HIGHER SPEED COMMERCIAL AIRCRAFT EVOLUTION

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Abstract

The paper addresses the technology developments and business conditions necessary for launching subsonic commercial transports in today's business environment. The possibilities for a second-generation SST and the potential economic payoff using evolving technology are discussed. The evolution of the first-generation high speed commercial transports is reviewed by looking back at the Concorde and U.S. SST development activity. Then, the technical requirements and evolution necessary for a second-generation SST are reviewed. Finally, observations of technology challenges facing hypersonic commercial transportation are made.

Development of Subsonic Commercial Airplanes

Boeing has been tremendously successful in the civil arena. The secret is developing the right derivatives and the right new airplane models at the right time to line up with air travel and airline business growth patterns. The evolution of models has been a prime reason for Boeing's continued success in the commercial field. Recent deliveries of the 767-300, a derivative of the 767-200, have started following its successful certification. Airlines already have signed up for the 737-400, which follows on the coattails of the already extremely successful 737-300. The improved technology 747-400 is scheduled for service in late 1988, and the all-new 7J7 is currently in development. The 7J7 concept offers a complete set of new technology, revolutionary cost targets, and significant improvements in overall airplane economics.

The airlines today are influenced by the pressures of airline wages, fuel prices, airlines competition, airport congestion, and regulatory and environmental pressures coming from the FAA and local communities. The airlines are also influenced by growth and expansion from overall leisure time increases, population growth, growth in the gross national product, and lower fares. The secret to profitable commercial airplane marketing and airplane designs lies in the correct and timely anticipation of, and reaction to, the result of these pressures.

Part of the success equation has to do with the development and implementation of improved technology at the right time. Figure 1 exhibits how Boeing has used continuous generic research and technology applications in 10-year cycles to develop models like the 707, 747, and the 767/757. The size of the arrows represent the magnitude of effort and dollars for each technology surge. After a large initial spurt of technology, evolutionary developments that are smaller in magnitude and lower in cost can be used to spin off technologies into other airplanes.

For example, the 767 development illustrates how the technology collection activity works, and how the business environment in the industry plays a key role in coming through with a successful airplane launch. (The 767 is

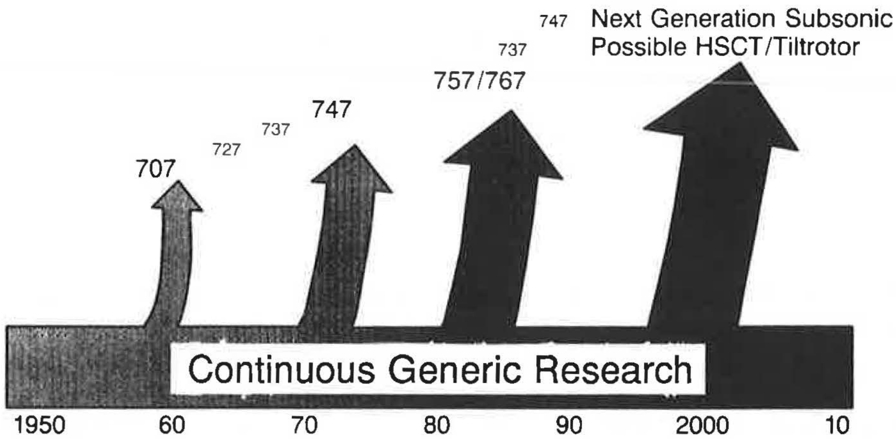


FIGURE 1. Advanced Technology Applications - Major Contributions

shown in the middle of Figure 1.) The 767 technology selection was done with a technology cutoff in mid-1978. The aerodynamics, structures, avionics, and propulsion features of the 767 were selected about four years prior to its first flight. Wings with advanced airfoils, simplified high-lift systems, and high-aspect ratio were developments made after the 747 went into production. Extensive use of Kevlar and graphite composite materials and high-strength aluminum were selected. Major avionics developments were exploited to develop the flight management systems and two-crew flight deck. Third-generation, high-bypass ratio engines were developed from the original 747 engines. Go-ahead conditions for the 767 were attractive in 1978 because net airline earnings were increasing. As has been historically the case, 767 orders tracked directly to these earnings (Figure 2). The program go-ahead conditions for this particular model were correct. Technology elements had been selected and airline earnings confirmed a go.

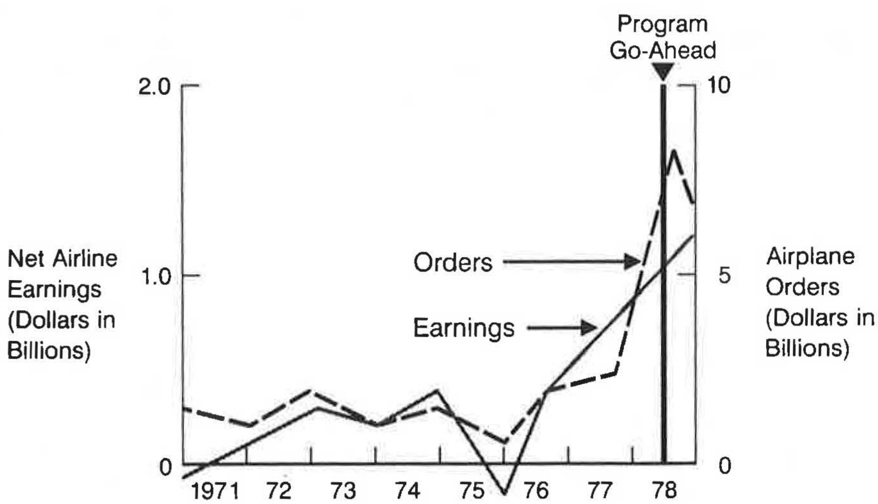


FIGURE 2. Go-Ahead Conditions - Airline Earnings

To illustrates how important it is in this business to be flexible and capable of adjusting quickly to market conditions, Boeing had completed studies of a

7X7 (the pre-go-ahead name for the 767) in a trijet configuration and then made a decision to go to a twin. In late 1977 when engineering effort was building, Boeing developed a final cost definition to determine how the airplane would play in the marketplace. The conditions were ideal for the airplane launch. At that particular time, the 767 airplanes, were defined with three-crew flight decks. It was not until 1981 that the president's commission decided on the two-crew flight deck issue, and Boeing modified and delivered all airplanes in 1982 with two-crew configurations. (See Figure 3.)

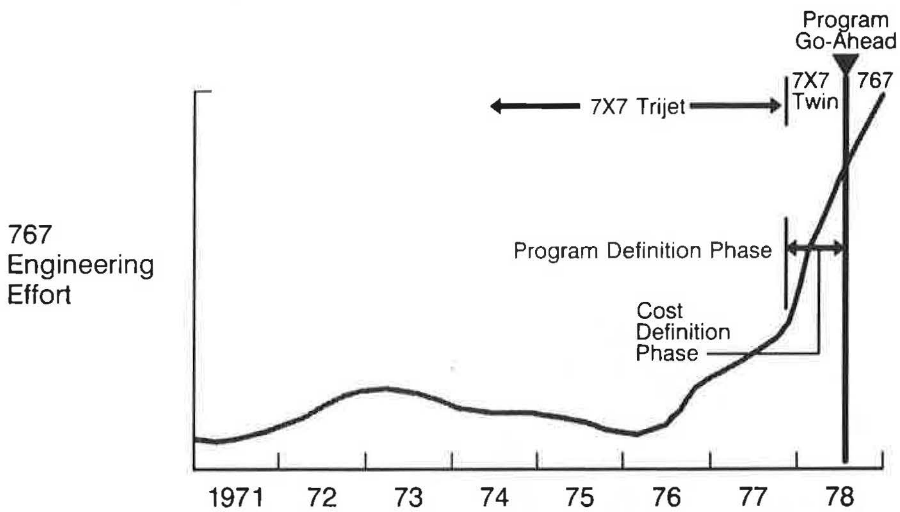


FIGURE 3. Go-Ahead Conditions - Engineering Effort

Technology elements were extracted from the successful 767 program and applied to the models like 757, 737-300, and 737-400. Boeing is now applying those technology features to the improved technology 747-400 that will be available for delivery in late 1988. The 747-400 will have a 50-percent improvement in seat miles/gallon compared to the original 747-100. This airplane will also feature a two-crew flight deck. (See Figure 4.)

There has been a change in environment since the mid-1970s, when technology was pacing and fuel was a dominant portion of the total direct operating cost for the airlines. The ownership portion of the direct operating costs was less important than the fuel portion. As we proceed into the future, goals must be adjusted to current reality. Fuel now is less dominant compared to ownership cots, as shown in Figure 5. All of our new designs are responsive to ownership cost and the right balance between ownership cost, maintenance cost, and fuel cost. In 1978, deregulation forced the airlines to become extremely cost and revenue conscious.

Technology incorporated in the next all-new airplane will be targeted for direct operating costs that consider ownership costs at the premium now being experienced. For example, the 7J7 currently being studied by Boeing incorporates radical new engine technology, exploiting counter rotating fans in an unducted fan or propfan configuration, new materials technology, and advanced, simplified systems to address lower ownership and maintenance costs.

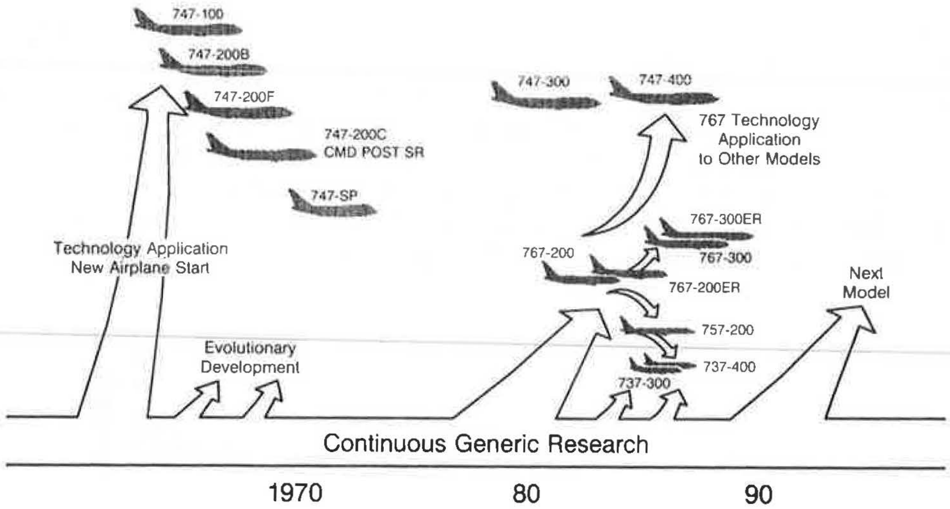


FIGURE 4. Advanced Technology Application

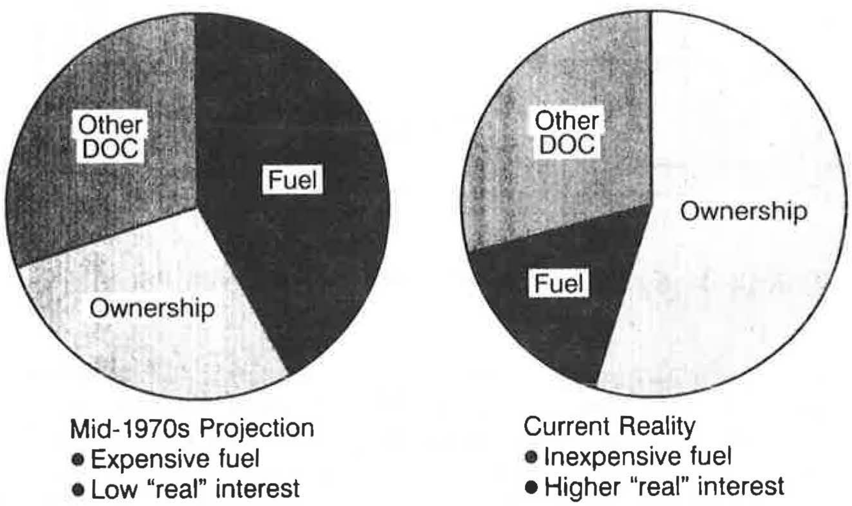


FIGURE 5. Change in Environment - Direct Operating Cost

Aluminum-lithium and composite primary and secondary structures are being studied together with significant improvements in systems and avionics. The ultrabypass engine represents fuel savings of 25 percent over the high-bypass-ratio engines available in the late 1980s. Technology elements of the 7J7 are being targeted to support airplane application in the 1990s.

Technology elements developed for the 7J7 could be applied at the turn of the century to a new version of the 747, for now called the 747-XXX. This new 747 model also features new, radically different, propulsion systems. Rather than the unducted fans studied for the 7J7, the 747-XXX could use ducted versions. The airplane will be studied with an all-new wing and a major body stretch. The all-new wing and the ducted versions of the new ultrabypass engine technology could result in a cruising speed of 0.9 Mach.

Second-Generation Supersonic Transports

Beyond the 7J7 and the 747-XXX concepts, the next thrust of technology will probably be oriented toward a supersonic transport (SST). Many important technology elements essential for the next SST will have been developed in the 7J7 program. Yet others, particularly those related to higher speed, are still required. Technology in the areas of laminar flow, high-lift devices for highly swept leading edges, thermoplastics and metal matrix composites, and variable cycle engines are some of the outstanding challenges to be addressed for a second-generation SST.

Insofar as the airlines are concerned, the bottom line for a future SST will be economic performance--return on their investment compared to other options. To address this subject, data on SST economic studies will be referenced to the 747-XXX which could be available around the year 2000. A comparison of a 747-XXX to a Boeing/NASA single-decker SST is given in Table 1. There are 525 passengers on the 747-XXX and 283 or 266 passengers on the SST, depending on passenger seating mix, equivalent or enriched. The enriched mix on the SST, resulting from increasing the percentage of first class and business class at the expense of economy class, improves the overall fare yield. (Note that the seat pitch between the 747 and SSTs has been adjusted to account for the difference in flight times.) Variations in the seat counts associated with changes in seat pitch are also an important factor.

Table 1. - SEATING-PASSENGER CLASS DISTRIBUTION

Aircraft	No. of Seats	Seating Mix	Class--Percentage (& Pitch (in.))		
			First	Business	Economy
747-XXX	525	(reference)	9 (62)	19 (38)	72 (34)
Single-Deck SST	283	Equivalent	9 (38)	19 (36)	72 (32)
	266	Enriched	14 (38)	30 (36)	56 (32)
Double-Deck SST	545	Equivalent	9 (38)	19 (36)	72 (32)
	524	Enriched	14 (38)	30 (36)	56 (32)

A possible double-decker SST gets closer in seat count to the 747-XXX. The 747-XXX has the same number of passengers as in the previous comparison, 525. The double-decker SST is a Boeing/NASA configuration, with 545 to 524 passengers depending on equivalent or enriched seating mixes.

The 747-XXX versus the single-decker and double-decker SST are compared in Figure 6. The net present value of the single-decker SST (left side) and the double-decker SST (right side) are compared to a base level of 100 for the 747-XXX. Until we further understand the true cost and therefore the price of the SST models, a 747-XXX price multiple is carried through all of our studies. The large double-decker airplane shows a significant advantage in net present value, particularly when using the high yields associated with enriched three-class SST seating. The single-decker version of the SST shows less of a possibility of matching the 747-XXX on this basis.

This study was conducted with the following assumptions: 2,600-nmi trip, 65-percent load factor, 15-year operation, 15-percent discount rate, and unrestricted routing. Also, three-class seating: 747s at (62/38/34) inch pitch and SSTs at (38/36/32) inch pitch; design cruise speed: 747 at Mach 0.85 and SST at Mach 4. In addition, 1985 operating costs rules and prices include airframe and engine spares.

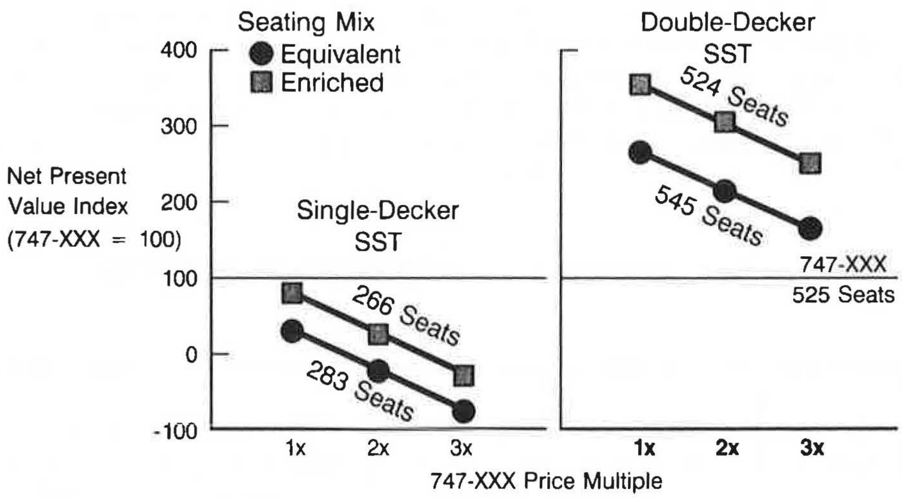


FIGURE 6. SST Earnings Potential (Mach 2.4) Compared with 747-XXX

Figures 7 and 8 show a coarse look at the effects of designing an SST for Mach numbers higher than 2.4. In these simplified "what if" type studies, the airplane gross weights were parametrically increased with increasing Mach numbers to account for structural changes necessary to satisfy thermal requirements. Fuel burn increased both as a result of the increase in gross weight and the propulsion and L/D effects that go with cruise at higher Mach numbers This data indicates the net present value of an SST to be about constant for this range of Mach numbers. It should be noted that these particular studies have not considered the higher temperature potential of the projected advancements in materials such as the powdered aluminums and titaniums or the metal matrix composites.

Evolution and Development of Supersonic Transports

Next, the evolution of the U.S. SST and a timetable for a 21st century SST will be discussed based on our experience in the previous SST program.

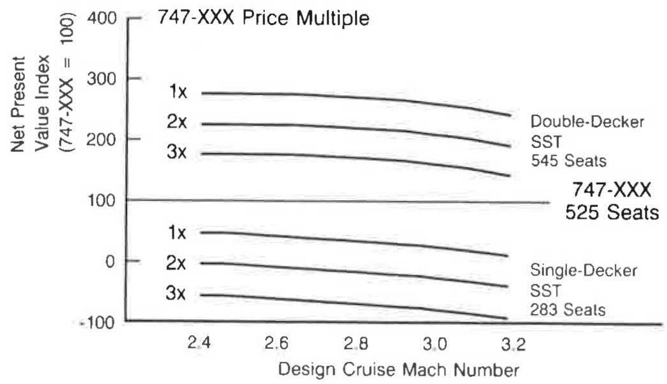


FIGURE 7. SST Earnings Potential - Equivalent Seating Mix

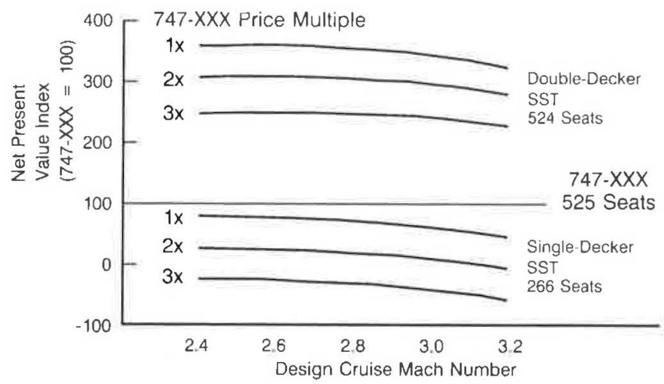


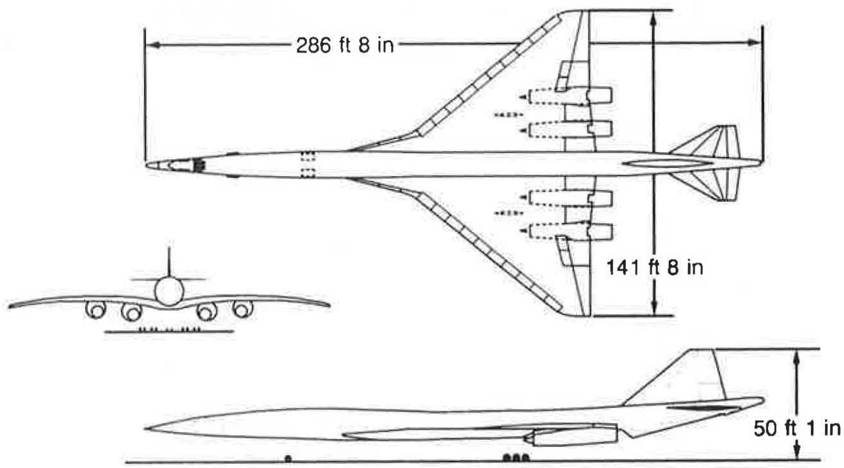
FIGURE 8. SST Earnings Potential - Enriched Seating Mix

Supersonic capability started in the late 1940s with the XS-1 when Mach 1 was first exceeded. High speed research programs were followed by military programs such as the F-104, F-105, B-70, and SR-71. Experience from the military programs formed the basis for the start of the prototype U.S. SST and, ultimately, the operation of the Russian TU-144 and the Concorde.

The "X" vehicles (X-1 through X-5) also contributed to the progress leading the U.S. SST program, the Russian TU-144, and the British/French Concorde. The intervening military developments were essential to the start of these SST programs.

Even though military forerunners are essential to advanced commercial undertakings, it is obvious that military requirements differ from commercial requirements. Economic and performance considerations such as price, profitability, and risk are different between the commercial arena and the military arena. Mission requirements, including range, equipment, and passenger provisions, tend to be different. Operational requirements such as airport and community noise considerations, utilization, and airport compatibility are drastically different. Design requirements are different. Long heat soak time, operational life, reliability, safety, maintainability goals, and growth goals are different. The SST impact on the ozone layer and the sonic boom are significant considerations for the commercial operation.

Looking back on the U.S. SST program, knowledge was gained from earlier military programs, but there still remained many commercial challenges such as weight and payload weight fraction, supersonic and subsonic range factor, low-speed performance stability and control, sideline and community noise, cooling and pressurization, cabin and fuel temperatures, overall thermal management, seal materials, and lubrication. The issues of sonic boom and upper atmospheric ozone were the factors that were not successfully addressed. The SST Model 2707-300 is illustrated in Figure 9.



SST Prototype Airplane Model 2707-300

FIGURE 9. U.S. SST Program (1968-1971)

The U.S. SST program planned to have the number one prototype in flight test by late 1972, 4 years after the 1968 configuration decision. The second protoype was scheduled for limit-load tests and then flight in 1974. The production airplane certification was to occur in 1978, 10 years after the prototype configuration decision.

Following cancellation of the U.S. SST program, continued development of military airplanes like the B-1 Bomber, F-16, F-14, and SR-71 has further enriched our technical capabilities and provided a better technology base for a future version of the SST. the 767/757 systems and structures technology developments toward the end of the 1970s have also contribute to this base. The British Aircraft Corporation's experimental Jaguar Digital Fly-by-Wire and other parallel programs have added to the necessary technology. And, the Concorde experience, where more people have flown supersonic than in all military programs combined, provides an important stepping stone for a next generation SST.

Variable cycle engine development activities sponsored by NASA have provided major breakthroughs in supplementing the technology elements required for a future SST. (See Figure 10.)

Nozzle noise suppression studies and research investigating thermal accoustic shields, coannular nozzles, and mechanical suppressors contribute to the technology base now available since the evolution of the original SST. Materials and structures technology improvements in the strength-to-density

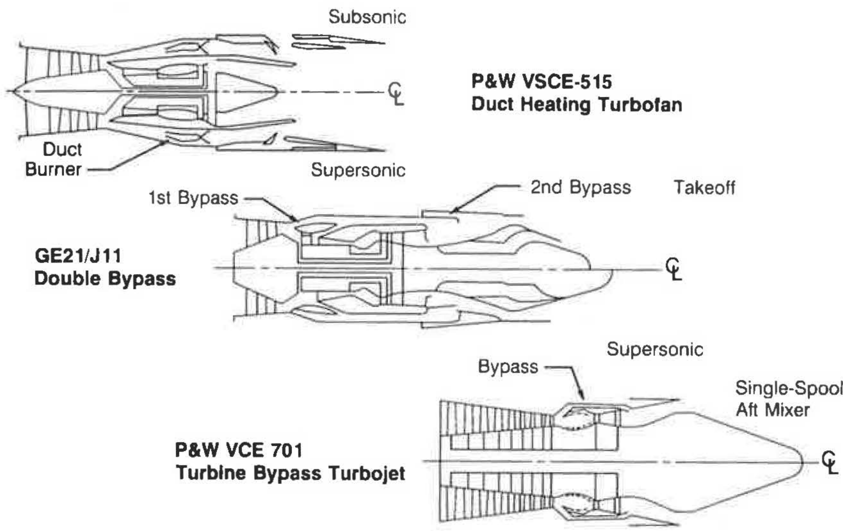


FIGURE 10. Variable Cycle Engine Development

ratio as a function of temperature show great progress since the earlier days of the U.S. SST. New materials incorporating rapid solidification rate technology and thermoplastics offer exciting possibilities. (See Figure 11)

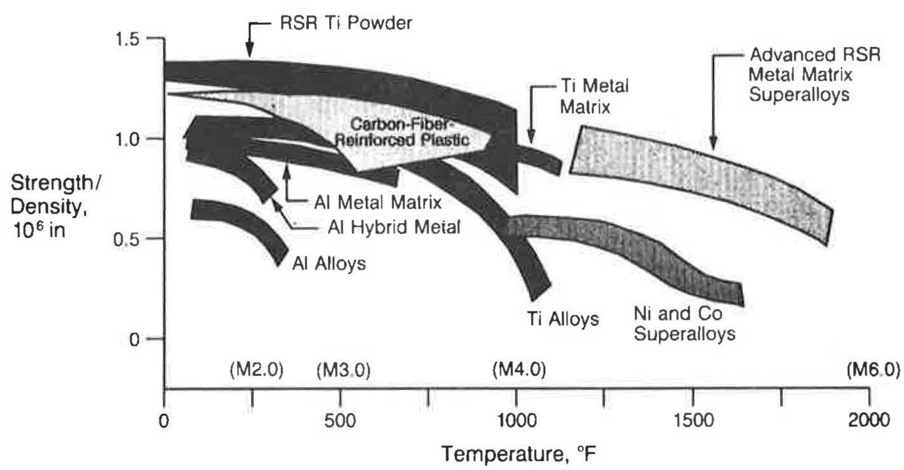


FIGURE 11. Materials and Structure Technology

Continued improvements in simplified lightweight systems could come from the 7J7 commercial experience. As an example, the large-scale use of the Boeing developed DATAC data-bus system for airframe subsystems control and monitoring results in significant weight savings. Substantial manufacturing cost savings are expected.

Significant improvements have been made in low-speed aerodynamics with the developments of variable camber and the leading-edge vortex flap. This will permit the use of higher lift coefficients for takeoff and landing and permit

wings sized for cruise flight to be compatible with existing runway and airport approach speed requirements. The earlier experience of the U.S. SST program, the experience of the Concorde, and the evolving technology elements appear to ensure that a second-generation SST could be viable.

Continued NASA studies and industry studies could lead to high-speed civil transport design and development culminating in an SST certification around the year 2000. Some of the required or enhancing developments to support such a plan are listed here:

- Propulsion noise suppression
- Variable cycle engine concepts
- Laminar flow control
- Low-speed aerodynamics
- Low-overpressure configurations
- Low-pollution engines
- Low-cost structures
- High-temperature seals, lubes, and fluids
- Fuel tank conductivity
- High strength-to-weight materials

Development of Commercial Hypersonic Transports

Recent attention from the administration and the press has been focused on the possibility of a hypersonic "Orient Express." To review that possibility, consider how continuous generic research has fostered the development of advanced commercial models, and how it could lead to the development of a commercial hypersonic transport. With the government plans for building the X30 hypersonic research vehicle, and ultimately, a military or space hypersonic vehicle, a commercial hypersonic transport could be considered. Figure 12 shows several hypersonic transport concepts.

The use of an experimental vehicle like the X-30 airplane can contribute to the knowledge base for Mach numbers from 2 to 20. A commercial hypersonic airplane development could come sometime following hypersonic military and space vehicle operations early in the 21st century.

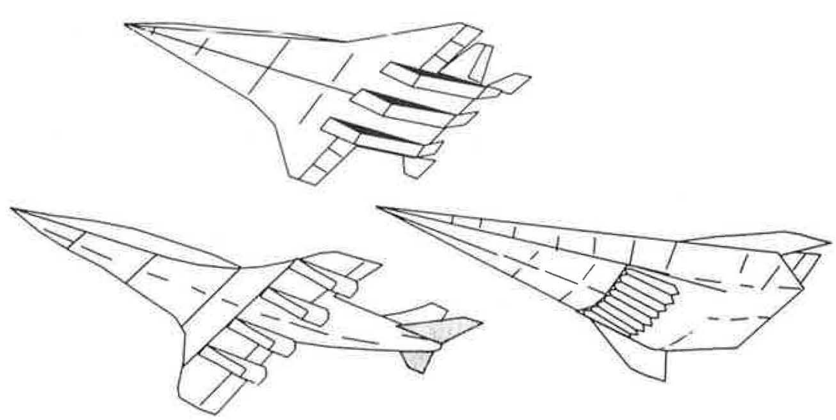


FIGURE 12. Hypersonic Transport Concepts

Even though it is very exciting to discuss travel between continents at hypersonic speeds, hypersonic transport design challenges still remain very significant.

The safety, reliability, and maintainability challenges associated with hypersonic flight are significant. For example, the operational procedure on current subsonic airplanes following a cabin pressurization failure is to execute an emergency descent to 14,000 feet and then cruise to the next point of landing. What will be the implications for a hypersonic airplane cruising at 100,000 feet? If the hypersonic airplane uses accelerator and cruise engines, an airline will expect extremely high probability of all the cruise engines starting when reaching cruise altitude, and vice versa when slowing from cruise to descent and reigniting the accelerator engines. Maintenance also raise a number of challenges. As we know, the faster an airplane flies, the more essential it is to quickly turn it around on the ground and get it back into the air in order to exploit its productivity. Will we able to service a hypersonic airplane that may have much of its structure still hot and turn it around in 45 minutes to an hour?

Design and operation challenges are significant. From an operational standpoint, accelerations imposed on the passenger are a prime consideration. And fuel costs and handling of the special fuel, sonic booms, utilization of aircraft, turnaround times, and navigation and air traffic control offer significant challenges.

Design requirements for structures, vehicle considerations for minimum overpressure, fuel insulation, thermal management, and propulsion system integration all offer tremendous challenges.

Several scenarios for hypersonic commercial travel can be envisaged. In one case, hypersonic airplanes are compatible with today's airports and surroundings. In another, more likely, scenario hypersonic commercial transports operate out of dedicated "space ports," which are fed by both subsonic and supersonic airplanes.

Conclusions

1. Second-generation commercial supersonic transport airline operations are a possibility for the turn of the century.

2. A commercial SST must be responsive to the challenging deregulated airline business requirements.

3. The SST and its supporting systems must offer competitive earnings capability and operating costs.

4. Coordinated and disciplined approach by industry and government is necessary to develop the required technology.

5. Environmental and political issues will have to be satisfied.

6. Timing of hypersonic commercial transport operations are dependent on a national aerospace-plane program to pioneer military/space developments and to provide technological spinoff for commercial consideration.