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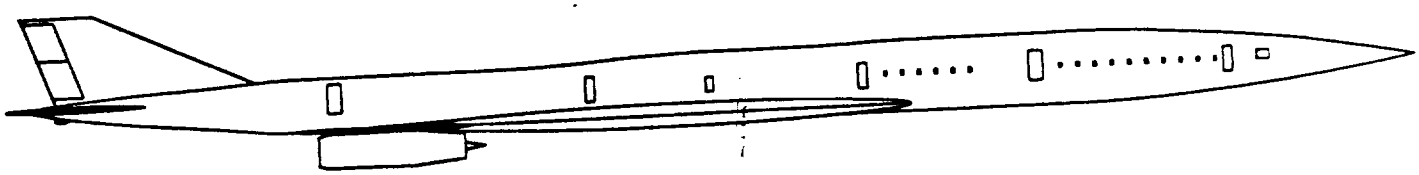
PROPOSAL AND PRELIMINARY DESIGN
FOR A HIGH SPEED CIVIL TRANSPORT AIRCRAFT

SWIFT

A HIGH SPEED CIVIL TRANSPORT FOR THE YEAR 2000



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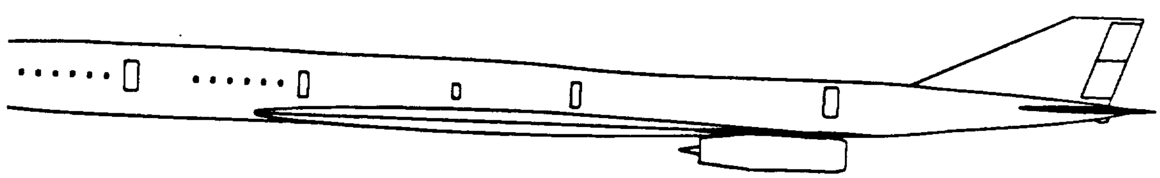

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Symbol	Description	Units
A	Aspect Ratio, b^2/S	
AC	Aerodynamic Center	ft
b	Span (from tip to tip)	ft
c	mean chord, S/b	ft
C_D	Total drag coefficient for the aircraft	
$C_{D\alpha}$	Change in coefficient of drag with respect to angle of attack	rad^{-1}
C_{d_o}	Profile drag coefficient	
$C_{l\alpha}$	Change in coefficient of section lift with respect to angle of attack	rad^{-1}
$C_{L\alpha}$	Change in coefficient of lift with respect to angle of attack	rad^{-1}
$C_{l\beta}$	Change in coefficient of rolling moment with respect to sideslip angle	rad^{-1}
$C_{l\beta}$	Change in coefficient of rolling moment with respect to rate of change in sideslip angle	rad^{-1}
$C_{l\delta r}$	Change in coefficient of rolling moment with respect to deflection of the vertical tail (rudder)	
C_{Lmax}	Maximum coefficient of lift for the aircraft	
$C_{M\alpha}$	Change in coefficient of pitching moment with respect to angle of attack	rad^{-1}
$C_{n\beta}$	Change in coefficient of yawing moment with respect to sideslip angle	rad^{-1}
$C_{n\delta r}$	Change in coefficient of yawing moment with respect to deflection of the vertical tail (rudder)	
C_{Y_β}	Change in coefficient of side force with respect to rate of change in sideslip angle	rad^{-1}
$C_{Y\delta r}$	Change in coefficient of side force with respect to deflection of the vertical tail (rudder)	
CG	Center of Gravity	ft
CGR	Climb Gradient	
D	Drag of aircraft, $0.5\ r\ V^2\ C_D\ S$	lb

LIST OF SYMBOLS

Symbol	Description	Units
e	Oswald efficiency factor	
g	local gravitational acceleration	ft/s^2
L	Lift of aircraft	lb
L/D	Lift to Drag Ratio	
M	Mach number	
OEI	One Engine Inoperative	
s	Leading Edge suction parameter	
S	Planform area, including area through the fuselage	ft^2
SFC	specific fuel consumption	
T	total engine thrust	lb
T/W	Power loading	
V	Velocity	kts
W	Weight of Aircraft	lb
W/S	Wing loading	lb/ft^2

ABSTRACT

To meet the needs of the growing passenger traffic market in light of an aging subsonic fleet, a new breed of aircraft must be developed. The Swift is an aircraft that will economically meet these needs by the year 2000. Swift is a 246 passenger, Mach 2.5, luxury airliner. It has been designed to provide the benefit of comfortable, high speed transportation in a safe manner with minimal environmental impact. This report will discuss the features of the Swift aircraft and establish a solid, foundation for this supersonic transport of tomorrow.

1.0 INTRODUCTION

The success of high speed civil transports has been mixed. But new technologies and favorable economic conditions have encouraged high speed aircraft development. Requests for proposals have been developed by economically driven factors. The Swift Proposal and Preliminary Design of a High Speed Civil Transport offers an aircraft that is economically viable, environmentally compatible, and technologically feasible by the year 2000.

1.1 Background

Commercial aviation has grown into a highly competitive service to both the business community and the pleasure traveler. The advancement of jet-powered aircraft in the 1950's and jumbo-sized aircraft in the 1970's have increased productivity and kept ticket prices below inflationary trends. However, the efforts to continue increasing productivity through supersonic transports have been unsuccessful.

When the English-French Concorde first flew on March 6, 1969, it was widely believed that an era of supersonic transportation had arrived. But the economic and environmental realities of the first generation aircraft stopped the production line after only sixteen aircraft were produced. The result was very limited service between the United States and Europe. However, the Concorde was successful in demonstrating that a supersonic transport can provide safe and reliable scheduled service.

Current economic predictions indicate that total worldwide passenger traffic will triple by the year 2000 (Ref. 1), with the demand for long-range air travel doubling by the same year (Ref. 2). These projections also suggest that the Pacific market portion of total long-range traffic will grow from 23 percent in 1986 to 36-50 percent in 2000 (Ref. 1). The Pacific market is characterized by long route segments and flight times, appropriate for high-speed transport aircraft. This growth in the overall market occurs at the same time as an increasing numbers of existing aircraft will be retired due to age and noise regulations (Ref. 2).

In light of this projected growth, several studies of high-speed transports have been conducted by the aviation industry.

In 1986, NASA granted contracts to the Douglas Aircraft Company, the Lockheed Corporation and the Boeing Corporation under the four-year High

Speed Civil Transport (HSCT) Research Program. This program lead to the High Speed Research (HSR) Program that will continue through 1998 .

In 1987, the Japanese High Speed Transport Study Committee was founded and initiated technical and market analysis on new generation supersonic transports.

In 1989, British Aerospace and Aerospatiale issued and agreement to cooperatively initiate a study on the possibility of a Concorde successor (Ref. 3).

The results of the of these studies indicate that an economically viable and environmentally compatible supersonic transport will be possible by the turn of the century.

1.2 Study Approach

In September, 1991, the California Polytechnic State University, San Luis Obispo, Aeronautical Engineering Department Senior Design Program initiated a 9-month study of the potential of a high speed civil transport (HSCT) under the guidance of the University Space Research Association (USRA).

The goal of the study was the definition and assessment of an economically viable and environmentally compatible aircraft concept guided by the Request for Proposal (RFP) (Ref. 4). The result of the study is the following proposal and preliminary design for the Swift High Speed Civil Transport.

1.3 The Request for Proposal

Based on the RFP, the following mission requirements were generated:

The payload consists of 300 passengers in three classes. This size of aircraft requires a fleet size of 350-400 units with a 15 percent economy class fare increase (based on a 50 percent time savings, 65 percent load factor and a 12 percent Return on Investment [ROI]) (Ref. 2). This fleet size is adequate for one manufacturer. The class distribution is 5 percent first, 35 percent business, and 60 percent coach.

With reserves, the range is 6000 nautical miles (NM) with full payload. This range includes all of the trans-Atlantic markets and most of the trans-Pacific markets including San Francisco-Hong Kong (SFO-HKG). The 6000

NM range is projected to capture 75 percent of trans-Pacific markets in the year 2000 (Ref. 1).

The cruise Mach number is 2.5. This cruise velocity provides a time savings of 50 percent versus subsonic flight (Typical block times for 6000 nm: HSCT, 5.75 hours (hrs.); Subsonic: 11.5 hrs.). Since time savings is the key feature of high-speed flight, increasing the cruise velocity increases the effect of passenger stimulation and fare surcharge sensitivity (Surcharge sensitivity is a measurement of the perceived value of passenger time.) (Ref. 3).

1.4 The Swift High Speed Civil Transport

Based on the analysis contained in this report, the following mission requirements were achieved:

The payload consists of 246 passengers in three classes. This size of aircraft requires a fleet size of 350 units with a 20 percent economy class fare increase (based on a 50 percent time savings, 80 percent load factor and a 12 percent Return on Investment [ROI]) (Ref. 2). The class distribution is 5 percent first, 34 percent business, and 61 percent coach.

The range is 5700 NM with full payload. This range includes all of the trans-Atlantic markets and most of the trans-Pacific markets including Los Angeles-Tokyo (LAX-NRT), San Francisco-Seoul (SFO-SEL), and Seattle-Hong Kong (SEA-HKG). The 5700 NM range is projected to capture 65 percent of trans-Pacific markets in the year 2000 (Ref. 1).

The cruise Mach number is 2.5. This cruise velocity provides a time savings of 50 percent versus subsonic flight (Typical block times for 5700 NM: HSCT, 5.25 hours (hrs.); Subsonic: 10.5 hrs.).

Table 1.1: Comparison of Swift Design to the Request for Proposal

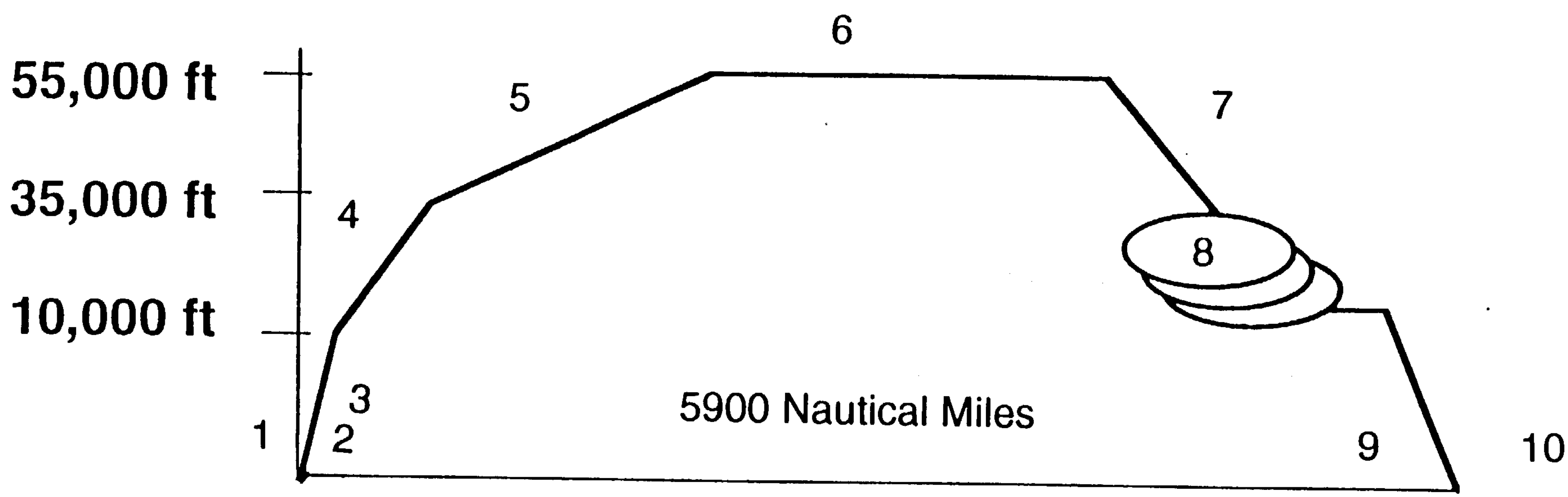
	Request for Proposal	Swift
Passengers	300	246
Range	6000 NM	5700 NM
Cruise Speed	Mach 2.5	Mach 2.5

2.0 MISSION DESCRIPTION

The Swift is designed to be compatible with subsonic aircraft throughout its mission profile. The climb gradients and airspeeds for the subsonic regime are similar to the Boeing 747-400. Although the cruise speed is Mach 2.5, the aircraft will avoid current subsonic traffic with a cruise altitude between 48,000 and 57,000 feet. The mission profile is broken up into ten major phases:

1. Start-up and taxi to active runway
2. Take-off
3. Subsonic Climb to 10,000 feet, velocity less than 250 knots.
4. Accelerate to Mach 0.95, climb and maintain 35,000 feet.
5. Accelerate to Mach 1.8, cruise climb to 50,000 feet.
6. Level, accelerate and maintain Mach 2.5.
7. Decelerate and descent
8. Divert or hold
9. Landing and taxi to terminal
10. Shutdown

The aircraft is capable of flying 5,700 nautical miles with a 200 nautical mile diversion and 30 minute hold. The mission profile is illustrated in Figure 2.1.



1. Start-up and taxi to active runway
2. Take-off
3. Subsonic climb to 10,000 feet at 250 knots
4. Accelerate to Mach 0.95; climb and maintain 35,000 feet
5. Accelerate to Mach 1.8; cruise climb to 48,000 feet
6. Accelelate to Mach 2.5; cruise climb to 57,000 feet
7. Decelerate and descent
8. Divert 200 NM and hold for 30 minutes
9. Landing and taxi to terminal
10. Shutdown

Figure 2.1: Swift's Mission Profile

3.0 CONFIGURATION SELECTION AND DESIGN RESULTS

A three-view of the Swift is shown in Figure 3.1. The selection of Swift's aircraft configuration was based on the mission requirements as well as the economic and environmental constraints.

3.1 Wing Selection

Tables 3.1 and 3.2 indicate the major advantages and disadvantages of various wing planforms and wing placement, respectively.

Table 3.1: Wing Planform Comparison

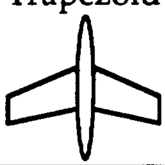
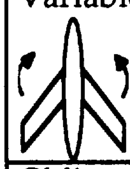
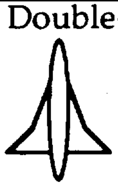
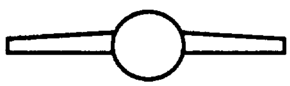
Wing Planform	Advantages	Disadvantages
Trapezoid 	- Very good low speed performance	- Very poor high speed performance - Large aerodynamic center (AC) shift (25%) - Poor stall characteristics
Variable Sweep 	- Very good low and high speed performance	- Weight penalty for sweep mechanism - Complexity
Oblique 	- Very good low and high speed performance	- Weight penalty for sweep mechanism - Complexity
Delta 	- Good high speed performance - Small AC shift (15%) - Simple fixed wing design - Low wing weight	- Poor low speed performance
Double-delta 	- Good low and high speed performance - Minimal AC shift (0-10%) - Simple fixed wing design - Low wing weight	- High wing-tip loads

Table 3.2: Wing Placement Comparison

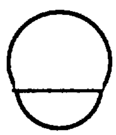
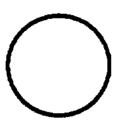
Configuration	Advantages	Disadvantages
High Wing 	- Large take-off rotation angle	- Fuselage must pass through wing loads (Heavy frames) - Gear must be stored in fuselage - Higher interference drag - Engines exposed to cabin
Mid Wing 	- Low drag due to the blended body	- Fuselage must pass through wing loads (Heavy frames) - Difficult to place exits in blended areas
Low Wing 	- Structural wing box unbroken (Less structure) - Gear in stowable in wing - Engines are easier to access due to height - Cabin is shielded by wing from engines	- Small rotation angle - Higher interference drag

The Swift chose the double-delta wing planform due to its good compromise between supersonic cruise and low-speed requirements. The simplicity of the double-delta wing outweighs the subsonic performance of the variable sweep and oblique wing. The Swift chose the low wing placement because of its structural, aerodynamic and maintenance advantages.

3.2 Fuselage Selection

Table 3.3 lists the advantages and disadvantages of various fuselage cross-sections. The Swift chose to incorporate both the semi-circular and the circular cross-sections in its fuselage design. The fuselage section forward of the wing box utilize the circular cross-section because of its simplicity and its ability to store baggage under the passenger cabin. The fuselage section aft of the wing box is also circular, and the space after the passenger section is utilized for fuel storage. The fuselage section that contains the wing box utilizes the semi-circular cross-section in order to minimize cross-sectional area.

Table 3.3: Fuselage Cross-Section Comparison

Cross-Section	Advantages	Disadvantages
Elliptical 	- Small cross-sectional area (Low drag)	- Very complex structural design - High structural weight - Small baggage volume
Double-Bubble 	- Simple structural design - Very large baggage volume - Low structural weight	- Very large cross-sectional area (Very high drag)
Semi-Circular 	- Small cross-sectional area (Low drag)	- Complex structural design - No baggage volume
Circular 	- Very simple structural design - Very low structural weight - Large baggage volume	- Large cross-sectional area (High drag)

3.3 Engine Selection

The Swift compared three supersonic engines which met the take-off thrust requirement: General Electric GE4/J5P, Rolls-Royce Tandem Fan, and NASA Mixed-Flow Turbofan. Based on the advantages and disadvantages of each engine presented in Table 3.4, the NASA Mixed-Flow Turbofan was chosen for the Swift based on its ability to produce enough thrust for both take-off and cruise, and for its short overall length.

Table 3.4: Engine Comparison

Engine	Advantages	Disadvantages
General Electric GE4/J5P	- High cruise thrust - Existing engine	- Low take-off thrust - High SFC - Long overall length
Rolls-Royce Tandem Fan	- High take-off thrust - Low SFC - Existing engine	- Low cruise thrust - Very long overall length
NASA Mixed-Flow Turbofan	- High take-off thrust - High cruise thrust - Low SFC - Short overall length	- Developmental engine

3.4 Design Results

This section will provide a brief overview of the Swift's final airplane configuration. The airplane components mentioned in this section will be addressed in greater detail in the subsequent sections.

The general configuration of the Swift is illustrated in Figure 3.1; principal geometric dimensions are presented in Table 3.5.

The Swift employs an area-ruled fuselage with a double-delta wing planform. The fuselage was supersonically area-ruled to aid in minimizing the wave drag.

The double-delta was selected due to its minimal shift in the aerodynamic center location between subsonic and supersonic conditions. The inboard wing panel is highly swept, 70.0 degrees. The outboard wing panel is moderately swept, 38.7 degrees. These sweep angles were selected to minimize drag while providing adequate take-off performance. The inboard wing panel thickness, 4 percent of the chord, was chosen to provide adequate structural strength and fuel volume. The outboard wing panel thickness was reduced to 3 percent of the chord in order to reduce supersonic drag.

Single-slotted trailing edge flaps are used to increase lift at take-off and landing. The horizontal stabilizer and elevator were sized to provide longitudinal control during take-off and landing. The vertical tail and rudder were sized to provide lateral control during a one engine-out condition during take-off.

The propulsion system consists of four variable cycle NASA mixed-flow, low-bypass, turbofan engines. The engines are mounted under the wing in two nacelles near the wing trailing edge to prevent landing gear and structural interference.

A modified tricycle type landing gear is installed on the Swift because of its good pavement loading distribution and efficient landing gear volume. The main landing gear is a four-strut arrangement with four wheels per strut. The two-wheeled nose gear is mounted aft of first class and retracts forward allowing for free-fall.

The length of the nose-cone fails to meet conventional external vision requirements without a variable geometry (droop-nose), or an auxiliary visibility system. Due to the droop-nose's mechanical complexities and additional structural weight, a synthetic vision system with a periscope backup was chosen.

Table 3.5: Swift Configuration Dimensions

Parameters	Wing	Horizontal	Vertical
Area (ft^2)	9088	800	551
Span (ft)	134.9	35.4	19.2
MAC (ft)	93.13	24.9	33.4
Aspect Ratio	2.03	1.56	0.68
Leading Edge Angle (deg)	70.0/38.7 (Inboard/Outboard)	54.7	64.7
Root Chord(ft)	150.1	35.1	46.1
Tip Chord (ft)	20.0	10.1	15.6
Dihedral (deg)	0	0	0
Incidence (deg)	1	5	0

Parameter	Fuselage
Length (ft)	300
Max. Diameter (ft)	15.75
Sill Height (ft)	17.6

Parameter	Tailcone
Upsweep (deg)	6
Max. Rotation (deg)	13

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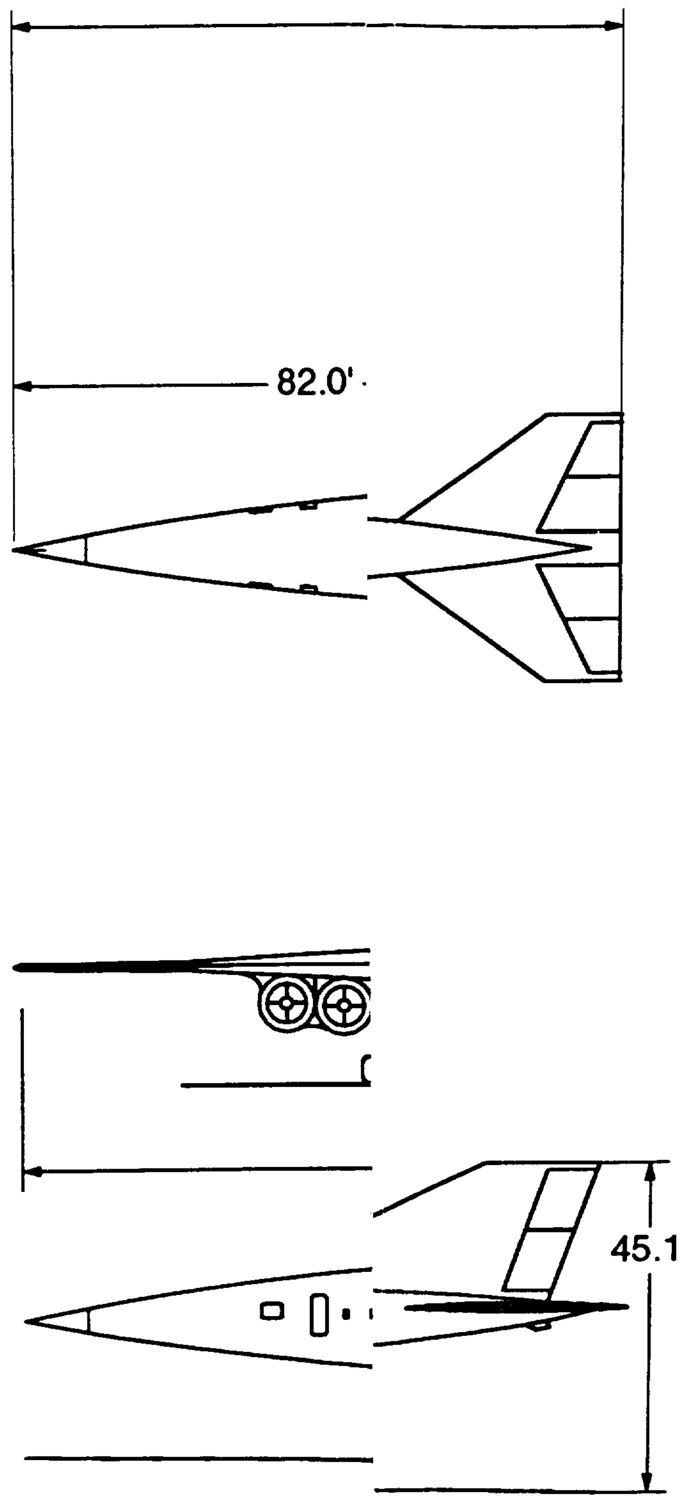
FOLDOUT FRAME

2.

FOLDOUT FRAME



4.0 SWIFT DESIGN POINT

This section will address the selection of the Swift aircraft thrust and wing loading. These parameters were obtained through performance and cost analysis.

There were several constraints that bracketed the Swift's design point. The main conditions that defined the aircraft's maximum wing loading and minimum thrust are the take-off and landing requirements.

An 11,000 foot (sea level, 86°F) FAR field take-off specification was required for the Swift to be compatible with current airports. The sea level, 86°F, condition was selected because the Swift would primarily operate over water, in its transcontinental missions, to avoid over-land sonic boom. This requirement produced a need for a relatively high velocity (190 knots) at take-off because the rotation angle was limited to 13 degrees in order to avoid tail strike. Unlike subsonic aircraft, wing stall at take-off is approximately 30 degrees and is not critical in determining take-off thrust to weight. The high velocity required and the 11,000 foot FAR field length created a need for high accelerations. This was satisfied with a propulsion system capable of generating a take-off thrust-to-weight ratio of 0.30 (the propulsion system selected is sized for take-off and provides excess power at the cruise condition). It was desirable to use a low thrust-to-weight ratio at take-off because the propulsion system would perform more efficiently at cruise. The smaller engine generates less drag at cruise when compared to larger engines and run more efficiently because they are operating near the maximum continuous power available. This increased efficiency would reduce the operating cost of the Swift. Furthermore, smaller engines would keep the cost of the Swift propulsion system at a minimum.

By maintaining a thrust-to-weight of 0.30 and all aircraft geometry constant, the FAR take-off field length was determined for several wing loading configurations shown in Figure 4.1. The wing loading was varied by changing the weight of the Swift aircraft.

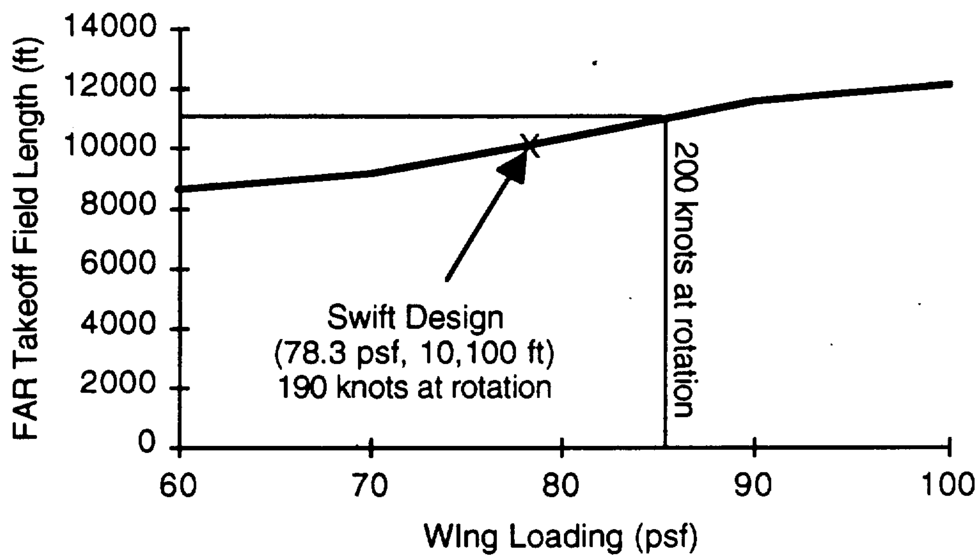


Figure 4.1: Swift Wing Loading

As the wing loading increased, the FAR take-off field length increased because the greater aircraft mass required more time to be accelerated to a given velocity. Furthermore, the maximum rotation angle requirement of 13 degrees forced the heavier (high wing loading) aircraft to higher velocities to generate the required lift coefficients at take-off.

A wing loading of 78.3 pounds per square foot (psf) was selected because the ground speed is 190 knots. The 190 knot velocity is the point were the tire rotation velocity is 5 percent lower than the maximum speed of 200 knots. Also, at this wing loading, an approach speed comparable to subsonic transports, such as 747/ DC 10 (~ 140 kts), was obtained. An approach speed of 155 knots is utilized by the Swift.

The aircraft take-off gross weight of 712,000 pounds was determined to be the required weight to accomplish the selected mission profile. The mission profile of 5,700 nautical miles is accomplished at a cruise lift to drag (L/D) ratio of 8.5 and a specific fuel consumption (SFC) of 1.20. The aircraft weight was determined by the fuel fraction method (Ref. 5). This method determined the required fuel weight for each segment of the mission profile based on aerodynamic and propulsion performance. The fuel weight obtained was then used to produce the gross take-off weight based on other supersonic transports (Ref. 5). This take-off weight was verified through structural analysis.

Propulsion and aerodynamic parameters used in the sizing requirements produced a sensitivity analysis listed in Table 4.1 (Ref. 5).

Table 4.1: Sensitivity Analysis for the Swift

Parameter	Amount Increased	Take-off Weight Change
Payload Weight	1 lb.	+11.8 lbs.
Range	100 nm.	+43,200 lbs.
Cruise SFC	0.01 (0.083%)	+20,800 lbs.
Cruise L/D	0.1 (1.2%)	-29,300 lbs.

This table shows the change in aircraft weight when mission or performance parameters are varied.

5.0 FUSELAGE DESIGN

Since the Swift is a commercial passenger transport, the passenger accommodations must be appealing and appropriate for the price charged by the airline. This means that the interior must be, at the least, similar to current long range subsonic aircraft. But the Swift is also a supersonic vehicle with special aerodynamic requirements. These aerodynamics require a slender and long fuselage for minimum drag. Unfortunately, these two factors (appealing accommodations and supersonic aerodynamics) often conflict and compromises must be made. The Swift interior layout accepts fewer passengers for lower drag.

5.1 Fuselage Layout

The final fuselage layout was guided by four major factors: lift-over-drag ratio (L/D) at cruise, fuselage length/area-ruling, passenger capacity, and take-off gross weight. The results of the analysis of these parameters is presented in Figure 5.1. The final fuselage layout is presented in Figure 3.1 and Figure 5.2.

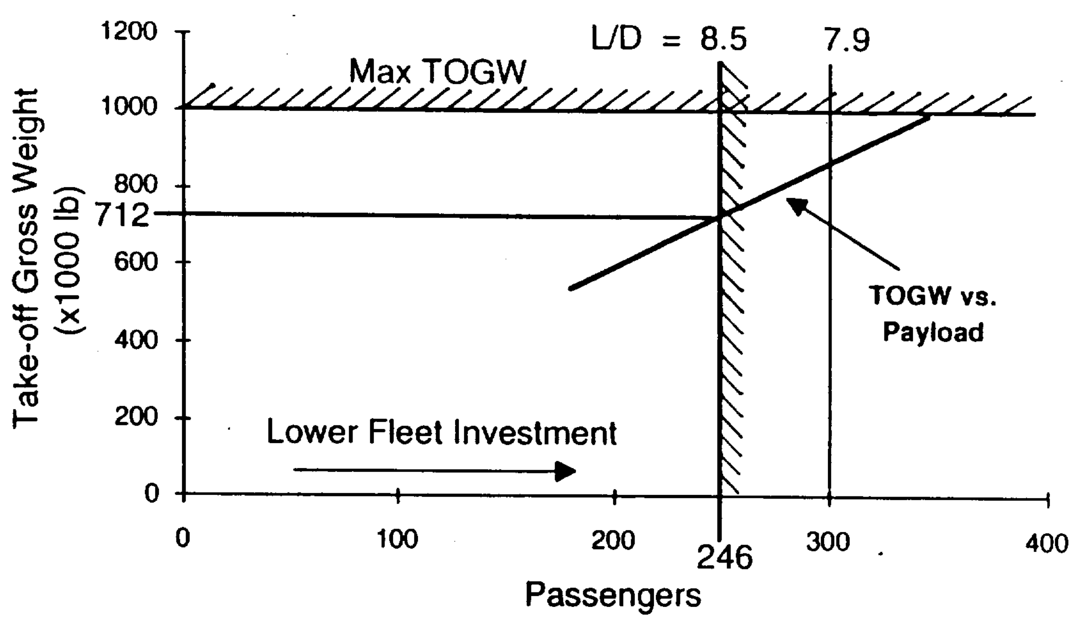


Figure 5.1: Passenger Capacity Constraints

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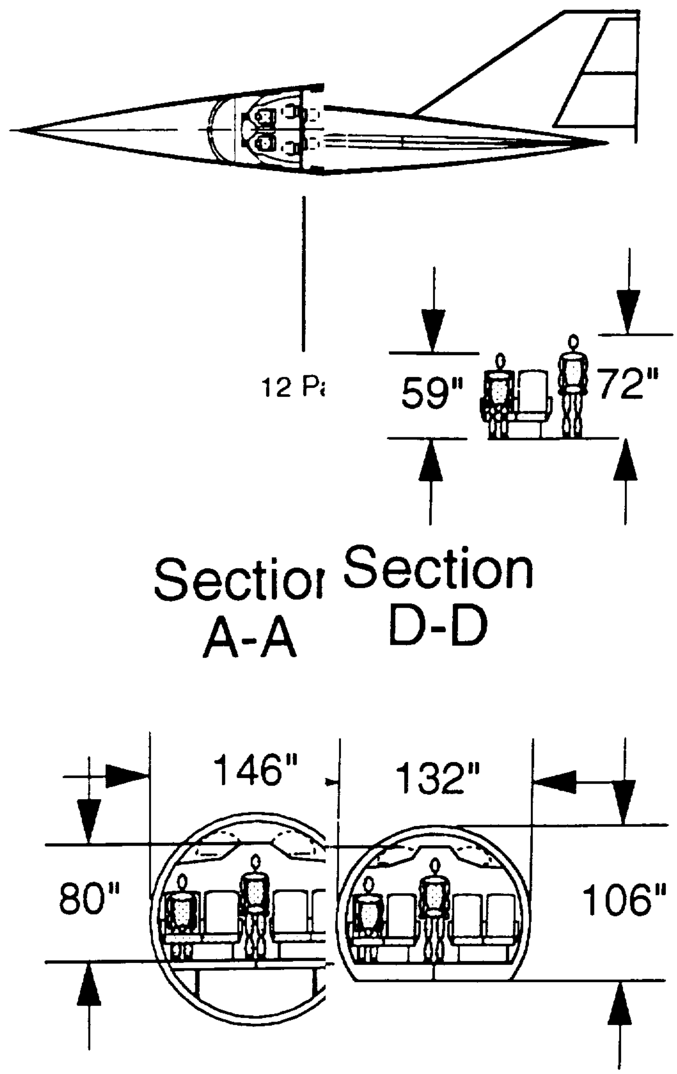


Figure 5.2:

5.1.1 Lift-Over-Drag Ratio at Cruise

An $(L/D)_{cruise}$ of 8.5 is required by the Swift to achieve the maximum range of 5700 nautical miles (NM) at the maximum take-off gross weight of 712,000 pounds (lbs.). This requirement can be met if the maximum cross-sectional area of the fuselage is 29,000 square inches (in^2) (A larger cross section would result in a higher wave drag). This area corresponds to a circular diameter of 15.75 feet (ft.). This circular diameter can accommodate three-by-three, single aisle, business class seating as seen in Figure 5.2, Section B-B. To expand the seating, a seven abreast coach seating arrangement can be utilized. However, a second aisle must also be added to form two-by-three-by-two twin aisle seating. The new cross-section has a 19.0 ft. diameter with a circular area of 40,800 in^2 (40 percent more area than the 15.75 ft. diameter cross section). This larger cross-section lowers the $(L/D)_{cruise}$ to 7.9: too low to make the required range. The 15.75 ft. cross-section is the largest that can be utilized.

5.1.2 Fuselage Length/Area-Ruling

The maximum fuselage length is limited to 310 ft. This length is the diagonal of the Boeing 747-400 and it is the maximum length of an aircraft that is compatible with current airport terminals. The overall fuselage length of the Swift is 300 ft.

The length of the nose and tail cones are set by aerodynamics. The nose cone maximum diameter is set by the size required for the flight deck (72 in. circular diameter). To decrease wave drag it is important to keep the strength of the shock at a minimum. This is accomplished by having a slender nose-cone. Specifically, a Von Karman nose-cone (Ref. 31) is used to minimize drag. The nose cone length is 30.7 ft. from the nose to flight deck. The tail cone maximum diameter is set by the size required for the coach class cross-section (132 in. circular diameter). The tail upsweep was limited to six degrees to minimize separation effects that cause drag, while allowing for the required 14 degrees of rotation angle for take-off (12 degrees for the required C_L plus 2 degrees for over-rotation safety). The 6 degrees upsweep is approximately half of a typical subsonic upsweep and is slightly smaller than other supersonic transport designs. The tail cone length is 59.2 ft. from the aft coach cabin to the tail.

For flight at supersonic speeds, drag can be reduced by area-ruling the aircraft. This method states that the drag can be reduced if the area changes are smooth and the shape of the area follows the Sears-Haack area distribution (A more detailed explanation of this method is offered in the Aerodynamics section of this paper). This method requires that the fuselage cross-sectional area should decrease as the wing cross-sectional area increases. The result is the fuselage must be longer for the same number of passengers than that of an aircraft that is not area-ruled. The area-ruled portion of the fuselage has a cross-sectional area of 11,500 in^2 with a maximum diameter of 132 in.

5.1.3 Passenger Capacity

The number of passengers that are economically viable for the design range of 5700 NM and cruise Mach number of 2.5 was determined to be 200 to 350 passengers per plane (Ref. 2). The lower passenger number offers the airframe manufacturer a fleet size 800 to 1200 aircraft depending on demand (Ref. 2). This number makes the aircraft program less risky by spreading developmental costs over a larger fleet size. The higher passenger number offers the airline the economic benefit of a lower fleet investment (Ref. 2). Also, passenger loading factors are not as critical because of the greater absolute number of passengers per plane (Ref. 30). An aircraft with 250 passengers allows for a fleet size of 350 to 500 planes, adequate for one manufacturer. This number also allows for economical operation by airlines assuming a load factor of 0.80 (A more detailed explanation of this method is offered in the Economic Analysis section of this paper).

5.1.4 Landing Weight

To be compatible with existing airport facilities, the maximum take-off gross weight (TOGW) must be less than one million pounds. Using an empirically based method (Ref. 5), the TOGW was determined for various passenger payloads. The TOGW is nearly linear from 175 passengers (550,000 lbs.) to 300 passengers (825,000 lbs.). The 246 passenger aircraft's TOGW is 712,000 lbs.

5.1.5 Fuselage Layout Results

The results of the analysis is presented in Figure 5.2. As seen in the figure, the limiting factor on the number of passengers per aircraft is the lift-over-drag ratio at cruise. By minimizing the airline fleet investment and by maximizing the number of passengers per aircraft, the maximum number of passengers is 246. This results in a TOGW of 712,000 lbs.

5.2 Interior Layout

The guiding principles of the Swift interior layout were meeting FAR safety requirements and providing an interior similar to current long range subsonic aircraft such as the Boeing 747-400.

5.2.1 Door Placement

The maximum center-to-center distance between two consecutive emergency egress doors is sixty feet as specified by FAR's (Ref. 4). Airport terminal compatibility requires a single loading door. The long fuselage length requires that the boarding door be located as close to the center of the plane as possible to reduce passenger walking distance. But loading over the wing is not desired because of the possible collision between terminal boarding equipment and the wing. A ten foot boarding ramp margin was established in front of the wing-body intersection and the main boarding door was located there. This Type A door is designated door L2 (the second door from the nose on the left side of the aircraft). The other doors were placed at sixty-foot intervals from door 2. The door types, dimensions, and locations are listed in Table 5.1. Door R2 is a Type A door for galley servicing. The aft-most doors (doors L6 and R6) are Type A to facilitate cabin cleaning and maintenance crew access. A Type III door is place in the middle of the forward coach section to enhance egress from the 90 passenger section. The remaining doors are Type I.

Table 5.1: Door Descriptions

Door Number	Type	Size	Location from Nose
1	I	24 x 72 in.	452 in.
2	A	36 x 80 in.	947 in.
3	I	24 x 72 in.	1276 in.
4	III	24 x 36 in.	1852 in.
5	I	24 x 72 in.	2099 in.
6	A	36 x 80 in.	2796 in.

5.2.2 Seating

The Request for Proposal (RFP) requires a tri-class arrangement with the class breakdown of 5 percent first class, 35 percent business class, and 60 percent coach class. Swift meets this requirement with a 246 passenger layout with 5 percent first class, 34 percent business class, and 61 percent coach class. The seating dimensions are compared to current long range subsonic aircraft in Table 5.2. All seats are equipped with serving trays, reclining back mechanisms, a fresh air supply, lighting, and entertainment equipment (a stereo and a television monitor for each set of seats). In addition, first and business class seats are equipped with fully articulating seats and phones and monitors at every seat. The first class section is isolated from the business class by a moveable partition. This offers flexibility for changes in demand. Figure 5.2 shows the overall interior layout.

Table 5.2: Seat Dimensions

		Swift	Boeing 747-400
Seat Width:	First	23 in.	25 in.
	Business	21 in.	22 in.
	Coach	19 in.	18.75 in.
Seat Pitch:	First	42 in.	60 in.
	Business	40 in.	40 in.
	Coach	36 in.	34 in.
Minimum Aisle Width:		20 in.	18 in.

5.3 Windows

Windows add considerable weight to an aircraft not only because of the weight of the window itself, but of the weight of the surrounding structure that must accommodate window placement. In order to minimize the weight, windows are provided for first and business classes only. To compensate for the lack of windows in the coach class seats, a video channel dedicated to a display of the exterior of the aircraft (as would be seen through a fuselage side window), will be available to all coach display monitors.

6.0 WING & EMPENNAGE DESIGN

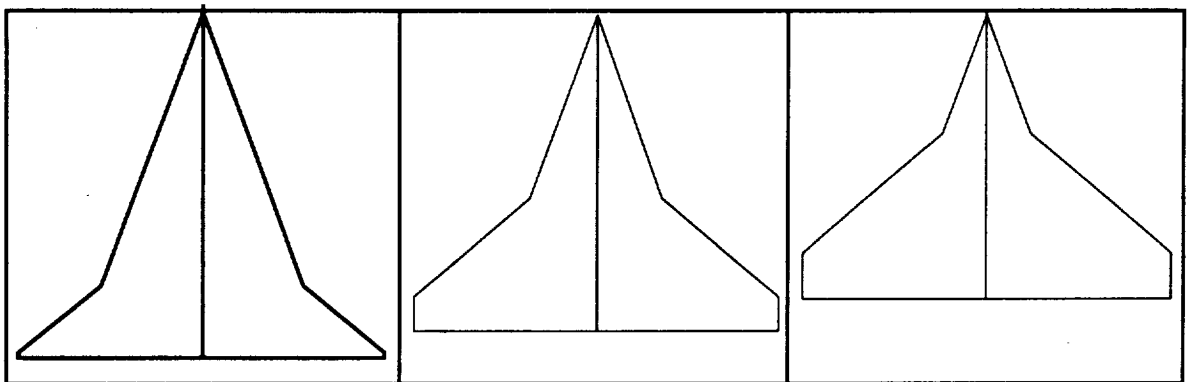
6.1 Wing Design

The double delta configuration utilized by the Swift is shown in Figure 3.1. The wing consists of two defining regions: the inboard panel and the outboard panel. Such wings are typically referred to as double deltas or cranked deltas.

The large, highly swept (70.0 degrees) inboard wing section was selected to allow adequate volume for landing gear, fuel, and necessary structures. A four percent thick wing accommodates the forward main landing gear which retracts into the region of maximum thickness. The aft main landing gear is retracted into the fuselage without the use of fairings. The elimination of fairings produces lower drag because flow separation is avoided and aircraft volume (which generates wave drag) is minimized.

The outboard wing panels have a lower (38.7 degrees) leading edge sweep. Although the lower sweep contributes to higher wave drag at the cruise condition, these panels are necessary to provide higher lift at low speeds which benefit the aircraft during take-off. Furthermore, the outboard panels minimize the wing aerodynamic center shift that takes place when the aircraft transitions from subsonic to supersonic flight.

A study was conducted to determine the location of the span where the outboard wing panel should be located. Three wing configurations of similar aspect ratio, but different outboard area to inboard area ratios, were compared at supersonic cruise velocities. The major drag contributors (friction, drag due to lift, and wave drag) were determined for each of the three wing using methods given in Reference 6 . Figure 6.1 defines the planforms studied and the corresponding drag coefficients.



Wing #1	Wing #2	Wing #3
$C_D = 0.0092$	$C_D = 0.0107$	$C_D = 0.0115$

Figure 6.1: Mach 2.5, 55,000 ft Drag Coefficients of Trade Study Planforms

A wing similar to wing #1 was selected because of the lower drag advantage and the ability to used a rounded leading edge airfoil on inboard panel (to be discussed below). Wings #2 and #3 were not selected because of the higher drag associated with these wings. The rounded leading edge provided additional wing volume for fuel and landing gear. The wing used by Swift provides the drag advantages of the smaller outboard panel while providing adequate take-off and landing performance as seen in the Performance section.

6.1.1 Airfoil Section

A NACA 64-004 was selected for the inboard delta because the 70 degrees leading edge angle lies within the Mach 2.5 cone. This provides a subsonic normal velocity component, Mach 0.86, to the leading edge. Since the inboard section remains subsonic through all flight regimes, a rounded leading edge airfoil section will be used. The rounded leading edge provides more fuel volume in the wing and removes the stress concentrations encountered with a biconvex airfoil by utilizing a continuous leading edge curve. Furthermore, the inboard wing panel leading edge is 3.6 degrees inside the Mach cone, and at supersonic cruise, the normal velocity component is Mach 0.855. This will eliminate transonic effects caused by the normal component of velocity when reaching Mach 1.

The NACA 64-004 was chosen because it allows the Swift to carry more fuel in the wing due to a larger volume at the airfoil leading edge. This region is not used for fuel because the Swift utilizes tail cone fuel storage (Section 13). However, the excess fuel volume in the wing can be used to increase the range on a later version of the Swift. The lift curve slope ($C_{l\,\alpha}$) for the NACA 64-004 is 5.01 per radian and the stall angle of attack is approximately 9.5 degrees at low speeds (Ref. 7 and based on a modified NACA 64-006).

At supersonic cruise, the leading edge of the outboard panel lies outside of the Mach cone and becomes supersonic, producing a normal component of freestream velocity greater than Mach 1. This panel uses a biconvex airfoil to reduce drag. The biconvex airfoil was selected over a wedge airfoil because of improved lift to drag (L/D) ratios at subsonic speeds. For the low speed condition the $C_{l\,\alpha}$ for this airfoil section is 4.30 per radian and the stall angle is at 8.0 degrees. These airfoils provided a wing critical Mach number of 0.94 (Ref. 8). The lift curve slope values were used in aerodynamic and stability & control calculations.

6.1.2 High Lift Devices

The Swift planform is capable of reaching a $C_{L\,max}$ of 1.1 without the use of high lift devices. Unfortunately the angle of attack to obtain this C_L is approximately 32 degrees and although the wing has not stalled, a large drag rise is encountered. Therefore, it is necessary to use high lift devices to decrease the angle of attack required for the C_L needed at take-off and landing (described in Section 11.1). Figure 3.1 shows the high lift system used by the Swift.

Trailing edge flaps are used to increase the lift coefficient by 0.32 at a given angle of attack. The Swift aircraft has a planform and flap devices similar to the McDonnell Douglas M2.2 Supersonic Cruise aircraft configuration (Ref. 9). Because of the unpredictable characteristics associated with high lift devices, wind tunnel data from the McDonnell Douglas M2.2 (Ref. 9) was used to approximate the effect of high lift devices on the Swift wing-body. Specifically, changes in the lift, drag, and pitching moment were obtained from Reference 9. After analysis, it was determined that leading edge devices were not beneficial for the Swift aircraft as seen in Figure 6.2

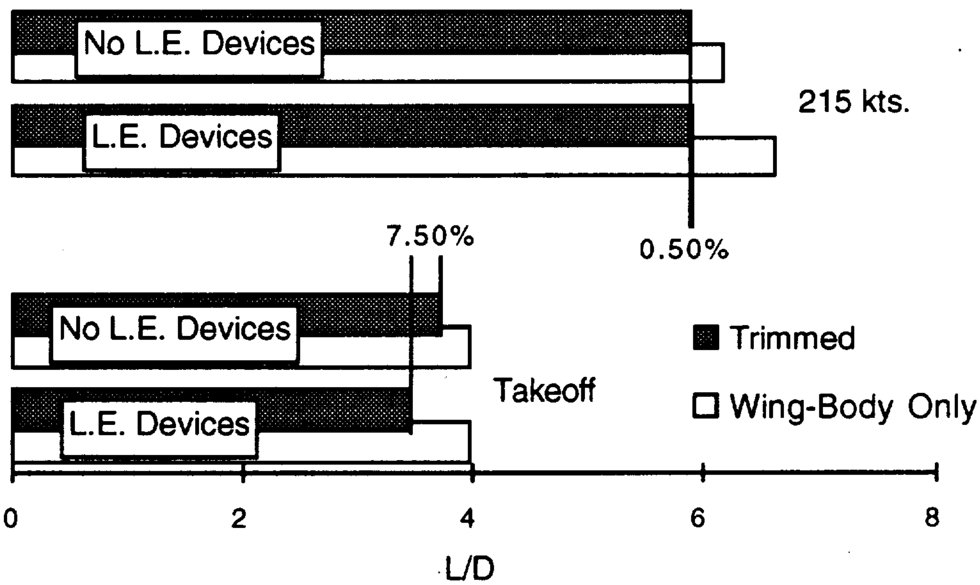


Figure 6.2: Effect of Leading Edge Devices (30° trailing edge flaps)

At 215 knots, leading edge devices (with 30 degrees of plain flaps) increase the untrimmed lift to drag (L/D) from 6.2 to 6.7 as seen by the white bar in Figure 6.2. However, the leading edge devices cause a significant nose down pitching moment. The trim drag required to overcome this pitching moment reduces the L/D (gray bars) and only a 0.5 percent improvement in L/D is obtained. Thus, no aerodynamic or performance advantages would be achieved if leading edge devices are added to Swift. Furthermore, leading edge flaps at take-off cause a 7.5 percent decrease in aerodynamic efficiency due to the associated trim drag needed by the Swift. Leading edge devices also increase complexity, maintenance, and cost of the aircraft. It is for these reasons that the Swift high lift devices consist of trailing edge flaps only.

The McDonnell Douglas M2.2 (Ref. 9) wind tunnel aircraft used only plain flaps. Swift uses single slotted flaps to insure that the flow is attached over the flaps. Although more efficient, a complex flap system was not selected due to the greater cost and maintenance involved.

The high lift data was obtained from the Douglas report (Ref. 9). Because of the uncertainty in scaling methods used to determine these coefficients, the change in drag due to the flaps, ΔC_{Do}, was multiplied by a factor of 1.5 to provide a conservative performance analysis. Specifically, ΔC_{Do} due to the take-off flaps (24 degrees) is 0.044.

6.1.3 Structural Consideration and Fuel Volume

A thickness ratio of 4.0 percent was sized for the entire wing to provide adequate structural strength and fuel volume. The 4.0 percent thick outer delta will provide enough strength to support the large amount of lift carried by the tips and should eliminate aerodynamic flutter. The 4.0 percent thick outer panel is less likely than a thinner airfoil to encounter flow separation at the rotation angles encountered during take-off and landing. Further discussion of the structural layout of the wing will be discussed in Section 11.

6.2 Empennage Aerodynamic Aspects

This section will briefly discuss the Swift empennage configuration. The stability and structural analysis of the empennage can be found in the appropriate sections of this report.

The horizontal tail was placed on the fuselage 7.8 feet above the wing center line. At this location the tail is not blanketed by the flow over the wing. Further aerodynamic improvements could be obtained if the horizontal tail was placed on the vertical stabilizer, however this location does not provide adequate support for the high loads that are encountered on the horizontal stabilizer during take-off and landing. The volume coefficient of the horizontal stabilizer is 0.111. This was the horizontal tail coefficient required to provide enough control power at take-off and landing and is discussed in the Stability and Control section.

The highly swept (54.7 degrees leading edge angle) stabilizer is necessary to prevent flow separation at the high angle of attack encountered during take-off and landing. A four percent thick biconvex airfoil section provide Swift with structural requirements while minimizing drag.

The vertical tail was selected to provide control during a one engine inoperative condition and is discussed in the Stability and Control section. Vertical tail volume coefficient of the vertical stabilizer is 0.046. A four percent thick biconvex airfoil section was selected to reduce the drag on the tail while meeting structural requirements.

7.0 DRAG ANALYSIS

The drag polars were generated by using methods from several references listed below. The skin friction drag and wave drag were determined using methods found in Reference 14. The drag due to lift was determined from Reference 6 and by using the leading edge suction method (Ref. 9 and 12). Subsonic and supersonic drag polars were developed.

Three critical flight regimes were selected for drag analysis. These regimes were chosen because it was felt that these were the most critical conditions during flight. These are shown below in Table 7.1

Table 7.1: Critical Conditions

Case	Altitude	Mach Number
I. Take-off	5,000 ft.	0.385 (250 kts)
II. Subsonic Cruise	35,000 ft.	0.8
III. Supersonic Cruise	55,000 ft.	2.5

7.1 Subsonic Drag Polars

The leading edge suction parameters described in reference (Ref. 14) were obtained from the McDonnell Douglas high lift report (Ref. 9) because of limited high lift data. These parameters represent the amount of suction force acting on the leading edge of the wing that opposes the induced drag. When s=1, the lift distribution is equal to that predicted by Oswald and the Oswald efficiency factor is equal to one (Ref 12). For Case I and II the Swift leading edge suction parameters were approximated by using the values obtained by McDonnell Douglas (Ref. 9). Specifically, the leading edge suction used for Cases I and II was 0.5. This increased to 0.75 when flaps were deployed. This relatively high suction parameter for the flap down condition is achieved because the spanwise lift distribution becomes more elliptical.

The drag polars developed for the take-off condition are seen in Figure 7.1.a.

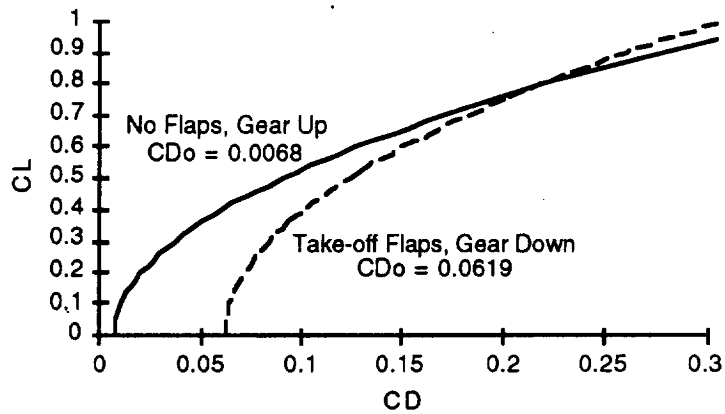


Figure 7.1.a: Subsonic Drag Polar for the Swift: Take-off condition, (V=250 kts., Sea Level, 86°F)

A maximum lift to drag (L/D) ratio of 10.4 for the aircraft when the flaps and gear are retracted was achieved. The Oswald's efficiency factor for this configuration is 0.47, and improves to 0.64 when flaps are extended. The flaps and gear cause the zero lift drag to increase from 0.0068 to 0.0619. The resulting L/D for this configuration is 4.0. Although the flaps produce higher drag, the devices cause the C_l curve to shift left by approximately 6 degrees angle of attack. This allows the Swift to reach the necessary take-off lift coefficient of 0.63 without tail strike.

Figure 7.1.b shows the subsonic cruise drag polar.

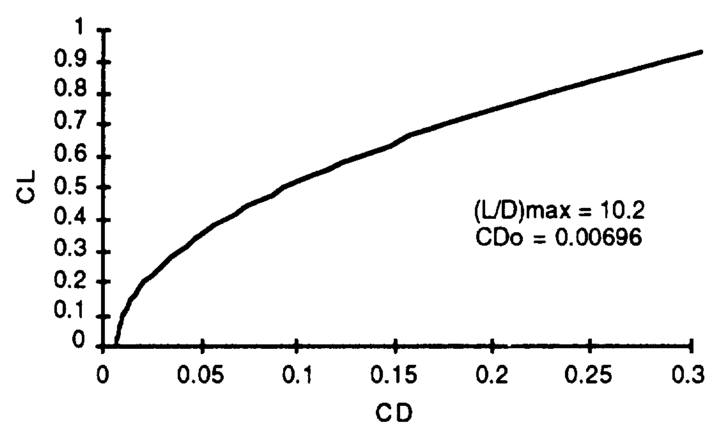


Figure 7.1.b: Subsonic Drag Polar: Subsonic Cruise Condition (M=0.8, 35,000 ft.)

When the Swift reaches the subsonic cruise altitude of 35,000 feet the maximum L/D is 10.2. This is 2 percent less than the L/D achieved by the clean aircraft at take-off. The aircraft will perform more efficiently at this altitude because of the increase in propulsion efficiency. An Oswald efficiency factor of 0.46 was calculated at this condition from the leading edge suction method described above.

7.2 Supersonic Drag Polars

For flight in the supersonic regime, wave drag must be considered in the analysis. "Area-ruling" is a method used to minimize wave drag for a body of constant volume. This method determines the cross sectional area of the aircraft as a function of fuselage length. The cross sectional area is calculated at areas parallel to the Mach cone (for Mach 2.5: 23.6 degrees with respect to freestream where 90 degrees is a standard cross section). Wing surfaces were numerically "sliced" and other segments were analyzed with a CAD system (Claris CAD 2.0 version 3). The cuts were taken on two angles 90 degrees from each other and the average area was determined as a function of fuselage length. Figure 7.2 shows the area ruling achieved by the Swift. Displayed on the graph is the Sears-Haack line which indicates the ideal theoretical distribution. Although methods of interpolation between cuts planes produced fluctuations in the curve, Swift's volume distribution closely follows the Sears-Haack body.

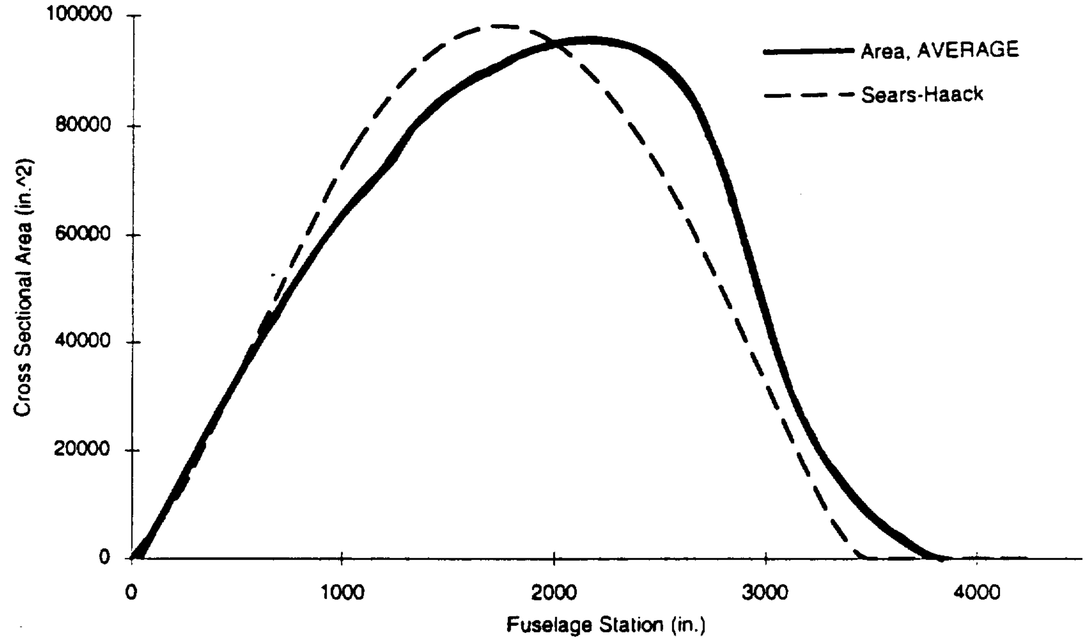


Figure 7.2 Area Ruling Diagram for the Swift (M=2.5, Cut Plane)

In order to meet the required cruise L/D of 8.5, it was determined that the skin friction and drag due to lift must decrease by 9.0 percent. Both of these achievements may be satisfied with a more comprehensive analysis. The highly blended configuration may have lower interference and form factors than those calculated. The lower interference will reduce friction drag. Aerodynamic tailoring of the wing twist and camber will optimize the lift distribution at cruise and reduce the drag due to lift.

The drag polar calculated for the supersonic cruise regime is seen in Figure 7.3.

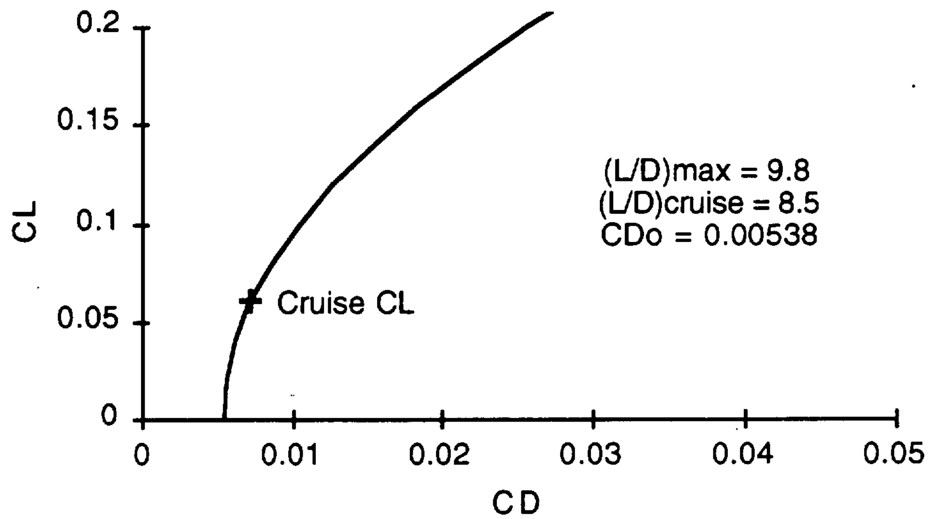


Figure 7.3: Supersonic Drag Polars (M=2.5, 55000 ft.)

It is important to note that the aircraft does not cruise at the maximum L/D. The Breguet range equation states that optimum range of the aircraft is achieved by using 86.6 percent of the maximum L/D. This produced a cruise C_L of approximately 0.06 for the Swift. The drag components are shown below in Figure 7.4 for this condition.

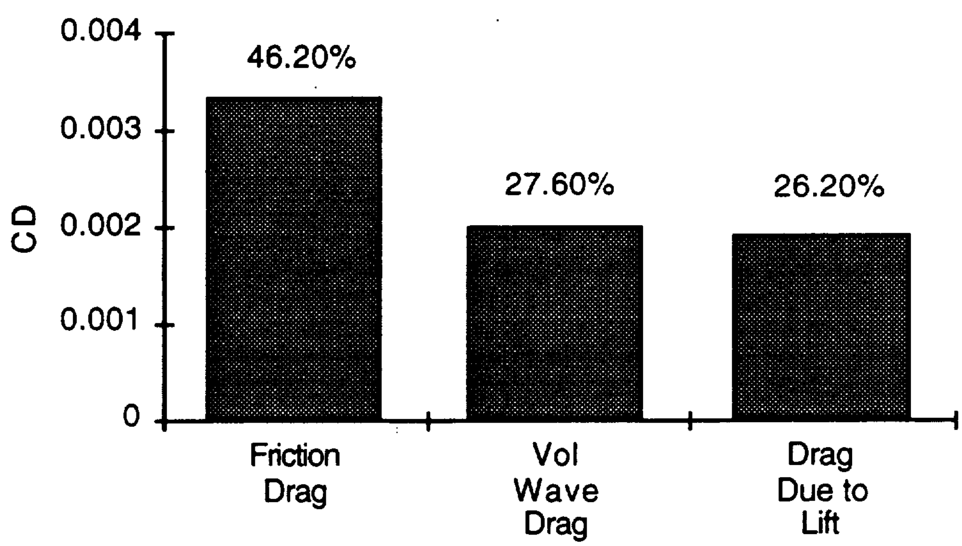


Figure 7.4: Supersonic Drag Polars (Bar Chart, M=2.5, 55000 ft.)

The friction drag is the dominating form of drag at cruise. Laminar flow control was considered to reduce friction drag. Laminar flow control is performed by applying suction to thousands of small ports on the wing surface. The suction removes any turbulence in the flow and allows a larger portion of the wing to experience laminar flow. The laminar flow has a lower skin friction coefficient and reduces drag on the wing surface. But, laminar flow control would greatly increase the complexity and maintenance of the aircraft. It is for this reason that the Swift does not use laminar flow control as a means to reduce friction drag.

8.0 PROPULSION INTEGRATION AND AIRCRAFT PERFORMANCE

In order for an aircraft to be feasible, it must have a realistic and reliable propulsions system. This section will present the Swift's propulsions system, its selection, and its advantages and disadvantages.

8.1 Engine Selection

The thrust required for take-off and one engine inoperative (OEI) situations are the most critical design parameters. At a gross take-off weight of 712,000 pounds and wing loading of 78.3 lbf/ft^2, the thrust to weight ratio,(T/W), is 0.30. The calculation of these numbers can be found in the performance section (Sec. 3.0) of this report. Based on the thrust to weight ratio, gross take-off weight and the parameters listed in Table 8.1, the Swift needs four engines. Each engine must be able to produce at least 53,400 pounds at take-off (sea level, M =0.3), 71,200 pounds at OEI situations, and 18,850 pounds at supersonic cruise (48,000-57,000 ft, M = 2.5).

Table 8.1: Engine Requirements for the Swift

Parameter	Requirement
Cruise Speed	Mach 2.5
Take-off Speed	190 knots
Landing Speed	150 knots
Cruise Altitude	48,000-57,000 ft.
Service Ceiling	60,000 ft.
Meet FAR 36 Stage III Noise Requirements	With 16 EPNdB of noise reduction provided by mixer-ejector nozzle.
Fuel	Thermally Stable Jet Fuel (TSJF+50°F)
Placement	Under wing mounting for easy maintenance Pusher type placement on aircraft

8.1.1 Propulsion Type

The Swift propulsion system consists of four variable cycle NASA-mixed flow, low-bypass, turbofan engines (Ref. 11). See Figure 8.1 for engine configurations. From here on the engine will be referred to as the NASA-engine. Each engine provides the necessary thrust required at take-off (sea level, M = 0.3), and at supersonic cruise (48,000-57,000ft.). Any additional thrust required during emergencies will be provided by an afterburner.

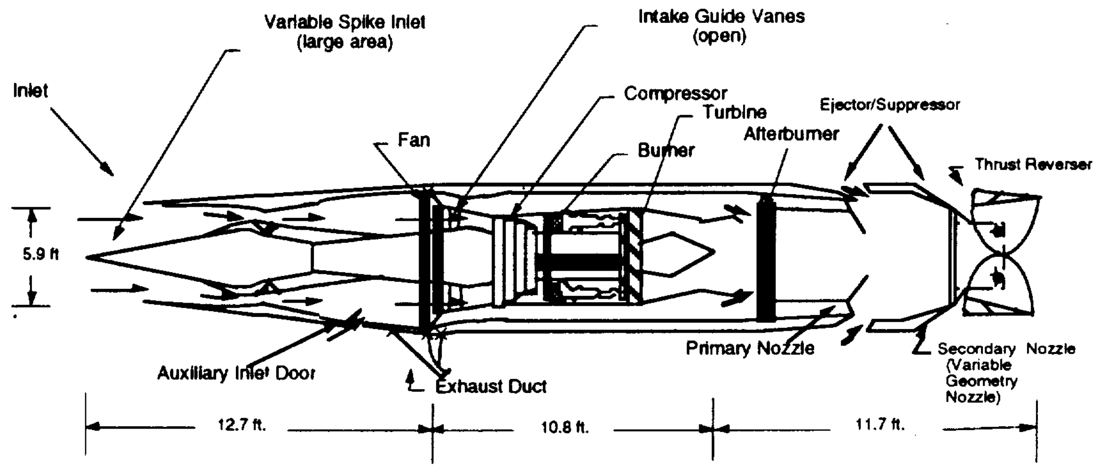


Figure 8.1: Mixed Flow Turbofan for the Swift

Both turbofan and turbojet engines were analyzed before the NASA-engine was selected. Although engine thermal efficiency and engine mass per unit thrust are greater for turbojet, the low bypass turbofan was selected for the following five reasons:

1) for the same propulsive efficiency (54 percent), it has lower SFC's (approximately 16 percent lower) than the turbojet (Ref. 12);
2) the mixing of core and bypass streams reduces jet noise emission Ref. 13);
3) engine overall efficiency is higher than for turbojets;
4) total airflow is much higher than for a turbojet of the same thrust;
5) it has a 20 percent weight reduction for the same air mass flow (Ref. 12).

In addition, because the NASA-engine is a variable cycle engine it is capable of providing the variation in thrust levels required for both subsonic and supersonic flight. Although the additional complexity causes an increase in weight, the variable cycle concept of the NASA-engine provides at least two different thermodynamic cycle modes of operation at specific flight conditions with a fixed mass flow rate.

Although the NASA-engine's fan produces drag, it does provide the necessary thrust for both take-off and cruise. Since the NASA-engine was sized for take-off conditions, the augmentation system will need to provide an additional 35 percent increase in thrust during OEI emergencies.

8.1.2 Engine Sizing

Installed thrust for the current engine at take-off (M = 0.3) is 51,000 lbs with a specific fuel consumption (SFC) of 0.84. However, because the current installed thrust is less than the thrust needed for take-off (53,400 lbs.), the engine data from Reference 11 needed to be increased by a factor of 4.7 percent. This information was used to scale the NASA-engine at take-off conditions.

From the engine sizing method in Reference 14, the NASA-engine has an available take-off (M = 0.3) thrust of 53,400-pounds, an available cruise (55,000 ft.) thrust of 23,300-pounds with an SFC of 1.2 at cruise, and a total length of 36.2 ft. It needs approximately 16 EPNdB of nozzle noise suppression to meet FAR 36 Stage 3 noise requirements (Ref. 11). Noise suppression is accomplished through the use of a flow mixer/ejector. Table 8.2 lists the engine's dimensions, weights, and performance characteristics based on the requirements listed in Table 8.1. Consequently, the scaled thrust at cruise altitude and speed (55,000 ft., M = 2.5) is 23,300 lbs, but the thrust required at this altitude is only 18,847. This implies that the Swift will be cruising at 75 percent of its thrust (SFC 1.2). The SFC includes a 10 percent improvement in technology forecasted for the years 2000.

Table 8.2: Swift Engine Performance Per Engine Specifications

DESIGN CYCLE CHARACTERISTICS	
Bypass Ratio	0.5 - 0.94
TAKE-OFF RATING (SL, 86°F)	
- Max Thrust (Static)	55,490 lbs
SFC	0.710
- Max Thrust (M=0.3 Installed)	53,400 lbs
SFC	0.808
- Max Thrust (M=0.3 Installed with augmentation)	74,760 lbs
SFC	1.43
CRUISE RATING (55,000 ft., M = 2.5)	
- Thrust	23,300 lbs
SFC (dry)	1.20
DIMENSIONS	
Max. diameter	93.6 in (7.8 ft)
Engine front face diameter	81.6 in (6.8 ft)
Inlet diameter	70.8 in (5.9 ft)
Total unit length	434 in (36.2 ft)
Inlet capture area at cruise (M = 2.5)	3,148.2 in^2
WEIGHT	
Engine + Inlet + Augmentation + Nozzle	16,000 lbs

8.1.3 Inlet Design

The geometry of the cowl lip has a major influence upon engine performance and aircraft drag, a sharp lip is desirable to minimize drag (Ref. 14). Thus the inlet cowl lip chosen for the Swift's engines is sharp with a lip radius of 1.6 in. (4 percent of the inlet front face diameter). Also important to the engine performance is the inlet geometry. Although the mechanisms to produce a variable geometry inlet are much more complicated and cowl drag is higher, it can be used for subsonic and supersonic regimes. The variable geometry spike inlet is typically lighter and has a slightly better pressure recovery (2.5 percent) than the two-dimensional ramp inlet. Furthermore, ramps are more commonly used for speeds up to Mach 2, whereas spike inlets tend to be used above that speed (Ref. 14).

Any inlet must slow the air to about M = 0.5 before reaching the compressor face to prevent adverse effects to the compressor aerodynamics (Ref. 14). Based on a cruise Mach number of 2.5, an axisymmetric variable geometry spike inlet (which produces three external shocks) was analyzed (Figure 8.2). Since analysis done on this type of inlet revealed that the three-shock (two oblique and one normal) external compression inlet is sufficient to decelerate the flow to M = 0.5 (Appendix), this type of inlet will be employed.

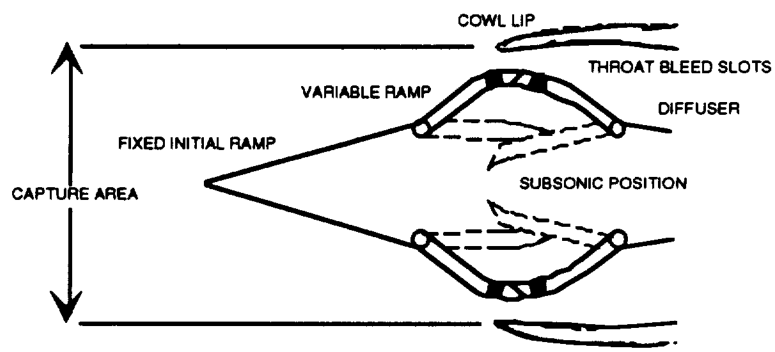


Figure 8.2 Inlet Geometry of the Mixed-Flow Turbofan for the Swift

The inlet area was found using Reference 14 at a condition of Mach 2.5 and a mass flow rate of 737 lbm/sec. It was estimated that a total capture area of 3,148.2 in^2 would be sufficient for most flight conditions. Because it was assumed that the capture area is equal to the engine front face area of 3,217 in^2, at take-off and landing the addition of 0.5 ft^2. auxiliary inlet doors will be necessary. See Figure 8.1. These doors may also be used to get rid off excess air at high subsonic speeds and to reduce spillage drag.

8.1.4 Nozzle Design

The nozzle will need to suppress approximately 16 EPNdB for FAR 36 Stage 3 noise requirements (Ref. 11). A 60 percent mass flow augmented mixer-ejector nozzle will satisfy this requirement (Ref. 15). See Figure 8.1 for a descriptive look of the mixer-ejector nozzle. This configuration provides a noise-level reduction of 16 EPNdB with an in-flight thrust loss of 5.4 percent at take-off (Ref. 16).

8.1.5 Thrust Reverser

Thrust reversing buckets similar to the Concorde's are located near the exhaust plane of engine to provide deceleration during landing (Figure 8.1). Using the thrust reversing buckets reduces landing distance by 25 percent, but increases landing noise due to the obstruction of the exhaust flow. However, this will not be a problem because the engines are equipped with enough noise suppression (discussed in Sec. 8.1.4) to meet FAR 36 Stage 3 noise regulations.

8.1.6 Engine Augmentation

Because the thrust needed for the OEI situation is 35 percent greater than that available at take-off M = 0.3, the engine was augmented (Ref. 12). This augmentation is capable of increasing the thrust available by up to 40 percent in emergency situations.

8.2 Engine Placement and Inlet Integration

To eliminate structural and landing gear interference, the engines are paired in pods and placed under both sides of the wing span, 12.5 ft. away from the fuselage. They are mounted through their center of gravity with the nozzle exit at the wing's trailing edge and set at a 5 degree downward deflection. They are located close to the wing trailing edge so that the gross thrust vector develops not only lift but also some supercirculation (Ref 12). Some other considerations for the placement of the inlets are foreign-object damage (FOD), and landing gear and structural interference. Because the inlets are approximately 1.5 inlet diameters (7.0 ft) above the ground, they are high enough to reduce the probability of foreign-object ingestion by suction (Ref. 14).

8.3 Engine Performance

Engine performance is affected by the inlet pressure recovery as well as power extractions. Figure 8.3 shows the engine performance at various altitudes and Mach numbers.

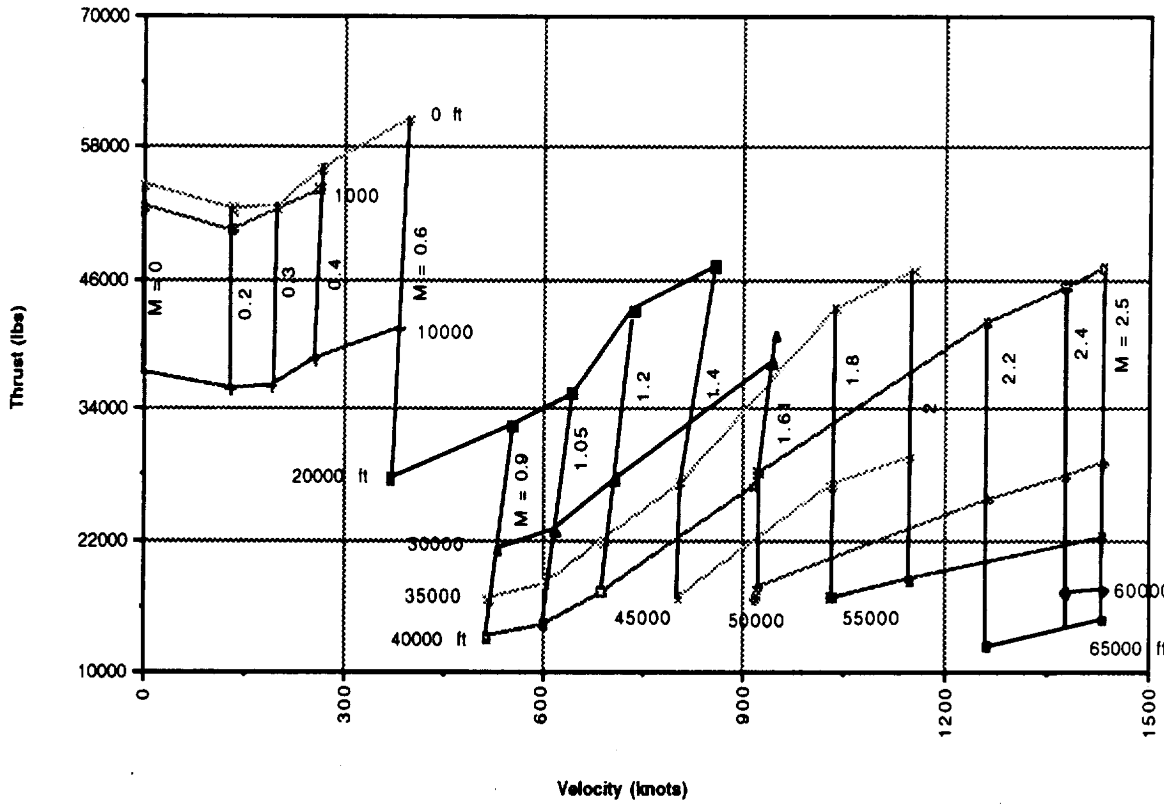


Figure 8.3: Mixed-Flow Turbofan Engine Performance (Non-Augmented)

The NASA engine emissions needs to meet the regulatory requirement at time of service, and need to be at levels that will not impose local operational restrictions or endanger the atmosphere. Pratt & Whitney and General Electric have teamed up to research several low NOx (nitric oxide) engines. The rich burn, quick quench method provides a 75 percent NOx reduction and a low technological risk. The lean pre-mixed, pre-vaporized method reduces NOx by 83 percent, however, this method has greater technological risks. The Swift's engines will incorporate whatever method is employed by the year 2000.

9.0 PERFORMANCE

Swift performance analysis has demonstrated that Swift is capable of accomplishing the specified mission (Section 2.0). The aircraft performs well at the cruise condition of Mach 2.5 for a cruise climb from 48,000 to 57,000 feet. The "off-design" conditions such as take-off, climb, and landing were optimized with fairly unconventional techniques such as high take-off velocities and emergency thrust augmentation capability.

9.1 Take-off and Landing Performance

Swift take-off and landing performance was based on several important parameters. Swift has a long, slender fuselage with low tail upsweep (six degrees) which is beneficial for supersonic flight by avoiding flow separation and strong expansion waves, unfortunately the configuration limits the angle of attack at take-off and landing due to tail strike. This produces a need for a high velocity (low angle of attack) at both take-off and landing.

The acceleration required to reach take-off velocity was determined by considering the average drag and thrust encountered during the ground roll. By dividing the average force acting on the aircraft by mass, the acceleration required to reach take-off lift coefficients is obtained (Ref. 32 and Ref. 14). A similar procedure was used to determine the landing roll distance. The take-off and landing performance data is listed below in Table 9.1

It was assumed that the drag encountered by Swift during the ground roll was one half the lift coefficient based on weight, dynamic pressure, and wing reference area. This assumption was made because the wing is at zero angle of attack relative to freestream velocities during the ground roll.

Because of the double delta wing, the Swift is capable of reaching lift coefficients greater than one without the use of flaps. Unfortunately these high lift conditions can only be achieved during a decent. Swift does not have sufficient power available to maintain level flight at a lift coefficient greater than 0.95. The minimum velocity was determined to be the point where the available thrust was equal to the drag at the maximum lift coefficient. This is the velocity point were the Swift could only maintain level flight.

Table 9.1: Swift Take-off and Landing Performance

	TAKE-OFF (sea-level, 86°F, wet concrete)	LANDING (sea-level, 86°F)
FAR Field Length	10,100 ft	10,600 ft
Weight	712,000 lb.	392,000 lb.
Velocity	190 kts. (1.2 V_{min})	150 kts. (1.9 V_{min})
CL	0.63	0.59
CLmax	0.95	0.95
Rate of Climb (GE = Ground Effect)	1,645 ft/min (in GE) 940 ft/min (no GE)	-800 ft/min
Flight Path Angle	2.9°	3.0° glideslope
Flap Deflection	24°	28°
angle of attack	11°	12°

9.2 Climb Performance

The Federal Aviation Regulations (FARs) require that certain climb gradients (CGR) must be achieved. During preliminary analysis it was discovered that the Swift would not meet certain regulations during a one engine inoperative (OEI) climb. Specifically, the second segment climb (OEI) and landing (OEI) could not be met with a take-off thrust to weight of 0.30. It was for this reason that the Swift is equipped with an emergency thrust augmentation system to replace the power lost due to an engine failure.

The emergency thrust augmentation provides enough power to exceed the FAR required climb gradients as seen in Table 9.2.

Table 9.2: Swift Climb Requirements

Condition	FAR CGR	Swift CGR
Initial Segment (OEI)	1.7%	9.2%*
Transition (OEI)	0.5%	8.5%*
Second Segment (OEI)	3.0%	4.4%*
Enroute Climb (OEI)	1.7%	2.7%*
Landing (AEO)	3.2%	3.9%
Landing (OEI)	2.7%	8.6%*

* Emergency Thrust Augmentation

9.3 Optimum Flight Conditions and Ceiling

The optimum flight altitude was selected by varying aircraft altitude for the specified weight at the beginning and end of supersonic cruise. Maximum L/D was determined from drag polar information at each altitude. The coefficients of lift and drag of the aircraft at the region of interest produced an L/D which was compared to 86.6 percent of the maximum L/D. (The Breguet range equation applied to jet aircraft yields an L/D for maximum range of 86.6 percent of L/D maximum). The altitude was varied until agreement between these two parameters was obtained. The altitude range covered during cruise climb varies from 48,000 to 57,000 feet.

9.4 Range Versus Payload

The entire 246 passengers can be carried a range of 5,700 nautical miles plus reserves. Any addition increase in range beyond this point must be obtained by decreasing the load factor. The range increases linearly from 5,700 nautical miles as the load factor decreases until a maximum range of 7,400 nautical miles (the maximum ferry range) is achieved by eliminating all passengers.

9.5 Hold Characteristics

The Swift hold characteristics were determined by determining the velocity were the minimum drag is encountered at 20,000 feet. This altitude was selected because the it is relatively uncongested airspace and produced good engine performance. The velocity where minimum drag occurred was found to be 410 knots. At this velocity a 1.05g holding turn would require 22 minutes to complete.

10.0 LANDING GEAR

A modified tricycle type landing gear is installed on the Swift because of its good pavement loading distribution and efficient landing gear volume. All gear have wide wheel spacing both longitudinally and laterally to lower pavement loading. The landing gear is designed to FAR requirements to withstand a sink rate of 10 feet per second (fps) at design landing weight and 6 fps at maximum gross weight.

10.1 Nose Landing Gear

The nose landing gear (NLG) location on the aircraft is shown on Figure 10.1. The maximum load on the landing gear occurs at braking during an aborted take-off. This load is 87,900 pounds (lbs.). The largest size tire that can fit into the nose wheel well is the 40 x 19 Type VII (Ref. 14). This tire has a maximum wheel loading rating of 49,500 lbs. Therefore, two tires are required to handle the maximum loads for the nose landing gear. Two nose wheels also retain steering control in a single nose-tire failure situation. The single nose landing gear uses two wheels in a dual pattern which retract into the fuselage. Hydraulic power is provided for landing gear extension and retraction, and for door actuation. The nose gear strut houses the oleo-pneumatic shock for landing and ground maneuvering shock absorption. Because it is nearly twice as efficient as other shock types, the oleo-pneumatic shock strut is the most common shock absorbing gear in use today (Ref. 14). A drag link leading the strut provides the nose gear with supplemental strength and stability. Figure 10.2 presents a detailed view of the main landing gear.

The steering system consists of two hydraulically powered self-centering actuators mounted on the steering collar of the strut. The system has sufficient torque to turn through the full steering angle of 78 degrees without requiring forward motion of the aircraft or asymmetric thrust. This capability is available with a 0.8 runway coefficient of friction at both the critical weight condition (712,000 lb. maximum ramp weight) and the critical center-of-gravity (CG) condition (landing with minimum fuel).

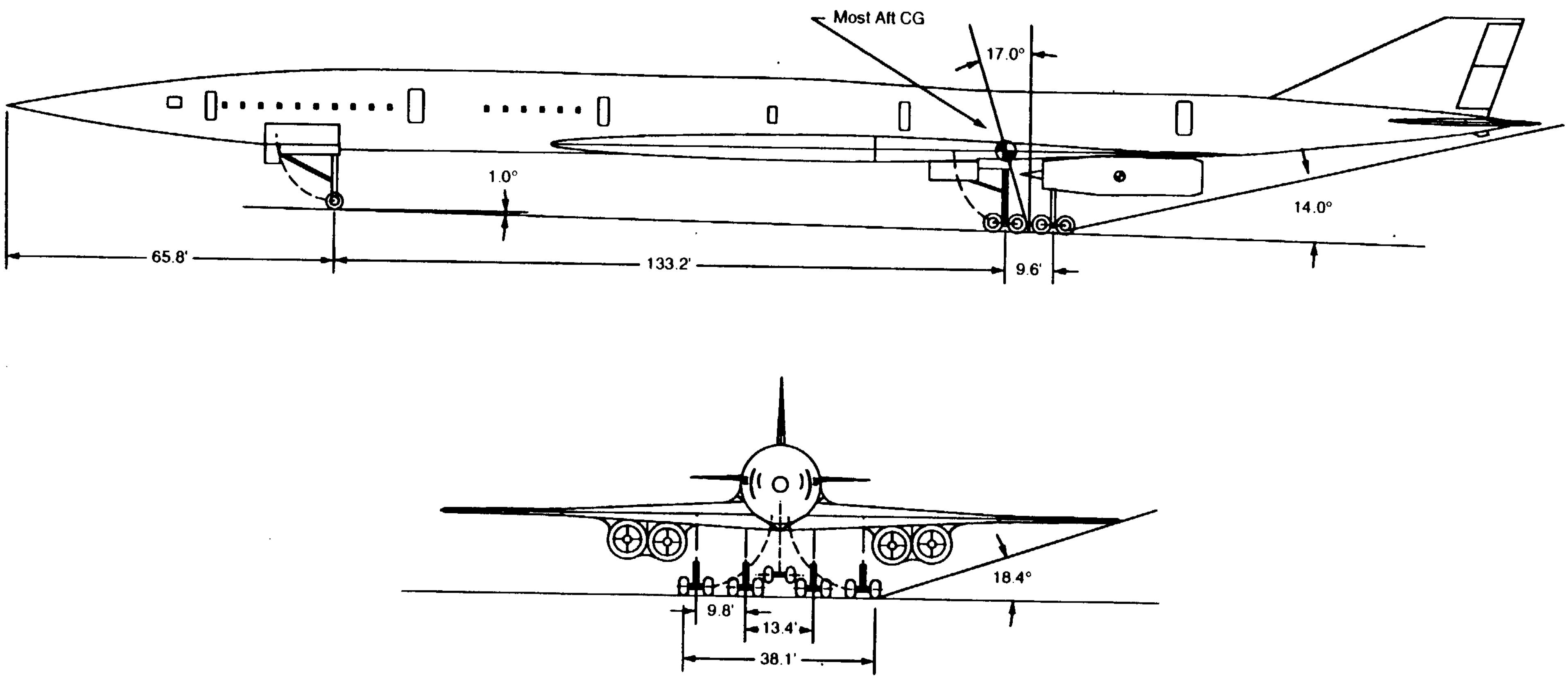


Figure 10.1: The Swift Landing Gear Location and Longitudinal Tip-Over Angle

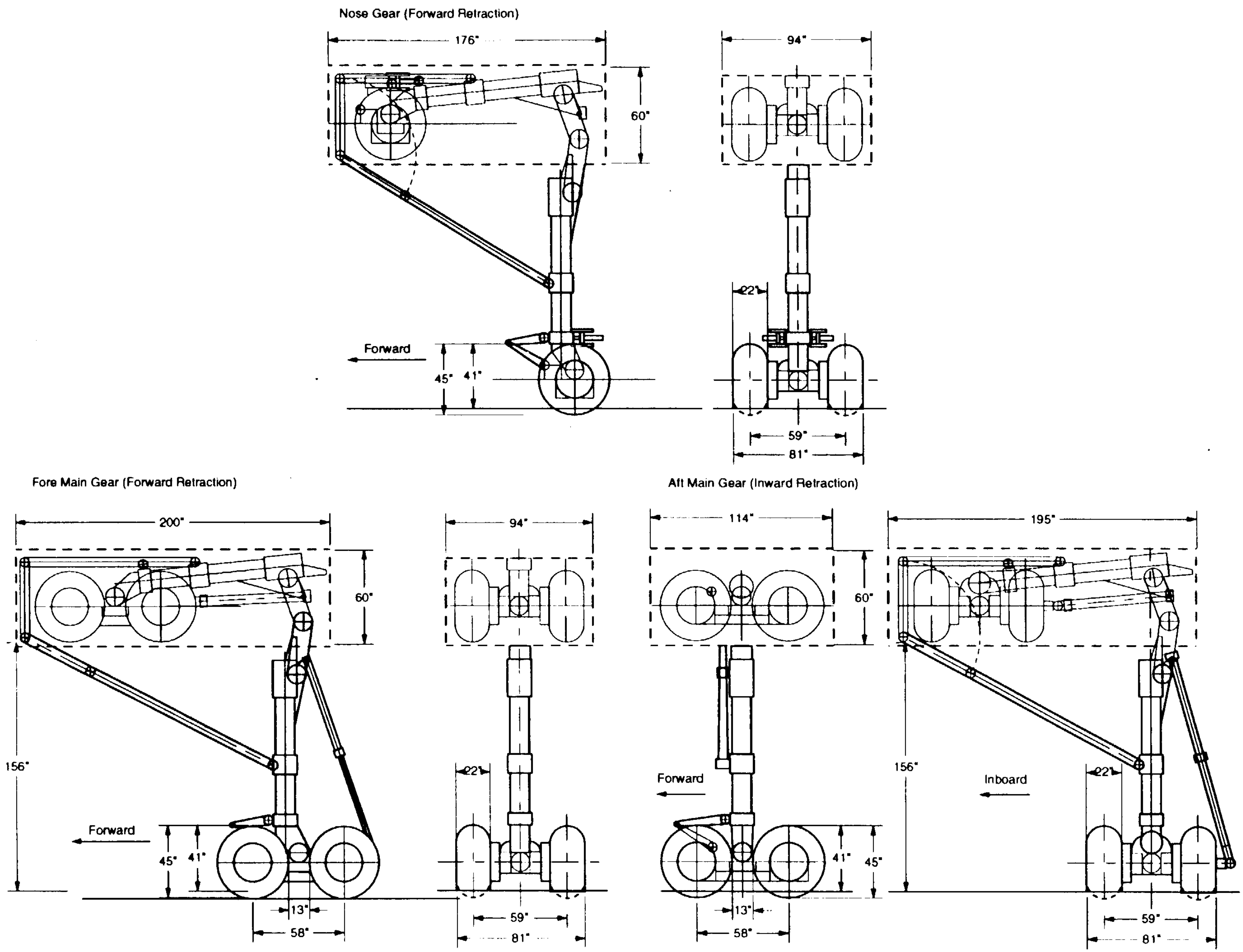


Figure 10.2: Swift Landing Gear - Detail

For emergency operation, all the landing gear and door uplocks are released manually from either pilot's position to allow the landing gear to freefall into the extended position. Downlocks are engaged automatically. TABLE 10.1 lists nose gear data (Ref. 17).

TABLE 10.1: Nose Gear Data

Strut:		Tire:	
Max. Static Load	62,500 lb.	Size	40 X 19 Type VII
Max. Dynamic Load	87,900 lb.	Max. Loading	49,500 lb.
Strut Length	13 ft.	Ply Rating	32
Strut Diameter	10 in	Pressure	245 psi
Strut shock stroke	12.5 in (8 percent)	Max Speed	200 knots

10.2 Main Landing Gear

The main landing gear (MLG) location on the aircraft is shown on Figure 10.1. The MLG is located inboard of the engine nacelle pods. The aircraft maximum weight is the maximum ramp weight (MRW) (726,000 lbs.; 102 percent of the take-off gross weight). For adequate nosewheel authority for steering, 90 percent of the MRW is carried by the main gear. This load is then increased by seven percent by FAR requirements and an additional 25 percent is added for future aircraft growth. (Ref. 14). The main gear design load is 874,000 lbs. The largest tire size that fits into the main gear wheel wells are the 45 x 22 Type VII tires. This tire has a maximum load rating of 55,000 lbs. Therefore, sixteen tire are required to carry the main gear design loads. Since pavement loading was required to be similar to a Boeing 747-400 (Ref. 4), the four main landing gear incorporate a four-wheel bogey in a widely spaced dual tandem arrangement. The forward main gear retracts forward and the aft main gear retracts laterally inward into wing root wheel wells. Hydraulic power is provided for landing gear extension and retraction, and for door actuation. Figure 10.2 presents a detailed view of the main landing gear.

An all-wheel digital anti-skid braking system controls the hydraulically powered brakes. The system comprises of a digital control unit and a wheel speed transducer and control valve on the two nose gear wheels and each of the sixteen main gear wheels.

The wide wheel spacing utilized in the landing gear bogey design and the wide tread between the main-gear bogies distribute aircraft weight so that pavement loads are in Load Classification Group II/Load Classification Number 76 (LCG II/LCN 76). Table 10.2 lists main gear data (Ref. 17).

Table 10.2: Main Gear Data

Strut:		Tire:	
Max. Static Load	175,000 lb	Size	45 X 22 Type VII
Max. Energy Absorption	110,600 lb-ft.	Max. Loading	55,500 lb.
Strut Length	15 ft.	Ply Rating	32
Strut Diameter	12 in	Pressure	245 psi
Strut shock stroke	14.4 in (8 percent)	Max Speed	200 knots

10.3 Tip-Over Criteria

The longitudinal tip-over criteria for the Swift is shown in Figure 10.1. The most aft location for the CG is the main factor in determining location of the main gear. Space availability for main gear stowage diminishes rapidly aft of the mid-chord of the wing root. The main landing gear placement resulted in a 17 degree angle between the most aft c.g. location and the main gear arrangement. This angle provides a 10 percent nosewheel load which is adequate for nosewheel steering requirements.

The lateral tip-over criteria is shown in Figure 10.2. The lateral tip-over angle for the Swift is 38.4 degrees. The outboard-to-outboard gear track of 457 inches gives the aircraft good ground stability and low pavement loading.

10.4 Retraction Sequence

All landing gear designs were derived from a four-wheel, forward retracting design that eventually was adopted for the front main landing gear. The landing gear retraction is performed by a hydraulic actuator attached to a moment arm at the top of the nose gear strut. Figure 10.3 shows the retraction sequence as the hydraulic actuator pulls on the moment arm. The strut pivots about a pin joint fixed to the aircraft main structure. The upper drag link collapses upward and into the wheel bay. As the gear rotates upward, the rear link pulls the rear wheels into the strut to for a compact structure. The lower drag link rotates toward the strut and stored gear is only 60 inches high.

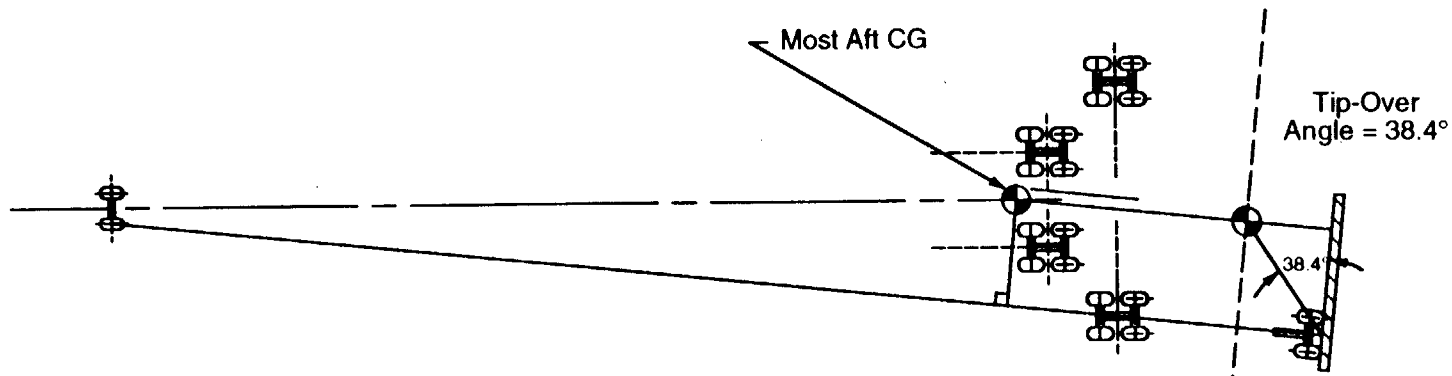


Figure 10.3: The Swift Lateral Tip-Over Angle

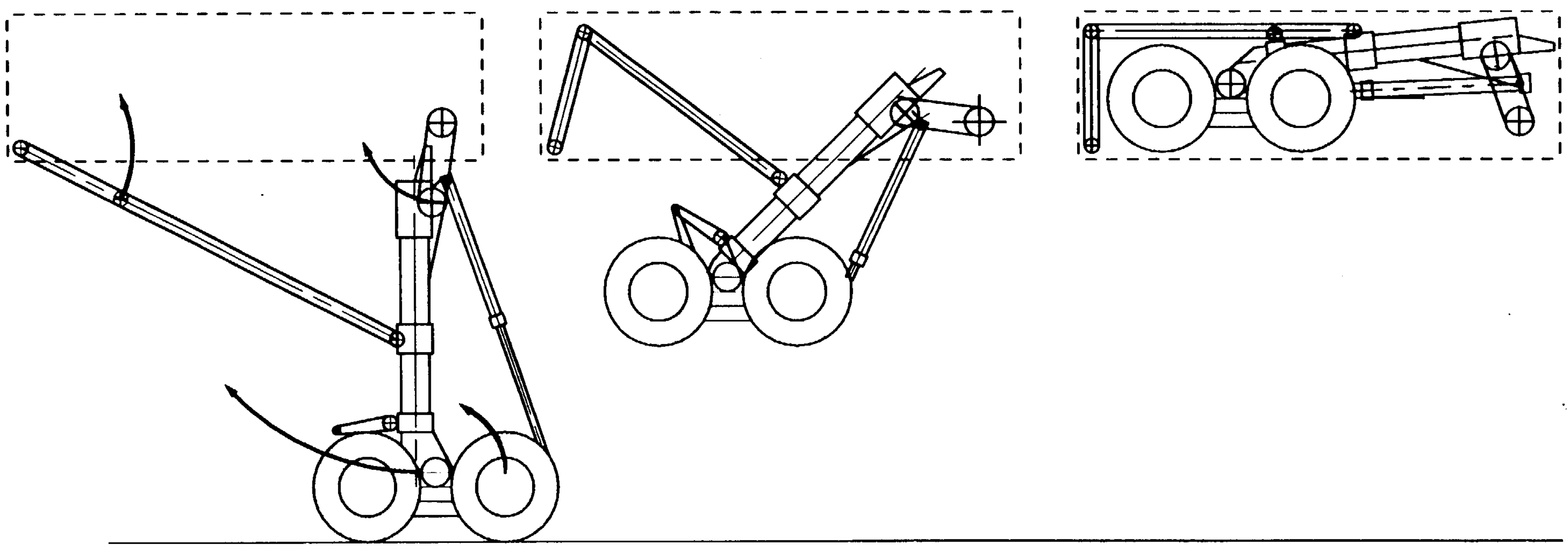


Figure 10.4: Landing Gear Retraction Sequence

11.0 MATERIALS AND STRUCTURES

This section deals with the selection of materials to be used in the construction of the Swift, as well as with the process of selecting a sound structural layout and calculating its weight. It should be pointed out that the material selection presented in this section can be improved if future research indicates the need to do so. As far as the structural layout is concerned, the guidelines followed where mostly derived from past experiences (ie Concorde, Boeing research..). A safety factor of 1.2 was used throughout the structure which allows for flexibility in the design.

11.1 Materials

Due to the high temperatures experienced during supersonic flight and the need for very light structures to make a supersonic design viable, the selected materials must have good strength to weight ratios at high temperatures. Advanced composite materials were considered, but the lack of accurate information on their performance characteristics, and the high cost of research, made the analysis of a fully composite structure impractical at this time. However, the rudder, flaps, spoilers and flaperons, outboard supersonic wing, and the cabin floor are among the sections of the aircraft for which advanced composites are deemed as the most appropriate choice.

The Tetracore/Ultraclore (TU/UC) structural design concept was selected to be used in the fabrication of all control surfaces, as well as the cabin and cargo compartment floors (Ref. 18). This composite structure makes use of the tetrahedron as its basic building block, and can be fabricated from any formable, castable, or filament windable material. Since the tetrahedron has a high surface area per unit volume its use provides a high structural efficiency. TC/UC was also selected because of its low cost (depending on material selection), its ability to absorb impact energy and withstand crash forces from all sides, and its superior resistance to high point loads. (Ref. 18). An advanced high-performance thermoplastic such as polyetherimide (PEI) is recommended as the matrix in the construction of the tail-cone and the rudder because of its resistance to high temperatures (up to 400°F), chemicals, and fuels. (Ref. 19).

For the remaining fuselage sections, titanium was deemed as the most appropriate currently available material. Its relatively high strength to weight ratio, and high temperature resistance, as well as the fact that it has already been proven in use at supersonic speeds were factors in this decision. Aluminum was not selected because of its lower temperature resistance. This decision increased the cost and weight of the aircraft. However, since aluminum could only be used for about 20 percent of the structure, due to the high temperatures over most of the aircraft, and would render weight savings below 3 percent while making it harder to integrate the airplane due to the different expansion ratios of both materials, it was decided that an all titanium structure would be more viable. Table 11.1 shows a breakdown of applied sectional loadings, material selection primary requirements, and material usual form of construction, and it gives the name of the material which was found to most closely meet those requirements.

Table 11.1: Breakdown of Ti Materials

Structural component	Principle Loading	Material form	Primary requirement	Selected material
Wing/Empennage				
skin upper lower	compression tension/ shear	extruded/ rolled plate	high comp. yield strength res. to crack	Ti-6AL-4V
ribs	shear	truss extrusions	high shear strength	Ti-6AL-4V
Spar web	shear	truss extrusions	high shear strength	Ti-6AL-4V
Spar upper cap	compressive buckling	machined extrusion	high comp yield	Ti-6Al-4V
Lower cap	tension	machined extrusion	high fatigue resistance	Ti-6AL-4V
Fuselage				
frames	bending tension	forging	fatigue	Ti-6AL-4V
longerons	compression	extrusions	tensile strength, fatigue	Ti-6AL-4V
skin	shear/ tension compression	sheet	high strength, resistance to crack growth	Ti-6AL-4V or metal matrix composite
Landing gear	compression/ shear	forging/ extrusion	fatigue	300M

Other components such as fasteners, and rivets will also be made out of titanium. While it is true that titanium is expensive, time and maintenance costs will be reduced by using an all titanium skin, and components as opposed to a hybrid. The use of all titanium will eliminate the need to use seals to prevent heat transfer to sections which can't handle heat, and it will solve the problem of dealing with different expansion ratios. The skin will be a metal matrix composite (MMC), using titanium as the principal metal, if the technology is available at lower cost than at present. The use of a MMC will save considerable weight while maintaining the high strength and temperature resistance characteristics of titanium. If the technology is not available Ti-6AL-4V will be used. Finally, the landing gear struts will be made out of 300M steel because of this materials low cost, high strength, and proven characteristics.

11.2 Structural Design Limits (V-n DIAGRAM)

The V-n diagram shown in Figure 11.1 was constructed according to current FAR regulations, and performance characteristics set forth in Reference 19. This diagram shows that the maneuver envelope sets the structural design limits for the Swift concept at cruise. In future studies it is recommended that this envelope be revised for subsonic flight. There is the possibility that the gust envelope will determine the structural design limits for this condition.

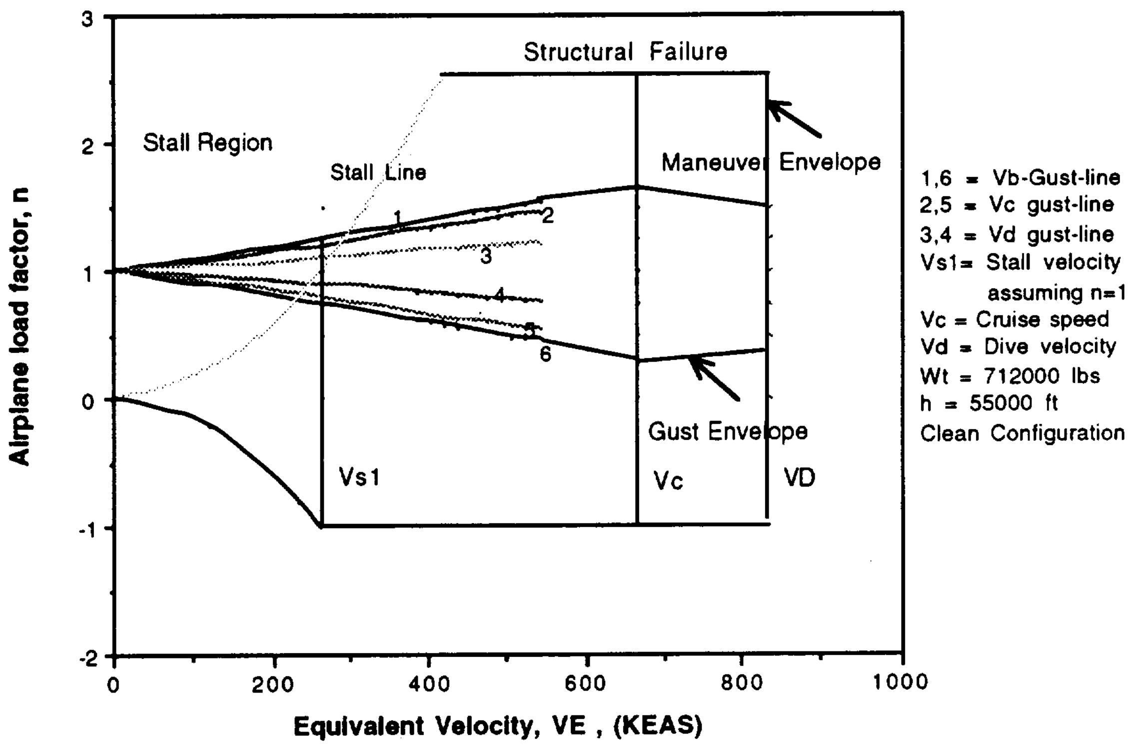


Figure 11.1: Swift's V-n Diagram

At the maximum dynamic pressure of 854 psf, the maximum level cruise flight speed, Vc, was found to be 700 KEAS. For preliminary design it was assumed that the normal force coefficient was evenly distributed along the wing. This method would yield a larger bending moment than if the lift was assumed elliptical. The shear and moment were then calculated at different locations using the method indicated in Reference 20. This method yielded a maximum moment at the root of only 18,000,000 in-lbs. Since this was considered too low for the actual requirements of this aircraft structure, the maximum structural loading due to the landing gear impact at a sinking speed of 13 ft/s was calculated, for the purpose of sizing the wing structural components.

The landing gear load factor was used to determine an inertia load factor of 2.38 acting on the airplane (Ref. 19). This number is lower than the limit set forth by the V-n diagram, but it is not difficult to correct the moment obtained to a 2.5g loading. The moment due to this load factor was significantly higher, at approximately 75,000,000 in-lbs. However, to make sizing to this loading safer this value was increased by a 1.2 safety factor.

11.3 Wing Structure

The wing of the Swift is a multiple spar design built with primarily shear material. Due to lack of other reliable information on supersonic wing structures, the Concorde's wing was used as a model in the design of the Swift's wing structure. The Concorde's spars, and rib-substitute trusses were scaled and spaced to comply with the larger size and higher stress conditions of the Swift. The spars were also sized to support the loads explained in the previous section.

The wing spars were sized to the moment due to landing times a safety factor of 1.2. Using the relation between allowable stress and moment of inertia (s_{all} = Mc/Iyy), it was found that a moment of inertia of 10,093 in^4 was required to withstand landing impact at a maximum stress allowable at the wing root of 140,000 lbs for titanium. From the moment of inertia, and making use of the parallel axis theorem, the required thickness for the I-beam modeled spar-cap was calculated as 2.5 inches. This value was used to size the caps of the spar which supports the landing gear, the spar that supports the engines (aft spar), and the first spar of the wing box. Other spars at 24' intervals were sized to 2/3 of this value, and some secondary spars, spaced to 12' were sized to a tenth of this value. In this manner, and using a density of .16 lb/in3 for Ti, a structural weight of 73,623 lbs was calculated for the wing shown below in Figure 11.2.

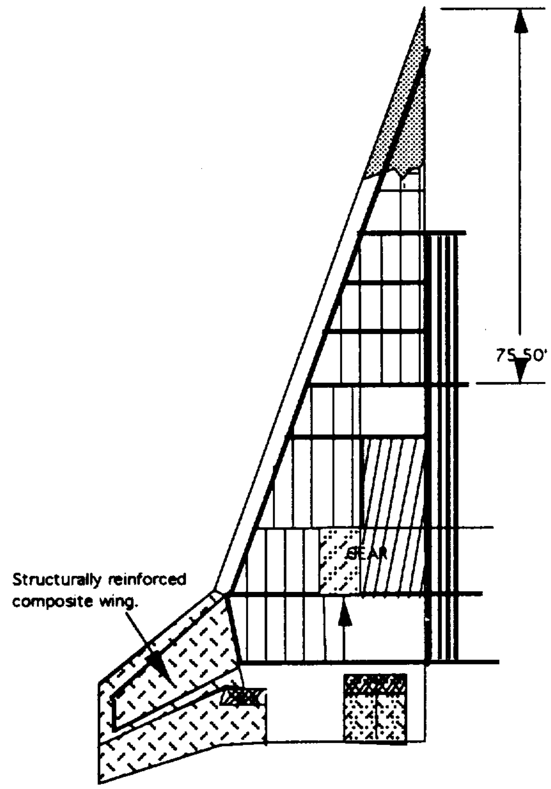


Figure 11.2: Swift Wing Structural Layout

The two primary conditions which determine the overall efficiency of a spar are its construction cost and efficiency as a load carrying member. The webs require a relatively simple cutting operation, and for the spar caps and vertical stiffeners, extrusions or bend-up sections are used (Ref. 19). This design also provides a better support for the span-wise bending material, and sloping spar caps will be used to relieve the web of considerable shear. In addition, the use of several spars permit a reduction in rib stresses. In fact, only a nominal number of ribs perpendicular to the fuselage will be included in the wing design which will consist mainly of spar-like trusses. The ribs will help maintain the contour of the wing in the chord direction, and will act as "fuel slosh inhibitors" (Ref. 19). The average thickness of the ribs is 0.03 inches titanium and have lightening holes which also allow the free flow of fuel within the fuel cell. Finally, because the upper surface of the wing supports higher compression than the lower surface, stiffening elements in the upper surface are larger, and more closely spaced than stiffeners in the lower surface.

11.4 Fuselage

The fuselage structural layout can best be described as conventional. The fuselage frames, ribs and longeron spacings and placement follow the guidelines set by current subsonic aircraft. Since a supersonic aircraft will be exposed to higher torsional forces a safety factor of 1.2 was applied throughout the layout. A safety factor of 1.5 was used for frames adjacent to cutouts (ie doors, first and business class windows...).

11.4.1 Frames and Bulkheads

The fuselage structure was laid out using the basic method outlined in Reference 21. The longerons were spaced at 10 inches, the frames were spaced every 22 inches, the maximum frame spacing specified in Reference 21. The frames depth were calculated at each station using the following equation:

$$\text{Frame depth} = .02df + 1 \text{ inches} \qquad \text{(Eq 11.4.1)}$$

Since the torsional forces at supersonic speeds are higher than those at subsonic speeds, it was decided to multiply the frame depth calculated with Equation 11.4.1 by a safety factor 1.2. To further increase safety a 1.5 safety factor was used to thicken the frames located were cutouts were effected. The result of this was an additional 8 percent of frame weight in each frame were the "thickening" was applied, but the overall weight increase provided the necessary safety factor for this structure.

Since fuel is going to be located in the tail-cone as well as in the wing, it was necessary to build a containment vessel in this section. The weight increase due to this extra-vessel is negligible as the structures in this section are thick enough to support the fuel vessel without additional "thickening". Finally, a skin thickness ranging from .03 to .11 inches was calculated for the different fuselage sections, by assuming a thin walled pressure vessel. The two bulkheads in the airplane were assumed to be as thick as the average skin thickness of the fuselage (.06 inches). The average skin thickness was used to calculate the weight of the fuselage.

11.4.2 Empennage and Vertical Tail

The empennage and vertical tail were assumed to support lighter loads than the wing. However, the spars on these surfaces were designed at the

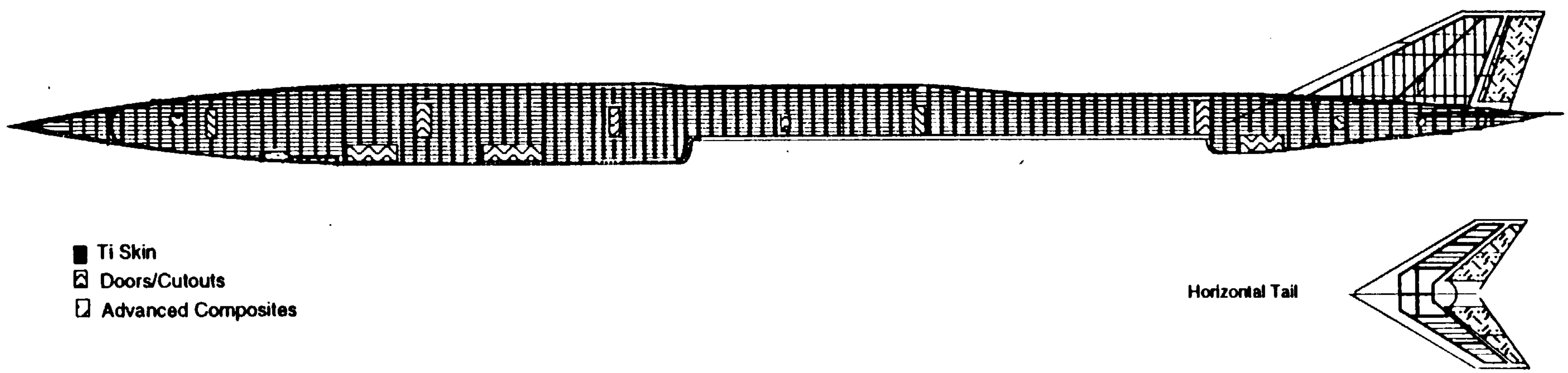


Figure 11.3: Swift's Structural Diagram of the Fuselage

same width as those of the wing to ensure safety. Figure 11.3 includes a side-view of the structural layout of the vertical tail, and a top view of the structures of the horizontal tail. The control surfaces of both the empennage and the horizontal tail are composites, as explained earlier, and they are all supported internally by spar structures to prevent the composite material from cracking under the high loads.

11.5 Fail-safe design

A fail-safe structure must not fail when a shear beam is damaged for any reason. Multiple beam construction for the wing has the advantage of supplying alternate load paths for tension in case any single beam web should fail. It was decided to thicken the web at the attachment of the spar cap as a fail-safe method. This decision will effectively increase the volume of the caps, and will add weight to the aircraft, but the safety advantages it provides were deemed more important.

11.6 Manufacturing Breakdown

The Swift is constructed of a hybrid of advanced materials. Titanium is the primary material that is utilized with limited amounts of High Temperature Polymeric Composites for control surfaces and outboard wing panels. This represents a tooling challenge that must be addressed because current technology for affordable high output production with extensive use of Titanium does not exist. It is proposed that the composite materials, because of their relatively small size, can be manufactured out of house by a specialized manufacturer which would reduce the overhead costs, by preventing the manufacturer from investing in new facilities. These parts could then be shipped to the final assembly line and integrated into the aircraft.

11.7 Product Assembly

The proposed assembly breakdown is illustrated in Figure 11.4. The primary components are control surfaces, inboard wing section, outboard wing section, empennage, engine group, and fuselage barrels. The center section of the aircraft will be completed first allowing easy installation access to the major systems. Wing-fuselage integration will then take place followed by empennage installation and then finally the engines will be installed.

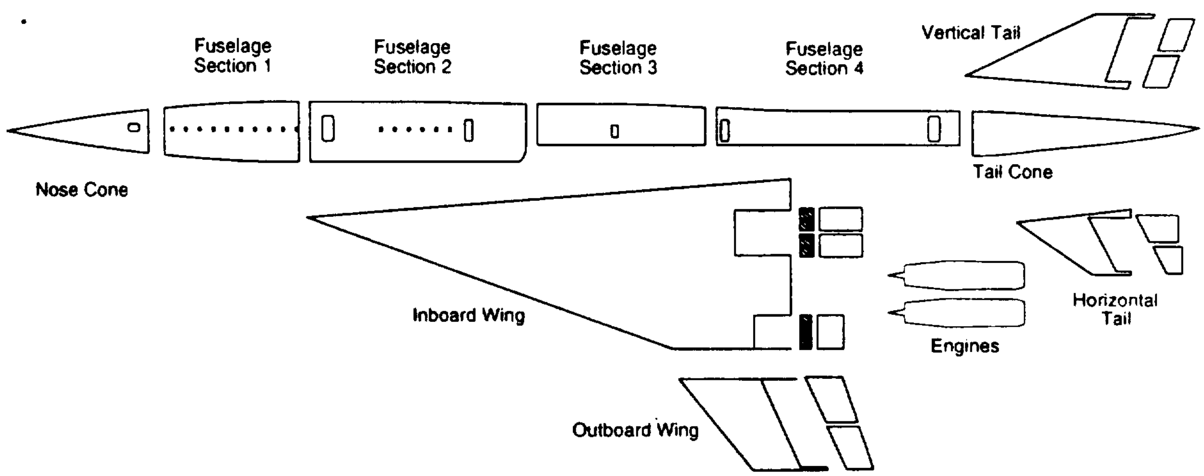


Figure 11.4: Swift Assembly Breakdown

12.0 WEIGHT AND BALANCE

The component weights were estimated by empirical methods outlined by References 14 and 22. Since the majority of empirical data used for this analysis is for aircraft that are primarily constructed of aluminum, and modern materials have higher strength to weight ratios, the weights were scaled down to reflect modern material use. These weight estimations are based upon the maximum take-off weight calculated in the preliminary sizing. The propulsion weights were based upon engine design and scaled for the required thrust Reference 14. The payload was estimated using a 175 lb passenger (95 percentile) with 35 lbs baggage. A listing of the estimated airframe, propulsion, aircraft equipment, and payload weights are listed in TABLES 12.1, 12.2, 12.3, and 12.4 respectively. All C.G. locations are with respect to the nose of the aircraft.

Table 12.1 Airframe Component Weight and C.G. Locations

Component	Weight (lbs)	Location (in.)
Wing	76359	2323
Horizontal Tail	5011	3446
Vertical Tail	6117	3355
Fuselage	76934	1856
Main Landing Gear	40515	2342
Nose Gear	3402	771

Table 12.2 Propulsion Component Weight and C.G. Locations

Component	Weight (lbs)	Location (in.)
Engine Group	40515	2612
Nacelle Group	15000	2612
Fuel Systems	3762	2612

Table 12.3 Aircraft Equipment Weight and C.G. Locations.

Component	Weight (lbs)	Location (in.)
Flight Controls	7979	2844
APU	1000	3342
Instruments	840	266
Hydraulics	5400	2668
Electrical	4753	2316
Avionics	2200	256
Furnishings	18051	1936
Air Conditioning	4854	2700
Anti-Ice	340	2400

Table 12.4 Payload Weight and C.G. Location

Component		Weight (lbs)	Location (in.)
Fuel	Trim Tank #1	17800	2760
	Trim Tank #2	78960	2964
	Main Tank Group	241452	2147
Crew	Flight Deck	410	342
	Cabin Attendants	410	413
	Cabin Attendants	410	931
	Cabin Attendants	410	1394
	Cabin Attendants	410	1484
	Cabin Attendants	410	2063
	Cabin Attendants	410	2718
Payload	Passengers	43750	1888
	Luggage	8750	1176

12.1 C.G. Excursion

The C.G. excursion for several possible operating configurations, including partial loading and partial fuel, was calculated. The configuration that resulted in the greatest excursion is the fully loaded case and is presented in Figure 12.1. The C.G. excursion is most sensitive to fuel placement and consumption. In order to maintain a favorable static margin throughout the flight, fuel is stored in the fuselage aft of the passenger compartment. The aircraft will necessarily require a fuel management system that ensures that the fuel is progressively consumed from the most forward tanks to the most aft tanks. This will keep the C.G. aft so it will tend to follow the aerodynamic shift associated with supersonic flight regimes. With a fuel management system the aircraft will operate with an excursion of 8 percent of the mean aerodynamic cord with the most aft C.G. of 191 feet at cruise climb and the most forward C.G. of 183 feet at landing.

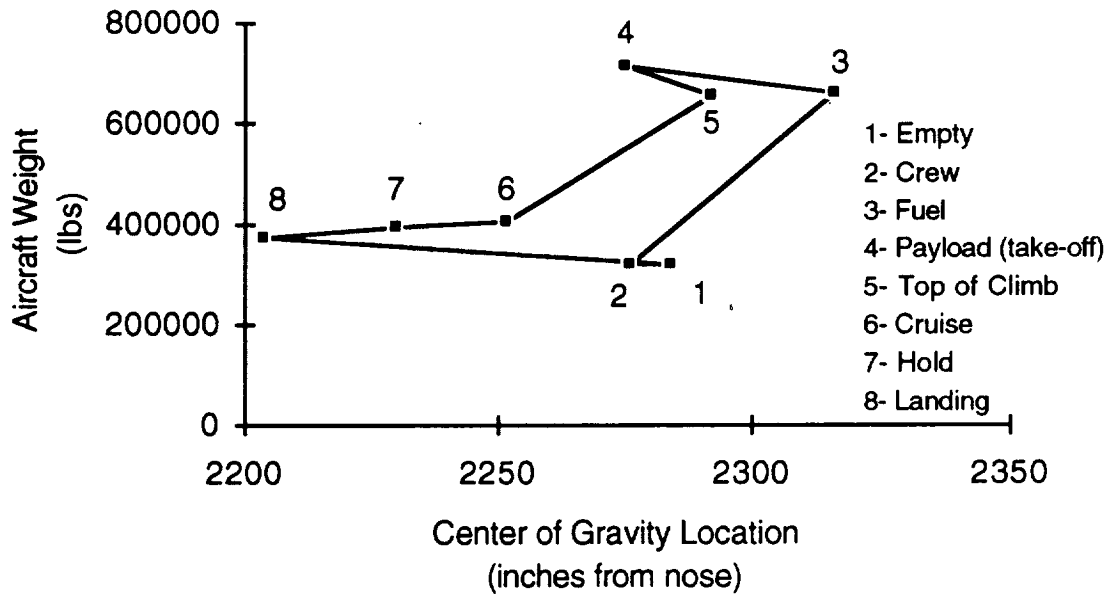


Figure 12.1: C.G. Excursion Plot for the Swift

12.2 Moments of Inertia

A preliminary calculation of the moments of inertia were conducted using weight and balance information and simulating components with simple geometries. The results are listed in Table 12.5.

Table 12.5: Moment of Inertia for the Swift

MOMENT OF INERTIA	Ixx	Iyy	Izz
Fully Loaded	2.50E+7	5.37E+7	7.02E+7

13.0 STABILITY AND CONTROL

The stability of the Swift was analyzed at three different flight conditions shown in Table 13.1, namely take-off, subsonic cruise, and supersonic cruise. These flight conditions will be referred to as Case I, II, and III, respectively, for the remainder of this discussion. At take-off and landing, the flaps and landing gear were extended. As stated in the Performance section, these conditions were chosen because it was felt that these were the most critical conditions during flight.

Table 13.1: Flight Conditions for Stability and Control Analysis

	Case I	Case II	Case III
Phase	Take-off /Landing	Subsonic Cruise	Supersonic Cruise
Mach Number	0.385	0.8	2.5
Altitude (ft)	5,000	35,000	55,000
Configuration	$\delta f = 24°/28°$, gear down	clean	clean

Semi-empirical methods were used to calculate the stability derivatives (Ref. 6, 22). All of the derivatives assume a rigid airplane in steady flight. Table 13.2 lists the calculated longitudinal and lateral derivatives of the Swift for each of the three cases. Since the flaps and the landing gear are extended only at take-off and landing, the effects of the flaps and the landing gear were only calculated for Case I.

Table 13.2: Stability Derivatives for the Swift

Derivative	Case I	Case II	Case III
$C_{L\alpha}$ (rad^{-1})	1.960	1.883	1.799
$C_{M\alpha}$ (rad^{-1})	0.176	0.075	0.038
C_{Lih} (rad^{-1})	0.151	0.174	0.128
C_{Mih} (rad^{-1})	-0.158	-0.171	-0.126
$C_{L\delta e}$ (rad^{-1})	0.0218	0.0279	0.0056
$C_{M\delta e}$ (rad^{-1})	-0.0229	-0.0274	-0.0058
$C_{L\delta f}$ (rad^{-1})	0.607	-	-
$C_{M\delta f}$ (rad^{-1})	-0.220	-	-
$C_{D\delta f}$ (rad^{-1})	0.139	-	-
$\Delta C_{M\,p}$	0.000	-0.001	-0.001
$\Delta C_{M\,Gear}$	-0.002	-	-
$C_{l\beta}$	-0.197	-0.205	-0.151
$C_{n\beta}$	-0.392	0.234	0.109
$C_{Y\beta}$	-0.092	-0.268	-0.849
$C_{l\delta a}$	0.164	0.427	0.621
$C_{n\delta a}$	-0.209	-0.226	-0.634
$C_{Y\delta a}$	0.000	0.000	0.000
$C_{l\delta r}$	0.000	0.031	-0.051
$C_{n\delta r}$	-0.015	-0.043	0.044
$C_{Y\delta r}$	0.022	0.048	0.528

13.1 Longitudinal Stability and Control

In order to evaluate the Swift's longitudinal stability and control, the aerodynamic center (AC) had to be calculated. Using the values from Table 13.2, the AC was calculated using the methods outlined in Reference 6. Reference 6 was chosen due to its comprehensive method of analyzing complex wing planforms, such as the double-delta wing, and the method includes the effects of the fuselage and the horizontal tail.

As seen in Table 13.3, the aerodynamic center of the Swift shifts aft from 56 percent of the mean aerodynamic chord (MAC) at take-off conditions to 60 percent MAC at supersonic conditions. This correlates to a minimal shift of the aerodynamic center, 4 percent of the MAC, which is characteristic of the double-delta planform.

Table 13.3 Static Stability Information for the Swift

	Case I	Case II	Case III
Aerodynamic Center	56% MAC	57% MAC	60% MAC
Static Margin	2% take-off 9% landing	4%	5% begin cruise 2% end cruise

In order to reduce trim drag, the Swift was designed to operate near neutral stability. Table 13.3 shows the static margin for the three cases. At take-off the static margin is at 2 percent positive stability. As the mission of the Swift progressed, the airplane became increasingly stable until the beginning of cruise where the static margin reaches a 5 percent static margin. This trend of increasing static margin is due to the aft movement of the aerodynamic center from subsonic to supersonic conditions. At the end of the supersonic cruise, the fuel can be shifted aft to obtain a static margin of 2 percent. At landing, even though the AC moves forward, the most forward CG occurs at this condition and the resulting static margin in 9 percent.

As stated in the Weight and Balance section, since the fuel comprises almost fifty percent of the total take-off weight, the CG is highly sensitive to the location of the fuel. Initially the fuel was placed in the forward fuselage and the wing but this resulted in a very large positive static margin. In a effort to obtain neutral stability, fuel placement was shifted as far aft as possible, which resulted in fuel placement in the tail cone. A fuel management system is also used to keep the CG aft so it will follow the AC shift associated with supersonic flight regimes in order to minimize the level of stability.

The sizing and placement of the horizontal stabilizer was critical to the stability and control due to its effect on the location of the aerodynamic center and its effective control power. Studying the effects of various sizes and placements of the horizontal tail is an iterative process due to the different trade-offs involved. As the area of the horizontal tail was increased, the tail alone was able to carry a larger load, but the aerodynamic center of the aircraft moved aft and shortened the moment arm to the tail and thus decreased the effectiveness of the horizontal tail.

In order to determine the effectiveness of the control surfaces, trim diagrams were evaluated at take-off and cruise. The control surfaces were sized to take-off since it produced the largest moment on the aircraft due to the deployment of the flaps and the landing gear. The Swift selected the planform and placement that produced enough control effectiveness for take-off rotation.

Elevator trim angles were computed for take-off. Figure 13.1 shows that -18 degrees of elevator deflection (δ_e) will trim the aircraft at its most critical condition. This configuration allows the aircraft to rotate with a lift coefficient of 0.63, a flap deflection (δ_f) of 24°, and the landing gear fully extended. During supersonic cruise, the aircraft can be set to trim with the horizontal stabilizer with as little as 2 degrees.

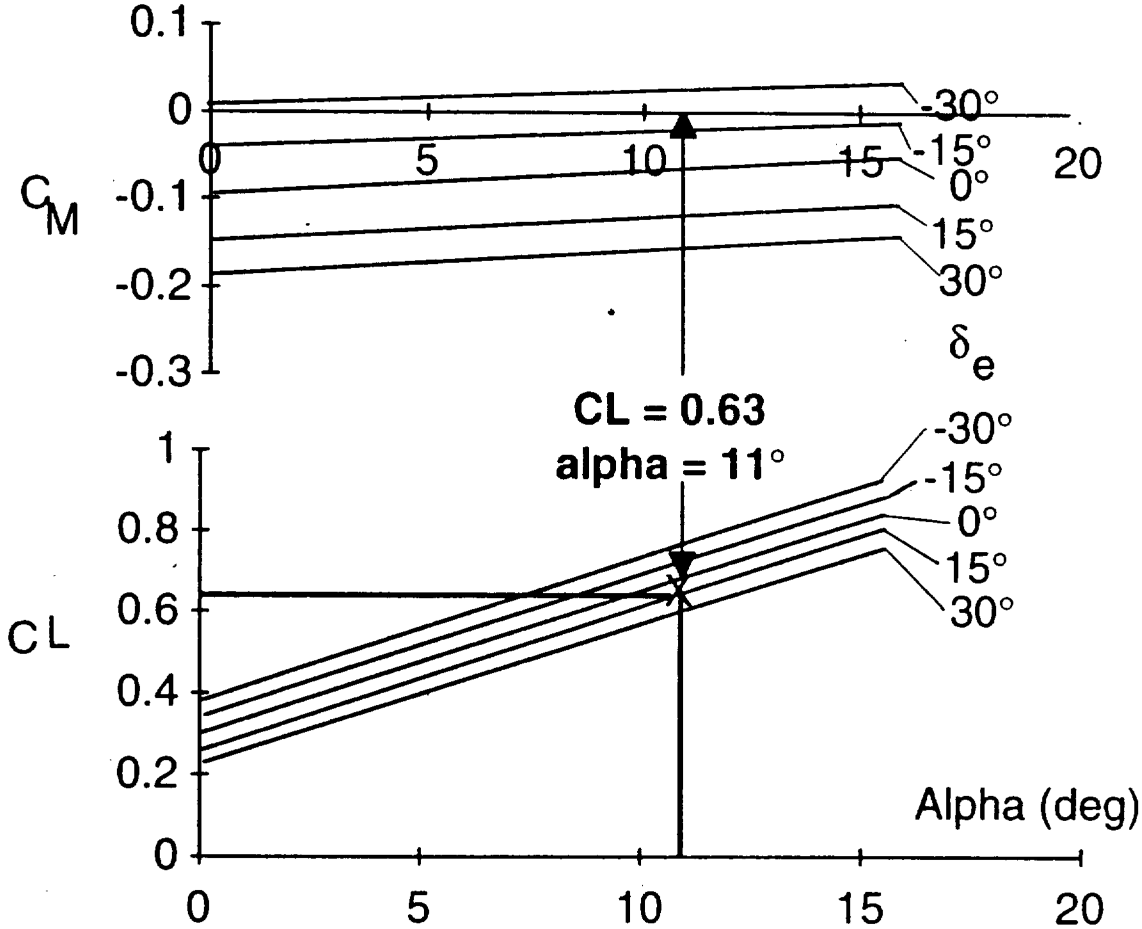


Figure 13.1: Take-off Trim Diagram for the Swift, δ_f=24°

The Swift control surface areas used in control analysis are shown below in Table 13.4.

Table 13.4: Control Surface Size

Rudder Area, S_r (ft^2)	111
Elevator Area, S_e (ft^2)	219
Flap Area, S_f (ft^2)	410
Spoiler Area, S_s (ft^2)	170
Flapperons, S_a (ft^2)	420

13.2 Lateral Stability and Control

The Swift's lateral stability was designed to comply with two major constraints. These constraints are a positive lateral static stability margin, $C_{n\beta}$, of 0.001, and engine out in the worst possible case which was determined to be take off. Since the aircraft will not require a high maneuverability, a positive lateral static was desired. This added stability has no impact on cruise performance and efficiency. The criteria that dictated the tail size was the desired positive static stability margin. Figure 13.2 is a plot of C_{nb} versus vertical tail area. This value was used to determine the stability derivatives and generated the necessary control deflections to counter the moments associated with the second criteria, namely take-off engine failure. This analysis indicated that the required rudder deflection for this condition was 14 degrees. The aileron deflection was determined to be five degrees while the side slip angle was determined to be only four degrees (appendix lateral stability and control). These deflections are well within the maximum allowable deflections as depicted in Reference 8. With these results it was then concluded that the optimum tail size is 430 square feet.

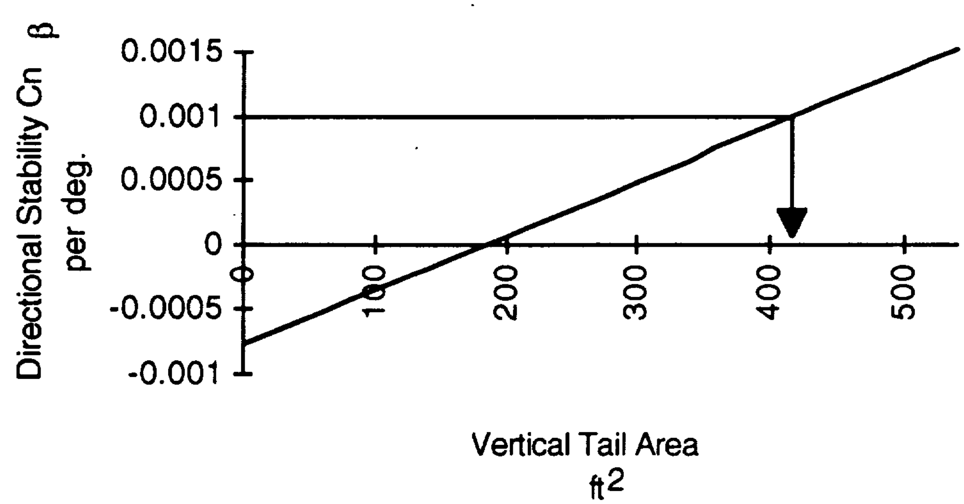


Figure 13.2: Swift Directional X-Plot

14.0 SYSTEM LAYOUT

Most of the systems presented below were derived from current subsonic transport aircraft systems and should not be taken to be the most effective or as the final selection. Further research on supersonic systems is needed.

14.1 Auxiliary Power Unit

The Swift auxiliary power unit (APU) is a gas turbine power unit with a 90 KVA ac generator and an integral air compressor installed in the lower fuselage afterbody . Figure 14.1 illustrates the location and placement of the APU on the Swift (Ref. 23). The APU is self-contained except for the battery located in the heated aft compartment, the fuel supplied from the aircraft system, and the controls and indicators required for APU operation. The APU contains a fire detection, warning, and extinguishing system.

The APU provides all necessary power for ground checkout and operation of the hydraulic, electrical, flight control, and environmental control systems. During flight the APU serves as a redundant system.

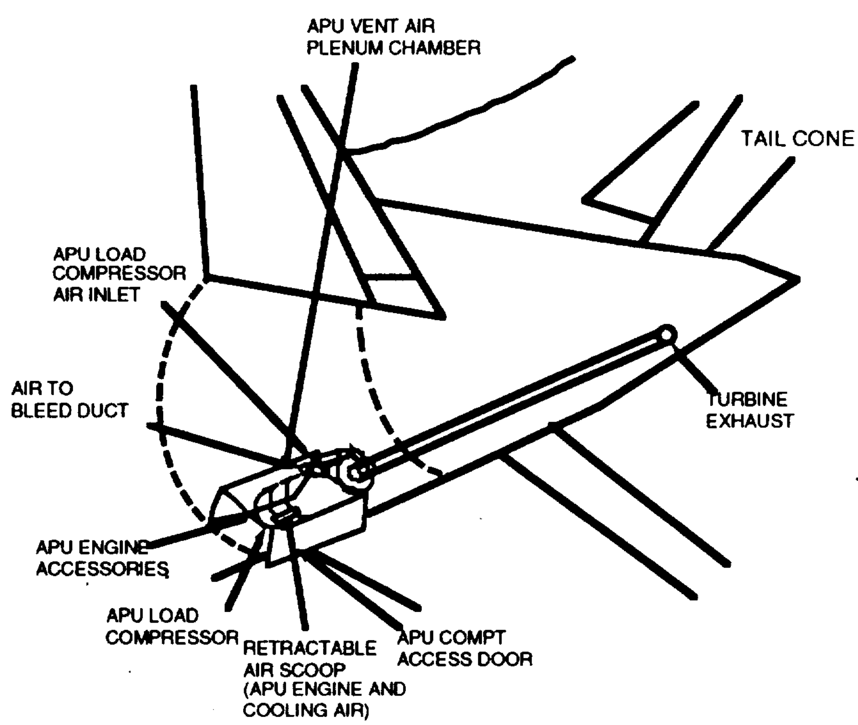


Figure 14.1: Swift Auxiliary Power Unit (APU)

14.2 Hydraulic System

The Swift contains four independent hydraulic systems. The system distribution is shown in Figure 14.2 (Ref. 2). Current hydraulic systems operate with 3,000 psia, however, future systems are projected to run at 8,000 psia (Ref. 24). The Swift hydraulic (with a pressure of 8,000 psia) has one engine driven pump, and one pneumatically driven pump. The pneumatically driven pumps supplement or substitute for engine driven pumps, as needed. The reservoir in each system is pressurized by engine bleed air via a pressure regulation module (Ref. 23). This system provides hydraulic pressure for the actuator of the fully-powered flight control system, the landing gear and brake functions, and the nose wheel steering. The system, based on four independent systems, is arranged to provide redundancy and full hydraulic capability if any hydraulic component failed.

14.3 Electrical System

The electrical system design for the Swift is a modified version of the McDonnell Douglas DC-10 electrical system and is illustrated in Figure 14.3 (Ref. 24). Normal electric power for the Swift is produced by five air-cooled 90 kVA, 400 Hz, ac generators and is distributed to all aircraft systems by an electrical load center. One generator is installed on each main engine. Frequency control for the fifth generator, installed on the APU, is provided by automatic close-tolerance regulation of the APU speed.

Power from each main engine generator is routed to an individual ac main bus in the load center. For normal operation, the main bus is connected in parallel by a tie bus which is also connected to the APU generator and to an external connector for ground power supply. Two ac emergency buses normally connected to ac main bus No. 1 and No. 4 are automatically switched to another ac main bus if the No. 1 or No. 4 system fails. Five transformer-rectifiers provide dc power to the dc main buses and the dc emergency buses.

A 24-volt battery connected to the dc emergency buses , as in the Boeing 747-400 (Ref. 25), provides enough power to operate flight-emergency ac and dc equipment for in-flight backup if all ac generators fail. A static inverter supplied by the dc emergency bus provides power to the ac emergency buses.

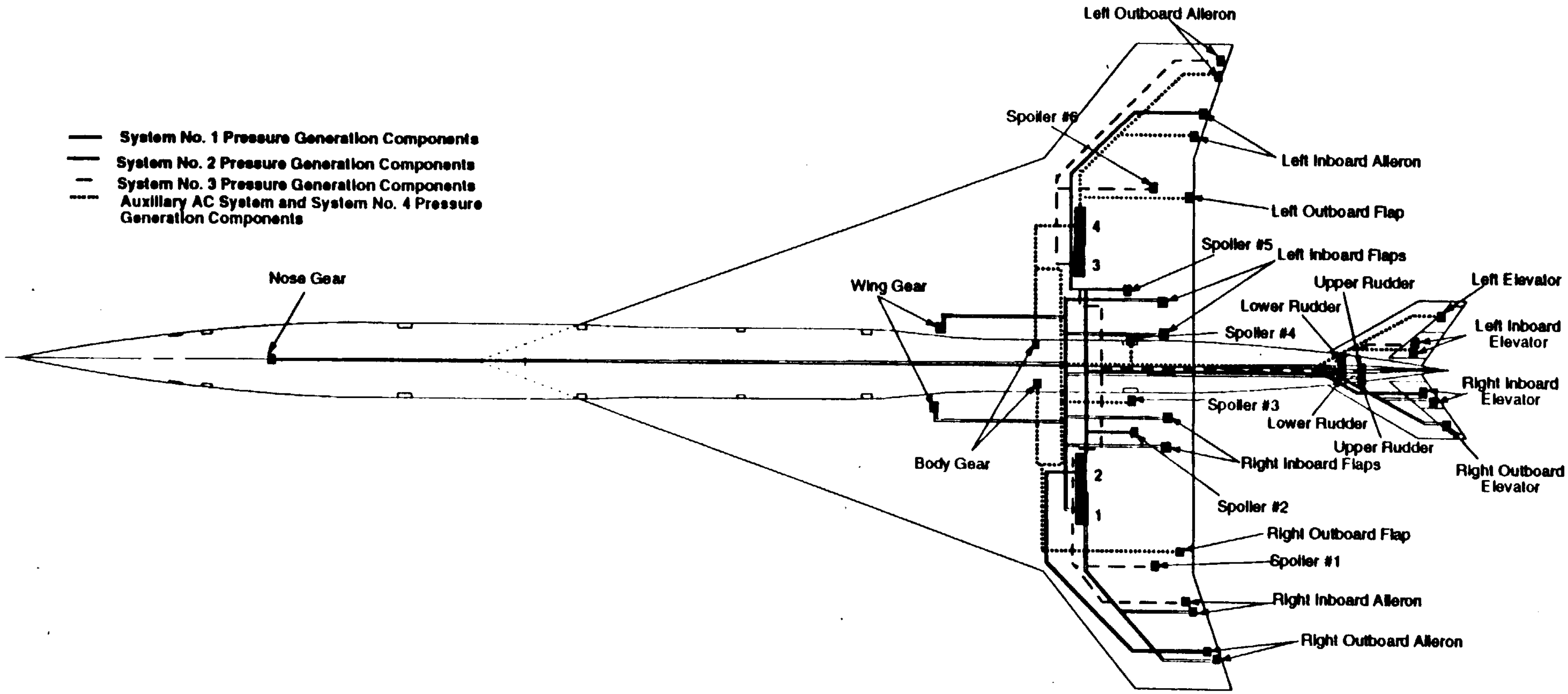


Figure 14.2: Swift Hydraulic System Layout

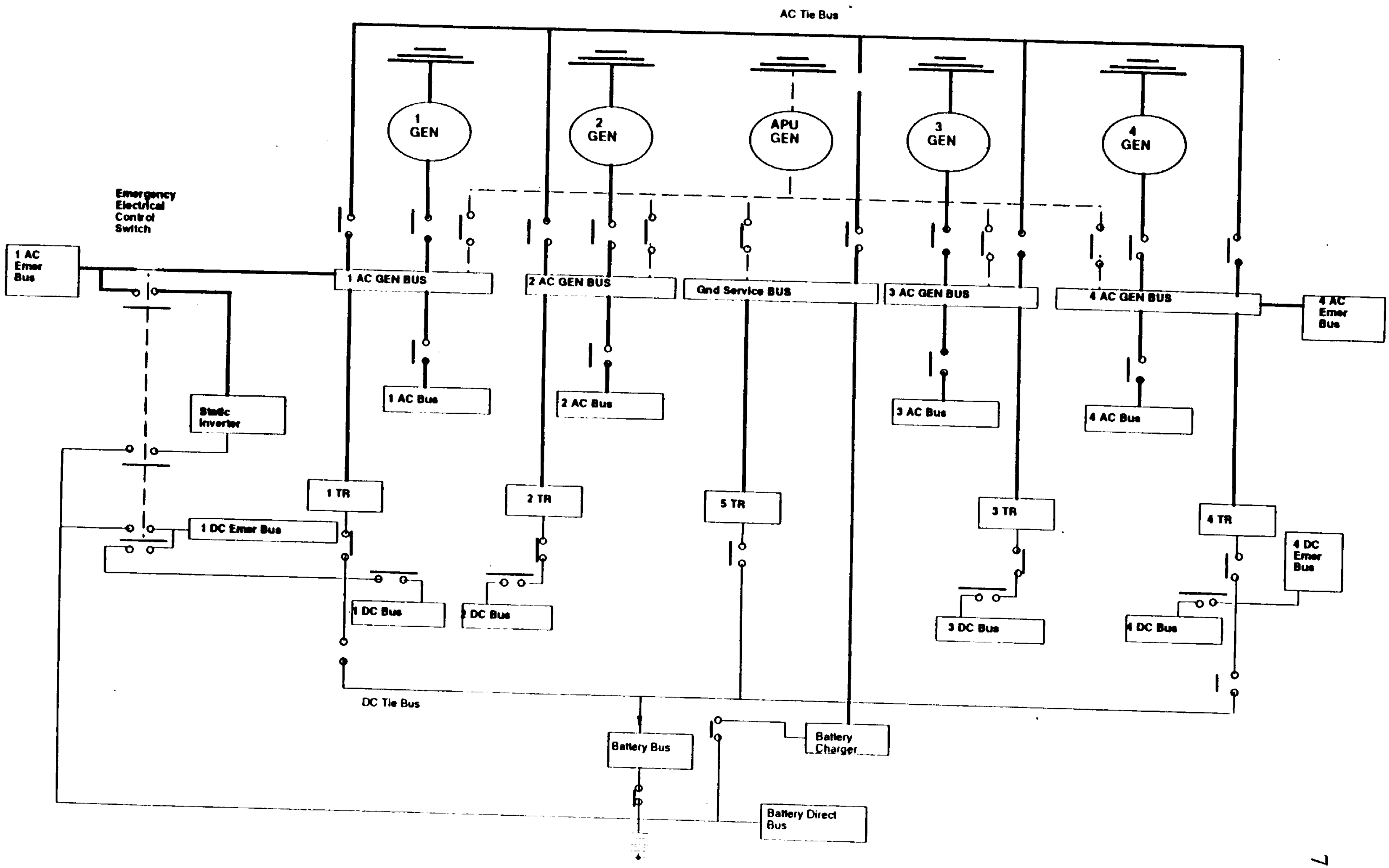


Figure 14.3: Swift Electrical Power System

14.4 Integrated Pneumatic System

The Swift integrated pneumatic system is similar to the McDonnell Douglas DC-10, as seen in Figure 14.4 (Ref. 24). It includes the environmental control system, and incorporates ducts, valves, and control devices which enable system pressurization and airflow from one, all, or any combination of the following sources (Ref. 23):

1. Main engine bleeds.
2. APU compressor discharge - capable of supplying airflow sufficient to maintain full ECS (Environmental Control System) operational capability.
3. Ground sources - the system can accept either hot or conditional air from the ground sources.

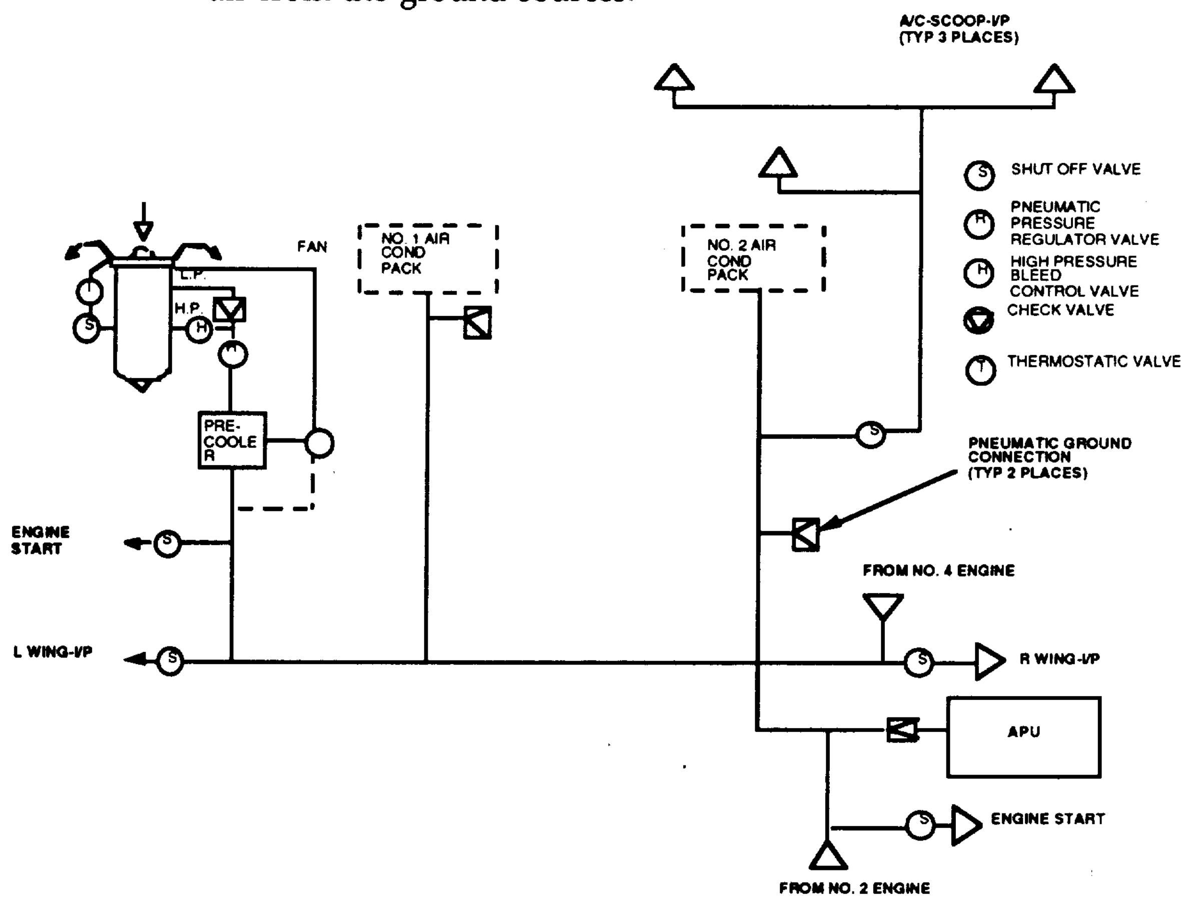


Figure 14.4: Swift Integrated Pneumatic System

Other valves and control devices permit utilization of system airflows for either one, all, or any combination of the following functions (Ref. 23).

1. Main engine starting - system permits starting any engine by either of the other engines, APU, or ground sources.
2. Environmental control system (ECS) primary supply for air-conditioning and pressurization - ram airflow is used for refrigeration package heat exchanger airflow.
3. Hot air distribution system supply for wall heating.
4. Engine inlet and cowl lip anti-icing.
5. Galley, lavatory, baggage compartment, electronics compartments, and engine compartments ventilation ejectors supply.
6. Aft and mid cargo compartment heating.

The pressurization system of the Swift, as seen in Figure 14.5 is similar to Boeing 767 mechanisms, has a positive pressure relief for a pressure differential larger than 9-10 psi and a negative pressure relief set for a pressure differential corresponding to about 10 inches of water (Ref. 24).

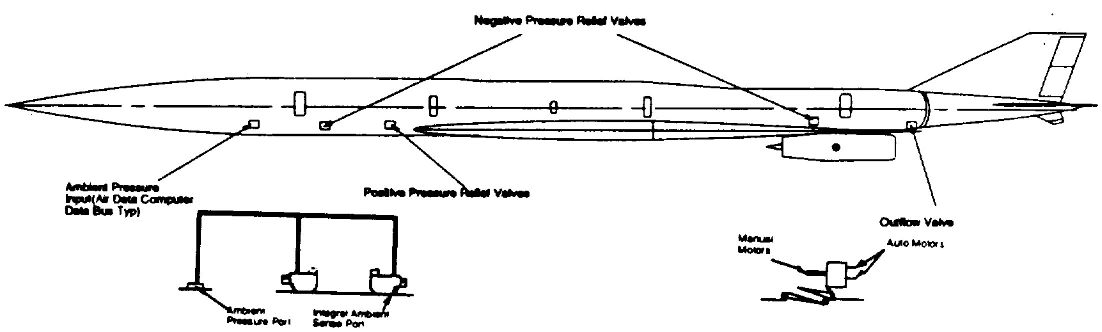


Figure 14.5: Swift Pressurization System

An emergency oxygen system is installed in the event of cabin pressurization failure. Gaseous and chemical oxygen will be available for the flight crew and passengers, respectively (Ref. 24).

Two air cycle refrigeration packages located in the tail, outside the pressure vessel, are used for the Swift. Any single unit is capable of maintaining aircraft internal temperatures at a comfortable level of 20 cubic feet per passenger (Ref. 24). Outputs of the units provide heating and cooling through a hot air manifold and a cold air plenum with distribution ducts and outlets arranged for optimum temperature and airflow distribution (Ref. 23). Cabin exhaust provides cooling for the electronics compartments and assists in heating the cargo compartments. The hot air distribution system provides cabin wall heating.

14.5 Fuel Systems

The required fuel volume was calculated using a numerical integration method (Ref. 10). The structural arrangement, gear volume, and engine blade containment regions were excluded in the integration. A 2.0 inch skin thickness was used (for skin, insulation, and unusable regions) when determining the fuel volume. The outboard wing panels are not used for fuel storage because of their volume inefficiencies and lightning strike considerations. The total fuel volume that can be contained in the wing with the above constraints is 6,850 cubic feet (358,700 pounds). The fuel cell locations are illustrated in Figure 14.6.

Since the Swift's fuel fraction is on the order of 50 percent of the maximum take-off weight, and the center of gravity (C.G.) is highly sensitive to fuel location, a fuel management system was required. An analysis of C.G. excursion indicates that the C.G. moves forward with fuel consumption making the aircraft more stable (section 12). It is desirable to operate with minimum positive stability during cruise, therefore, systematic fuel consumption is required. Although the wing is capable of capacitating all the fuel, fuselage tanks in the aft section are used to trim the aircraft for cruise conditions. The six main fuel cells in the wing store 71 percent of the total fuel volume, while two fuel cells located aft of the rear pressure bulkhead store the remaining 29 percent Figure 14.6. The fuel management system is designed to burn the fuel from the most forward fuel cells and progressively consume fuel towards the tail. The system keeps the aircraft's C.G. moving aft with fuel consumption and tends to follow the aerodynamic center shift associated with subsonic to supersonic regimes. This eliminates the need to move fuel from cell to cell thus decreasing the complexity of the system and eliminating the need for large heavy transfer pumps. Furthermore in straight and level flight the aft fuel tanks are located 7 feet above the wing tanks allowing a gravitational assist in fuel transfer to the propulsion platform. The aircraft remains within ground operation C.G. limits with any fuel placement configuration.

The Swift is designed to fly at altitudes in excess of 50,000 feet. In order to avoid fuel pump cavitation due to the reduced atmospheric pressures, the fuel cells are pressurized. The system uses compressed air ducted from the engines.

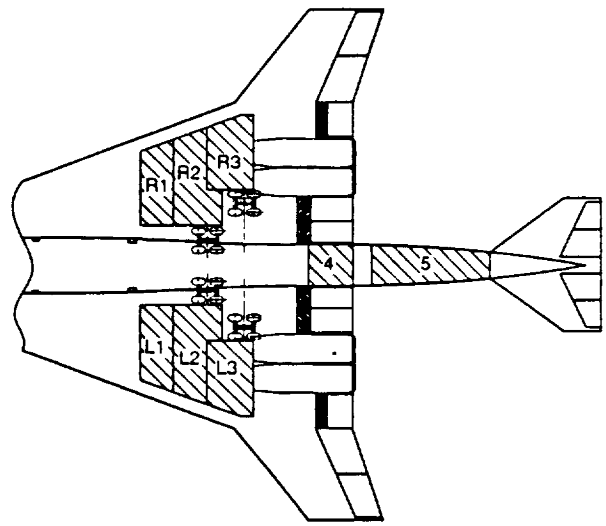


Figure 14.6: Fuel Location

In the case of an emergency during take-off when the aircraft is fully loaded, a fuel dump apparatus was designed so the aircraft can land at a safe weight. The dump apparatus samples the fuel levels and works in parallel with the flight computer to purge fuel from the appropriate tanks to maintain favorable longitudinal stability. The fuel is ducted through the belly aft of the rear pressure bulkhead.

14.6 Fire Protection System

The Swift fire protection system includes the means for fire or overtemperature detection, warning, and control in fire-hazard zones; the four main engines and the APU. Some features for fire protection incorporated in the design are:

1. The engines are installed with efficient fire walls to isolate fire zones from aircraft structure; the APU is installed in a closed fireproof compartment.
2. As much use as possible of fireproof and fire-resistant materials in fire zones will be made.
3. Combustibles are separated from ignition sources.
4. Fuel and hydraulic lines and bleed air ducts are fitted with fire wall shutoff valves.

Temperature-sensitive detection elements with sensors detect compartment overtemperature conditions resulting from actual fire or other causes (Ref. 23).

Pressure cannisters containing an extinguishing agent are located adjacent to the fire zones. Also, are two pre-pressurized bottles per engine and one larger bottle for the APU are included.

14.7 Anti-Icing System

The Swift contains thermal anti-icing systems. Air heated anti-icing systems employ hot air to heat surfaces where ice would otherwise form. Engine bleed air provided by the pneumatic supply system is used to prevent ice buildup on the engine inlet cowl. Hot air is taken from the pneumatic supply duct in the fixed leading edge and flows through an anti-icing pressure regulator and shutoff valve. The regulator is monitored by high- and low-pressures switches. The wing anti-icing air then flows to a spray tube inside the cowl lip. Small holes in the spray tube control the amount of hot air delivered.

14.8 Water and Waste System

For the Swift passengers, 74 US gallons of potable water based on a 0.3 gallons per passenger ratio (Ref. 24) are pressurized with air from the pneumatic system. Warm water is supplied by running cold water through an electrically heated heat exchanger. The Swift contains waste tanks and flushing units that mix the waste with chemicals in the flushing liquid (Ref. 24). Servicing will be done by lavatory and potable water trucks through the aft service door.

14.9 Avionics System

Electron/avionics is considered to be the discipline integrator which will permit us to fully realize the anticipated benefits of advances in aerodynamics, structures, and propulsion (Ref. 26). The Swift will have an all fly-by-wire flight control system, and a flight management system which integrates, optimizes, and controls the airframe-propulsion functions including active controls for load alleviation and airplane relaxed static stability to reduce trim drag.

Fly-by-wire systems, aside from proving their reliability, weigh less than standard, previously used mechanical flight control systems. Electrohydrostatic actuators are used for all control surfaces because they also reduce the weight and cost of the control system by eliminating a voluminous hydraulic system. Each electrohydrostatic actuators has its own hydraulic reservoir, eliminating the threat of any main hydraulic lines being damaged, resulting in the total loss of control. They also provide easy maintenance and repair and are compatible with next generation optical flight control systems (Ref. 27). Some of the more sensitive avionic equipment found in supersonic aircraft are the fuel management system and the two dual/dual autopilot system. Because stability is harder to control in a supersonic aircraft, the fuel management system is used to control the C.G. location. Therefore, autopilots need to be more reliable. For global positioning the Swift will incorporate a satellite (or global) communications system (Ref. 27).

14.10 Flight Deck

Because the Swift will have no front windscreens, only side windows, it will be equipped with the latest in glass cockpit technology available by the year 2000. The glass cockpit incorporates a fully integrated digital avionics system, flight management system (FMS), and synthetic vision system.

The flight deck is designed for a two-person crew and employs six 8 X 8-in integrated display unit cathode ray tubes (CRT) arranged across the front of the panel, in either T-formation or straight-formation. Figure 14.7 shows the general T-formation set-up. Such set-up is currently being used by the MD-11 and the Airbus A320. Each pilot will have a primary flight display on the outboard CRT next to a navigation display. Engine Instrument (EI) and Crew Advisory System (CAS) data will be presented on the middle two displays along with systems information and data-link messages. A fully automated digital fly-by-wire (FBW) flight control system, two dual-dual autopilots for Category 3B automatic landings, and a system that incorporates global positioning, air data and inertial reference (GPADIRS) will also be incorporated into the flight deck.

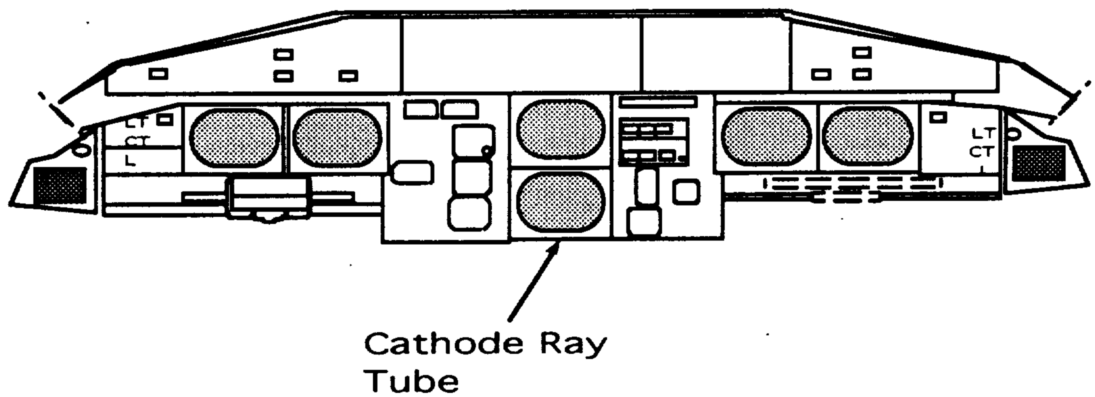


Figure 14.7: T-formation Flight Deck Panel

Even though the Swift will have a fully automated FBW flight control system, the pilots' control wheel and throttles will move in concert with aircraft control surfaces. This incorporates force-feel feedback techniques that pilots rely upon, making sure the aircraft is communicating with the pilot (Ref. 28).

The advanced flight deck design of the Swift features improved ergonomics and human-centered automation. Improved ergonomics is achieved by such features as large screen panel displays with touch-sensitive overlay, attitude and propulsion controls integrated into armrests, and improved external visibility with synthetic vision and reach accommodation. Figure 14.8 shows the general set-up of the flight deck. Human-centered automation is achieved by systems providing flight planning/replanning, take-off performance monitoring, checklist/documentation management, and synthetic vision/autonomous landing (Ref. 27).

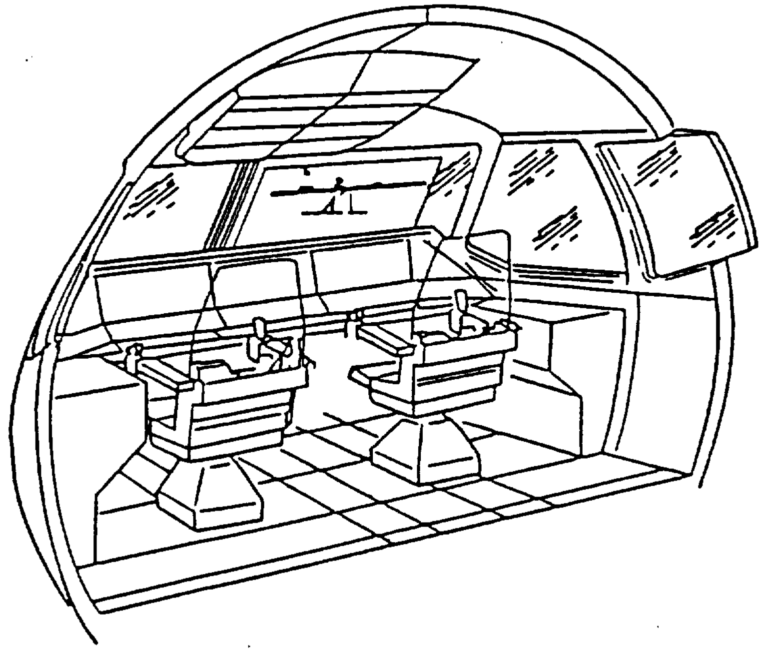


Figure 14.8: Flight Deck Set-up

Since the flight deck will have only two windows, one on each side with 30 degrees of visibility to either the front or the back, the pilots will rely entirely on life screen displays for aircraft maneuvering. The most reliable, most up to date Synthetic Vision System will be incorporated to provide the pilots with the needed visibility. Possible choices are active matrix liquid crystal displays or cathode ray tubes capable of showing live video in color without blurring. Since the cathode ray tube can show video with motion, it is the display of choice for aircraft forward looking infrared sensors (Ref. 29). As a backup for the the Synthetic Vision System a periscope will also be used.

The Swift's flight deck layout is designed to reflect the latest technology available in digital avionics system, flight management, and synthetic vision system, thus, providing improved ergonomics and human-centered automation.

15.0 AIRPORT COMPLEX REQUIREMENTS

The portions of the airport complex that must handle the Swift consist of the airport, airfield, fueling facilities, terminal area, and maintenance facilities. The Swift is compatible with most of the world's airports that already service the DC-10 and the Boeing 747 aircraft.

15.1 Airport Requirements

The best location for the Swift to operate is at an existing airport facility, located as close as possible to the center of demand. Since the key factor of high speed transport is time savings, this concept optimizes the time spent by the traveler by not wasting time traveling to special or new remote airports. To meet this requirement, the Swift was designed to be compatible with existing coastal airports.

The Swift's requirements for airport take-off, approach, and landing include performance compatible to subsonic aircraft in the following areas: approach speed, touchdown speed, take-off field length, and noise emissions. Swift compatibility to these requirements is listed in Table 15.1.

Table 15.1 Swift Airport Compatibility

Compatibility Issue	Swift	Subsonic (DC-10/Boeing 747)
Approach Speed	155 kts.	140 kts.
Touchdown Speed	150 kts.	138 kts.
TOFL	11,000 ft.	11,000 ft.
Noise Emissions	FAR 36, Stage 3	FAR 36, Stage 3

15.2 Airfield Requirements

The Swift will affect three airfield characteristics: ground maneuvering space, clearance areas and pavement strength. The Swift's overall length (300 ft.) and wheel track (37.1 ft.) will present challenges in maneuvering on existing smaller (less than 150 ft. radius fillets) taxiway-to-taxiway and runway-to-taxiway intersections. However, to accommodate large main gear tracks of the DC-10 (35 ft.) and Boeing 747 (36 ft.) and proposed large-capacity aircraft, airports have increase their pavement fillet size.

The length of the Swift also poses a problem with operations on close-parallel runways (700 ft. center-to-center). In this case, aircraft over 151 ft. long will not be able to hold on a connecting perpendicular taxiway between the two runways without restricting operations on one of the runways. Swift shares this operational delay problem with both the DC-10 (182 ft. overall length) and Boeing 747 (231 ft.).

The Swift pavement loads were designed not to exceed those of current aircraft by specification of the number of tires and their spacing. The Swift compatibility to airfield requirements is listed in Table 15.2.

Table 15.2.: Swift Airfield Compatibility

Compatibility Issue	Swift	Subsonic (DC-10/Boeing 747)
Gnd Maneuver Wheel Track	37.1 ft.	36 ft.
Clearance Area (Delay if over 151 ft.)	300 ft.	231 ft.
Pavement Loading	LCG II/LCN 76	LCG II/LCN 88

15.3 Fueling Facilities

The thermally stable jet fuel (50 degrees Fahrenheit [50°F] above the minimum jet fuel specification or TSJF+50) used by the Swift requires no special handling or contamination control. With no new storage, distribution, or dispensing facilities required, fuel costs will be nearly equal to subsonic fuel prices. Most jet fuel deliveries exceed the minimum thermal-stability requirement. Test data of actual fuel delivered to world airports shows that over 70 percent of these airports receive fuels that satisfy a stability requirement 50°F above the jet fuel specification minimum. This 50°F improvement satisfies the thermal-stability requirement for aircraft up to a Mach 2.8 cruise velocity (Ref. 2).

15.4 Terminal Compatibility

Most major terminal gate parking areas were developed to handle aircraft that are no longer than 231 ft. in length with door sill heights up to 17.6 ft. By using angled parking, terminal gate facilities will not have to undergo changes to accommodate the Swift's 300 ft. length or 17.6 ft door sill height.

The procedure of angled parking takes advantage of the fact that the Swift can fit into the same terminal area as a Boeing 747-400 if it can fit within the 747's diagonal dimension of 310 ft. The Swift will have to be angled parked, as illustrated in Figure 15.1, at existing gate areas. Angle parking does not require additional terminal frontage beyond that required for a Boeing 747-400 because the wing span of the Swift is relatively small.

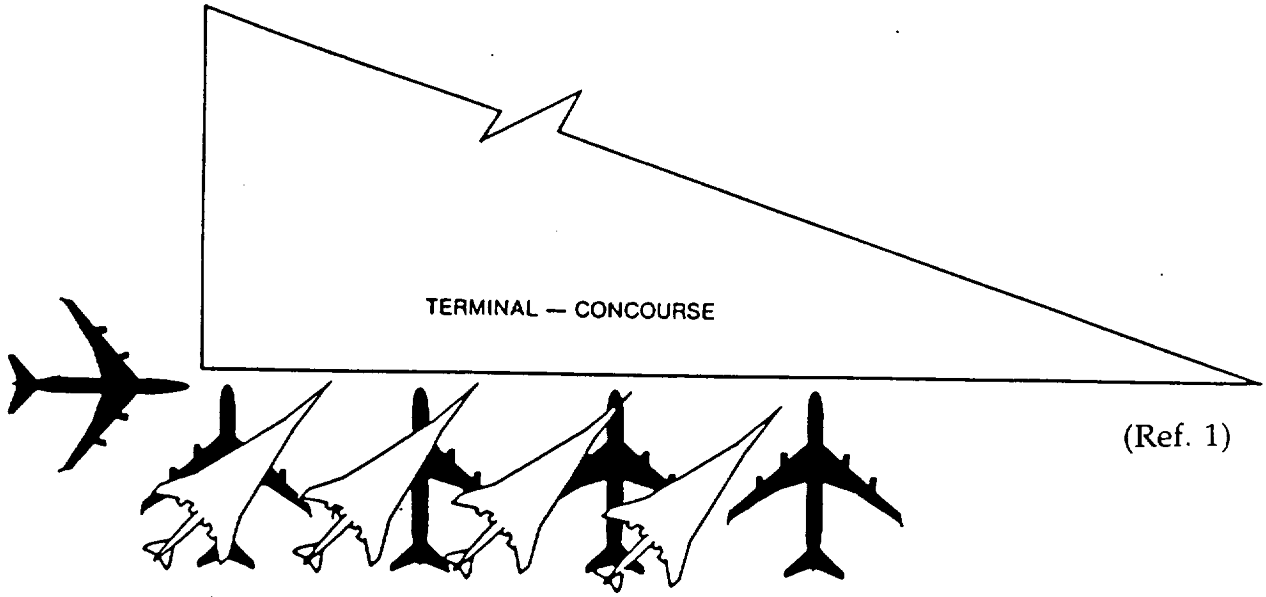
All aircraft servicing will require no special service equipment modification. The Swift will be compatible with current ground service equipment for the galley service, bulk cargo, potable water, lavatory service, cabin cleaning, fuel, air conditioning, electrical power, and ramp towing. The location of servicing equipment is presented in Figure 15.2.

The delta wing planform makes it difficult to gain access to mid-fuselage doors and discourages use of mid-fuselage doors for servicing. The L2 door (the second closest door to the nose on the left side) will be used for all passenger entry and exit; galley servicing will be through the R2 door. The aft right and left doors will be used for cabin cleaning and crew access.

Aircraft servicing will be turn-around activities as opposed to through-stop activities. A turn-around time of 75 minutes has been projected. This time take into account a highly automated system self-testing sequence (Ref. 1).

15.5 Engine Maintenance

The propulsion systems were integrated into the aircraft structure to minimize maintenance requirements. The engine cowling and pylon fairings are removable allowing the entire engine to be exposed for routine inspections of the inlet, compressor, hot section, exhaust nozzle, and augmentor without the removal of the engine. This allows better maintenance turn around times thus reducing the overall maintenance cost. The engine has three main mounting points that are easily accessible for any engine with or without the neighboring engine installed. The inlet and the engine are structurally integrated however, they are mounted to the airframe independently to allow separation, removal and installation of either component without the other. The engines are located 7.0 feet from the ground allowing the use of current engine caddies and hoists. All pre-flight access doors are located on the underside of the engines for easy accessibility.



(Ref. 1)

Figure 15.1: Swift Angled Parking

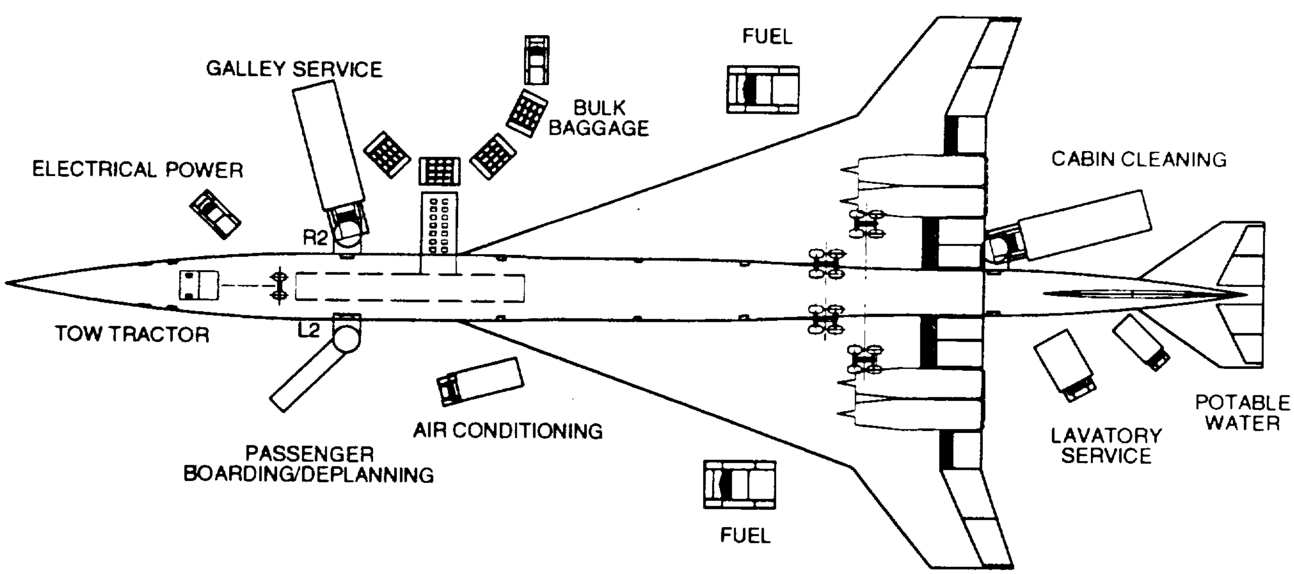


Figure 15.2: Swift Ground Servicing

16.0 ECONOMIC ANALYSIS

Throughout the evolution of the Swift design, it was important to maintain a philosophy of producing an economically viable HSCT that can compete with the current long-range subsonic aircraft. In order to analyze the economic viability of the Swift aircraft, a life cycle cost (LCC) analysis based largely on statistical data and judgment factors reflecting the anticipated difficulties in design and manufacture was performed (Ref. 30). This analysis results in a unit price of $215.0 million per aircraft, with all costs estimated in 1992 US dollars. The Swift's LCC analysis consists of the following categories:

1. Research, Development, Test and Evaluation Cost (RDTE)
2. Acquisition cost
3. Operations Cost
4. Disposal Cost (Ref. 30).

Table 16.1 shows a numerical breakdown of the LCC estimate based on the following parameters:

1. T/O weight = 712,000 lb.
2. Empty weight = 318,908 lb.
3. Cruise velocity = 1432 knots
4. Number of production A/C = 350 aircraft
5. Avg. production rate = of 4.5 A/C per month.

Figures 16.1, 16.2, and 16.3 show the percentage breakdown of the RDTE cost, acquisition cost, and the operations cost, respectively. Calculations can be found in the Appendix. The RDTE and acquisition costs include program costs for the aircraft from the initial design to the production, including tooling and materials. The RDTE cost is composed of the research, development, and testing expenses of four flight test airplanes and a 10 percent profit. The acquisition cost reflects the level of advanced technology utilized in the aircraft and the degree of difficulty associated with the use of advanced materials. Values for the judgement factor associated with the level of advanced technology utilized range from 1.0 to 2.0. The value 1.0 is typical of a non-sophisticated aircraft, and 2.0 is represented by such aggressive users of advance technology as the X-29 and the National Aerospace Plane. Values for the degree of difficulty associated with the use of advanced materials range form 1.0 to 3.0, with 1.0 representing airframes made primarily of conventional aluminum alloys, and 3.0 airframes made of composites. A very aggressive use of advanced technology (2.0) and an extremely high degree of advanced materials difficulty (3.0 plus 20 percent more to compensated for high temperature resistant materials) are assumed for the production of the Swift. The cost of the engines were assumed to be $7 million, which is about twice that of subsonic engines. The cost of the avionics was assumed to be 10 percent of the purchase price (Ref. 27). The avionics cost takes into account the year 2000 latest technology available in synthetic vision and digital fly-by-wire (or fly-by-light) systems.

The operating cost include the expenses for crew, fuel, basic maintenance, depreciation, and indirect cost. These costs were based on the following parameters: a service life of 20 years; an average mission time of 5.25 hours; an annual utilization of 3,835 hours; and 350 aircraft in service. From these non-ownership related costs, it is calculated that with an 80 percent load factor and a 12 percent ROI, Swift can achieve a 20 percent fare premium compared to subsonic aircraft. This is because subsonic aircraft operate at a 9.1 cent/nm Revenue Per Passenger Mile (RPM) (Ref. 2). Coupled with a 50 percent times savings, the 20 percent fare premium is predicted to capture 40 percent of the market share (Ref. 2). The 5700 nm range represents 75 percent of long range travel. This means that the Swift can capture 98.4 billion RPM, which is 30 percent of the total international passenger traffic for the year 2000 (Ref. 1).

The disposal cost is the cost to dispose of the aircraft after it has completed its service life. Since the aircraft still has a price value on the resale market, a negative disposal cost of 10 percent of the purchase price was assumed (Ref. 14). However, since this is a negative cost it is not included in the LCC analysis.

As the LCC analysis reveals, the Swift is an economically viable aircraft capable of competing with the current wide-body subsonic aircraft. Its low unit price and fare premium make this aircraft extremely competitive in the long-range markets.

Table 16.1: Life Cycle Cost Breakdown for the Swift

(Note: All costs are in millions of 1992 dollars)

RDTE Cost			
Airframe, Engineering, and Design			1124.0
Development, Support, and Testing			401.3
Flight Test Aircraft (4)			2652.3
Flight Test Operations			115.7
Test Simulation Facilities			82.0
Finance (10%)			546.9
Profit (10%)			546.9
	Total RDTE Cost		**5469.1**
Acquisition Cost			
Airframe, Engineering, and Design			1429.0
Airplane Production			55668.2
Engines & Avionics		17325.6	
Interior		439.0	
Manufacturing Labor		17529.2	
Manufacturing Materials		16110.3	
Tooling		1985.4	
Quality Control		2278.8	
Production flight Test Operations			0.8
Finance (10%)			6344.2
Profit (10%)			6344.2
	Total Acquisition Cost		**69786.5**
Operations Cost (350 Airplanes)			
Direct Operations			407359.0
Flying		181413.0	
Maintenance		17005.2	
Depreciation		169785.2	
Landing, Navigation, and Registry		10640.5	
Financing		28515.1	
Indirect Operations			148471.1
	Total Operations Cost		**555830.1**
Life Cycle Cost			**631085.7**
Airplane Estimated Price			**215.0**
Life Cycle Cost per Airplane			**1803.1**

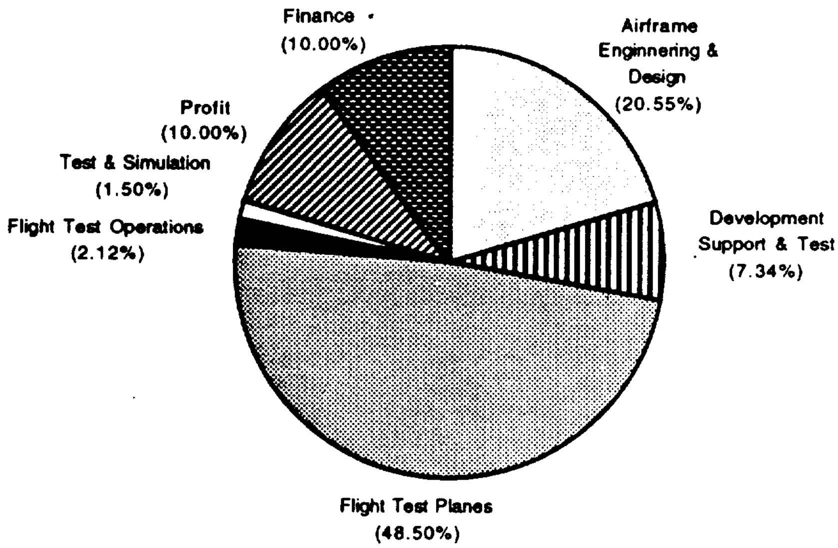


Figure 16.1: Research, Development, Test and Evaluation (RDTE) Breakdown for the Swift

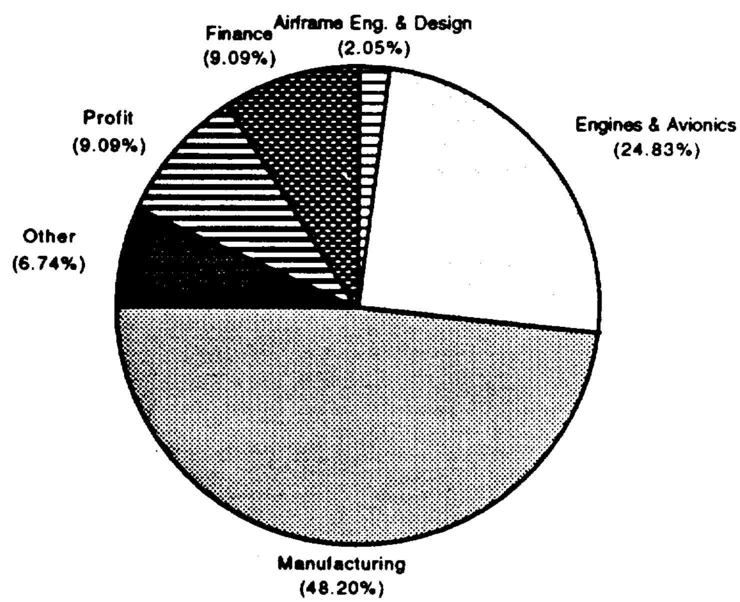


Figure 16.2: Acquisition Breakdown for the Swift

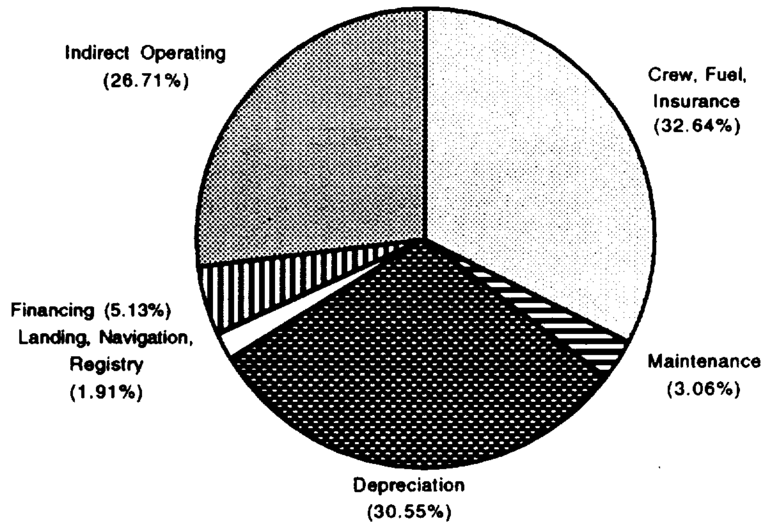


Figure 16.3: Operating Breakdown for the Swift

17.0 CONCLUSION

This report has demonstrated that the Swift will be highly competitive in the airline market of the year 2000. The luxurious interior and personal service will satisfy the most demanding first class passenger. The 50 percent time savings will convince time-conscience business passengers of Swift's value. And with its low 20 percent fare premium, the Swift will stimulate tourist demand by providing fast and affordable travel.

These results are based on a solid foundation by using historical methods with state of the art technology and resources. Several fundamental problems were solved by the Swift design team. The need for high technology avionics, advanced materials, low take-off rotation angles, and necessary stability and control are only a few of the design problems solved by the Swift team. By continual research in areas such as advanced propulsion systems, materials, and aerodynamics, the Swift will be a leader in the commercial fleet of the future.

18.0 FUTURE RECOMMENDATIONS

High speed flight brings with it new challenges in analytical methods: supersonic aerodynamics, advanced structures and materials, and advanced propulsions. Although all of these area are addressed in this proposal, further studies are needed. Key elements that must be investigated further include:

- Supersonic aerodynamics. The effects of twist and camber on drag must analyzed. Optimization of wing planform for best cruise and take-off performance must be performed. Also, a study of wing-fuselage interaction and interference should be conducted. Computational fluid dynamics would be the analytical method of choice for these studies.

- Advanced structures and materials. Using high strength materials that are also resistant to high temperatures (due to aerodynamic heating effects) allows for the implementation of advanced structure concepts. Finite element analysis coupled with the application of the latest techniques for advanced metal composites could significantly reduce structural weight and complexity.

- Advanced propulsions. Propulsion systems are required to have low fuel consumption with adequate thrust and low noise. The application of any advances in propulsion technology could significantly increase design range and efficiency.

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