIMIARY AIRPLANE DEVELOPMENT PLAN</td>
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<td>PRODUCTION PROGRAM</td>
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PRELIM. CERT. BASIS
PRELIMINARY CONCEPT SELECTION
CONCEPT SELECTION
TECHNOLOGY SELECTION
CONFIGURATION FREEZE
CERT. BASIS
GO AHEAD
BOEING VIEW OF HSR PHASE I

• NASA HSR PHASE I PROGRAM ON TARGET
  - GOALS, OBJECTIVES & TECHNICAL PLAN FORMULATED VERY WELL
  - EXCELLENT START TOWARD PROGRAM GOALS

• NEED TO MAINTAIN FOCUS

• KEY TO SUCCESS OF PHASE I WILL BE TIMELY DELIVERABLES
BOEING VIEW OF HSR PHASE II

• HSR PHASE II PROGRAM ESSENTIAL FOR DEVELOPMENT OF ENABLING AND HIGH RISK, HIGH PAYOFF EMERGING TECHNOLOGIES

• AGREE WITH PRIORITIES AND RELATIVE FUNDING LEVELS

• A MORE DETAILED PHASE II NASA HSR TECHNOLOGY DEVELOPMENT PLAN NEEDS TO BE DEVELOPED WHICH:
  - USES PRESENT HSR PHASE II PLAN AS A BASE
  - IS INTEGRATED WITH INDUSTRY PRODUCT & TECHNOLOGY DEVELOPMENT PLANS
  - IS CENTRALLY MANAGED WITH BUY-IN BY THE NASA CENTERS
  - IS NOT CONSTRAINED BY NASA MANPOWER