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SUPERCRUISER ARROW HS - 8

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Abstract

Technology in aeronautics has advanced dramatically since the last design of a production High Speed Civil Transport (HSCT) aircraft. Newly projected requirements call for a new High Speed Civil Transport aircraft with a range of approximately 5500 nm. and at least 275 passenger capacity. The aircraft must be affordable and marketable. The new HSCT must be able to sustain long-duration flights and to absorb the abuse of daily operation. The new aircraft must be safe and simple to fly and require a minimum amount of maintenance. This aircraft must meet FAA certification criteria of FAR Part 25 and environmental constraints. Several design configurations were examined and two designs were selected for further investigation. The first design employs the delta planform wings and conventional empennage layout. The other design uses a swing wing layout and conventional empennage. Other engineering challenges, including materials and propulsion are also discussed. At a cruise flight speed between Mach 2.2 and Mach 3.0, no current generation of materials can endure the thermal loading of supersonic flight and satisfy the stringent weight requirements. A new generation of lightweight composite materials must be developed. A new class of engines must also be developed for the HSCT. With the enforcement of stage 3 noise restrictions, these new engines must be able to propel the aircraft and satisfy the noise limit. The engine with the most promise is the variable cycle engine. At low subsonic speeds the engine operates like a turbofan engine, providing the most efficient performance. At higher speeds the variable cycle engine operates as a turbojet power plant. The two large engine manufacturers, General Electric and Pratt & Whitney in the United States, are combining forces to make the variable cycle engine a reality.

Introduction

The Concorde, a supersonic passenger transport resulting from the joint efforts of the British Aircraft Corporation and the French Aerospatiale, flew for the first time on March 2, 1969. It was a monumental technical achievement; however, economically it proved to be a tremendous failure.

The obstacles facing the High Speed Civil Transport (HSCT) are mainly technical, economical and environmental. Because of the sonic boom generated by supersonic flight, the HSCT is banned from overland flight. Other environmental restrictions include the Federal Aviation Administration's requirement of low nitric oxide emissions and new lower noise level requirements. With these restrictions the building of an aircraft that meets these requirements will impose a major technical challenge. With the overland supersonic flying restriction, the HSCT market is thus limited. This reduced market threatens to make the HSCT an economically unfeasible aircraft.

The challenge to produce an environmentally and economically acceptable HSCT is the subject of the senior design project study of a team of undergraduate aerospace engineering students at California State Polytechnic University, Pomona.

Requirements

The request for proposal (RFP) supplied to California State Polytechnic University, Pomona, included requirements proposed by the Association of European Airlines (AEA). The objective is the design of a High Speed Civil Transport aircraft for entry into the marketplace by year 2015.

Design Mission

1. Incorporate payload of 275 passengers (minimum) with baggage.
2. Cruise to a point 6500 nm from takeoff.
3. Land with sufficient reserves.

Performance

1. Determine best cruise Mach number.
2. Do not exceed 1.25g rate of climb to assure passenger comfort.
3. Satisfy second stage climb requirements performance.
4. Take off and land from 10,000 ft runway with 50 ft obstacle.

Environmental

1. Meet any regulatory requirement for emissions at time of service.
2. Reduce the effect of the sonic boom.

Propulsion

The engines should be designed to be operated with standard jet fuel.

Supportability

To remain profitable, an airline must be able to utilize its aircraft around the clock throughout its useful life. Since corrosion, wear, and aging degrade an airplane, the aircraft must be easily inspectable. If a problem with a critical part is discovered, the part must be available to the mechanic and easily installed. The main structure should be designed and tested for a fatigue life of not less than 75,000 flight hours and 25,000 cycles.

Certification

The aircraft must meet standards, rules, and regulations in FAR Part 25.

The aircraft is intended to be used in long range flights so it must be safe, simple to fly, and require minimal maintenance. Furthermore, this aircraft should require minimal personnel conversion training in both operation and maintenance. In addition, this aircraft must be able to be certified and fit in with the current designs in both the air traffic system and in the ground support system. A safety factor of 1.5 must be incorporated into the design.

Vehicle Development

Concepts

The first consideration was the type of fuselage needed in order to meet the RFP requirements. With this in mind, four fuselages were considered: cylindrical, twin fuselage, blended wing/body, and oblique flying wing. A comparison of the practicability of these configurations in the marketplace was considered along with market acceptability. The second consideration was the type of particular wing configuration that would optimize the HSCT performance in subsonic, transonic, and supersonic regimes. Four wing configurations have been considered the most practical for a HSCT aircraft. These four wing configurations are: fixed swept, variable sweep, double delta/cranked arrow, and oblique wings. These four wing designs have been experimentally tested in the realm of supersonic cruise flight and have been proposed as viable design features for our HSCT program.

Fuselage Configurations

The first fuselage configuration to be considered is the conventional cylindrical fuselage. This configuration is a streamlined tube shaped for supersonic flight. Another configuration considered is the twin fuselage. The twin fuselage configuration offers more capacity and internal layout flexibility than the conventional single fuselage layout. The third fuselage configuration to be considered is the blended wing/body configuration. This particular configuration integrates both the fuselage and wing configurations into one composite body to offer better aerodynamics.

The final fuselage configuration to be considered is the oblique flying wing. This configuration is the most radical of all the fuselages considered. The oblique flying wing does not have the same interior fuselage attributes as the cylindrical fuselage configuration. The only noticeable difference between the two fuselage designs is that there is basically no fuselage, by definition, present in the oblique flying wing. Unlike the other fuselages at subsonic speeds, the oblique flying wing would be capable of maintaining aerodynamic efficiency while accelerating from subsonic to supersonic speeds.

Wing Configurations

The first wing configuration design considered was the fixed swept wing. Even though this wing configuration provides sufficient performance at supersonic speeds, its performance is poor when flying at subsonic and transonic speeds. In order to improve the poor aerodynamic performance of the fixed swept wing in subsonic flight, a variable sweep wing configuration has been proposed. This configuration has similar supersonic performance to the fixed swept wing, and good subsonic performance with the wings extended outward. However, the variable swept wing adds a weight penalty.

The third wing configuration to be considered for the HSCT program was the double delta/cranked arrow wing configuration. The double delta/cranked arrow wing shows the most potential. The arrow wing helps smooth out the area distribution of the HSCT, thus reducing the sonic boom overpressure. This configuration takes advantage of the physical and aerodynamic characteristics of the fixed swept and variable sweep wing design configurations.

The final wing design to be considered was the variable sweep oblique wing. This configuration has been shown to be quite efficient at low and supersonic speeds. Aerodynamic, aeroelastic, structural, and flight control studies have indicated that this variable sweep oblique wing concept leads to a more fuel efficient and quieter aircraft than those designed for the same HSCT requirements.

Initial Configurations

An investigation was made into the possibility of supersonic flight over land. The sonic boom overpressure would have to be lowered such that the aircraft could maintain supersonic flight over land and populated areas. However, the acceptable overpressure level was difficult to attain. A mixed flight profile consisting of supersonic and subsonic phases was developed as an alternative to achieve overland flight. This criterion required that the aircraft have a good performance in both the subsonic and supersonic flight regimes.

Out of the initial vehicle concepts researched and reviewed, the following was concluded: The four fuselage configurations (cylindrical, twin fuselage, blended wing/body, and oblique flying wing) were studied and compared with each other. The missile (cylindrical) fuselage was the most economical in terms of passenger, payload, and production considerations. The twin fuselage and oblique flying wing configurations, on the other hand, exemplify distinctive ideas based on theory. The blended wing/body configurations represent a unique step into the integration of the fuselage and wing components into one composite body. This design is worth investigating for future possibilities, since it conforms to the passenger capacity of the missile fuselage and exploits the aerodynamic characteristics of an entire lifting surface. However, it has been ruled out due to its greater manufacturing cost.

From the four wing configurations (fixed, variable sweep, double delta/cranked arrow, and oblique wings) the fixed swept has poor subsonic performance. The variable sweep wing configuration adds unwanted structural and weight problems. In order to compensate for the above mentioned problems, the double delta/arrow wing configuration provides both good subsonic performance and less complicated structure. A unique wing configuration is the oblique wing, which was studied by the Boeing Commercial Airplane Company. However, with its radical looking configuration, getting public acceptance of the oblique wing will be difficult. From the comparison between the various wing configurations proposed, the double delta/arrow wing appears to be the design best suited for supersonic transportation. Two designs will be investigated further, the swing wing and the double delta/arrow wing, in order to determine the best design.

Variable Geometry Wing

The first configuration selected for detail study is the variable geometry wing. Figure 1 shows the evolution of the variable geometry wing as it survived the initial design phase. The most beneficial characteristic of the swing wing was the aerodynamic compromise between the supersonic and subsonic flight regimes. With the wing swept back, the configuration maximizes its supersonic cruise performance. When the wings are fully extended, the configuration's subsonic performance resembles that of a subsonic aircraft.

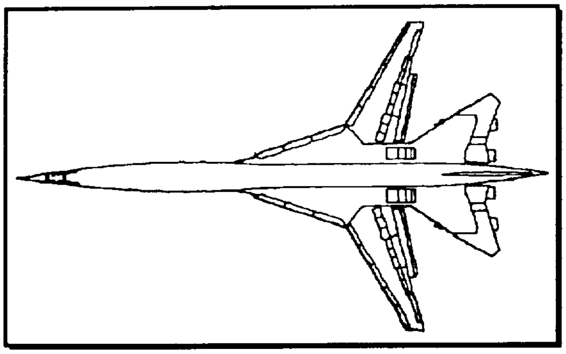

Fig. 1 Variable swept wing design

In the supersonic flight regime, the swing wing could reduce its aspect ratio to 2.17 with the wings fully swept. In this configuration, the aircraft would have less wave drag, thus reducing the required fuel load for the mission. With the exception of its variable geometry system, the swing wing would have structural similarities to those of the current subsonic aircraft. Even though the variable sweep wing appears to be the ideal wing configuration of choice, it is unfortunately not immune to the disadvantages. Due to the complexity of the mechanisms constituting the variable sweep wing, this variable sweep feature poses structural design and weight penalties. The variable sweep wing configuration for the HSCT was abandoned after the first quarter of detailed study.

Double Delta/Cranked Arrow Wing

The evolution of the double delta configuration as it survived the first iteration of the design process is shown in Figure 2. Like the swing wing, the double delta configuration offered good subsonic and supersonic characteristics. This optimum balance between the two flight regimes is achieved by the breaking of the wing into two regions. One region falls within the supersonic Mach cone and the second region is outside the Mach cone. The region outside the Mach cone allows for better subsonic performance, since it has less sweep. The inverse is true for the inboard portion of the wing. In addition to the favorable aerodynamic qualities of the double delta configuration, the wing is capable of carrying a large fuel capacity. Thus the double delta was chosen as the final wing configuration to be used in the second iteration phase.

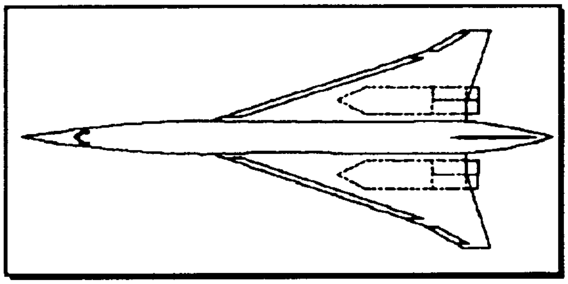

Fig. 2 Double delta/cranked arrow design

Constraint Diagram

Constraint diagrams were optimized for aircraft flight profile and aircraft flight requirements, with the additional limitations set by the environmental restrictions. The following flight requirements were considered for the Supercruiser design.

- Range: 6,500 nm
- Rate of climb: 89 ft/s
- Takeoff Distance: 10,000 ft
- Landing Distance: 10,000 ft
- Cruise Speed: Mach 3.0

The Mach 3.0 cruise speed was chosen for the first design iteration, between the Mach 2 and 5 range. A sensitivity study for the cruise speed was conducted concurrently. The study showed that the cruise speed should be reduced to around 2.6. Unfortunately, due to time constraint, a second design iteration was not completed.

The constraint diagram is shown in Figure 3. The Supercruiser's design will fall within the area that satisfy the RFP requirements and associated constraints. The figure shows that the optimum aircraft designs falls between wing loading of 23 and 110 pounds per square foot, and thrust to weight ratio between 0.4 and 1.4. The initial design point was selected with 0.3 thrust to weight ratio and a wing loading of 104 lb/ft^2.

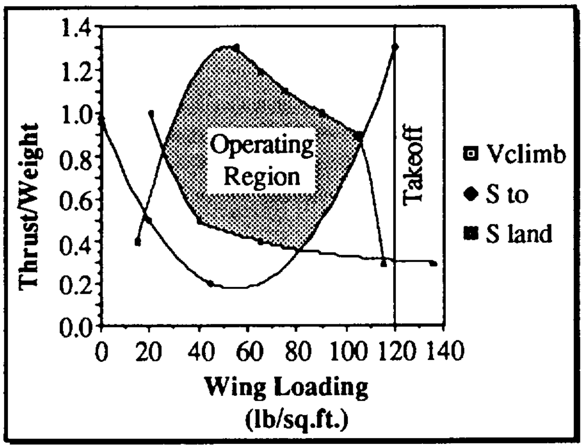

Figure 3. Supercruiser Constraint Diagram

Aerodynamics

Wing Design

Before any wing can be designed, appropriate airfoils must be selected. Compromise between structural integrity and aerodynamic effectiveness is required for a supersonic airfoil. The airfoil selected for the Supercruiser is a modified NACA 65-006. The maximum thickness is moved to be 3 percent of the chord. The wing planform chosen for the Supercruiser is a double delta, which is shown in Figure 4. The wing span of 130 feet and a total planform area of 10,000 ft^2 was selected for the Supercruiser. The aspect ratio and the inner and outer wing taper ratios are 1.69, 0.28, and 0.25, respectively. The inboard leading edge of the wing is swept back 72 degrees so that the wing is contained within the Mach 3 Mach cone. A rounded leading edge airfoil was selected for the inboard portion of the wing. The outboard leading edge is swept back 61 degrees. This portion of the wing will experience supersonic flow normal to the leading edge.

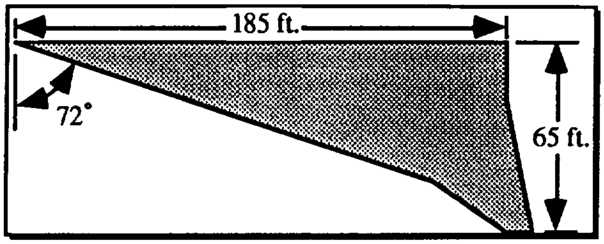

Fig. 4 Supercruiser wing semi-planform

High Lift Devices

In order for the Supercruiser to have superior takeoff and landing performances, high lift devices such as trailing edge flaps and leading edge flaps were considered. The Arrow HS - 8 configuration has been fitted with full-span leading edge flaps to improve the takeoff performance of the aircraft. These leading edge flaps provide adequate control for pitch acceleration at the designated rotation speed to achieve the required liftoff speed.

Trailing Edge Flaps

The design of trailing edge flaps depends on the following parameters:

- Airfoil used: 65A003
- Airfoil Lift Curve Slope: 0.106/deg
- Airfoil zero lift angle of attack: -2.6 deg
- (C_L)max: 1.6

The behavior of the airfoil section as a function of flap deflection is shown in Table 1.

Table 1
Behavior of airfoil section as a function of flap deflection

Deflection (deg)	Zero lift (deg)	Stall (deg)	C_L max
10	-7.01	-0.5	0.69
15	-9.89	-0.8	0.96
20	-11.22	-1.0	1.08
25	-11.92	-1.4	1.17
30	-13.26	-1.8	1.21
35	-13.75	-2.4	1.26
40	-15.43	-3.0	1.32
45	-16.73	-3.7	1.38
50	-17.19	-4.2	1.38
55	-18.13	-5.0	1.39
60	-18.94	-5.8	1.39

Once the airfoil behavior was determined, the wing behavior was then calculated. The (C_L)max of the wing was determined to be 1.13 and the stall angle of attack was found to be 28 degrees. These two parameters were shown to vary with flap deflection. Table 2 shows the variation of C_{Do} with trailing edge flap deflection.

Table 2
Behavior of the wing as a function of flap deflection

Flap deflection (deg)	C_L max	C_{Do}
10	0.198	0.006562
15	0.2755	0.009843
20	0.310	0.019687
25	0.3358	0.022968
30	0.3473	0.026775
35	0.3317	0.038062
40	0.3789	0.04725
45	0.3961	0.0525
50	0.3961	0.063
55	0.399	0.070875
60	0.399	0.078225

Trailing edge flaps do not prevent flow separation; in fact, they aggravate flow separation slightly due to the increase in upwash at the leading edge due to increased circulation. Trailing edge flaps become less effective as the wing sweep is increased. Trailing edge flaps are very effective on wings that are swept up to 35 degrees.

Leading Edge Flaps

With the facilities currently being utilized, only experimental and statistical data were used to predict the change in (C_L)max for a wing with leading edge devices. The computed values for the change in (C_L)max due to leading edge flap deflection are shown in Table 3.

As noted earlier, the trailing edge flaps are not as effective with increasing sweep angle. The leading edge flaps are able to achieve the desired (C_L)max at landing and takeoff. Therefore, limiting the complexity of the wing while still maintaining adequate lift and control of the Supercruiser, the trailing edge flaps were dropped from the final design configuration.

Table 3
Change in (C_L)max due to leading edge flap deflection

Deflection (Deg)	$C_L$max
10	0.4329
15	0.6023
20	0.6778
25	0.7338
30	0.7593
35	0.7908
40	0.8284
45	0.8660
50	0.8660
55	0.8724
60	0.8724

Vertical Tail Design

Two vertical tail concepts were considered for the Supercruiser's lateral directional control. The two concepts are an all-movable vertical tail and a conventional vertical tail/rudder combination. Control about the lateral directional axis is sensitive to changes in Mach number, dynamic pressure, and load factor. This sensitivity is due to strong nonlinearities in key stability derivatives and considerable reductions of control effectiveness caused by structural flexibility.

Utilizing stability computer simulation, the Supercruiser's stability behavior was analyzed for the all-movable vertical tail and the conventional vertical tail. Dynamically, the vertical tail with rudder was preferred because higher overall flying quality was achieved. However, the magnitude of the lateral force generated on the tail is proportional to flight speed and it was calculated to be 13,700 lb at Mach 3.0. This force, which is acting only on the rudder area, could twist the tail structure to a point at which it would fail and no longer function properly. Therefore, it was determined that the Supercruiser would utilize the all-movable vertical tail as its vertical stabilizer.

Fuselage Design

One of the primary drivers in the fuselage design was its ability to accommodate the 275+ passengers including the associated baggage. With this requirement in mind, a baseline payload of 300 passengers including baggage was considered. The length of the fuselage and its maximum diameter was determined according to its ability to accommodate 300 passengers including baggage, flight deck, and required facilities and systems to properly maintain the aircraft. Those parameters resulted in a fuselage length of 318 ft and a maximum diameter of 17.1 ft.

Utilizing area ruling and wave-drag computer simulation, the fuselage's diameter was varied according to longitudinal location. This was done in order to optimize its performance in the supersonic flight regime. Figure 5 shows the final configuration of the fuselage.

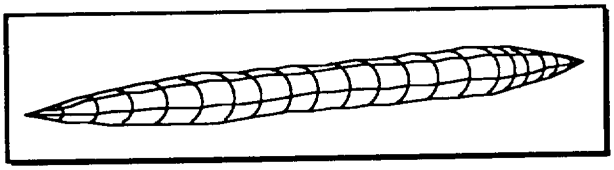

Fig. 5 Supercruiser's final fuselage shape

In order to determine the fuselage's impact on the overall performance of the aircraft, the fuselage drag coefficient was evaluated at three different stages. The three stages are as follows:

- Subsonic drag coefficient
- Transonic drag coefficient
- Supersonic drag coefficient

Subsonic Fuselage Drag Coefficient

In calculating the drag coefficient due to lift, the angle of attack was assumed to be 6 degrees. The value of the coefficient was predicted to be 0.0026 at Mach 0.3 and an altitude of 20,000 feet.

Transonic Fuselage Drag coefficient

The transonic drag coefficient was determined to be 0.0027, at a Mach number of 1.1, altitude of 30,000 feet.

Supersonic Fuselage Drag Coefficient

For the supersonic drag coefficient, the angle of attack was assumed to be 1 degree. The value of the supersonic drag coefficient was calculated to be 0.0015 at Mach 3.0 and an altitude of 60,000 feet.

The drag coefficients of the fuselage evaluated at three different Mach regimes are comparable to or less than those of current supersonic aircraft. The lowest drag is achieved at the supersonic cruise phase, since the aircraft is optimized for cruise. This indicates that our chosen fuselage configuration is aerodynamically acceptable.

Propulsion System

Engine Candidates

In order for the Supercruiser to achieve the optimum cruise number specified in the RFP (ultimately determined to be Mach 3.0) and to be environmentally acceptable, its engines must provide a considerable amount of thrust with low specific fuel consumption and low emissions. In this section, an evaluation of engine candidates will be conducted.

Turbojet

At Mach numbers above 2.5, the afterburning turbojet becomes significantly efficient due to the pressure rise linked with diffusion in the inlet. This raises the nozzle pressure ratio to a higher value. However, the turbojet suffers in the subsonic region and does not meet the current noise and emission limits.

Turbofan

The turbofan engine has better propulsive efficiency than the turbojet engine. The high values of static thrust ratio at low bypass ratios show the usefulness of the turbofan engine for takeoff, which is one of its main advantages.

Future Engine Designs

Research has indicated that there are three different engine concepts which seem very promising for future utilization. These three engines concepts are a result of research done by General Electric and Pratt & Whitney. The engine concepts are listed below.

- GE 21/F14, augmented variable-cycle engine
- GE 21/FLA1, two-stream exhaust, nonaugmented high-flow fan variable-cycle engine
- GE 21/FLA, three-stream exhaust, nonaugmented high-flow fan variable-cycle engine
- P&W STF947 augmented variable-stream control engine, with chute suppressor and with a high-flow mixer/ejector nozzle
- P&W STJ950 single spool nonaugmented turbine bypass engine with a convergent-divergent ejector nozzle with suppressor

Two important parameters in engine performance evaluations are cruise overall efficiency and takeoff thrust-to-weight ratio. Another important engine performance parameter is specific fuel consumption during climb, which accounts for approximately 25 percent of the total block fuel. Takeoff thrust-to-weight ratio is important because engine thrust requirements are generally sized by takeoff field length.

After much analysis it was determined that there is no engine concept that exists at this point which will adequately satisfy all HSCT propulsion system requirements. There is a tradeoff between noise-level and range. However, with the further research and development of the variable cycle engine, a satisfactory candidate should appear around year 2010.

Engine Inlet System

For sustained supersonic cruise (cruise at Mach numbers greater than approximately 1.4 for prolonged operation), there are basically two types of inlets. These inlets are the conical inlet (also referred to as the axisymmetric or conical spike inlet) and the two-dimensional ramp inlet. The conical spike inlet is known to have better pressure recovery than the two-dimensional inlet, the difference in pressure recovery being approximately 1.5% for well designed inlets. The conical spike inlet also tends to be lighter than the two-dimensional inlet. While the conical spike inlet offers better pressure recovery and weight savings, the two-dimensional inlet offers more simplicity in the variable geometry systems. From a reliability and maintainability point of view, the two-dimensional system was selected for the Supercruiser.

Inlet

A mixed compression inlet was chosen for the Supercruiser. The external compression is to be achieved by a double wedge variable geometry ramp splitter system. The splitter translates horizontally to insure that shock wave impinges on the cowl lip. The total range of travel for the splitter system from Mach 1.5 to Mach 3.0 would be 8.5 ft.

The maximum mass flow rate of a rubber engine sized by compressor diameter to meet the demand of an HSCT aircraft was calculated. The mass flow rate was determined to be 607 lb/sec per engine. Thus the total mass flow rate for the two-engine pod inlet system is 1215 lb/sec. The total cross-sectional capture area for the two-engine inlet was determined to be 95.82 ft. From this value, the inlet height and width were determined to be 6 ft and 15.97 ft, respectively. The total inlet length was calculated to be 55.37 ft. For this design, the total pressure recovery was determined to be 76% at Mach 3.0.

Future Design Considerations

The inlet design is an important part of the conceptual design of the aircraft. It was for this reason that the time was taken to develop an inlet design for a rubber engine since no current engine has been selected for the aircraft. Once the actual engine is selected, the optimum ramp angles can be determined for all the stages of flight. With the addition of a boundary layer removal system and system optimization, the pressure recovery would rise to between 80% and 87% at Mach 3.0.

Structural Analysis

To reduce the weight of the Supercruiser, a sandwich construction panel method is utilized instead of the conventional skin-stringer stiffening design. Sandwich construction offers higher strength-to-weight ratios, better stability and load carrying capacity, increased fatigue life, and higher sonic fatigue resistance. Sandwich construction structures have the potential of reducing the structural weight by 12% to 25%.

Advanced composite materials are utilized to further reduce the weight of the aircraft. With composite materials, the best material properties are utilized for maximum material load-carrying efficiency. In selecting materials to construct an HSCT, many important factors must be taken into account in order to select the "best" material. Factors that must be considered are yield and ultimate strength, stiffness, density, temperature limit, fatigue properties, crack resistance, fracture toughness, corrosion, creep, cost, and producibility.

Since the Supercruiser will operate above Mach 2.0, the skin of the aircraft will incur temperatures ranging from -50° F to 600° F. Therefore, the chosen material must be able to withstand extreme temperature variances. Furthermore, the chosen materials must also have high strength-to-weight, and stiffness-to-weight ratios in order to keep the aircraft weight as low as possible so that fuel consumption is kept at a minimum. In addition, these materials must be able to maintain their integrity so that the transport will require minimum maintenance and repair through its 15 to 20 year life span.

After comparing various types of materials, it is determined that composite materials are best suited for the Supercruiser. The specific strength and stiffness of composites are about 3 to 5 times greater than aluminum. An all-composite aircraft has the potential of reducing empty weight by 25 to 30 percent in comparison to an all-aluminum aircraft. Note that thermal expansion for composites is about 5 to 10 times less than that of titanium. This would greatly reduce the thermal expansion problem that high speed aircraft encounter while in flight.

The Supercruiser will use high temperature, unidirectional fiber polymeric, and metal matrix composites. The fiber will be graphite and the matrix materials will be thermoplastic, thermoset, and aluminum. In selecting composite materials, some additional aspects that must be considered are moisture absorption, impact resistance, thermal stability, and thermal expansion. Currently, there are composites that can operate in the temperature regime of the Supercruiser. Graphite/polymide and aluminum metal matrix composites can operate in environments exceeding 600° F, but they do not have enough thermal stability to meet the required life cycle of the aircraft. In addition to thermal stability, impact resistance is another property that must be improved. More research is required for a better understanding of these materials. For the Supercruiser, the feasibility of using composites will depend on their development in the next 10 to 15 years.

Thermal Management

At Mach 3.0, aerodynamic heating is a problem that requires investigation. The temperature on the skin can reach as high as 600° F. Therefore, the Supercruiser must be properly insulated in order to maintain a comfortable cabin temperature as well as keeping the fuel below its boiling point.

Criteria for insulation sizing included insulation weight and thickness and heat flux into the cabin and fuel. The fuselage shell consists of a graphite-polymide/ aluminum honeycomb core panel, a layer of insulation, an air gap, and the cabin lining. The wing shell construction is exactly the same as the fuselage except that the insulating material is attached to the fuel tank instead of the skin panel.

It is noted that active cooling will be required for the engine inlet and nozzle, wing leading edge, and nose tip.

Wing Structure

For the Supercruiser, the face sheets of the sandwich skin panel consist of 18 plies of graphite polymide with the fibers oriented in the [0,-45,+45,90] deg directions. The laminate is stacked up symmetrically to prevent tension and twisting coupling. Aluminum is used for the honeycomb core. The cell size ranges from 1/8 to 1/4 inch. Smaller cell sizes are required for bolt connection areas.

A finite element (FE) analysis was conducted on I-DEAS for structural sizing. The finite element model of the Supercruiser's wing represents the skin panel, spars and ribs. It consists of 208 nodes and 672 elements. In the FE model, the 18-ply laminate was modeled as a 7-ply laminate and the honeycomb core was modeled as an orthotropic laminate. The face sheets and the honeycomb were combined into one element. Quadrilateral and triangular thin shell elements were used to model the wing skin panels and spar and rib webs. Beam elements were used to model the flange.

The total force on the wing for a 3g lift load is 960,000 lb. For the double delta wing configuration, the first 20 feet of the wing span from the root will carry 50% of the total load, while the next 20 feet and the last 20 feet of the span will carry 32% and 17% of the total load, respectively. A thermal loading applied to the wing was also modeled.

For the wing, the maximum tip deflection for 3g loading is 8.15 feet. Furthermore, Tsai-Wu failure criterion was used to check for laminate failure. All the laminates were well below the maximum failure index, and the strain energy was located at the center of the wing. For structural optimization, thicker spars will be required in this region. However, the thickness of the spars and ribs everywhere else on the wing can be reduced to minimize the weight.

Fuselage Structure

The fuselage of the Supercruiser uses the sandwich construction concept described in the Wing Structure section. The stiff skin panel greatly reduces the size of the ring frame and longerons, while in the case of the wing, the bending load was carried by the skin panel.

The fuselage structural elements are primarily designed based on the loading conditions defined below.

Dynamic heating. At the nose tip of the Supercruiser, it is expected that the skin temperature at a cruise condition of Mach 3.0 could reach 600° F. Representative temperatures and temperature gradients at certain fuselage stations are obtained from experimental data of the NASA supersonic aircraft model 969-512B.

Fuselage concentrated loads. The calculated static load of the nose landing gear is 82,751 lb acting at fuselage station 99 ft from the nose tip. Reaction loads at the wing root due to load factor of n=3 are the primary loads considered in the design of the wing box.

Pressurization. Pressurization of the fuselage was analyzed using the pressure gradient between the inner and the outer wall of the fuselage. Assuming standard atmospheric conditions, the value was calculated to be 2022 lb/ft^2.

Fuselage Structural Elements

The fuselage structure is divided into forward, mid, and aft sections. The three sections have very similar semi-monocoque structures. However, for each section, specific design criteria drew special attention.

Fuselage forward section structure. The forward section structure covered fuselage sections (FS) from zero to 99 ft. The sandwich shell construction is the primary structural design concept. The supporting frames are joined using mechanical fastening and bonding. The nose tip skin should be made of Ti-alloy whose temperature limit is high enough to withstand the dynamic heating problems incurred at Mach 3.0.

Fuselage midsection structure. The primary structure of this section is the wing box construction. A design concept of the wing box is based on the typical design of most modern transport aircraft in which main frames of the fuselage are bolted to the main spars of the wing box. Both spar moment and shear connections are spliced into the fuselage forward and aft bulkheads. The bulkheads and wing spars are rigidly connected together as one integral unit. This concept is chosen primarily because of its wide usage and high reliability.

Fuselage aft section structure. The main concern of the construction of this section is the mechanism that supports and rotates the vertical tail. The two main spars of the vertical tail structure are connected to the aft fuselage bulkheads by means of a system of gears driven by a hydraulic system.

Tail Structure

Sandwich construction is also applied to the tail structure. The required thickness of the sandwich panel is approximately 1.0 inch in order to provide stiffness and prevent fluttering. Two spars and three ribs are used to help support the skin.

The tail leading edge could reach temperatures near 479^{o} F. Therefore, it is suggested that Ti-alloy be used in the leading edge section.

Landing Gear

The Supercruiser will employ a tricycle landing gear configuration. The location of the gears with respect to the center of gravity (CG) location indicates that the overturn angle is 66 deg, which satisfies the requirement outlined by FAA regulations. Calculation of the rotation angle yielded the value of 16 deg, thus guaranteeing that the tail section has sufficient clearance during takeoff.

Both the nose and main gear use oleo shock absorbers which have the highest energy absorbing efficiency of all absorbers presently available. The nose gear is operated by a hydraulic system which retracts the landing gear system forward and mechanically releases with free-fall in an emergency condition. The twin wheel nose gear could withstand a maximum static load of 86,000 lb. The main gears are also hydraulically operated to retract forward into the wheelwells located in the wing structure. The two six-wheel bogie main gear could carry a maximum static load of 732,000 lb.

Stability and Control

The Supercruiser's supersonic cruise stability is surprisingly well-behaved. Cruise stability is achieved without the use of flaps, ailerons, or a horizontal tail. Instead, cruise stability is achieved by the management of the aircraft's CG. The aircraft's CG management gives it natural stability without the use of a stability augmentation system (SAS). Although complete stability was not achieved in all realms of lateral motion, management of the CG allowed for a less complex stability enhancement system. During takeoff and landing the Supercruiser demonstrated level 2 flying qualities; thus a stability augmentation system is employed during takeoff and landing, as well as an ILS system.

Fuselage Interior Layout

Passenger Seating Arrangements

The main driver for the passenger seating arrangement was that the Supercruiser was to be capable of accommodating 300 passengers including baggage, eight flight attendants, and a flight crew of two. With these parameters in mind, the maximum diameter of the fuselage was calculated to be 17.1 ft. The diameter of the fuselage at specific points along its length was dictated by area ruling and a wave-drag computer simulation program. This was necessary in order to reduce supersonic drag.

Due to marketability demands, the seating arrangement was designed by considering a tri-class arrangement. The three class seating arrangement is as follows: 7, 36, 57 percent for first, business, and economy classes, respectively. The first class section is positioned in the forward zone of the fuselage, the business class section is positioned in the mid-zone, and the economy class section is in the aft portion of the fuselage. A 20-inch minimum aisle width and 84-inch aisle height accommodate passenger space requirements. Seat widths are 47-inch double-seat assembly for first class, 40-inch double-seat assembly for business class, and 39-inch double-seat assembly and 55.5-inch triple-seat assembly for economy class. The first, business, and economy classes have a four-across, six-across, and seven-across seating arrangement, respectively. The comfort levels for the passengers are implemented at a level comparable with the standards of current subsonic carriers.

Capacity and Payload Accommodations

The Supercruiser's cargo/baggage holds are designed in order to accommodate the passengers' baggage and secondary items such as freight and mail. The overhead stowage bins, which are located along both sides of the entire cabin, are capable of holding 1.8 cubic feet per passenger, while lower cargo bays, located underneath the cabin floor, are proportionally sized for multi-shelf containers. Thus, the belly capacity per passenger seat is set around 8 cubic ft. and the baggage weight per passenger is averaged around 45 lb.

In order not to incur additional costs, the Supercruiser will utilize standard containers and pallets currently being used by other airline carriers.

Interior Facilities

The interior facilities provide contemporary service for 300 passengers based on a maximum flight duration of four hours. Each class has its own galley, lavatories, closets, and cabin attendant stations. The cabin attendants are adjacent to each exit door.

Interior facilities such as service areas and lavatories are positioned with the maximum interior flexibility in mind. Each class section has its own service area and other interior facilities that are equal to those standards set by long-haul subsonic carriers. Furthermore, flight entertainment is provided by separate view-screens located in each class section and music control units located on each seat. For the protection of passengers from lethal doses of ozone and radiation, a climitization system is installed to deliver maximum climatic comfort comparable to subsonic carriers.

Doors, Emergency Exits, and Windows

Since all doors, emergency exits, and windows are potential sources for leaks, noise, drag, and excess weight, they are designed to maximize passenger comfort and meet those emergency requirements dictated by the FAA. The number and the particular size of doors and emergency exits required in the HSCT type aircraft are defined in FAR 23 and 25 parts 807-813. The number and types of required exits for the Supercruiser was dependent upon the number of passengers carried.

Since all doors and emergency exits must meet the "unobstructed access" criteria, the designers used Type I, II, and III access doors to fulfill this requirement. There are a total of 6 access doors: two passenger Type I doors, two emergency Type II doors, and two emergency Type III doors. Service access doors are located mainly on the starboard side of the aircraft to ease the ground support operation.

Each emergency exit and the two passenger doors are equipped with an Emergency Escape Chute Deployment System. This system is composed of evacuation slides that are deployed in case of an emergency. The following are the characteristics of such a system.

- Inflatable slides automatically deploy upon opening of each exit.
- Stored gas inflates slides.
- Escape system disarms when door is opened from outside airplane.
- Slides usable in all landing gear conditions.

Note that standard life rafts would be stowed in overhead stowage bins located near each emergency exit and passenger door.

The passenger windows on the Supercruiser are shaped like circles that are spaced according to the fuselage's frames and not necessarily spaced according to passenger seat location. This particular shape of the window is utilized in order to avoid unnecessary stress concentrations and large pressure differentials that will be encountered while flying supersonically. The windows are located so that there is no discomfort to the average passenger when viewing through them.

Marketability

Potential Markets

In order to produce a viable HSCT, the market demand must be sufficient to sustain a fleet of approximately 500 aircraft. A preliminary analysis determined that the Supercruiser could acquire a significant portion of the growing long-range Atlantic and

Pacific Rim markets. Present statistical data projects that the worldwide demand for long-range air travel will almost double by the year 2000, with a growth potential of 53% in the Pacific Basin and 27% in the North Atlantic region. Figure 6 shows the international traffic distribution based on the year 2000 with a traffic distribution of 200,000 passengers per day. This figure shows that the greatest market demand is located in both the Atlantic Rim and Pacific Rim regions.

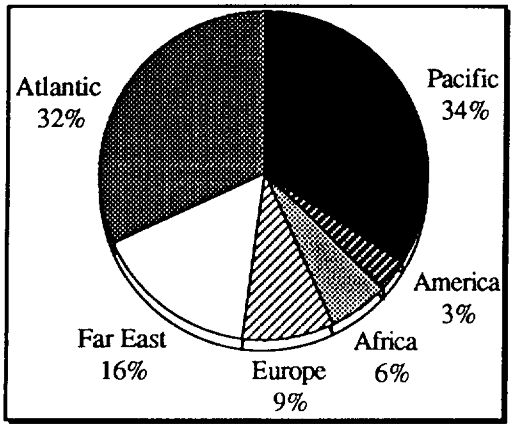

Fig. 6 International traffic breakdown by year 2000

The Supercruiser's potential as a viable long-range carrier is dependent not only on the market demand but also on its performance characteristics such as speed, design range, and total number of passengers carried. For this airplane configuration, the speed is fixed at Mach 3.0 and the range was determined to be below 4000 nm. Even though the range falls short of the expected 5500 nm, the effectiveness of the Supercruiser to capture a proportional amount of revenue passenger miles (RPM) depends upon the market in which it operates. The revenue potential for the Pacific and Atlantic Rim markets are as follows: first class projected 6% of total revenue, business 45%, and economy 49%. Therefore, by concentrating on the revenue potential, the Supercruiser can be a viable addition to the current long-range carriers operating in these markets.

Airport Compatibility

Operations from conventional airports require that the Supercruiser must meet anticipated weight and field-length constraints as well as operate in conjunction with subsonic carriers during approach to avoid system degradation. Since the Supercruiser weighs less than 800,000 lb and takes off within 12,000 ft, it can be accommodated by selected high-demand airports such as Los Angeles Airport (LAX) and Tokyo Airport (NRT). The high speed of travel and the high altitude of the Supercruiser don't require special equipment on part of the Air Traffic Control (ATC) services. Since the Supercruiser will be outfitted with enhanced avionics systems, it will easily integrate into the ATC environment.

Because the Supercruiser is considerably larger than subsonic carriers such as the 747-400 (length of 231.8 ft), some modifications to the runway fillets may be necessary in order to maintain an acceptable runway-edge safety margin while maneuvering on the ground from runway-to-taxiway and taxiway-to-taxiway intersections with the cockpit over the centerline.

Gate parking in front of a terminal can be achieved with the Supercruiser positioned at an angle. Because of the Supercruiser's length and door sill height, minor adjustments might have to be made in order to connect the passenger entrance umbilical to the passenger doors.

Supercruiser servicing operations will be tasked to minimize 'turn-around' time as much as possible. Typical services such as loading and unloading of passengers and cargo and refueling and reoiling are pertinent tasks that must be performed in a minimal amount of time.

Cost Analysis

For the Supercruiser to become marketable and meet the demands of future air travel, it must be cost effective within its life cycle. Utilizing a cost analysis computer simulation program, the Supercruiser was determined to be unprofitable with its range less than 3183 nm. Three primary costs were determined: Research, Development, Test and Evaluation cost (RDTE); manufacturing and acquisition cost (MACQ); and operating cost (OPS). The life cycle cost is being considered over a 16-year period. Note that an estimated cost for a prototype program consisting of two airplanes cost roughly $423 million 1992 United States dollars (USD)

In order to accurately surmise the cost evaluation of the Supercruiser, it was compared with three potential competing aircraft: the 747-400, the MD-12, and the A340-300. These three aircraft represent the primary competition that the Supercruiser will face in the 21st century. Figure 7 shows the cost comparison with the competitive aircraft. Note that the Supercruiser does cost more in development and manufacturing; however, as more units are sold the cost becomes considerably less. It was determined that the operating cost of the Supercruiser and its LCC is three times less than the competing aircraft.

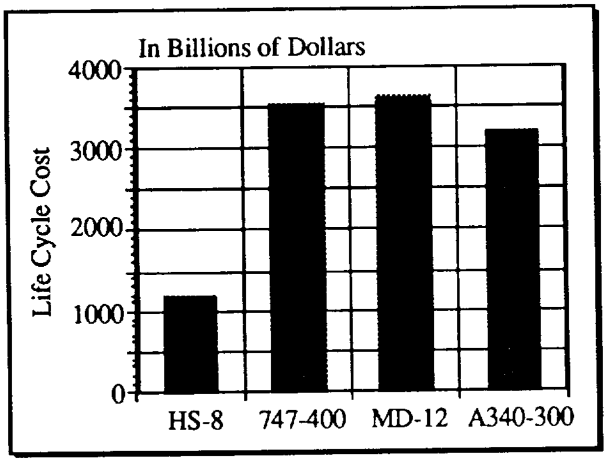

Fig. 7 Life cycle cost comparisons

In a competitive market such as the airline industry, one of the primary drivers for market capture is the airfare charged to passengers. In order for the Supercruiser to be competitive, its airfare must be comparable to those of the competing subsonic carriers. For ranges greater than 5000 nm, coach fares are set between $600 and $800 1992 USD. These fares were determined from current airlines such as United, Northwest, and American. To be competitive, the Supercruiser must charge a coach fare rate between $650 and $950 1992 USD. This coach fare is based on a range greater than 5500 nm, 80% of available seats filled, and a profit range between 10% and 62%. The 80% of available seats filled is acceptable in current subsonic carriers. In addition, the profit range mentioned above is considered acceptable for continuing operations. Utilizing the same methods to determine the primary costs, it was determined that the Supercruiser meets the above criteria for the coach fare charged to passengers. Therefore, if a range of 5000 nm was achieved, the Supercruiser will be a profitable carrier and a competitive opponent of the subsonic carriers.

Environmental Impact

Sonic Boom

The environmental disturbance of the sonic boom is well known by those individuals who live near certain military facilities. As a result of the annoyance of this disturbance, a possibility of supersonic flight over land exists. Many tests have been conducted which aimed at determining the maximum levels of overpressure (measure of sonic boom intensity) which could be produced by supersonic aircraft which would be acceptable to the public and the environment. The results of such studies have varied. Depending on the author of the study, the range of acceptable overpressures is from as low as no increase in overpressure to a maximum increase of 0.5 to 1.0 psf. Today, the absolute best levels of overpressure that can be achieved are about 1.5 psf. As a result, it is not expected that the HSCT will be allowed to travel over land supersonically in the near future.

Recommendations for the Future

Technology changes in leaps and bounds. The future poses increased possibility for the impossible to become possible. Limitations become viable and economical alternatives. Currently, aircraft engine technology has not progressed far enough where we can meet the range requirement of 5,500 nm. Furthermore, the engine's fuel consumption is much too high, thus reducing the range of the Supercruiser. In order for the Supercruiser to meet the RFP range of 5500 nm, a more fuel-efficient engine needs to be conceived. This aircraft is expected to be introduced in the year 2020, and it is assumed that an engine fulfilling noise and emissions requirements, as well as the necessary fuel consumption and thrust rating, would have been conceived and introduced into the mass market.

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