THE CASE FOR A PRACTICAL SMALL SUPERSONIC TRANSPORT

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ABSTRACT

This paper assesses the feasibility of introducing a small supersonic transport aircraft into the commercial business jet market. The study considers issues both endogenous and exogenous to the aircraft manufacturer, including a market analysis, technological considerations, regulatory and political constraints and business economics. To bound the solution space and add realism it takes the perspective of an incumbent aircraft manufacturer serving the high-end business jet market. The study concludes that the following key aircraft characteristics optimize a combination of marketing, financial, and technical factors:

- Mach 1.6 cruise
- 4,200 nm range
- 100,000 lb maximum takeoff weight
- 8 passengers in a double-club cabin
- $85 million maximum acquisition price

1 INTRODUCTION

Commercial supersonic aircraft design studies have been carried out in industry and academia alike since the late 1950s. Elements of this work culminated in the introduction of the British Aerospace Concorde in the 1960s. In the 1980s the aviation media started reporting serious design efforts by major airframe manufacturers to bring a smaller, business jet-sized supersonic transport to the general aviation market. However, to this date a supersonic business jet (SBJ) aircraft has not been brought to market.

The 2001 MIT Aircraft Systems Engineering (ASE) design team surveyed past and present design efforts, examined the current market, political and technological situations surrounding an SBJ product, and concluded that the introduction of a financially successful small supersonic transport aircraft (SSST, hereafter referred to as S3T) by the close of this decade is possible. The MIT ASE course is a unique offering from the MIT Department of Aeronautics and Astronautics in conjunction with the Engineering Systems Division at MIT. This course affords graduate-level students the opportunity to examine aircraft conceptual design from a real-world perspective, considering not only technological considerations in aircraft design but also business, political and other factors that influence aircraft product development. Class research is supplemented by lectures and consultations from experts in appropriate fields, stemming from industry, government, research labs and academia. Students in the 2001 MIT ASE class were required to *Prepare for the Board of Directors of a large aerospace company a compelling business case and*

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specification for a small supersonic transport aircraft product. This paper presents the key considerations of the 2001 ASE team in arriving at their conclusion regarding introduction of an S3T aircraft. The study underlying this paper was conducted in the spring of 2001 by a team of graduate students at MIT. All findings represent the views of the authors, not those of MIT. For a more detailed analysis and comprehensive list of references please consult the 2001 ASE team final report [1].

2. OPPORTUNITY CONDITION AND PRODUCT SPECIFICATION

To bound the solution space and add realism, this study takes the perspective of an incumbent aircraft manufacturer serving the high-end business jet market. The "high-end market" considered in this study is characterized by long range jets such as the Gulfstream GV and the Bombardier Global Express.

2.1 A New Product is Required

Historically, manufacturers of high-end business jets have differentiated themselves by moving up the technology curve, most notably in cabin size and range. To this point the brand names of these manufacturers have been synonymous with luxury, quality and technological leadership. However, the current high-end product lines, with entry-into-service dates in the late 1990s, will be dated by 2010. The ultra-long range, large cabin market is also under pressure from non-traditional business jet offerings such as the Boeing BBJ1 and BBJ2 and the Airbus ACJ. Additional market entrants are inevitable (e.g. Boeing BBJ3), forcing current high-end business jet manufactures to choose between four options:

1. Compete on margins by reducing manufacturing costs and traditionally high profit margins, and by offering incremental improvements in operating costs and aircraft performance.
2. Switch markets, where the choices are limited to competing downward in lower-end business jets with diminished profit margins, or moving laterally into regional jets where the market is already saturated with competitors.
3. Exit the market, thereby forfeiting a lucrative source of revenue.
4. Switch differentiating technology.

The latter option is the most attractive of the four and is explored in this study.

2.2 Supersonic is the answer

The traditional metrics of product differentiation at the high-end of the business jet market – cabin size and range – are no longer effective. Manufacturers cannot compete with the Boeing BBJ cabins, which may soon be trumped by Boeing's BBJ3 offering of the 757. Ranges beyond 8,000-nm are unattractive at Mach 0.90 as travel times approach 20 hours. Incremental reductions in field length, operating costs and noise levels, while welcomed by customers, will not sufficiently differentiate a manufacturer from its competitors. Increasing cruise speed is the only viable option.

Pushing existing products to slightly higher cruise Mach regions will not suffice. Technological barriers prevent efficient cruise in the transonic region (approximately Mach 0.9 to 1.1) and another few hundredths of a Mach will not sufficiently differentiate the product, especially considering the potential increase in acquisition and operating costs. As will be shown, Mach number must increase to at least 1.3 before the product will become sufficiently attractive to the market to justify program investment.

2.3 The Window is Open

Despite the increasing demand for faster travel, efforts to develop a supersonic business jet have, to date, been unsuccessful. Several recent developments make such a project practical now for the first time.

The technological base for civil supersonic flight has matured with programs such as the high-speed civil transport (HSCT), DARPA's Quiet Supersonic Platform (QSP) and commercial initiatives such as joint Gulfstream-Sukhoi, Gulfstream-Lockheed, and Dassault studies. Such programs have also identified the limits of current technology and led to a relaxation of certain unrealistic constraints, such as reducing cruise speeds from Mach 2.2+ to Mach 1.6-1.8.

The emergence of fractional ownership programs has, for the first time, established a reliable customer base with sufficient resources to place critical mass launch orders. Fractional programs have also lowered the bar for aircraft ownership, with the potential of transforming an $80 million aircraft into 1/8 shares at a more palatable $10 million. Some of the larger fractional programs have expressed interest in adding a significant number of supersonic aircraft to their fleets.

The late 1990s downturn in United States defense spending left military contractors looking for other investment options. With their experience in supersonic aircraft, these companies make good risk-sharing partners with critical technological competencies. A small supersonic transport aircraft is a good match for them as well, offering a stepping-stone to the next generation military jet.

2.4 The Time is Now

There is a sense of urgency to launching an S3T project. The market will likely not sustain two such vehicles to the extent that they would be sufficiently profitable for the manufacturer, so the successful S3T manufacturer must be first to market. Competitors in Europe, Russia, and Japan, as well as the United States, are currently studying supersonic projects.

The regulatory environment continues to become more hostile to a supersonic transport. Stage 4 noise limitations take effect for aircraft applying for certification basis after January 2006, and a Stage 5 restriction may be developed late in the next decade. In addition, researchers continue to enhance their understanding of high altitude aircraft engine emissions, perhaps leading to more stringent environmental regulations in the near-term. It is important that a supersonic aircraft be certified under current regulations (including Stage 4 noise) to establish a toehold in an increasingly restrictive regulatory environment.

The overall program returns are quite sensitive to schedule length. As time between capital investment and vehicle delivery increases, the time value of money drives net present value down dramatically. It is therefore critical that time delays are limited.

The DARPA QSP program is developing technology beneficial to an S3T configuration. It is, however, not key technology that should delay program launch. QSP will not absolve the need for a flying demonstrator, nor will it yield a candidate engine. Additionally, the entire program could be cancelled if political support is lost.

Finally, and most importantly, high-end business jet manufacturers will need a new product early in the next decade. Interestingly enough, the aerospace industry as a whole may need the supersonic transport program as well. The number of new aerospace engineering graduates is declining as students opt for high-demand, higher-paying computer-related careers [2]. Budget cuts, program cancellations, corporate mergers and business-as-usual policies that trade innovation and vision for assured short-term returns are sapping the aerospace industry's strength. An S3T development program is needed to revitalize the industry.

2.5 Product Specification

A development schedule and basic set of performance and design parameters are proposed by the ASE team for introduction of a financially and technologically successful S3T aircraft. The team proposes a design and manufacturing schedule consisting of phased investment decisions, with launch of a flight demonstrator program in 2003, a final investment decision and program launch in 2005 (certification basis application before 2006) contingent on the outcome of the demonstrator program, and full-scale production and entry-into-service in 2010. The basic performance and design parameters of the proposed S3T aircraft are laid out in Table I. These parameters, as well as the development schedule, were selected to provide the highest program financial returns for minimal risks. The key elements of the specification and development plan will be discussed in this paper (see [1] for full details).

Table I: S3T Product Specification

NBAA IFR Range	4,200 nautical miles (nm)
Cruise Mach	1.6
Max Take-off Weight	≤ 100,000 lbs
Design Payload	8 pax, double club cabin (19 pax airline cabin)
Crew	2 + 1 cabin attendant
Cabin Size	minimum 1,000 cu ft maximum 1,300 cu ft
Max Aircraft Length	≤ 120 ft
Balanced Field Length	≤ 6,000 ft
Market Price	$85 million ($2001)
Direct Operating Costs	≤ 4,200 $/hr ≤ 6 $/nm
Environment	
Sonic Boom Signature	Goal: over land supersonic flight
Airport Noise	Stage 4
Emissions	Minimize impacts
Cranked Wing Configuration	
2 Derivative Engines	
Thrust each, SLS	~20,000 lbs

3. MARKET ANALYSIS

A market analysis was performed to determine the projected number of sales, the price limitations imposed by the market, and the design specifications needed to enter the market. A variety of different approaches have been taken in an attempt to deduce the correct mix of attributes to maximize product success. Lacking direct access to customers, a best estimate has been made of the optimal mix of attributes for the product. In the assessment of this design team, investment in marketing research will prove equally, or perhaps more important than investing in technical understanding.

3.1 Projected Sales and Price

Industry analyst projections for sales of a small supersonic transport range from 100 to 400 units over 10 years, depending on the cruise speed and range of the aircraft. Sales would be evenly split between private individuals, corporations and fractional ownership programs, and governments or heads of state. These projections assume that the aircraft would have the ability to fly supersonic over land. If that capability is not granted it is thought that sales would be severely impacted and perhaps fall to only 20-30% of the totals quoted here.

Analysts also offered opinions on acceptable vehicle prices, ranging from $60 million (2001 USD) as quite acceptable, $85-95M as a pain threshold, and $100M as the absolute maximum. For financial analysis and technical decisions, $85M was treated in this study as the maximum desirable price for the S3T.

A separate analysis of potential sales to the existing “high-end” business jet community indicated total sales of between 50 and 250, depending on the level of optimism for market growth and the percentage of the market captured by the S3T. A look at alternate markets such as the military, parcel delivery and medical transport indicated an additional boost in sales of between 10 and 60 aircraft over 10 years. Again these estimates assume a supersonic capability over land.

Since the business jet market is highly sensitive to supersonic flight over land, alternate sales markets were investigated to reduce program risk in case overland supersonic flight would not be permitted. An outstanding candidate emerged from exploring alternate markets: scheduled 19-passenger supersonic service on transatlantic routes to supplement regular subsonic airline service. Ticket prices, even with a healthy profit margin, would be competitive with equivalent transatlantic subsonic business- and first-class fares, and market demand for such a capability could boost S3T sales by as much as 300 units over 10 years [1].

3.2 Vehicle Specifications

An effort was made to distinguish between customer desires and actual vehicle requirements for successful market entry. The following three specifications were developed for the S3T:

1. Range: The minimum acceptable range for the S3T will be 3,500 nm, enabling transatlantic crossings without a stop. It will be seen later from a financial and technical perspective that a 4,200 nm range is possible without undue added manufacturing and design expense, and with some gain in the market. Although transpacific range (5000 nm) is desired by the market, it will not be critical to the financial success of the program and, based on best available knowledge to this design team, may in fact be detrimental.
2. Cabin Size: A minimum cabin size of 1000 cu ft (in comparison to the Gulfstream GV: approx 1900 cu ft, Cessna Citation X: approx 750 cu ft), accommodating up to eight executive passengers, is required to compete in the "high-end" aircraft market. Customers would likely be willing to accept this smaller cabin as the compromise for supersonic speed.
3. Cruise Speed: The S3T must possess a "unique capability" to meet the anticipated sales projections, thus speeds below Mach 1.3 are not considered viable compared to the higher vehicle costs. Technical considerations will limit the top speed of the aircraft.

4. TECHNOLOGICAL CONSIDERATIONS

In this section the capabilities of existing or near-term technology are assessed for possible use on an S3T aircraft. Principle areas for investigation are indicated by Breguet's formula for range (constant speed cruise):

$$R = a_\infty M_\infty \frac{L}{D} \cdot \frac{3600}{TSFC} \cdot \ln\left(\frac{W_{TO}}{W_{empty}}\right) \quad (1)$$

where $a_\infty M_\infty \frac{L}{D}$ is dependent on the aerodynamics of the aircraft, $\frac{3600}{TSFC}$ represents the propulsion system, and $\ln\left(\frac{W_{TO}}{W_{empty}}\right)$ is governed by the weight of the aircraft. Each of these areas was examined in turn by this design team for critical issues in determining the performance of a supersonic aircraft.

4.1 Aerodynamics

A family of aircraft wing configurations was selected to facilitate discussion of issues dealing with aerodynamics. Five issues were considered in identifying the configuration:

- marketability and aesthetics
- the desire for subsonic flow over the leading edge in cruise
- a maximum lift coefficient of 1.4-1.6 to limit approach speeds to ≤ 150 kts and balanced field lengths to ≤6,000 ft
- existence of a test database to minimize risk
- minimization of weight and complexity in the configuration.

Although a specific, detailed planform design is not being advocated, a configuration of the cranked arrow wing type, as shown in Figure 1, was selected as offering the best balance between the various risk factors.

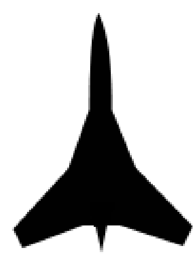

Figure 1: Cranked Arrow Wing Configuration

4.1.1 Lift and Drag

As shown by Breguet's range formula (Equation 1), the lift-to-drag ratio (L/D) in cruise is important in determining the range of an aircraft. The Concorde reportedly cruises at Mach 2.0 with L/D ≅7.5, and current predictions for the theoretical maximum L/D for large supersonic transport aircraft are in the 10 to 12 range. However, due to cabin size and airport compatibility constraints, it is likely that the fuselage fineness ratio, ℓ_f / d_f , for a small supersonic aircraft will be lower than that for a large transport, which will in turn lower the maximum L/D [3]. For this study an L/D of 8 at Mach 1.6 was chosen as a realistic operational value at cruise.

Reducing drag will be important to maximizing L/D and thus minimizing weight, and technologies such as laminar flow control (LFC) and natural laminar flow (NLF) were examined for their suitability for use on a near-term S3T. The NASA Technology Readiness Level for LFC and NLF was considered too low for application on this project so, to minimize risk, conventional drag reduction techniques are recommended for the S3T.

4.1.2 Sonic Boom

It is believed that the aerodynamics of a supersonic aircraft can be designed ("shaped") such that the sonic boom noise is reduced to an acceptable level [4]. There are three key considerations in addressing the sonic boom noise challenge:

1. Acceptable sonic boom noise levels for flight over land are undefined, both in political terms and in the percentage of the population annoyed by the noise
2. Shaping technology is at a relatively immature level
3. For a given design cruise speed and weight (or alternatively, range), shaping constraints will drive the aircraft length to exceed 100 ft

Assuming that "acceptable" noise levels can be defined for the sonic boom over land then the aircraft shape can, in theory, be optimized to meet that threshold. With today's understanding of aircraft shaping and annoyance levels it appears possible to design a Mach 1.6, 100,000-lb, 120-ft long aircraft which would have a sonic boom signature acceptable for supersonic flight over land. Reducing aircraft weight or flight speed appears to offer significant gains in increasing the acceptance of the sonic boom noise. To gain greater certainty in using the shaping technology, a brief, highly-focused flight demonstrator program is advocated by the ASE team.

4.2 Propulsion

Industry experts and the methods of [5] place the cost of developing an all-new engine for an S3T in the neighborhood of $2 billion. This is a prohibitive investment for an initial S3T development when examining the business case. The use of derivative engines based on currently available engine cores was studied (with an associated development cost of $500 million), but there are conflicting opinions on whether the use of a currently available engine is practical. Valid concerns exist regarding the prolonged higher turbine temperatures associated with supersonic flight, plus maintenance, noise and emissions issues.

Before launch of an S3T program, an airframe manufacturer will need to conduct a thorough peer review of the several engine manufacturers to assess the critical issues and determine whether a new development program will indeed be necessary. The need for a new engine development program will likely render an S3T financially unsound for a commercial consortium unless substantial government funding is available.

4.2.1 Engine Sizing and Candidate Selection

A two-engine configuration was selected for the S3T design to reduce costs (acquisition and maintenance) while ensuring adequate safety and reliability. A preliminary engine sizing was conducted to aid in selecting candidate engines, and thrust required at Mach 1.0 was identified as the critical driver for engine size. Based on the limited knowledge available to the design team, use of a derivative engine on the S3T appears feasible with certain modifications.

Based on the thrust sizing exercise, four candidate engines were identified from those currently in commercial use: Pratt & Whitney JT8D-200, Rolls-Royce BR715, IAE V2500, and CFM56. Four additional engines were identified from military candidates: Pratt & Whitney F119, P&W F100-PW-229, GE F414, and SNECMA M-88. The Rolls-Royce Trent 800 was also identified, but too late to be included in this study.

The candidate military engines appear to offer adequate thrust levels for use on the S3T, and the reduced duty cycles associated with civilian flight will enable these engines to meet a required time between overhaul of 2,000 hours. The civil engines all have high bypass ratio fans that would likely need to be replaced with lower bypass fans to reduce the engine size and also to provide a good value for the ratio of thrust-to-engine weight at supersonic cruise. In addition to the engine refan, some modifications to the core compressor and turbine, plus a new nozzle would likely be required for the civil engines to cope with the higher temperatures associated with supersonic flight. A crude engine model was developed by the ASE team to estimate civil engine performance at supersonic speeds with a modified bypass ratio. All eight candidate engines indicate that a thrust specific fuel consumption (TSFC) of 0.9 lb/lb/hr may be realistic for the S3T.

4.2.2 Inlet Selection

A fixed geometry, 2-shock inlet was selected due to the light weight and reduced cost to develop and maintain versus that of a variable geometry inlet. Since the inlet will be point-designed for the supersonic cruise condition, a performance penalty will be paid in terms of pressure recovery during subsonic flight. For the moment the subsonic portion of the S3T mission is considered negligible (one-half hour climb, 200-nm NBAA diversion profile), as are the penalties for having an inefficient inlet at those conditions. Should the operational plan for the aircraft change and the subsonic portion of the mission become more significant, then the use of a fixed geometry inlet would need to be reassessed.

4.2.3 Airport Noise

It will likely be necessary to comply with Stage 4 noise restrictions when operating in and around airports. The low bypass ratio and high thrust levels (high exhaust velocities) required of S3T engines will make them inherently noisy. It is anticipated that excess thrust will be available at takeoff due to the thrust required to accelerate through Mach 1.0. Use of partial throttling at takeoff should decrease the engine exhaust velocity, thus reducing the engine noise, and the use of an ejector nozzle to increase air mass flow rate at the exhaust may reduce noise as well. Alternate engine configurations may also be considered for reducing noise levels, such as shielding the engines for flyover and approach noise by placing them above the wing [6].

4.2.4 Emissions

Any potential engine manufacturer will have to comply with requirements for take-off engine emissions as well as yet-to-be-defined supersonic cruise altitude emission regulations. Civilian engine candidates already meet take-off requirements, though the military counterparts do not have to currently meet these regulations.

The most troubling emissions problem for the S3T is depletion of ozone in the stratosphere. Emission regulations for supersonic cruise will need to be defined by the appropriate authorities (Federal Aviation Administration (FAA), Environmental Protection Agency, etc.) before the engine manufacturer can determine eligibility of specific engines for use on the S3T vis-à-vis emissions. A technological solution may not be available at reasonable cost and in the near-term, so it is likely that emissions offset strategies (e.g. emissions credits trading) will have to be employed to mitigate the environmental impacts of supersonic flight.

4.3 Weight

Aircraft weight may be estimated as a function of range, speed, L/D and TSFC. Payload and crew weights were calculated for an eight-passenger design with a crew of three (pilot, co-pilot and attendant). Empty weight and take-off weight were then estimated using the methods of [7]. Trade studies indicated that an aircraft weight of 100,000 lbs provided a reasonable balance between maximizing range and preventing the aircraft weight from exceeding operational constraints (e.g. executive airport runway pavement loadings).

5. REGULATORY AND POLITICAL CONSIDERATIONS

The viability of the S3T will be dependant on the program's ability to resolve a number of key regulatory and political issues. Several key issues challenge the program viability, including authorization to exceed Mach 1.0 over land, airport noise, and engine emissions. Additional issues such as high altitude operations, cockpit visibility, and air traffic control system integration were also considered and found to be manageable.

The most challenging regulatory and public perception aspect of the S3T project is the authorization to exceed sonic velocity over land. According to the market analysis performed for this study, failure to achieve this authorization seriously degrades the market basis for the aircraft. United States Federal Aviation Regulation (FAR) 91.817 prohibits operation of an 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.

Although there is some hope for designing an aircraft with low sonic boom overpressure levels, the FARs at this time do not recognize any measurable sonic boom signature as being acceptable. Furthermore, public opinion and political issues may play a larger role than technical factors in keeping the S3T restricted to subsonic flight over land.

The risks involved with gaining permission for supersonic flight over land can be reduced in several ways. First, a flight demonstrator program is highly recommended to validate sonic boom minimization (“shaping”) technology and to establish the exact sonic boom signature limits in conjunction with certification authorities (e.g. FAA and Joint Aviation Authorities). Also, maximum advantage should be taken of past NASA High Speed Civil Transport (HSCT) research results as well as any available information from the DARPA QSP effort.

The FAA and other certification authorities should be engaged early in the S3T program specifically on the sonic boom issue. This may increase the chances of gaining over-land flight capability, but more importantly will indicate as early in the program as possible if those rights will be denied so that alternative strategies can be employed. One alternative is to aggressively pursue non-business jet markets such as the scheduled transatlantic airline routes mentioned previously.

Industry experts anticipate a 3-4 year process to promulgate the final rule allowing supersonic flight over land if the acceptability issue is solved. The sonic boom issue must be addressed early and pursued vigorously throughout the S3T program to maximize the chances of gaining the capability to fly supersonic over the United States.

6. BUSINESS ECONOMICS

In this section the program non-recurring engineering and recurring engineering costs are examined. The investment returns are analyzed in terms of net present value (NPV) to the airframe manufacturer.

6.1 Non-Recurring Engineering Cost Analysis

The cost of the recommended demonstrator phase will be largely dependent on the purpose of the demonstrator. In this study it was concluded that program returns would be optimized with a relatively low investment in a demonstrator for the twin purposes of validating sonic boom shaping technology and establishing a foundation for regulatory change. A three-year flight demonstrator program is envisioned (commencing in 2003) with an investment of $500M and an overlap at the end of the flight test program for full-scale design (commencing in 2005). An alternate scenario with a minimal demonstrator priced at $150M was also investigated (see [1] for details).

Costs of developing a brand new engine for the S3T as well as modifying a current civil or military engine were examined. New engine development would cost approximately

$2 billion and ruin the financial viability of the program for any engine manufacturer (and consequently, for the airframe manufacturer). Costs for a derivative engine program were estimated at $500M or less with production costs at approximately $5M per engine.

The research, development, test and evaluation (RDTE) costs for a Mach 1.6 aircraft (excluding engine RDTE) were estimated at approximately $1.7 billion using the methods of [7] and [8] and assuming the use of conventional aluminum-alloy materials (made possible by the relatively low supersonic cruise speed).

Cost reductions from the use of lean manufacturing practices and design for manufacturing have not been considered in these RDTE estimates, although potential savings are significant and were examined in detail [9].

6.2 Recurring Engineering Cost Analysis

The cost of manufacturing one "green" aircraft was estimated (using methods of [7]) at approximately $42M without amortizing the costs of the RDTE phase or including a cabin outfitting allowance.

The hourly direct operating costs (DOC) for a Mach 1.6 aircraft were estimated at $4,120 per hour, or $5.9 per nautical mile flown. Although the hourly DOC is more than twice that of a high-end subsonic business jet, the costs per nautical mile traveled are somewhat more comparable to the cost of subsonic flight. This alternate way of showing DOC may be preferable when marketing the S3T to DOC sensitive customers.

6.3 Net Present Value Analysis

A relatively simple optimization program was developed to analyze the S3T program financial returns given aircraft performance specifications and marketing assumptions. In all cases, the program's NPV is maximized by a common vehicle: Mach 1.6 cruise, 4200 nm range, market priced at $85M ($2001). This is based on three findings:

- Speeds above Mach 1.6 reduce profit margins due to cost growth (due to the use of exotic materials, etc.), while below Mach 1.6 lower sales volumes occur
- Ranges beyond 4,200 nm reduce profit margins due to cost growth (due to greater fuel requirements and the associated rise in takeoff weight) while ranges of less than 3,500 nm are markedly less attractive due to known usage patterns that severely impinge on the accessible market size
- Prices above $85M increase profits by a small amount, but produce a significant increase in the risk of losing market share due to the higher price

Sensitivity studies (Table II) clearly indicate that the market scenario (i.e. annual sales rate) which emerges for the S3T will be the most critical factor to the financial success of the program. Alternate market scenarios (such as 19-passenger transatlantic service – see full study [1]) indicated that a sales rate of 25 aircraft per year may be conservative, even if rights to over land supersonic flight are not granted. If so, the returns for an S3T consortium have the potential to be quite significant. Determining the market for the aircraft will be critical in making the final investment decision when launching the S3T program. A greater depth of analysis is presented in the full study.

Table II: S3T Program Projected Net Present Value and Internal Rate of Return (IRR)

Market Demand	Manufacturer's Discount Rate 15%	25%	35%	IRR
50 per year	$3,714 M	$638 M	-$54 M	33.5%
35 per year	$2,220 M	$202 M	-$208 M	28.0%
25 per year	$1,269 M	-$76 M	-$306 M	23.5%
15 per year	$264 M	-$369 M	-$409 M	17.5%

7. CONCLUSIONS

The product specification in Table I has been developed for a small supersonic transport (S3T) aircraft. The study presented in this paper concludes that successful introduction of an S3T aircraft by the close of this decade is technically feasible and commercially attractive.

The challenges and risks inherent with an S3T program are numerous, including being able to achieve a sonic boom signature level acceptable for supersonic flight over the continental United States, identification of an existing engine core that meets technical as well as regulatory requirements, and accurately quantifying the market for an S3T aircraft.

A best estimate has been made of the optimal mix of attributes for the product vis-à-vis the market, but it must be emphasized that this estimate is built upon a relatively limited data set. This study indicates that a thorough market analysis will be key to the financial success of a supersonic aircraft program.

Successful execution of the S3T program will establish its manufacturer as the technological leader in the worldwide aerospace industry as well as secure its position as the pre-eminent business jet provider well into the 21st Century. The initial S3T entrant discussed in this study could serve as the first in a family of supersonic vehicles as range, cabin size and speed are further refined on subsequent models. The successful introduction of a small supersonic transport will also serve to revitalize an aerospace industry exhausted from budget cuts, program cancellations and corporate mergers.

INFORMATION

For further information on this study or the MIT Aircraft Systems Engineering class, please contact the corresponding author, or Dr. Earll Murman, Department of Aeronautics and Astronautics, murman@mit.edu.

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