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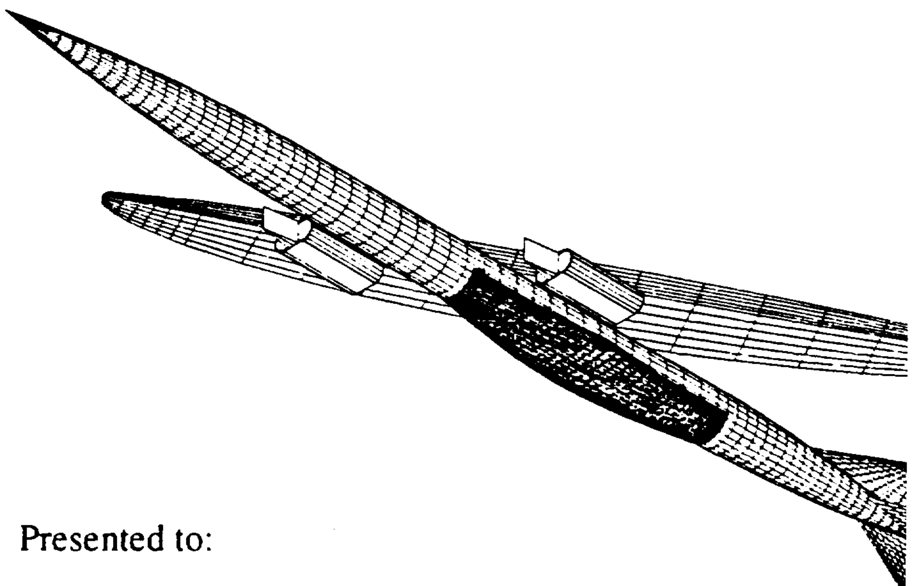
RTJ-303

VARIABLE GEOMETRY, OBLIQUE WING SUPERSONIC AIRCRAFT



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SUPERSONIC OBLIQUE SWING WING TRANSPORT STUDY

by:

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Design Team

SUMMARY

This document is a preliminary design of a High Speed Civil Transport (HSCT). This study was done for a required class of the Aeronautical Engineering curriculum at California Polytechnic State University. The study involved groups of six to eight Aeronautical Engineering seniors and was implemented over three quarters.

The resulting aircraft design, named the RTJ-303, is a 300 passenger, Mach 1.6 transport with a range of 5000 nautical miles. It features four mixed-flow turbofan engines, variable geometry oblique wing, with conventional tail-aft control surfaces. The preliminary cost analysis for a production of 300 aircraft shows that flyaway cost would be 183 million dollars (1992) per aircraft. The aircraft uses standard jet fuel and requires no special materials to handle aerodynamic heating in flight because the stagnation temperatures are approximately 130 degrees Fahrenheit in the supersonic cruise condition. It should be stressed that this aircraft could be built with today's technology and does not rely on vague and uncertain assumptions of technology advances.

Included in this report are the following sections discussing the details of the preliminary design sequence:

A description of the mission to be performed,

The operational and performance constraints that bracketed the design point,

A discussion on the aircraft configuration and the tradeoffs of the final choice,

A discussion on the wing design including planform design, airfoil section selection, volume for fuel, and the pivot,

Fuselage design, with details on internal layout, cross-section, and location of key sections and components,

Empennage design, sizing of tail geometry, and selection of control surfaces,

A discussion on propulsion system / inlet choice and their position on the aircraft,

Landing gear design including a look at tire selection, tip-over criterion, pavement loading, and retraction kinematics,

Structures design including load determination, and materials selection,

A discussion on how well the aircraft performs its intended mission,

A look at stability levels, stability augmentation, cg excursion, and controllability, and handling qualities,

A demonstration of systems layout including location of key components,

A discussion on operations requirements and maintenance characteristics,

A preliminary cost analysis,

And lastly, a section discussing conclusions made regarding the design, and recommendations for further study.

The request for proposal document, which outlined customer requirements, and sample calculations of typical parameters are included in the appendix.

LIST OF VARIABLES / NOMENCLATURE

AC	=	Aerodynamic Center	
β	=	Beta	[degrees]
δa	=	aileron deflection	[degrees]
δe	=	elevator deflection	[degrees]
δr	=	rudder deflection	[degrees]
δ	=	deflection	[degrees]
c	=	chord	[inches or feet]
CD	=	Drag Coefficient	
CG	=	Center of Gravity	
CL	=	Lift Coefficient	
Cl	=	section lift coefficient	
Cm	=	Moment Coefficient	
Cn	=	Yaw Moment Coefficient	
Cm	=	Pitch Moment Coefficient	
D	=	Drag	[lbs]
deg	=	degree	
F	=	Fahrenheit	
Fd	=	Difficulty Factor	
ft	=	feet	
g	=	gravitational acceleration	[slug·ft/s^2]
L	=	Lift	[lbs]
L/D	=	Lift to Drag Ratio	
M	=	Mach number	
n	=	load factor	
psi	=	pounds per square inch	
S	=	Surface Area	[ft^2]
T/W	=	Thrust to Weight Ratio	
V	=	Tail Volume Coefficient	
W	=	Weight	[lbs]
W/S	=	Wing Loading	
X	=	distance along the x-axis	[inches or feet]
Y	=	distance along the y-axis	[inches or feet]
Z	=	distance along the z-axis	[inches or feet]

<u>Acronyms</u>

APU	=	Auxiliary Power Unit
BAC	=	British Air Company
DOC	=	Direct Operating Cost
FAA	=	Federal Aviation Administration
FAR	=	Federal Aviation Requirements
GE	=	General Electric
HSCT	=	High Speed Civil Transport

KSM	=	Static Margin Gain
LCC	=	Life Cycle Cost
LDW	=	Standard Aircraft Container
LE	=	Leading Edge
MAC	=	Manufacturing and Acquisition, Mean Aerodynamic Chord
NACA	=	National Advisory Committee for Aeronautics
NASA	=	National Aeronautics Space Administration
PAX	=	passengers
P&W	=	Pratt and Whitney
RAT	=	Ram Air Turbine
RDTE	=	Research, Development, Test and Evaluation
RFP	=	Request For Proposal
RR	=	Rolls Royce
SFC	=	Specific Fuel Consumption
SST	=	Supersonic Transport
TE	=	Trailing Edge
TSFC	=	Thrust Specific Fuel Consumption
Tu	=	Tupolev

<u>Subscripts</u>

cr	=	cruise
e	=	empty
end	=	endurance
eo	=	operating empty
fwd	=	forward
i h	=	stabilizer-incidence derivative
land	=	landing
max	=	maximum
pl	=	payload
ref	=	reference
sub	=	subsonic
sup	=	supersonic
to	=	takeoff

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INTRODUCTION

The demand for an aircraft that can meet the requirements of fast efficient travel to the Pacific Rim has been projected to be a design driver of tomorrow's transport. The California Polytechnic State University Aeronautical Design Class was assigned to design an economically viable high-speed civil transport that would minimize environmental impact. These requirements were to be met by all groups participating in this design exercise. The RTJ-303 meets these requirements and either complies fully with the Request For Proposal (RFP) document, or is justified and discussed in the corresponding section.

In recent years, designs for high speed civil transports have been studied for their feasibility in the commercial market. The oblique, variable sweep wing supersonic transport configuration was first proposed by Dr. R. T. Jones, former chief scientist of the NASA Ames Research Facility, who spent most of his life studying oblique aerodynamics. Studies of the oblique wing concept have shown substantially improved transonic performance at Mach numbers up to 1.4 and the elimination of sonic booms (audible at ground level) in flight at Mach numbers as high as 1.2. Predicted is also an increase in low-speed performance, as well as the potential for increased range and/or reduced takeoff weight for a given payload. Further, a reduction of airport and takeoff noise to well within current standards is expected. Data for this rather unique type of configuration is limited, but enough research has been done to demonstrate some of the clear advantages of this type of aircraft. Although no supersonic flight test data has been obtained to date, supersonic wind-tunnel data has been obtained by NASA in reference (16) for Mach numbers up to 1.4 with wing sweep angles up to 60 degrees. Subsonic flight tests have been conducted by NASA using a remotely piloted aircraft and a low-cost piloted vehicle known as the AD-1.

The final payload of 300 passengers was a compromise between length restrictions on the aircraft weighed against the desire to remain competitive in the market with the maximum number of passengers carried for each flight. The range of 4700 nautical miles (nm) was decided upon to include Los Angeles to Tokyo in the city pairs to the Pacific Rim. Three hundred (300) nm are given in addition to this range to account for reserves and a flight to an alternate airport. This resulted in an aircraft sized for a range of 5000 nm.

MISSION DESCRIPTION

Figure 1 shows the mission profile for the RTJ-303. The mission description begins with startup and taxi out for take-off. After take-off, the initial climb will be to 10,000 ft. During its climb from ground level to that altitude, the aircraft will fly at less than 250 knots as required by the Federal Aviation Requirements (FAR). Once at 10,000 ft. the aircraft will continue its climb to cruise segment to an altitude of 50,000 ft. smoothly accelerating to its design cruise Mach number of 1.6. Upon reaching its destination, which is a maximum of 4700 nm away, the aircraft decelerates and descends to 1500 ft. Approach and landing procedures allow for 8 minutes of holding time to meet Federal Aviation Administration (FAA) standards. After landing, the aircraft taxis to the terminal for unloading of passengers and baggage and subsequent shutdown. In addition, the aircraft has the option of 30 minutes of holding time available and the option to fly to an alternate airport at a distance of 100 nautical miles.

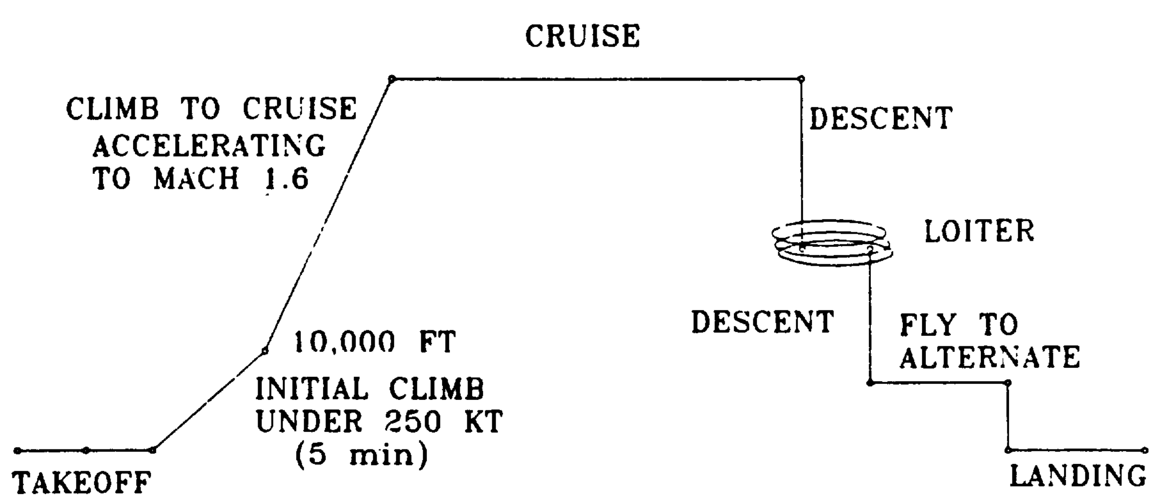


Figure 1: MISSION PROFILE

PRELIMINARY SIZING

Preliminary sizing for the RTJ-303 was done on computer spreadsheet as outlined by Roskam in reference (1). The outputs of this method include gross takeoff weight, and required fuel to complete the mission. Typical input parameters were L/D at all flight conditions, thrust specific fuel consumption, mission range, number of passengers, and many others. Figure 2 shows the design point located on the thrust-to-weight (T/W) versus wing loading (W/S) graph.

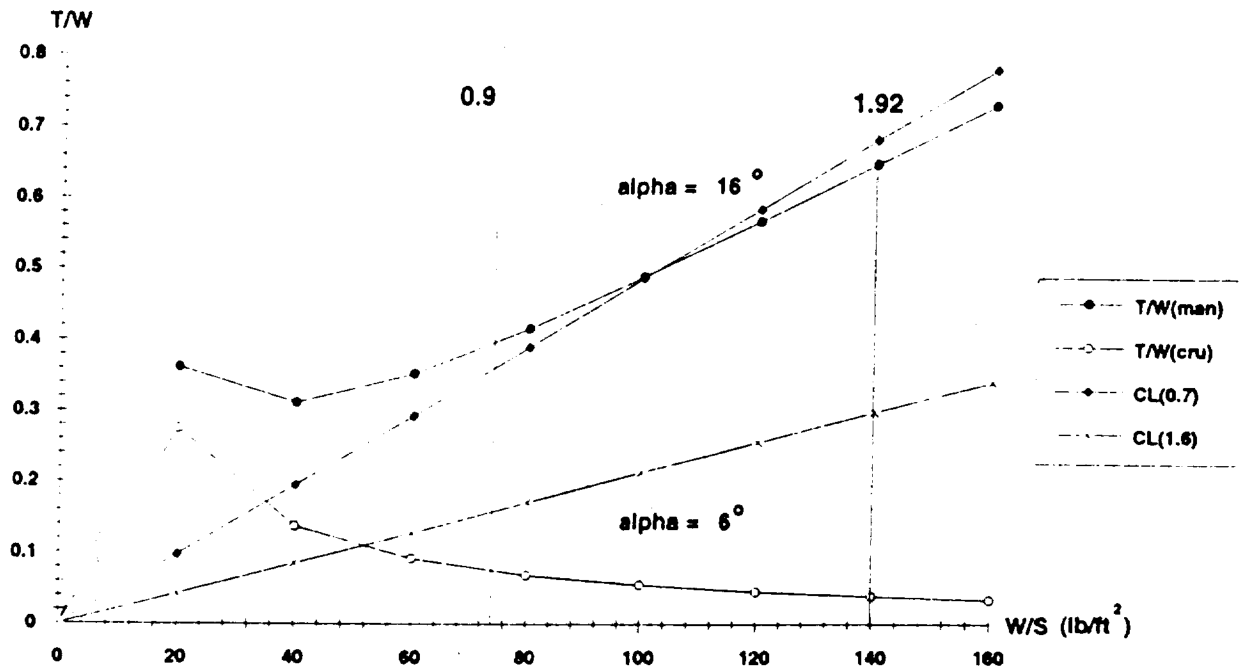


Figure 2: THRUST/WEIGHT vs WING LOADING

The sizing tool on the computer spreadsheet enabled sensitivity studies to be done in order to determine the driving parameters of the design. These sensitivities of takeoff weight to a variety of parameters vs number of passengers are graphed in Figures 3a-f. The driving parameters are $TSFC_{cruise}$, L/D_{cruise}, Empty Weight, Endurance, Range, and Payload in order of highest to lowest sensitivity. Trade studies were done to aid in the selection of the optimum aircraft configuration, mission range, number of passengers, etc.

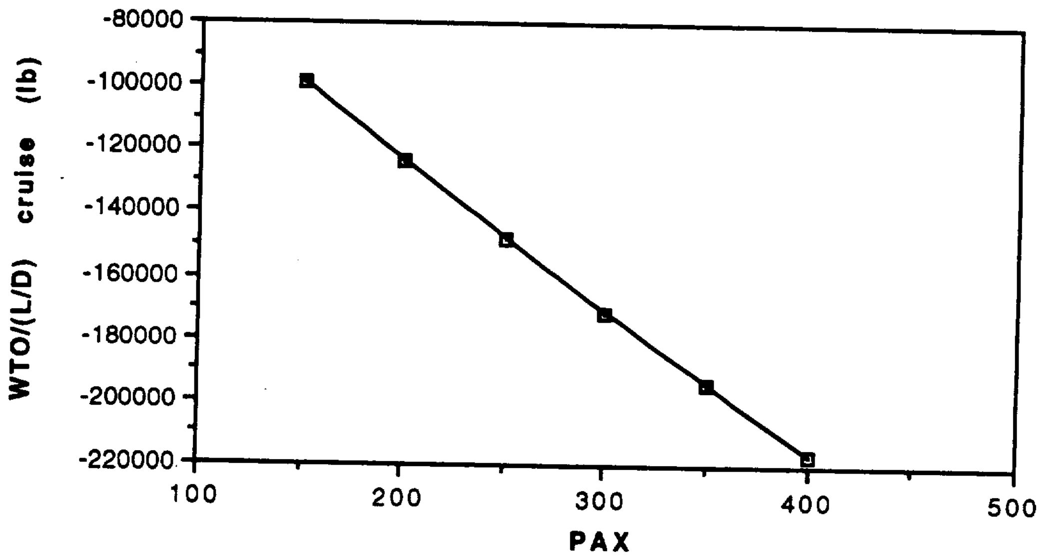


Figure 3a: SENSITIVITY OF $W_{to}/(L/D)_{cruise}$ vs #PAX

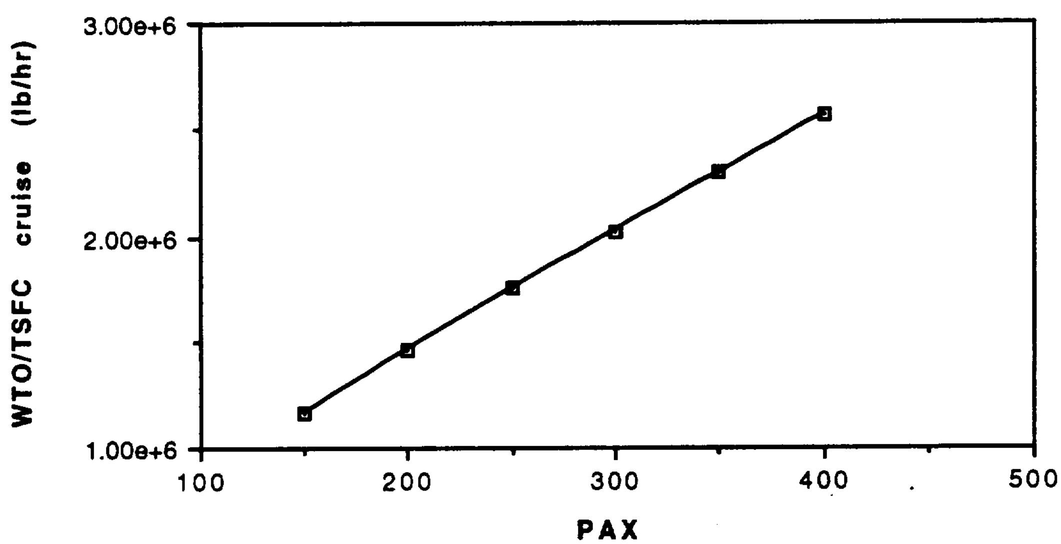


Figure 3b: SENSITIVITY OF $W_{to}/(TSFC)_{cruise}$ vs #PAX

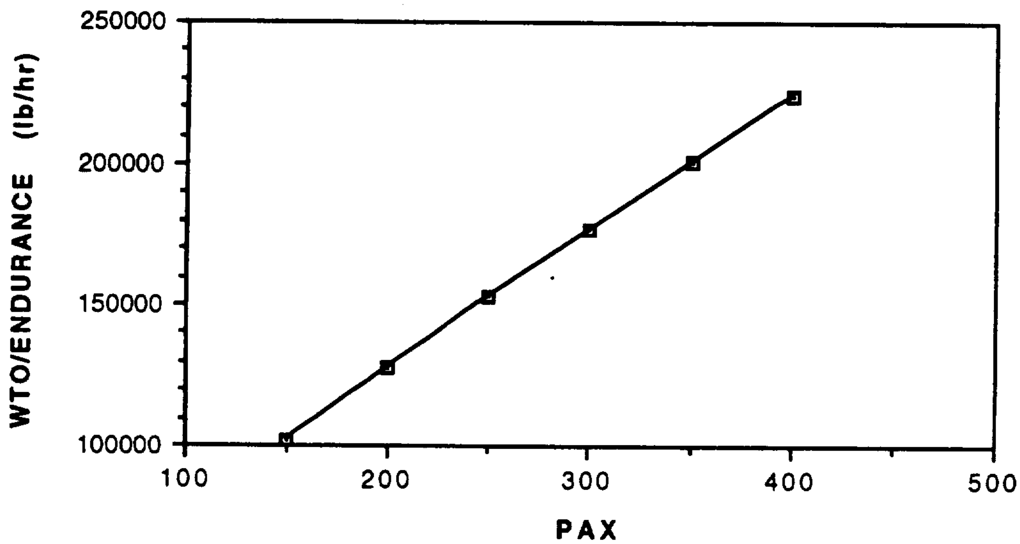


Figure 3c: SENSITIVITY OF W_{to}/ENDURANCE vs #PAX

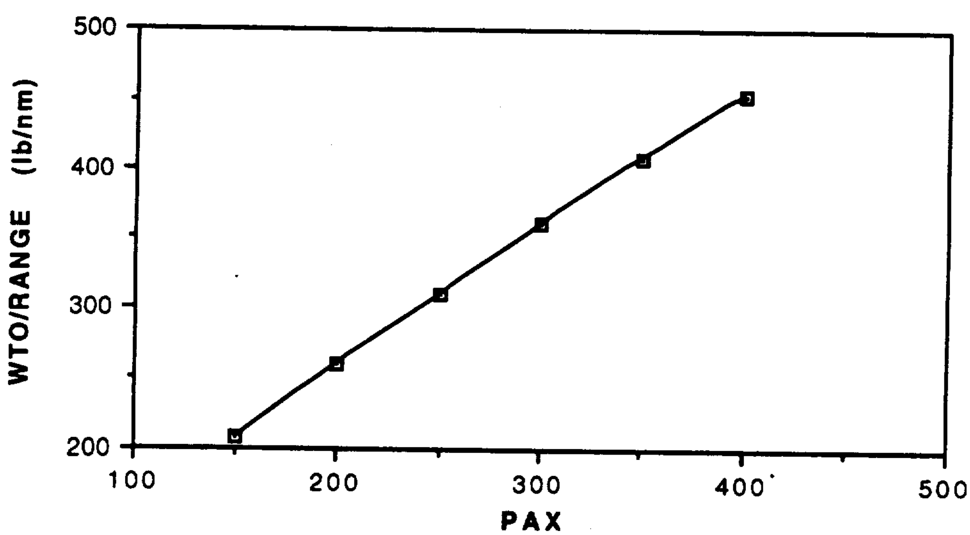


Figure 3d: SENSITIVITY OF W_{to}/RANGE vs #PAX

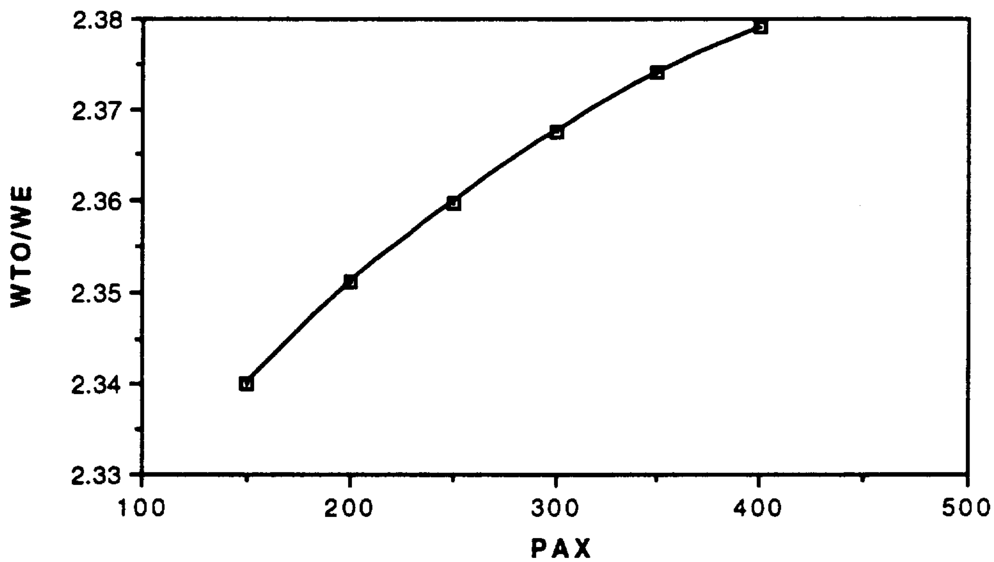


Figure 3e: SENSITIVITY OF $W_{to}/(W)_{empty}$ vs #PAX

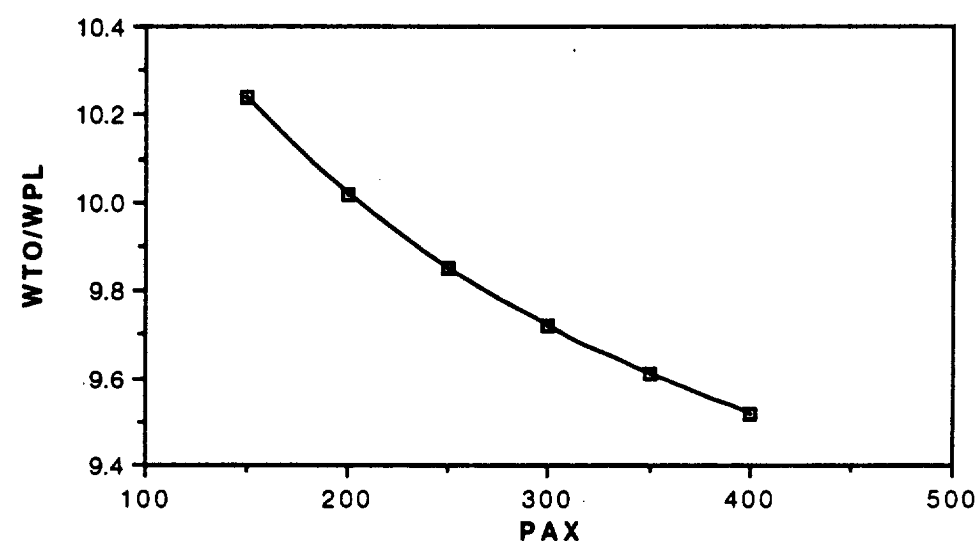


Figure 3f: SENSITIVITY OF $W_{to}/(W)_{payload}$ vs #PAX

The RFP document states certain operational requirements that must be met. First and foremost are the 300 passenger requirement, range of 5000 NM, and noise requirements. The fuselage size was governed mostly by the passenger requirement, as this is one of the largest volume drivers of any transport fuselage. The range requirement necessitated a fuel volume that was to be carried mostly by the wing. Environmental requirements such as noise levels helped bracket the engine selection and size. The engines are at reduced power at takeoff, lowering their sideline noise levels.

Other operational requirements such as boardability, service door heights, and ground support equipment logistics froze certain parameters such as floor angles, height of aircraft above the ground, and door placement. A maximum height of boarding doors of 17 feet above ground level was the maximum to be allowed in order to use current boarding ramps. In order to keep the baggage loading as simple as possible with the use of current loading equipment, the maximum floor angle allowed was set at 2 degrees.

AIRCRAFT CONFIGURATION

The configuration resulting from a series of iterations and corresponding trade studies was the RTJ-303 (shown in Figure 4), a variable sweep oblique wing aircraft. Some of the attractive features of this configuration are the constant cross-section fuselage, and the variable wing geometry. Studies have shown that the aircraft is somewhat area-ruled by the swept wing, and the fuselage does not need to be "bottle-necked" as in many of the more conventional designs. This allows for a fuselage of constant cross section to be utilized, which simplifies manufacturing processes, and allows the fuselage to be easily "plugged," or lengthened, to satisfy increasing payload requirements of the design.

As with any variable geometry planform configuration, cruise efficiency can be optimized for a multitude of flight conditions. The oblique wing has a high aspect-ratio wing of 10:1, and in the unswept configuration looks like most other subsonic transports that are optimized for this condition. This has operational advantages if supersonic flight remains unlawful over land, because it can be efficiently flown in this condition. The geometry can then be adjusted to optimum supersonic efficiency as the section of flight over water is encountered. Having a wing that can take on the straight unswept configuration is the primary reason for reduction in takeoff noise and distance. The engines are sized to other requirements and only partial throttle is required to become airborne in the given takeoff distance, which also reduces takeoff noise

The final design parameters of the RTJ-303 configuration were a culmination of optimized parameters weighted by practical concerns. A maximum wing sweep angle of 62 degrees was limited by a dramatic loss of aileron control effectiveness, and aeroelastic divergence problems on the forward swept wing. At this angle the wing leading edge normal Mach number is just below drag divergence for the airfoil section of the wing. Mach numbers above 1.6 required wing sweep angles that were beyond the available practical constraints. Also the aeroelastic challenges become increasingly great at Mach numbers much higher than this due both to Mach buffeting and divergence.

The RTJ-303 has an elliptical, high aspect ratio wing which is mounted above the fuselage. The fuselage nose and tail cones consist of modified paraboloids joined by a cylindrical center section. The aircraft features four mixed-flow turbofan engines grouped into two separate pods. The engine pods themselves are staggered and mounted on either side of the fuselage. The empennage is of the conventional aft mounted type. The vertical and horizontal tail surfaces are swept at 65^{o} to facilitate the use of rounded leading edges on the conventional NACA airfoil sections. The landing gear are of a retractable, tricycle design.

The overall length for the RTJ-303 is 325 ft, while the unswept wing span is 231 ft. Since the 747-400 is the largest commercial transport in operation today, the length of its diagonal has been the measure for airport compatibility in terms of space. The RTJ-303 however does not fit into this diagonal, but if the wing is swept during all ground operations except takeoff, the aircraft is much more slender than conventional winged aircraft. Based upon the assumption that subsonic design increases will be accommodated in the future, the designers of the RTJ-303 feel that the length is justified.

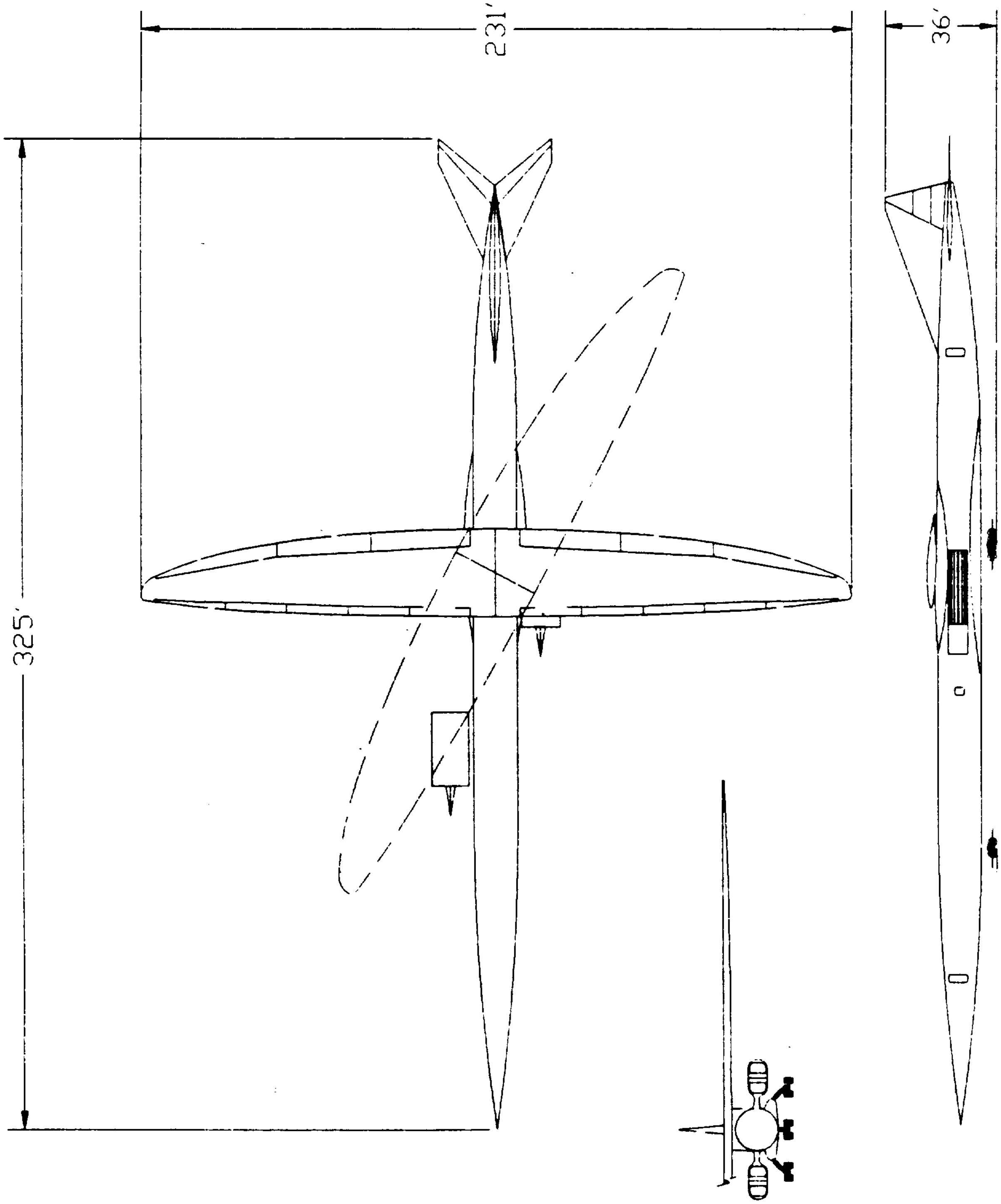


Figure 4: RTJ-303 CONFIGURATION

WING DESIGN

Conventional wing planforms have called for delta wings for supersonic aircraft, due to their good performance at higher Mach numbers, and their relatively small shift in center of pressure. The subsonic and supersonic lift of a delta planform is primarily generated with vortex lift, and at low speeds, it requires high angles of attack to maintain reasonable lift coefficients. Unfortunately, the large angles required at takeoff are greater than what is practically possible with the rotation limitations of the geometry of most designs.

Reasonable subsonic performance is required of a good design due to restrictions of supersonic flight over land. This requirement necessitates an efficient planform for subsonic cruise. The delta wing, however, does not do well in this flight regime, calling for many innovative and often complex augmentations of the once simple planform. These modifications in turn add weight, involve higher costs of manufacturing, and increase the maintenance required on the aircraft. If an HSCT were to perform at a supersonic design point throughout its flight regime, and could be designed for unusually high takeoff lift coefficients, the delta wing might be ideal.

An alternative choice for planform design that would address the needs for subsonic flight is the elliptical planform. Historically, small fighter planes in the 1940's used this type of planform to increase the efficiency of the spanwise lift distribution. The high aspect ratio variable sweep elliptical wing performs admirably in the subsonic range because it is not swept at takeoff and subsonic cruise. The elliptical planform performs comparably to delta wings at supersonic speeds because it minimizes drag as discussed in reference (2). However, unlike delta wings, the variable sweep elliptical planform is limited by practical considerations to a maximum Mach number of 1.6.

Planform design

The wing planform chosen for the RTJ-303, shown in Figure 5, is a moderately high aspect-ratio wing with an elliptical planform. The ellipse has a major to minor axis ratio of 8:1, and an aspect ratio of 10. The elliptic planform coupled with the relatively high aspect ratio serve to minimize induced drag as discussed in reference (2). The limiting factor to the aspect ratio was the expected aeroelastic twisting and bending problems of an oblique-wing that is relatively long and thin.

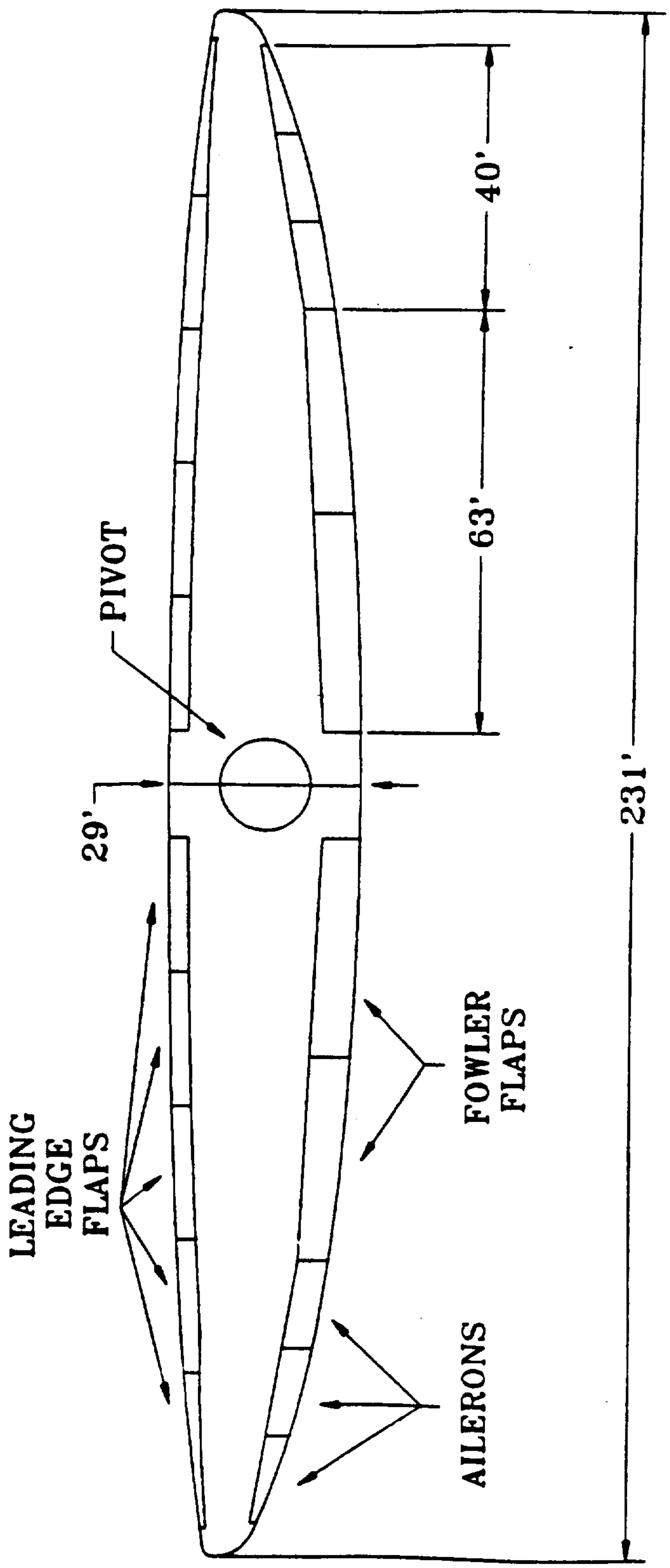


Figure 5: WING PLANFORM

The wing planform design was partially driven by considerations found in reference 3 which describes wind tunnel tests that compared three oblique wing elliptical planforms defined by specifying a straight line through a constant chord location as c/4, c/2, and 3c/4 as shown in Figure 6a. Reference 3 found that the drag characteristics of the planforms varied little, but the rolling moments, Figure 6b, varied greatly. The RTJ-303 has a planform with a straight quarter chord line because it produced the smallest rolling coefficient at our selected cruise coefficient of lift.

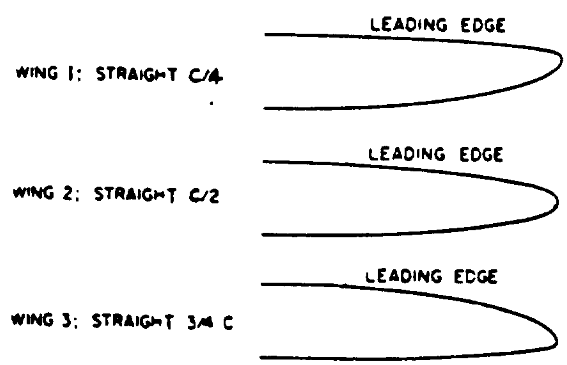


Figure 6a: PLANFORM COMPARISONS

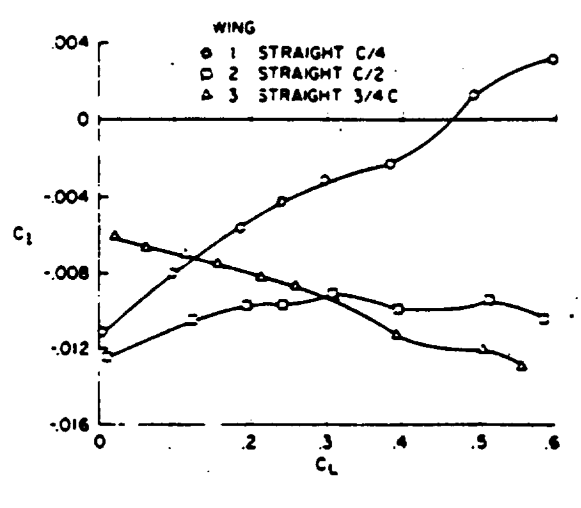


Figure 6b: EXPERIMENTAL ROLLING MOMENTS

The projected area of the wing is 5235 ft^2. A tradeoff study was performed to determine the wing area and wing loading and cruise altitude by optimizing for takeoff, thrust to weight ratio and noise requirements. The tradeoff study compared the weights of the plane with differing wing areas (and wing loading), the cruise coefficient of lift and L/D, the takeoff coefficient of lift for a given takeoff speed and the corresponding thrust to weight ratio required for that combination of parameters. The driving factor in wing area choice was the thrust to weight ratio which was limited to 0.30 in order to use reasonably sized engines. The choice of altitude was determined by the cruise coefficient of lift desired for the airfoil.

Airfoil selection

The airfoil selection involved many practical considerations as well as the requirement of good aerodynamic performance at a multitude of flight conditions. The NACA 64-210 shown in Figure 7 was chosen primarily for the critical Mach number of the airfoil at the coefficient of lift seen by the airfoil during supersonic cruise. Other considerations in the airfoil choice involved the required fuel volume in the wing, and structural efficiency which demand a relatively thick airfoil section. The 64-210 shows relatively good performance characteristics with adequate thickness for fuel and structure. The bulk of fuel is carried in the wing alone. and the fuel volume of the wing is estimated at 56,000 gallons, which satisfies the required mission fuel volume.

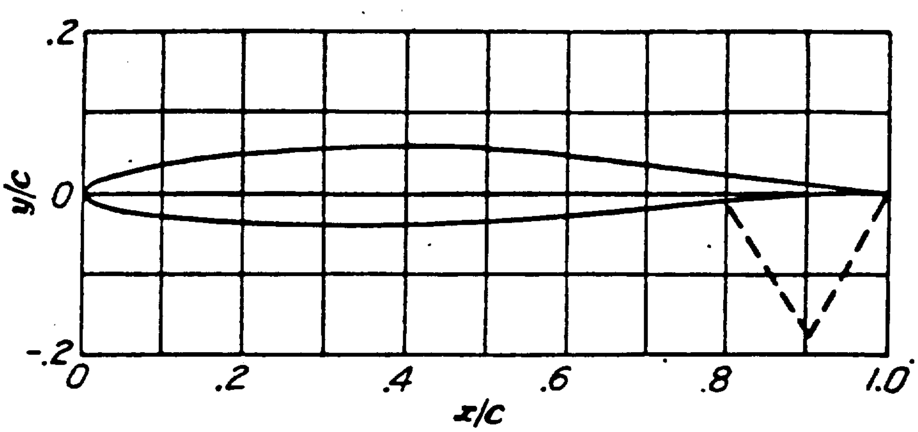


Figure 7: WING AIRFOIL SECTION

The component of airflow velocity normal to the wing leading edge is just below the drag divergence Mach number of the airfoil section as described in reference 4. This implies that the airfoil will behave as if it were in subsonic flow without suffering a severe drag penalty. The penalty in wave drag due to volume from the thick section is somewhat offset by the greater wing loading, and consequent reduction in area, because of the higher CL_{max} obtainable with thicker sections. This also allows for a lighter wing structure because the spars can run at a greater distance from their neutral axis. This is important in a design such as this where a stiff and strong wing is essential.

High lift devices

High lift devices are required for takeoff and landing with the available rotation. The increase in wing area due to flap deflections was estimated to be 15% which satisfied takeoff and approach requirements. This called for trailing edge Fowler Flaps along 60% of the span and leading edge Krueger Flaps along 90% of the span. The resulting increase in CL was calculated to be satisfactory to make a fully-loaded RTJ-303 airborne. Table 1 lists the specific numbers for the RTJ-303. Figure 8 shows a schematic of the high lift devices employed.

Table 1: LIFT INCREMENTS DUE TO FLAP DEFLECTION

$Cl\ max_{clean}$	$\Delta\ CL_{takeoff}$	$\Delta\ CL_{landing}$
1.43	0.77	1.09

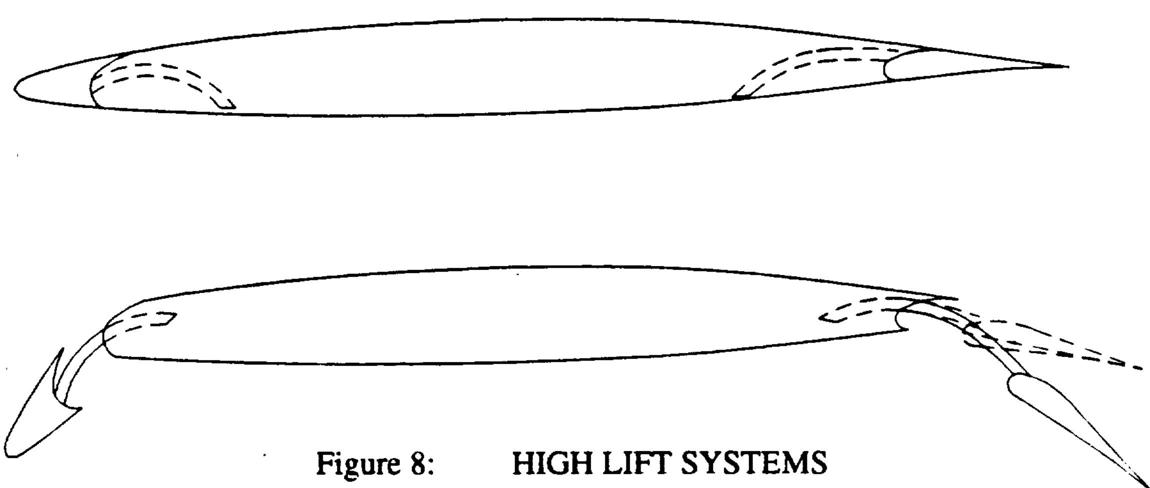


Figure 8: HIGH LIFT SYSTEMS

FUSELAGE DESIGN

Supersonic transports need to be designed in such a way as to minimize the supersonic wave drag, a pressure drag due to the formation of shocks. This is done by area-ruling of the aircraft, in other words, trying to change the cross-sectional area of the plane in the slowest possible manner. When area-ruling an aircraft, the cross-sectional area at various fuselage stations must be obtained from averaging area slices made through the configuration at the angle of the Mach cone (M_{cruise} of 1.6 = 39^o) and rotating the aircraft through 180^o about the freestream axis. The areas obtained are plotted against their corresponding fuselage stations. The ideal shape of this plot is a bell-shaped curve found using the Harris Wave Drag Code. (Ref. 4) When the configuration's area plot follows the idealized curve closely, its supersonic wave drag is consequently minimized. With conventional delta wing configurations, this process of area-ruling tends to force the fuselage into a coke-bottled shape.

NASA reports on various oblique swing wing configurations (Ref. 3, 5) claim that the fuselage of the swing wing aircraft is one that lends itself easily to area ruling due to the fact that the wings are generally elliptical and, area-wise, are distributed evenly along the length of the fuselage. This should allow for a constant fuselage cross-section along the length of the swept wing. An AIAA paper (Ref. 6), studying a 300 passenger oblique wing HSCT furthermore stated that "area ruling of the fuselage is unnecessary allowing a constant section...". The designers of the RTJ-303 therefore decided to lay out the interior as though the fuselage would be of constant cross-section. As the design progressed, an area ruling was performed on the configuration to verify the validity of the earlier reports. Area slices along the Mach cone at Mach = 1.6 , rotated every 45 degrees, were calculated and averaged for each fuselage station. These areas were plotted against fuselage station and qualitatively compared to a Sears-Haack form as shown in Figure 9 to determine the need for area ruling.

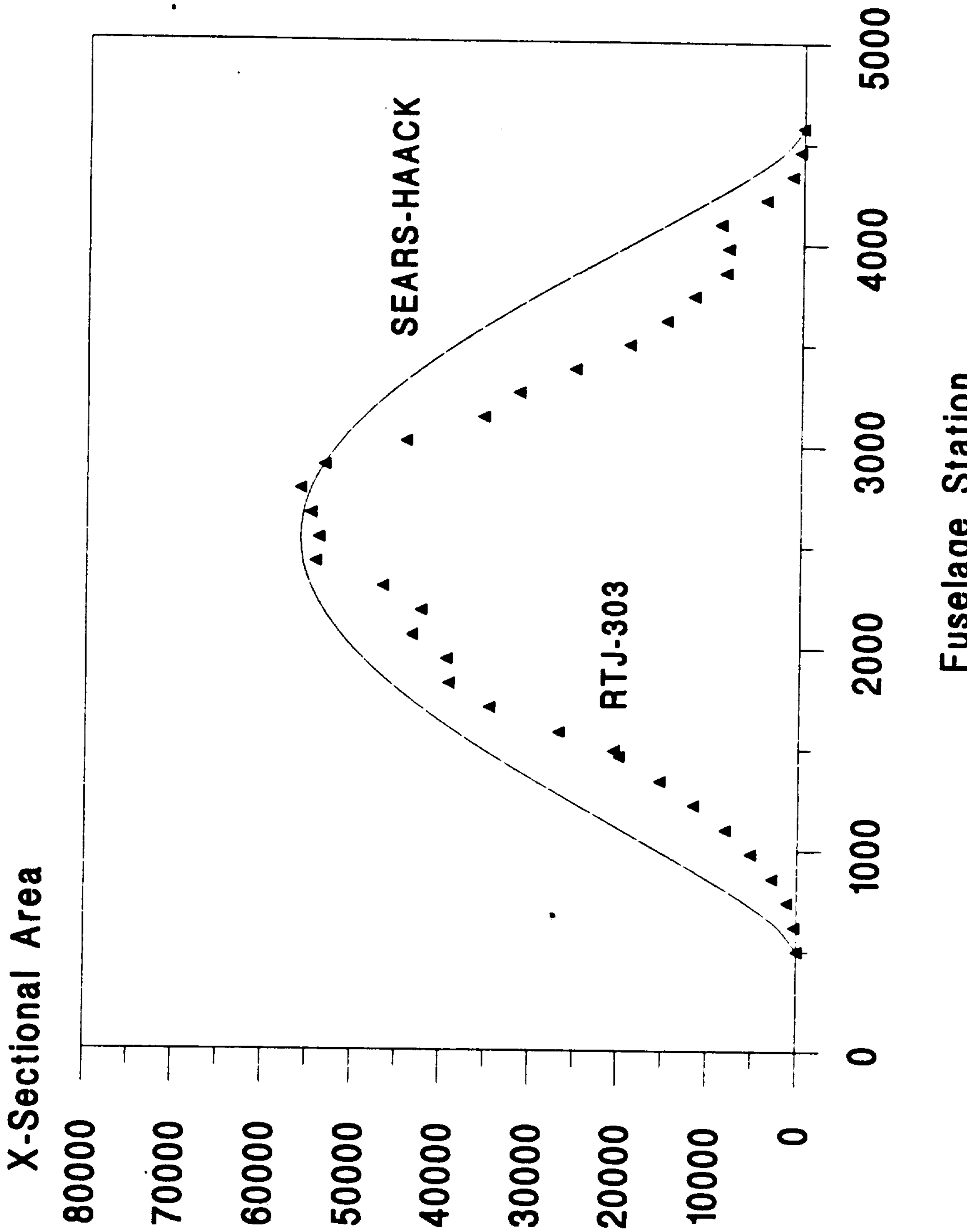


Figure 9: AREA DISTRIBUTION USING HARRIS WAVE DRAG METHOD

The results of these calculations overall confirmed the area ruling characteristic of oblique swing wing configurations. However, there was a slight dip in the amount of cross-sectional area in the vicinity of the pivot due to the wide staggering of the engines. As the new landing gear bulge was added to the preliminary Harris Wave Drag calculations, although the large fairing would seem to have detrimental effects on drag at first glance, it was found that adding this cross-sectional area actually helps in contouring the Harris Wave Drag plot to its desired bell-shape. The constant cross-section fuselage was thereby justified.

The interior layout of the RTJ-303 was broken down into three classes, as called for in the Request For Proposal (RFP). The classes (first, business, coach) were partitioned to be 10, 60, and 30% respectively. Since this aircraft is intended to be mostly for the rushed businessman, 60% of the passenger seats are allocated to business class. The presidents, vice presidents, and higher paid executives have the option to fly in the plush luxurious first class. Due to the relatively high ticket price in this section, a 10% passenger loading was thought to be reasonable. The remaining 30% are reserved for coach class passengers, which are expected to be business men with a more constrained budget.

Due to the fact that a long skinny fuselage minimizes drag, the interior was laid out to have a single aisle along the entire length of the passenger cabin. Figure 10 shows the internal layout of the RTJ-303 cabin. The resulting cabin length was 220 ft. The overall length of the fuselage increased to 310 ft with the addition of the flight deck, nose, and tail cone. A maxium fuselage diameter of 14 ft was needed around the pivot area to allow for six inch frame depths while also providing acceptable comfort levels for the business section and room for LDW containers beneath the cabin floor. It should be noted that this constant center cross-section allows for the addition or removal of plugs and is easier to manufacture than a fuselage of varying cross-section.

The number of galleys, lavatories, flight attendants, boarding doors and emergency exits all were design points taken into consideration during the layout of the interior. All but the emergency exits and boarding doors were outlined in the RFP, and those numbers were followed. The emergency exits were placed to satisfy the FARs whereas the two boarding doors were placed in the very front and back to allow for quick and easy boarding.

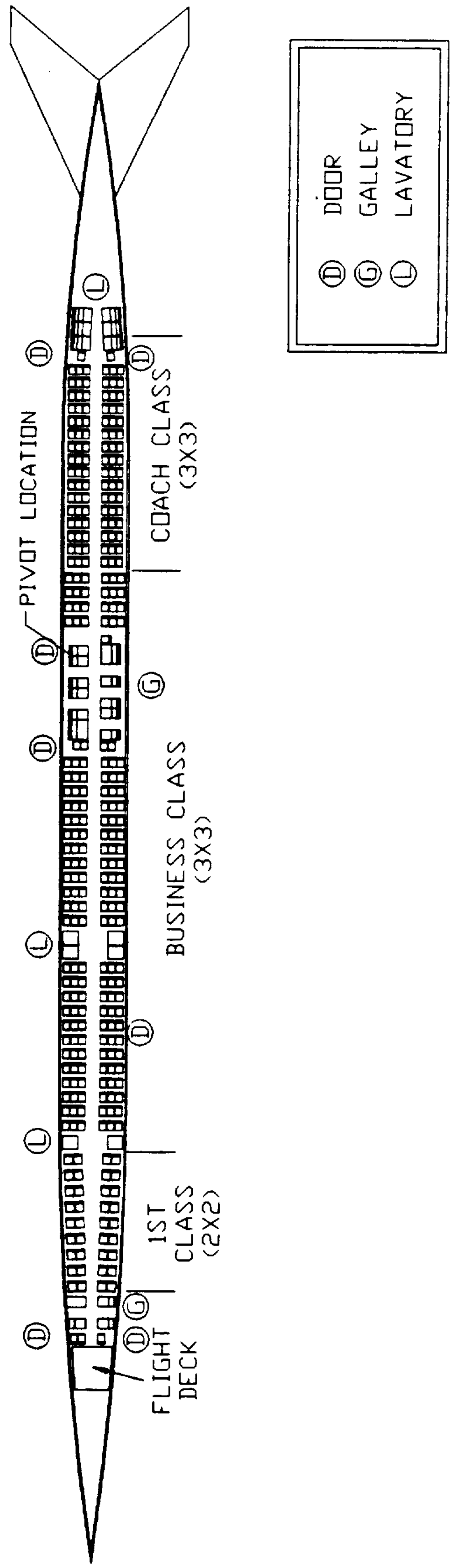


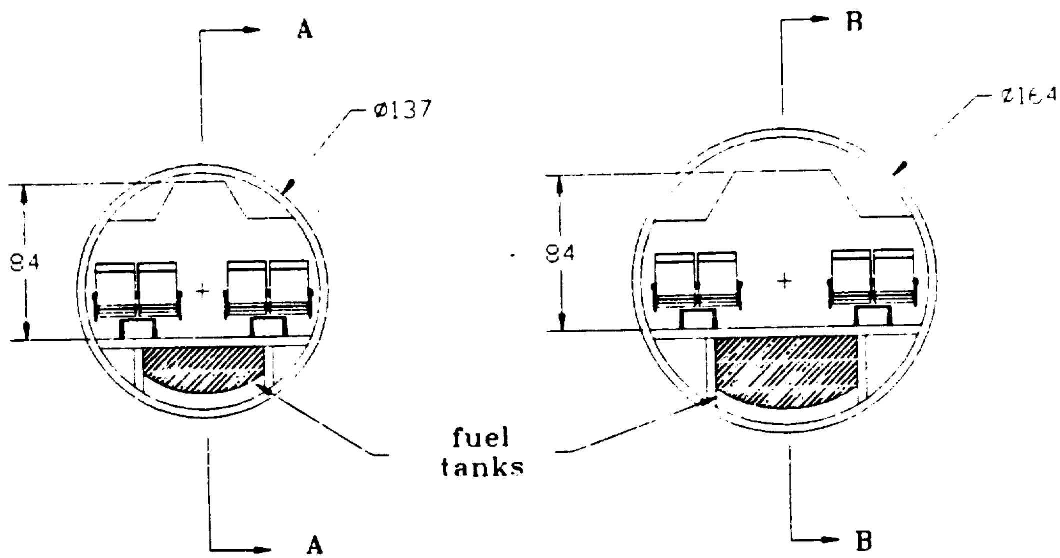
Figure 10: RTJ-303 INTERIOR LAYOUT

First Class

First class is located at the front of the plane just aft of a section of galleys and flight crew storage compartments. This section seats 36 passengers and is 2x2 with seat widths of 21 inches and seat pitches of 40 inches. As a reference point, the RTJ-303's seat pitch exceeds that of the 767-200 by 2 inches. Due to the fact that the transcontinental flight duration of the 767-200 is approximately that of the RTJ's transpacific routes, the 767-200 is a valid comparison. Figure 10a shows the first class layout with selected cross-sections. Three flight attendants serve the first class passengers. The flight attendants' seats are located by the boarding door and service door and fold up during boarding and egress. Three galleys hold the gourmet dishes served to the first class passengers. Two lavatories in the aft section are reserved for first class passengers. The boarding and service doors double as emergency exits in the event of one.

Business Class

Business class begins aft of the first class lavatories and is separated by 8 galleys (serving both business and coach classes) and 2 pivot mechanism compartments. The front section of business class seats 144 passengers while the aft part of business class seats 24, coming to a total of 168 passengers. Business class is 3x3 with seat widths of 17.5 inches and seat pitches of 36 inches. This makes the RTJ-303 roomier than the 767-200's 32 inch pitch. Figure 10b shows the business class layout with one of its constant cross-sections. Five flight attendants serve the business class passengers. Four flight attendants' seats are located in one row just before the business class division at the longitudinal station of the right side emergency exit. The two seats on the side of the emergency exit fold up in case of one. The fifth flight attendant seat is located on the left side after the business class division. Eight galleys ensure that the coach and business class passengers are fed adequately, and four lavatories centered between first class and these galleys are considered to be more than adequate for the business class passengers. In the coach section of the RTJ-303 several more lavatories are allotted for the business class passengers. Altogether, there are three emergency exits in business class. One emergency door is located on the left side between business class rows 5 and 6, another is positioned on the right side just before the business class division, and a final emergency exit is placed on the right side just after the division.



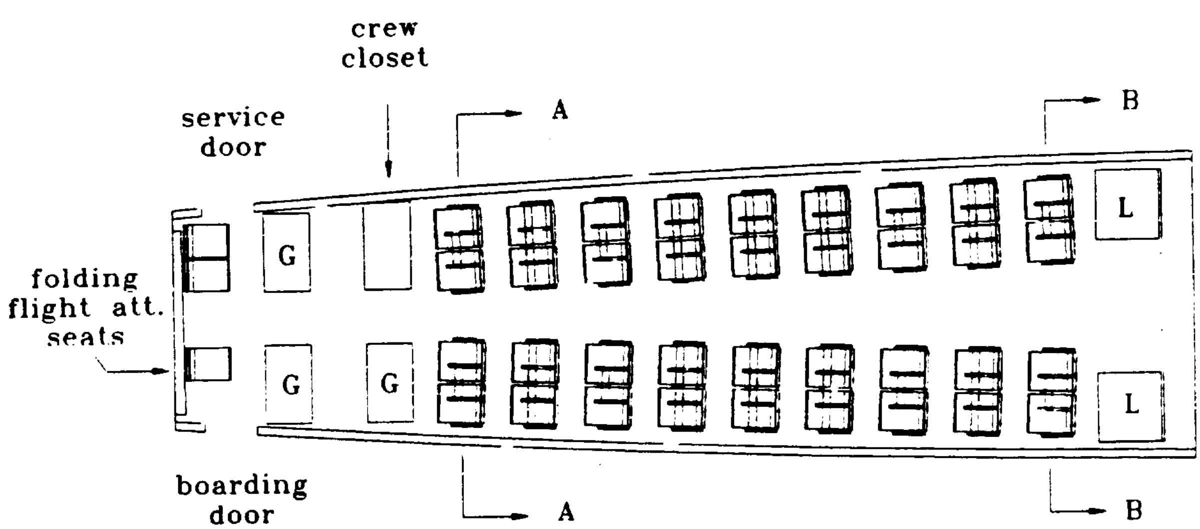


Figure 10a: FIRST CLASS SECTION

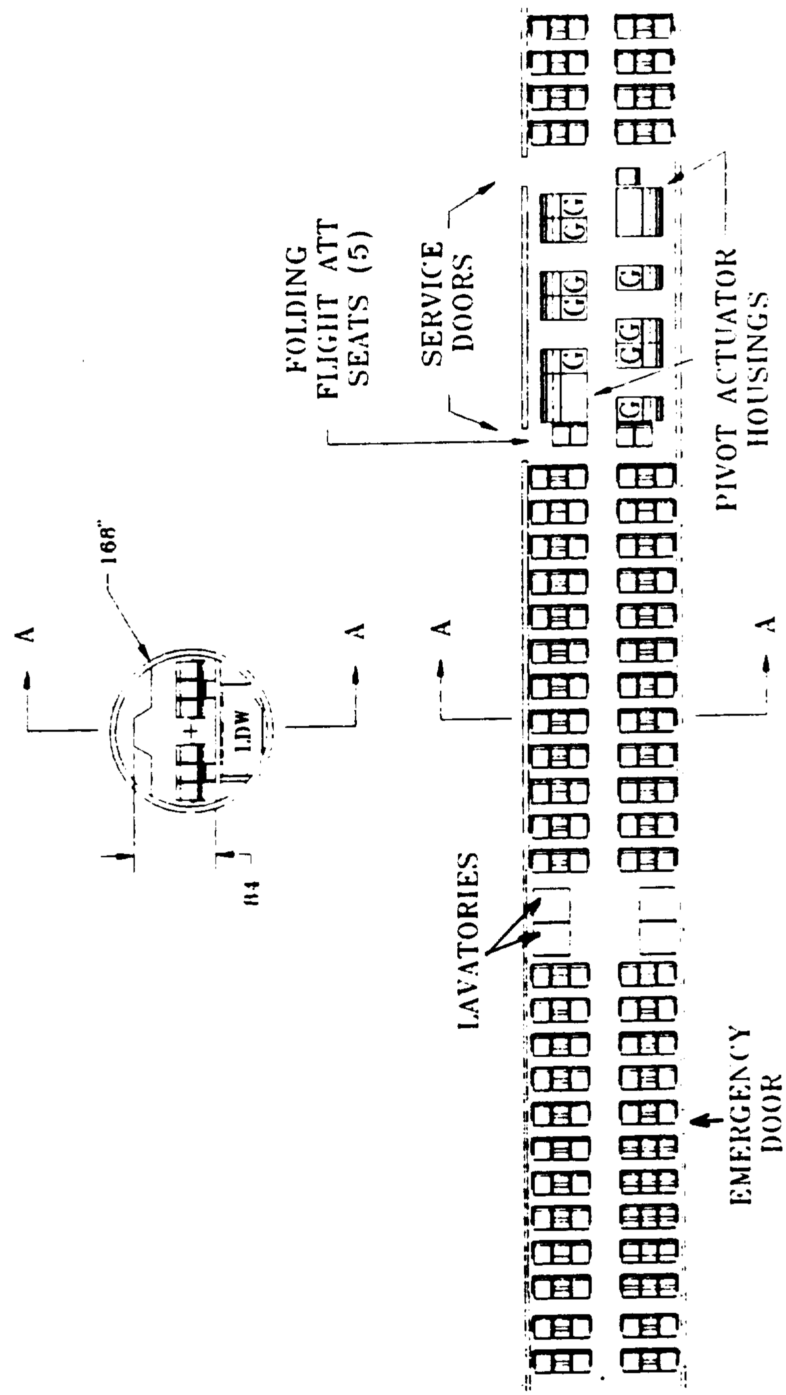


Figure 10b: BUSINESS CLASS SECTION

Coach Class

Coach class is located aft of the business section. This class seats 96 passengers and is 3x3 with seat widths of 16 inches and seat pitches of 32 inches (equal to the 767-200 coach class layout). Figure 10c shows the coach layout with selected cross-sections. Two flight attendants serve the coach class passengers. The flight attendants' seats are located by the aft boarding door and service door and fold up for boarding and egress. Six lavatories in the aft section are intended for coach and business class passengers. The boarding and service doors double as emergency exits in the event of one.

In summary, the single aisle and 3x3 seating keeps the maximum cross-section of the fuselage down to a 14 foot diameter (767-200: 16 foot diameter), giving the RTJ-303 a fineness ratio of 22:1. The RTJ-303, when fully loaded, carries 36 first class passengers in a 2x2 seating arrangement, 168 business class and 96 coach class passengers in a 3x3 seating, coming to a grand total of 300 passengers.

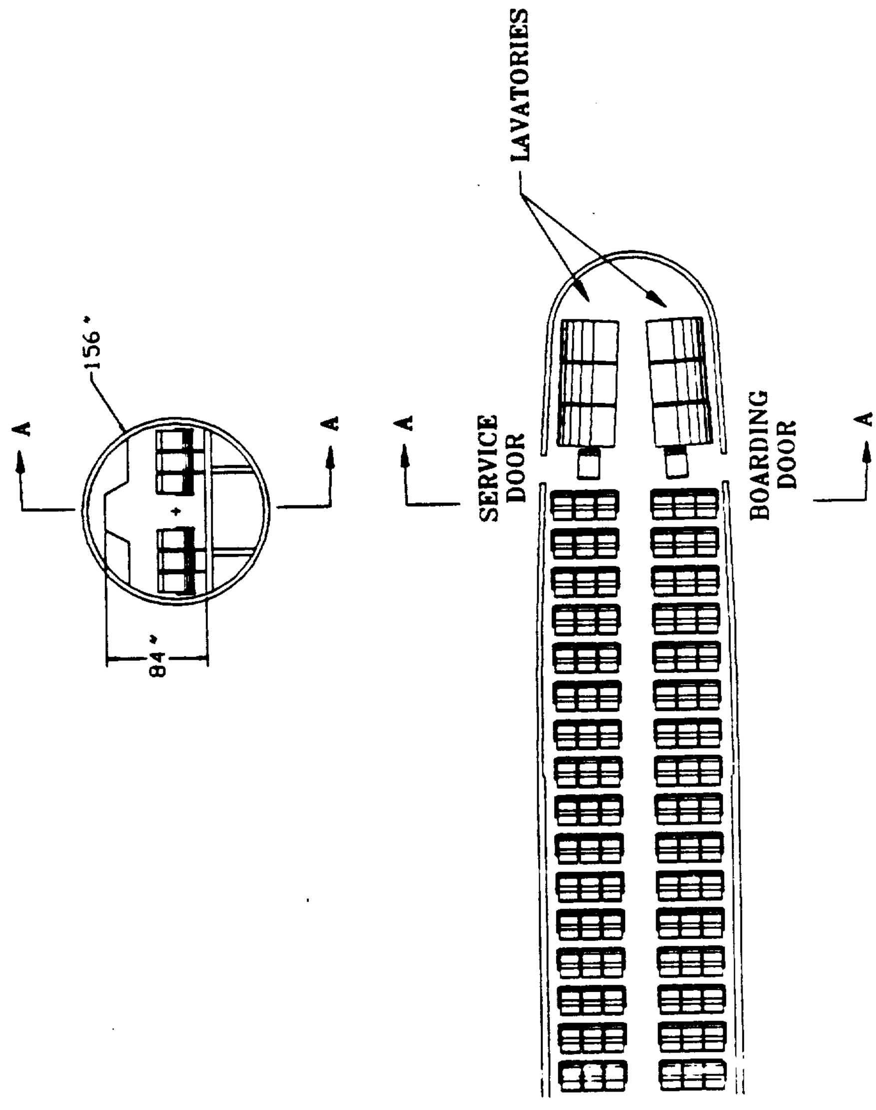


Figure 10c: COACH SECTION

EMPENNAGE DESIGN

The empennage was initially sized using the tail-volume coefficient method outlined by Roskam, Part II (Ref. 4), which compares the empennage volumes of a design with statistical data. For Roskam's Class I design tasks, the surface sizes were checked to see if they provided the required levels of stability and control, and revised using an X-plot as described later in this section. For class II design tasks, a complete estimation of the stability derivatives was used to determine if the surfaces were effective enough to provide the necessary control authority and required level of stability, as well as the gains required for the electronic control system. The surfaces were then adjusted as necessary to provide the required levels of the above.

Geometry

Figure 11 shows the layout of the vertical and horizontal stabilizers for the RTJ-303. The leading-edge sweep angles of the horizontal and vertical stabilizers are both 65 degrees in order to create subsonic normal components of Mach numbers across these surfaces and enable the efficient use of subsonic airfoil sections. The airfoil for both surfaces is the NACA 64-006. This airfoil was chosen to be consistent with the wing, making use of a high critical Mach number. The thickness ratio of this section was determined to be adequate for structural considerations and low enough to keep wave drag due to volume at a minimum. Since the empennage was not expected to carry fuel, an adequate structure could be maintained with a NACA 64-006 section. Therefore, a thin airfoil, such as the NACA 64-006, was chosen.

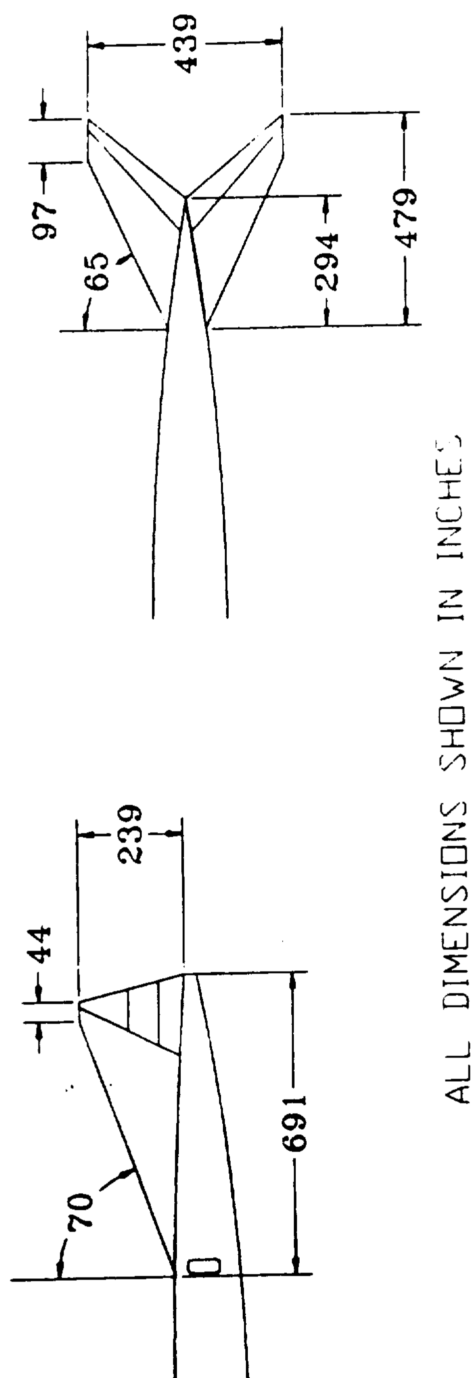


Figure 11: EMPENNAGE DETAIL

Horizontal Stabilizer

Significant parameters of the horizontal tail are summarized in Table 2. The airfoil section of the horizontal tail is uniform throughout and there is no twisting. The stabilizer has no incidence angle. It is a fixed incidence tail using elevators for longitudinal control power. The elevator chord is a constant 25 percent of the tail chord and covers the entire span of the tail.

Table 2: HORIZONTAL TAIL PARAMETERS

LE Sweep angle:	65 deg
Area:	625 ft^2
Planform:	arrow wing
Airfoil:	NACA 64-006
Elevator chord:	0.25c

Vertical Stabilizer

The airfoil section of the vertical tail is uniform throughout and there is no twisting. The significant characteristics of the tail are summarized in Table 3. The rudder chord is a constant 25 percent of the vertical tail chord and is segmented into three parts.

Table 3: VERTICAL TAIL PARAMETERS

LE Sweep angle:	65 deg
Area:	600 ft^2
Planform:	diamond delta
Airfoil:	NACA 64-006
Rudder chord:	0.25c

Empennage Sizing

Initial sizing of the empennage used the tail volume coefficients cited in chapter eight of reference 7 for the Boeing SST oblique wing study project. The size and location of the control surfaces were also initially sized using reference (3). The initial control surface sizes of 625 ft^2 for the horizontal, and 600 ft^2 for the vertical produced tail volume coefficients of 0.631 and 0.059 respectively. These values and other statistical values that were used to compare it to are listed in Table 4. Inspection of this table indicates that the volume coefficients are within the range, and near the upper end of values for other designs.

Table 4: STATISTICAL TAIL VOLUME COEFFICIENT COMPARISON

	WING AREA	WING MAC	WING SPAN	S_h	S_v	X_h	X_v	V_h	V_v
RTJ-303	5235	22.7	231	625	600	120	118	0.631	0.059
RA-5C	700	15.7	53	356	102	17.1	21.8	0.560	0.060
BOEING SST	9000	29	174	592	866	161	88.5	0.360	0.049
BOEING AST-100	11630	96.2	138	547	890	107	121	0.052	0.067
NASA SSX-I	965	30.6	42.1	65.0	75.0	47.2	38.3	0.100	0.071
NASA SSX-II	965	30.6	42.1	80.0	75.0	47.2	35.5	0.090	0.066
NASA SSX-III	1128	33.1	45.6	80.0	97.0	41.9	32.1	0.090	0.061
Tu-22M	1585	15.4	113	727	437	37.2	35.6	1.11	0.087
Tu-22	2062	23.7	90.9	620	376	34.7	29.6	0.440	0.059
F-111A	530	9.12	63.0	352	115	17.6	18.6	1.28	0.064
B1B	1950	15.8	137	494	230	49.9	45.8	0.800	0.039

Figure 12 is the longitudinal X-plot for the RTJ-303 showing the stable static margin of 1/2% for this tail area. The X-plot shown is that for a full passenger load which produces the most forward center of gravity. Reductions in passenger load will cause an instability in the RTJ-303 which will require a fly-by-wire feedback control system. This characteristic is discussed further in the stability and control section of this report.

The resulting vertical tail area is a minimum value such that the RTJ-303 has de-facto directional stability with a sideslip to rudder feedback gain less than the maximum 5 deg/deg . The vertical tail and rudder combination are still such that the magnitude of the directional control surface deflection is still within acceptable levels as discussed in the section on stability and control.

The elevator and rudder chords as a percentage of the corresponding empennage chords were determined from reference 7 using the most inboard value and keeping the chord value constant along the span of the empennage for simplicity. The resulting control surfaces sufficient for lateral and directional control.

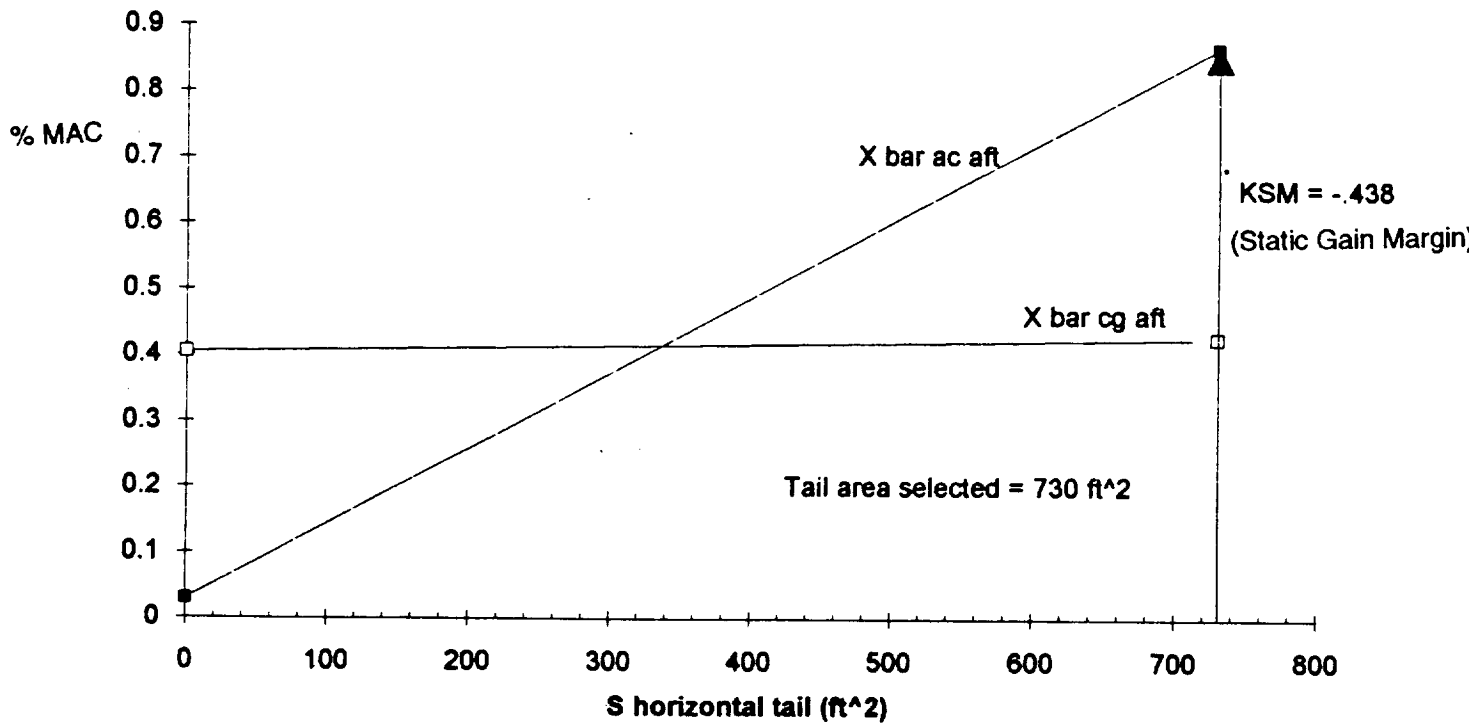


Figure 12: LONGITUDINAL X-PLOT

PROPULSION SYSTEM

Power Plant Selection

Since industry does not yet have an off-the-shelf propulsion system that is capable of meeting the FAR 36 Stage III noise regulation and the required low specific fuel consumption (SFC), most of the selection process relied on reports from current studies and wind tunnel tests of proposed production engines. In the selection of the propulsion system, high emphasis was placed upon fuel economy, engine emissions, and noise levels. These factors are directly related to two of the main problems that made the Concorde an economically unacceptable venture.

A variety of propulsion systems were considered for RTJ-303. After a preliminary study of many propulsion systems, the SNECMA ATAR 9K50 Turbojet Engine, Pratt & Whitney Turbine Bypass Engine, Rolls Royce Tandem Fan Engine, and NASA Lewis Mixed-Flow Turbofan Engine were considered further for fuel efficiency, noise level, and thrust to weight ratio. Table 5 shows the performance comparison data of these four engines. This comparison of these engines is based on the required net thrust of 48,800 lb. at takeoff.

Table 5: ENGINE PERFORMANCE DATA COMPARISON

	Weight	Inlet Diameter	Overall Length	TSFC Cruise	TSFC Takeoff	Noise Level Compatibility
SNECMA ATAR 9K50 Turbojet	18,400	6.1 '	35.7 '	1.3	.97	very poor
P&W Bypass Turbine	17,400	6.25 '	34.1 '	1.2	.8	unknown
R.R. Tandem Fan	17,000	5.76 '	40.9 '	1.17	.618	unknown
NASA Lewis Mixed Flow TF *	**15,800**	**5.8 '**	**34.5 '**	**1.08**	**.808**	**satisfactory**

* **ENGINE SELECTED FOR DESIGN**

After maximizing the tradeoffs, the NASA Lewis Mixed-flow Turbofan was selected for its expected lowest noise level and specific fuel consumption at cruise which is the most dominant flight regime. The thrust to weight ratio was also competitive. Figure 13 shows the schematic of the Mixed-Flow Turbofan Engine/Inlet with the inlet diffuser.

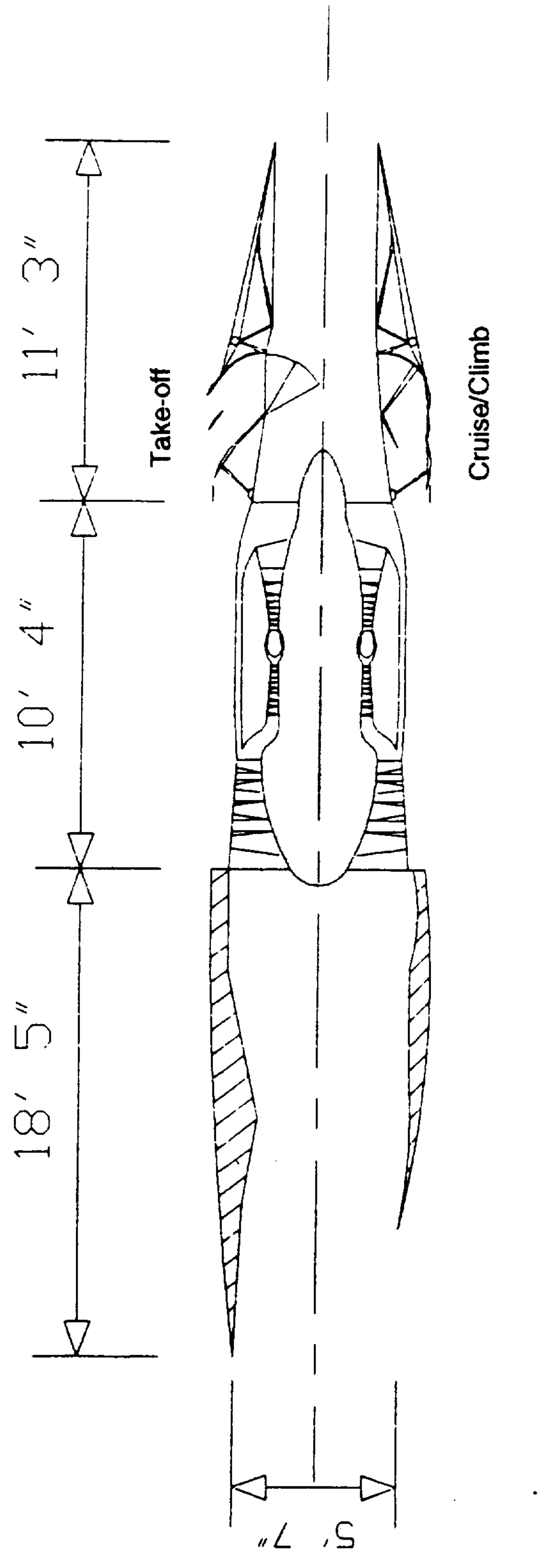


Figure 13: MIXED-FLOW TURBOFAN ENGINE SCHEMATIC

The top section of the figure shows the takeoff position with the mixer and ejector nozzle in operation. The bottom portion of the figure shows the operation in climb and cruise conditions with the ejector stowed away. Table 6 lists the performance and dimensions of the Mixed-Flow Turbofan.

Table 6: MIXED FLOW TURBOFAN SPECIFICATIONS

Takeoff Thrust per Engine	48800 lb.
Total Weight per Engine Including Inlet and Nozzle	15700 lb.
Overall Length Including Inlet and Nozzle	40.0 ft
Inlet Diameter	5.58 ft
TSFC Cruise	1.08
TSFC Takeoff	0.808

According to NASA-Lewis, the noise level of this engine can be assumed to be 5 EPNdB below FAR 36, Stage III levels, which makes this engine ideal for operation in an HSCT. The emissions from the mixed-flow turbofan were studied to examine if any damage will be done to the atmosphere. The stratospheric ozone layer which is at about 60,000 ft. at most locations is at least 10,000 ft. higher than RTJ-303's cruise altitude. Even though there is no emission standard that needs to be met momentarily, RTJ-303 will be able to meet most stringent emissions standard that might be imposed in the future.

Engine Disposition and Inlet Integration

The unique oblique wing design of the RTJ-303 has made engine disposition difficult, if impossible to mount on the wing. Mounting the four engines on the wings was considered. However, the engines had to be mounted on a structure that would rotate as the wing rotated into the swept position. The structural weight penalty of additional pivots, and the possibility of pivot failure ruled out this option. The next option considered was placing the engines on the fuselage sides about halfway between the tail and the wing. This method of engine placement was used on several airliners such as the Boeing 727, McDonnell Douglas DC-9, BAC 111, and the Fokker F-28. Reference 8 indicated that with a pusher configuration, this position is best in terms of acoustics and installation drag. Figure 14 shows the installed engines. Two pods containing two engines were placed in a position so that if a fan or turbine blade were to be lost, it would not damage any vital mechanism on the aircraft such as the pivot or control surfaces, or the other set of engines. However, the possibility of one engine uncontained failure taking out the engine right next to it can not be ruled out. Two engines inoperative analysis suggested in reference (1) was performed and the result shows that the aircraft would be able to continue flying safely if this rare incidence were to occur. The pods will be mounted on a pylon that will extend the engines outside the fuselage boundary layer. This insures that the boundary layer flow will not be fed to the inner engine. The length of the engine pods was determined using the curve of reference 9 in order to minimize interference drag between the engine pods and the fuselage. This curve shows a large reduction in interference drag for y/D_n (distance between engine and fuselage / engine diameter) values up to about 0.5, after which a longer pylon does not pay off due to the increasing structural weight of a long pylon. Pylon lengths of three feet were chosen. The two sets of engines will also be staggered to insure similar inlet conditions when the wing is in the swept configuration.

The major challenge of installing the engines was accounting for the structural bending moment that had to be transferred into the fuselage. Each engine pod weighs over 30,000 lb. and has a pylon length of 3 feet which creates a large bending moment. In order to transfer this bending moment, a relatively thicker structural members were required at the sections of the fuselage where the pods are mounted. For the engine on the left side, this was lesser of a problem because there were structural members there already to carry the pivot loads into the fuselage. For the front engines, there was more structure required to be integrated into the frames. Lavatories were located at these sections that carried the engines to provide a room for a thicker member without having to remove passenger seats. In addition, the walls of the lavatories and the galleys are used as the integral member of these thick structural members.

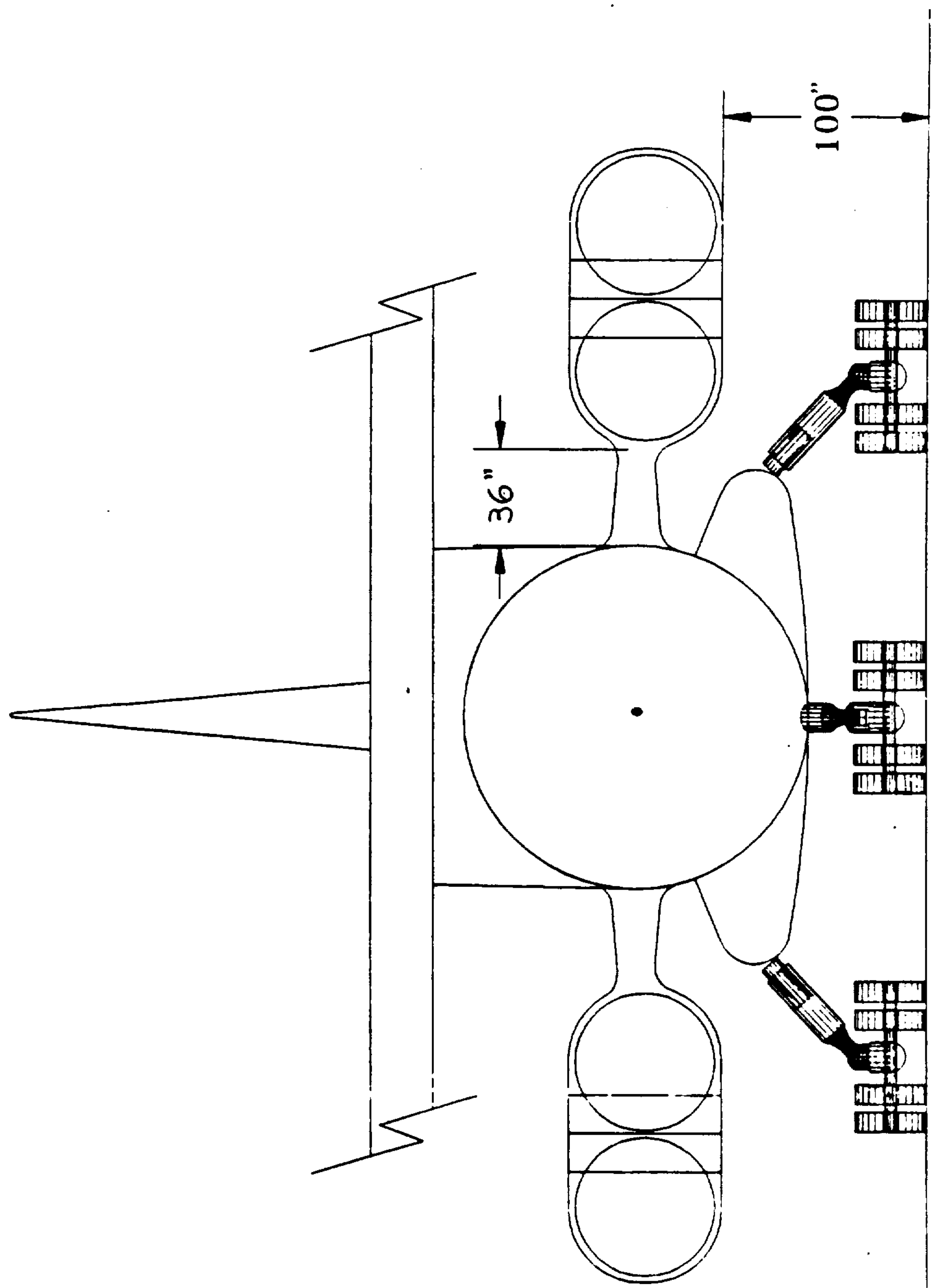


Figure 14: ENGINE LOCATION

Inlet Design

Since the diffuser is responsible for about 75 percent of the installed thrust at cruise condition, diffuser design was extremely critical. The major issue considered on inlet design was high pressure recovery. The pressure loss in an inlet makes the life and performance of the engine very difficult. For these reasons different inlet design options were considered. Since RTJ-303 is a Mach 1.6 aircraft, a pitot (1 shock) inlet was one of the options considered with pressure recovery of 0.93. However, three-stage ramp inlet was chosen for its better recovery factor. The pressure recovery factor for this inlet was calculated to be over 0.97 for all flight conditions which is the ceiling of good inlet design suggested by reference 10. The three stage inlet will have two oblique shocks (8 deg & 10 deg) followed by a normal shock. A boundary layer diverter was not necessary to ensure proper inlet operation. The boundary layer thickness at the most aft pod (worst case) was calculated to be 2.1 ft. Since there is a three foot pylon extension between the fuselage and the pods, which was designed for the lowest interference drag, the engine inlet conditions should not vary noticeably.

LANDING GEAR DESIGN

Three major landing gear types were studied: tricycle, bicycle, and tailwheel arrangements. The gear layout chosen for the RTJ-303 was a tricycle type as found in most commercial aircraft. This gear configuration was decided upon due to the benefits of tricycle gears over the other types of landing gears. Unlike tailwheel gears, the fuselage remains relatively level, which is important for loading cargo and passengers. This ruled out the use of a tailwheel configuration. Another advantage of the tricycle gear is the fact that the available takeoff rotation angle is favorable. Finally, the weight of this type of gear, although greater than that of a taildragger, is less than that of a bicycle gear (Ref. 11) as used in the B-52. Since weight is a driving factor in the design of any commercial transport, the tricycle configuration was chosen over the bicycle gear. From the weight and balance spreadsheet in the appendix, the overall landing gear weight was calculated to be 42000 lbs, or 6% of the gross takeoff weight.

Conventional long range aircraft have long used fully retractable landing gear for reasons of drag minimization. The landing gear of the RTJ-303 must be fully retractable and should have minimal frontal area in order to minimize drag.

It is expected that the RTJ-303 will operate from major airports only, and the gear is therefore designed for Type 2 and 3 surfaces (runways with flexible or rigid pavement).

It was determined that for a 720,000 pound aircraft at least three main struts were needed to distribute the load of the plane onto the runway without damaging the surface. As the number of gears are increased, however, the weight of the gear layout also rises. In order to keep the weight of the aircraft to a minimum, the three-strut main gear configuration was chosen. The maximum shift in the CG of the aircraft calls for a single nose gear able to support up to 13% of the aircraft's total takeoff weight. The range of nose gear loadings for the shift in CG is between 9% and 13% of the gross takeoff weight. This is above the recommended minimum 8% for steering purposes and below the maximum 15% based on structural constraints (Ref. 11).

Tires:

In order to reduce maintenance costs on the tires, all tires for the nose and main gears were chosen to be of the same size and type. As a result of this decision, the nose gear is slightly "overdesigned". However, the savings in maintenance and training costs were thought sufficient to justify the use of the same size and type wheels for the main and nose gears. The specifications on the B.F. Goodrich tires used on the RTJ-303 are given in Table 7 below.

Table 7: TIRE SPECFICATIONS

TIRE DIMENSIONS		TIRE DATA		
outside diameter	width	maximum loading	unloaded inflation pressure	maximum speed
34.5 "	9.75"	30,100 lb	340 psi	259 mph

With the maximum loading per tire known, eight tires per main gear truck and six tires for the nose gear are required. The landing gear allows for an aircraft weight increase of 10%, which is less than the recommended 25% growth factor (Ref. 11), but this aircraft is not expected to undergo much additional upscaling, since it is already 325 feet long and is at the limits for airport compatibility.

Shock Absorbers

The shock absorbers were designed for the FAR specified sink rate of 12 fps. The maximum shock compression of the nose gear is 54 inches, whereas the main gear is 10 inches. Shock absorber diameters were calculated to be 14.6 inches for the main struts and 11.8 inches for the nose gear.

Landing Gear Positioning

Since the RTJ-303 is a high wing configuration which swings for supersonic flight, the landing gear was restricted to be housed in the fuselage. Wing mounted landing gear was judged impractical if not impossible due to retraction kinematics and possibility of the pivot locking in the swept position. This lateral restriction as well as the vertical clearance imposed on the landing gear by fuselage rotation causes the tip-over criteria to become a driving factor in the location of the outside main gears. A rotation angle of 4° was found to be the absolute minimum required for takeoff. For reasons of safety, the rotation angle was increased to 6° as shown in Figure 15. Since the longitudinal location of the main gear is known, the ground clearance could be determined. This in turn yielded the minimum lateral distance of the outside main gear in order for the RTJ-303 to be below the critical tip-over angle of 63° designated for transports (Ref. 11). The outside main gears (on the ground) were placed at 13' 11" from the centerline of the fuselage, yielding a tip-over angle of 54.2° as shown in Figure 16. However, since the fuselage extends only 7 feet beyond the fuselage centerline, the housing for the landing gear pivot needed to be faired. In order to reduce this fairing, the landing gear was pivoted in such a way that the shocks are angled outward in the static position. This moves the lateral location of the pivot inward by 4.5 feet.

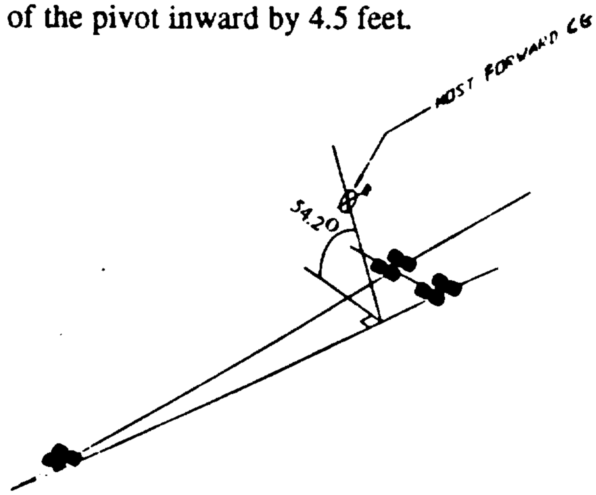


Figure 16: TIP-OVER CRITERIA

Landing Gear Retraction

The two outside main gears retract inward and are housed next to each other in the faired belly of the fuselage. The center main gear as well as the nose gear retract forward. Retraction sequences for the nose gear and main gears are shown in Figure 17. All gear retractions are carried out by rotary actuators, which torque the two main links to their final positions. In case of actuator failure, the nose and center main gears can free-fall and lock into position. The two outside main gears free-fall to the vertical position where vanes force the gears into the final locked positions, utilize the freestream dynamic pressure.

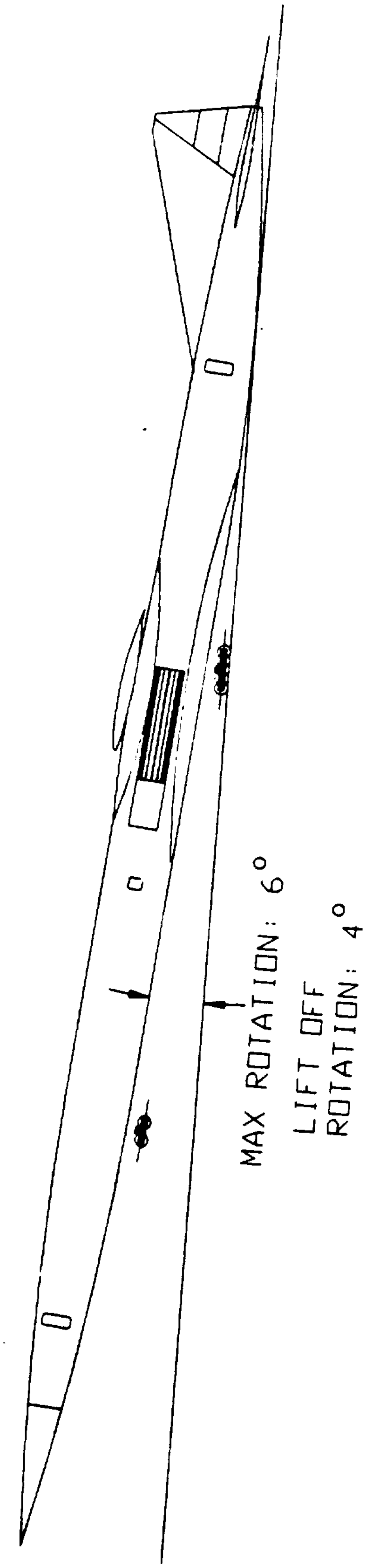
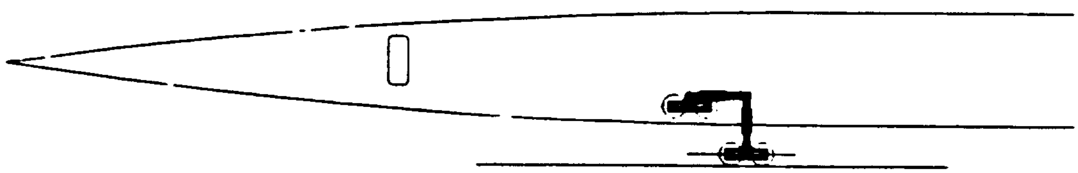
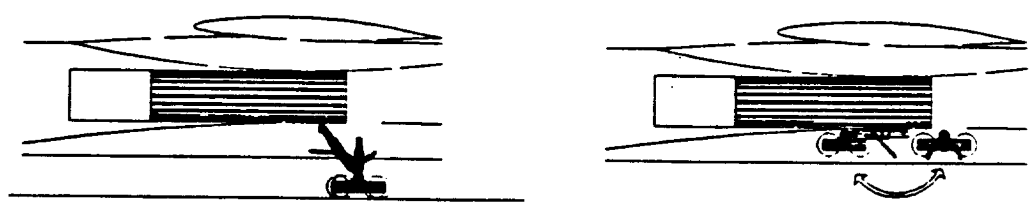


Figure 15: ROTATION ANGLES



NOSE GEAR - SIDE VIEW



MAIN GEAR - SIDE VIEW

MAIN GEAR - FRONT VIEW

Figure 17: LANDING GEAR RETRACTION SEQUENCE

STRUCTURES

Figure 18 shows the V-n diagram for the RTJ-303. Since the configuration is one of variable geometry, the V-n diagram shows gust loadings and maneuver loadings for both subsonic and supersonic cases. The figure shows that the aircraft is designed for maneuvering loads at airspeeds above 180 knots equivalent airspeed and gust loadings below that speed.

Many of the structural features of the RTJ-303 are similar to existing subsonic aircraft. The constant cross section of the fuselage, along with the fact that stagnation temperatures are low, enable the design to utilize most of the materials and methods of current aircraft. This also will reduce design and production costs since the technology level to be used is current, and research efforts can be minimized. The exception to this is the wing structure which is to be entirely co-cured from a carbon/epoxy composite.

Fuselage

Figure 19 shows the structural layout of the fuselage. Frame depths were determined using statistical parametric equations. These values were then increased to account for the higher stresses expected due to the long and narrow fuselage. Since there is a very high stress concentration at the pivot location and added structural support is needed to hold the engines and main landing gear, the frame depths were increased in the section between the right and left engines to 6" from the otherwise 4.5" depths (Ref. 12).

The frame spacings were determined using statistical data. The frame spacing range for current commercial transports was given in Reference 12 to be between 18 and 22 inches. The higher end of the statistical range was used for the front section of the fuselage since relatively low moments are expected in this section. In order to carry the concentrated loads of the engines, landing gear, and pivot assembly into the fuselage, the frame spacings were reduced to 16" at the pivot section. In the aft section, the frame spacing was determined to be 18" to carry the moments generated by the empennage.

Longeron spacings for the fuselage were determined using statistical data for current transports. The same criteria used in determining frame spacings (front-lighter structure, pivot-reinforced structure, aft-somewhat reinforced structure) were applied

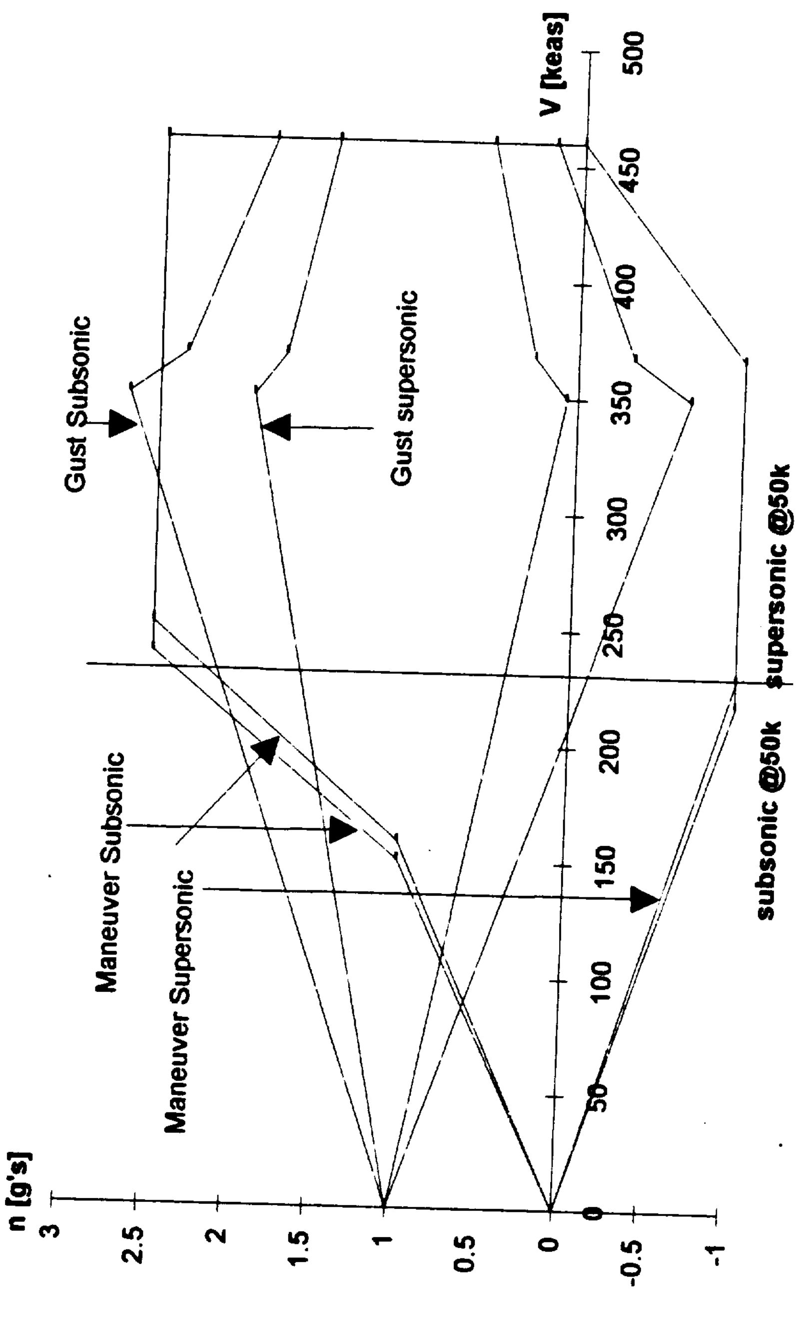


Figure 18: V-n DIAGRAM

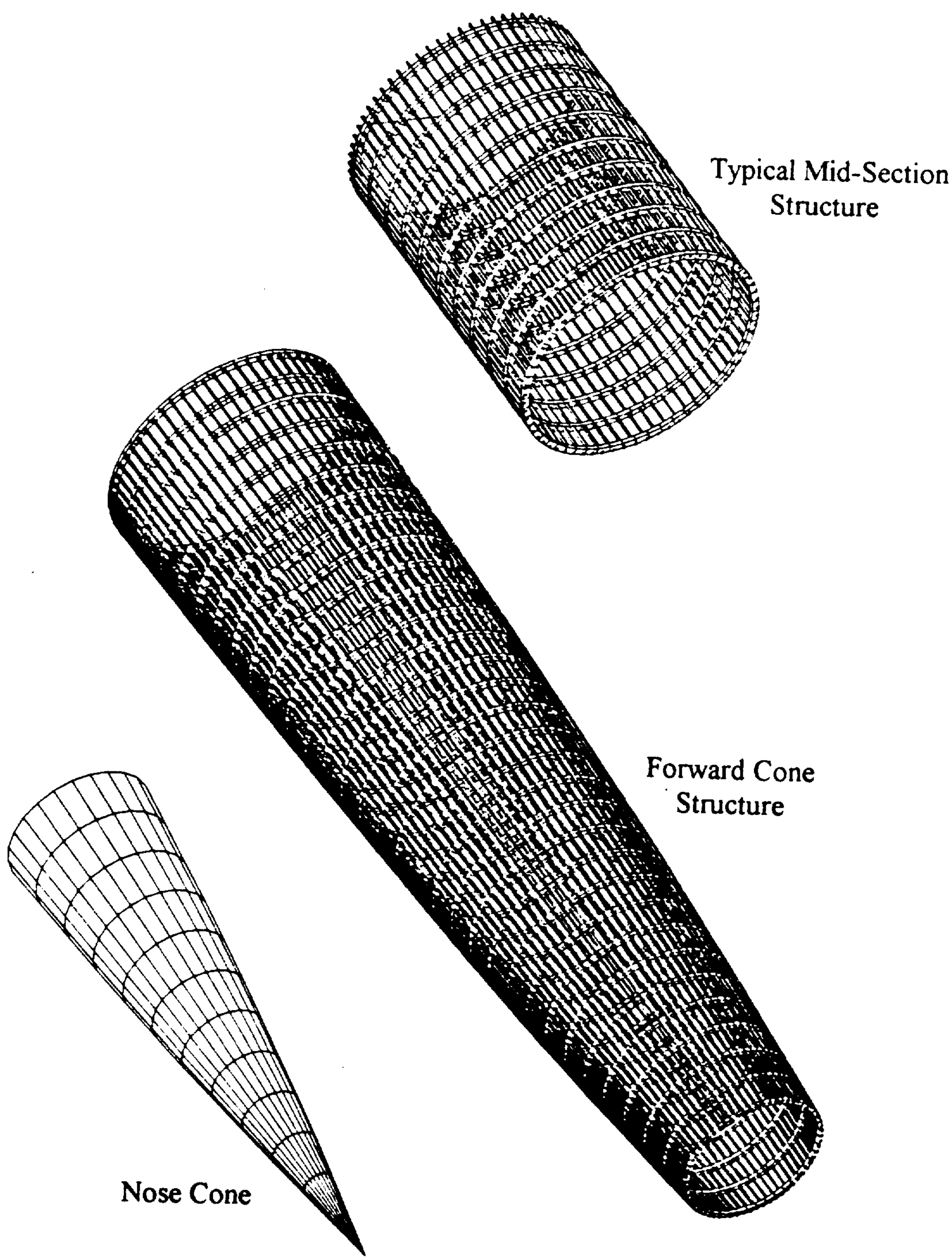


Figure 19: STRUCTURAL LAYOUT OF THE FUSELAGE

for the longeron spacings in the various sections. The final spacings were determined by the smallest required spacing (needed at the pivot section), since the longerons run along the entire length of the fuselage. The spacings turned out to be 8" at the maximum diameter of 14 feet (Ref. 12).

Wing

The unique loads encountered in the wing of this design require a unconventional wing structure. Due to the high aspect ratio wing, the bending moments encountered along the span are unusually high for supersonic transports. This coupled with the radical asymmetric twisting caused by the oblique sweep of the wing calls for an aeroelastic structural tailoring that is best addressed with the use of unidirectional fiber composites.

The entire wing structure is composed of carbon fibers in an epoxy matrix, due to its inherent tailorability of directional strength properties. The wing box was designed to carry the spanwise bending loads through its vertical spars and the stabilized skin. The torsional loads are carried by the skin over the wing box and around the leading edge D-section. Due to the fact that the forward swept wing tends to wash in and diverge, and the aft swept wing wants to wash out, the elastic axis was tailored via fiber orientation to provide the maximum resistance to these tendencies. Figure 20 shows this fiber orientation of the wing skins. As the forward swept wing encounters the divergence tendency and the wing begins to bend and twist upward, the fibers in the lower skin go into tension, creating a restoring twist which will aerodynamically create a restoring bending force, tending to return the wing to its original unbent untwisted state. The offset angle of the fibers from the quarter chord line was estimated at approximately 8^{o}. This angle was defined by a single fiber connecting the leading edge of the tip of the wing box to the trailing edge of its root, thereby maximizing the restoring force of the deflected wing. The same fiber orientation angle continues through to the aft swept wing, connecting the leading edge of the root of its wing box to the trailing edge. This creates an effect just the opposite of the forward swept wing, namely a restoring force which compensates for the wash out tendency of the aft swept wing. The combination of high strength composites and unidirectional fiber orientation attempts to return an asymmetric aeroelastic phenomenon to that of a more symmetric one.

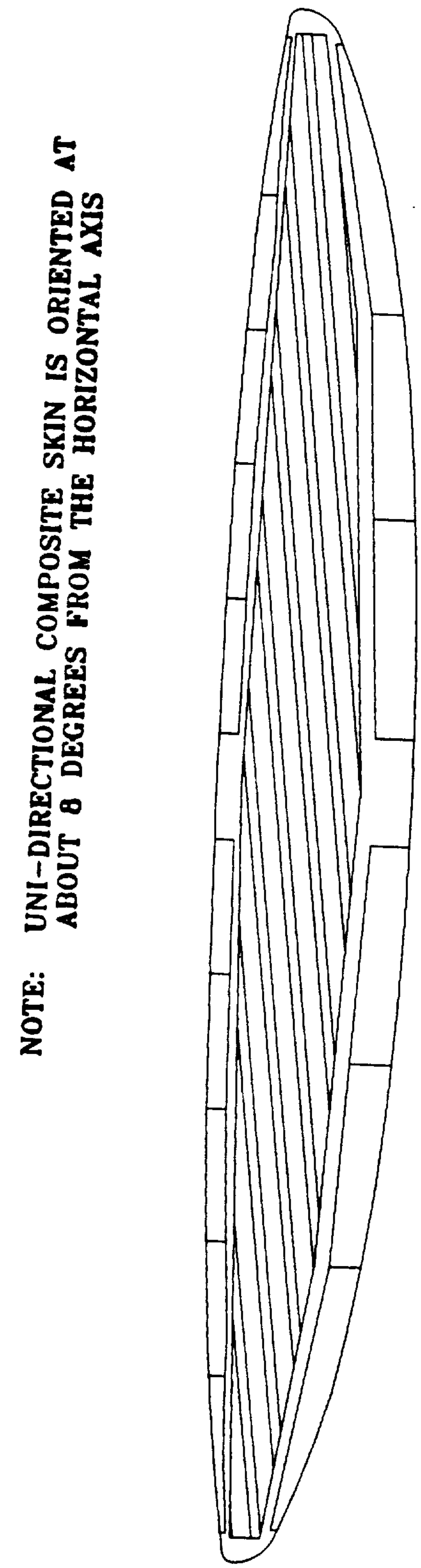


Figure 20: SKIN FIBER ORIENTATION

The wingbox detail is shown in Figure 21, and its cross section in Figure 22. The skin is stabilized with stringers running along the span, and with chordwise ribs. The wing loads were calculated using an aerodynamic load determining application called Lin Air. (Ref. 13) The local lift forces were integrated to determine the spanwise bending moments in order to determine the minimum required structural area properties. A bending moment of 626 million inch pounds was determined to exist at the wing root at n = 2.5 g's requiring an area second moment of inertia of 22 thousand in^4 to safely carry the bending (allowable stress = 450,000 psi).

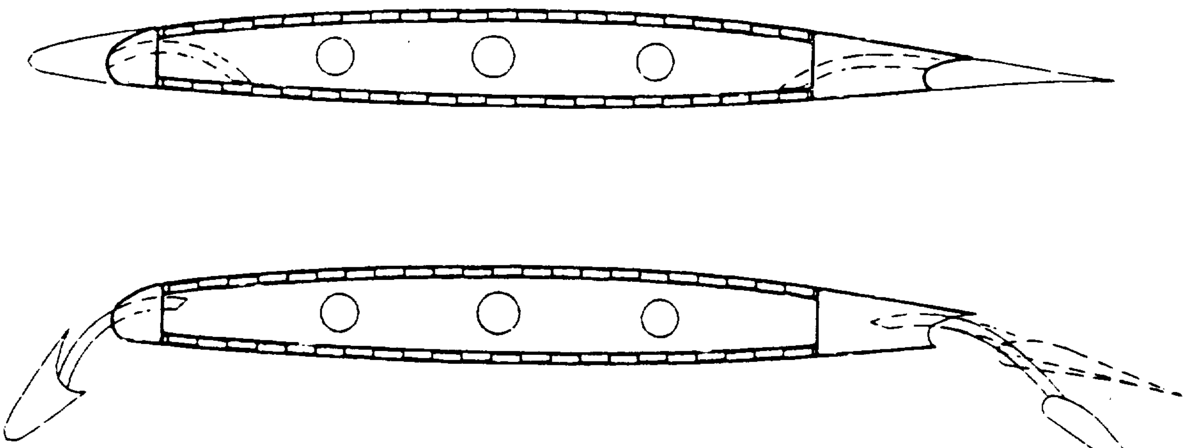


Figure 22: STRUCTURAL CROSS-SECTION OF THE WING

Pivot

The pivot structure (shown in Figure 23) is integrated directly into the fuselage frames via the vertical sections shown, to transfer lifting loads from the wing to the fuselage. Tie-ins to the longerons are at the forward and aft sections of the lower pivot structure, and serve to transfer the drag loads of the wing into the fuselage. Pivot shear loads are carried to the fuselage by the stabilized skin on the sides of the vertical lift-carrying frames. Torsional pivot loads in the yaw direction are carried by the pivot jack-screws to their actuators, to the fuselage through the actuator mounting bolts. The area around these bolts is reinforced to distribute the stresses. Wing loads are distributed into the upper pivot structure by the wing box, as they are co-cured as a single structure. The pivot diameter was made as large as practically possible to transfer the wing loads into the fuselage as efficiently as possible, with the minimum structural weight. The diameter at the wing is the dimension of the wing box chord at the wing root. Any greater pivot diameter at this point would not be carrying any load, and would be excess weight.

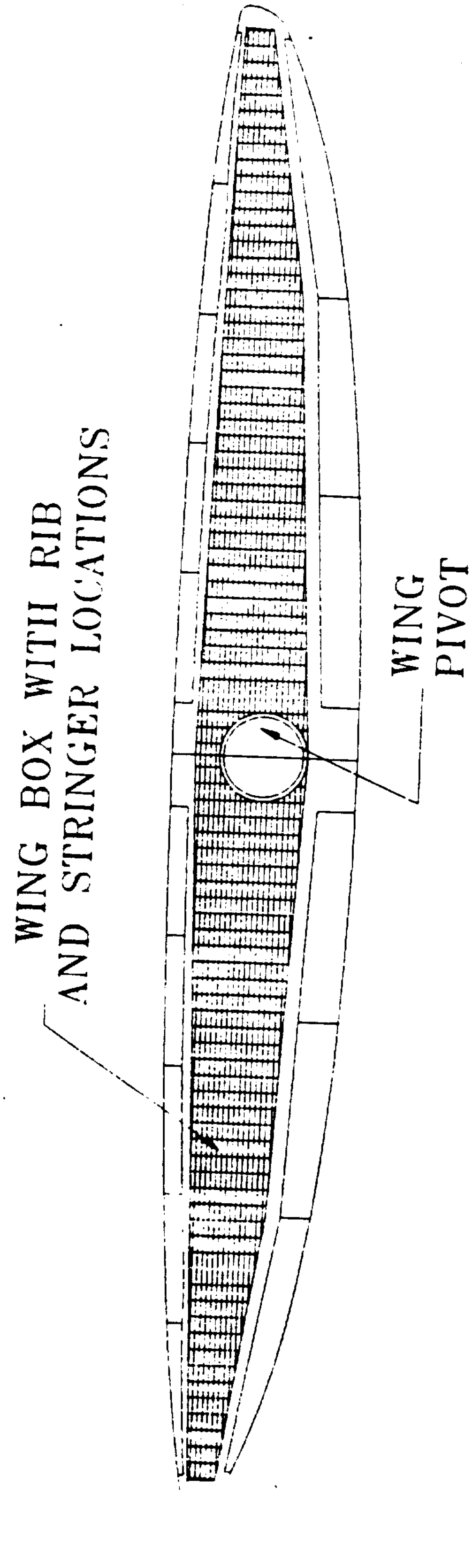


Figure 21: WING BOX DETAIL

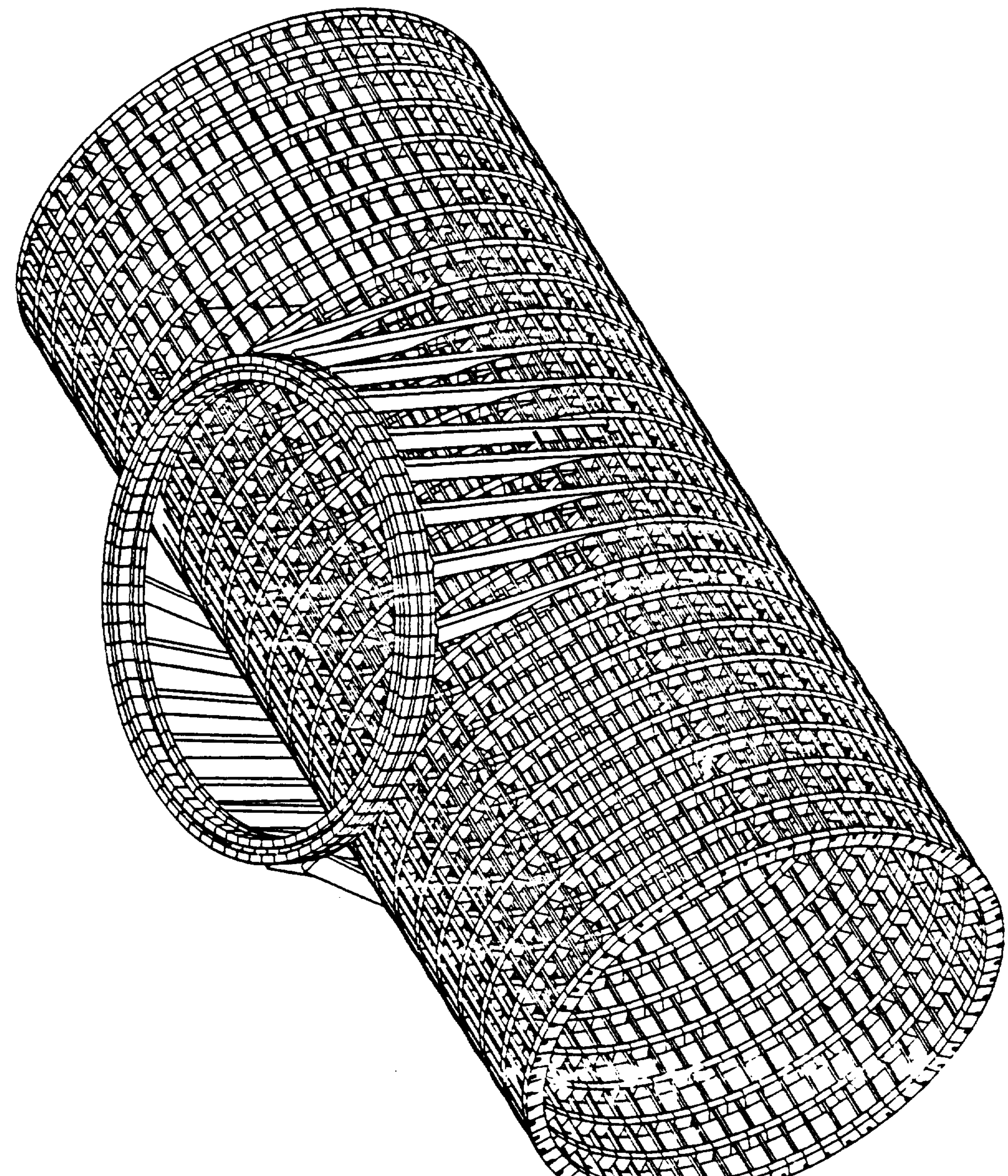


Figure 23: PIVOT STRUCTURE DETAIL

Pivot Bearing

In designing any swing wing, the actual point about which the wing swivels is obviously a major area of analysis. The pivot bearing chosen for the RTJ-303 was the same one chosen by BOEING in their report (Ref. 14). The bearing design is a highly complex analysis, and BOEING has done by far more research than was possible in the time alloted to this design team. The fail safe nature of the pivot and the self-lubricating characteristics of BOEING's chosen Teflon-coated bearing (see Figure 24) seemed ideal for the RTJ-303's flight demands.

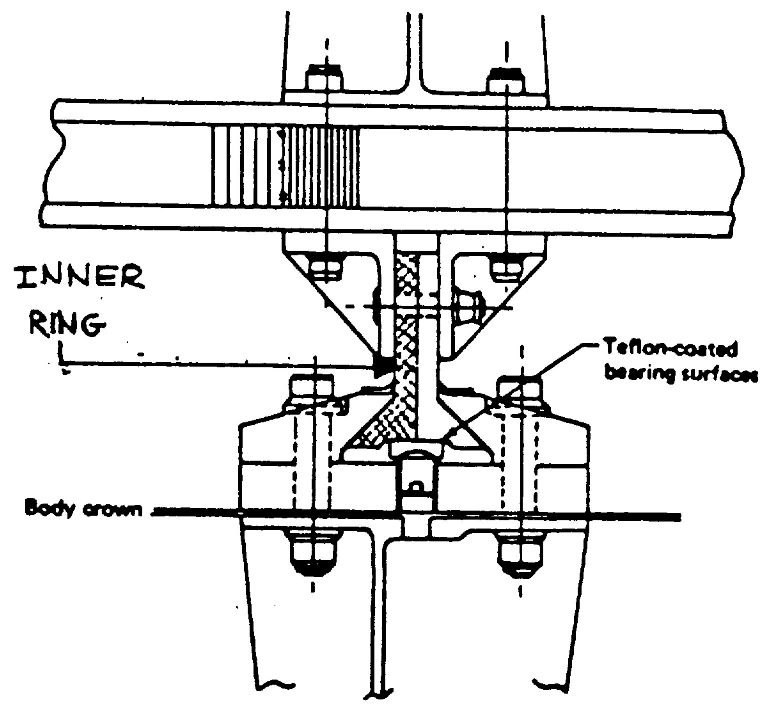


Figure 24: PIVOT BEARING DETAIL

Control Surfaces and Material

All horizontal control surfaces have similar structural arrangements. The fixed portions are built up with ribs, spars, longerons, and stressed skins, all from aluminum sheet metal. The control surfaces are honeycomb cores with carbon skins. Figure 25 shows the material layout for all major structures.

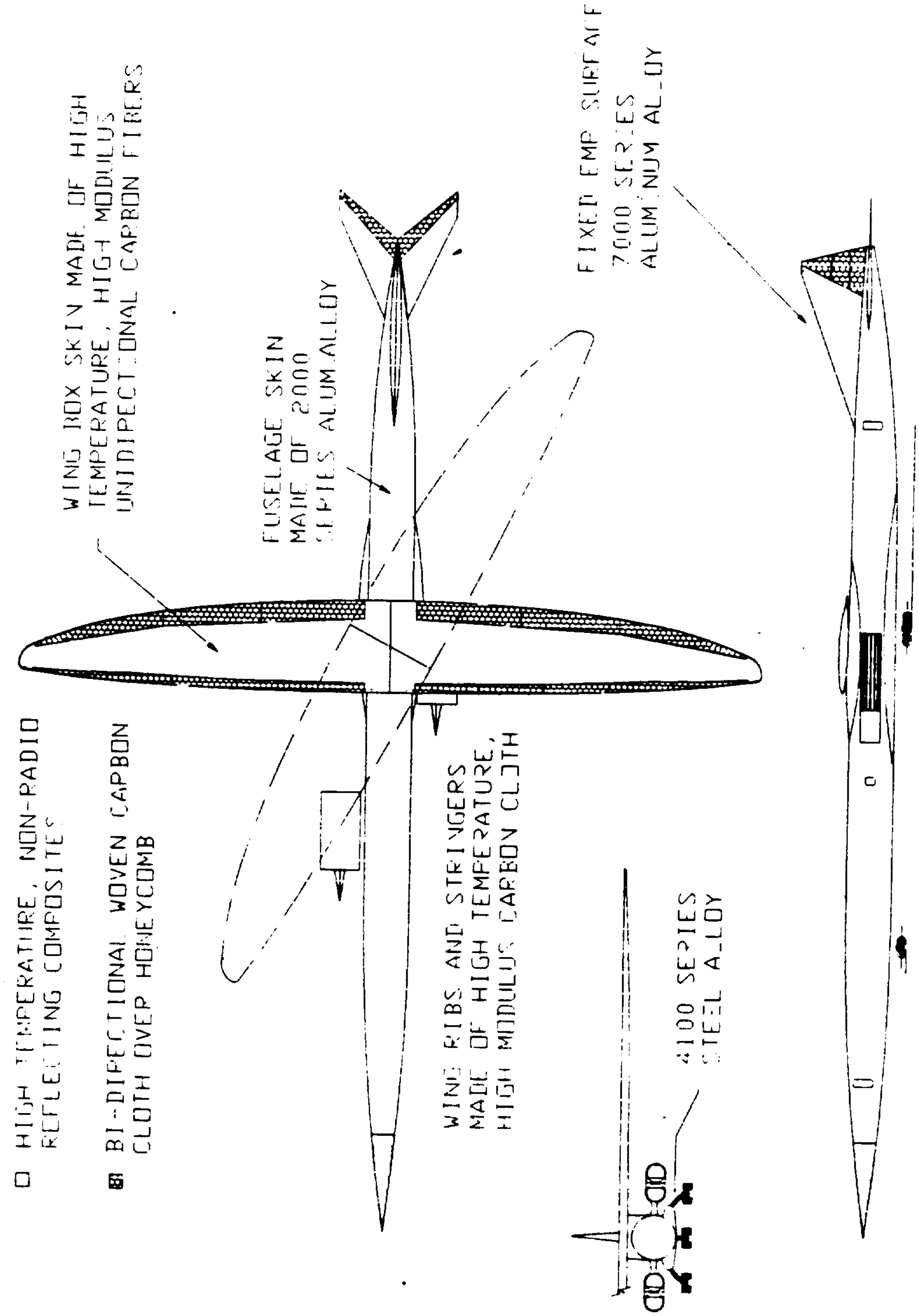


Figure 25: MATERIALS LAYOUT

PERFORMANCE

Drag Polars

The drag of the RTJ-303 should be minimized by varying the wing geometry during flight for various flight regimes. Figure 26 shows the optimum leading edge sweep angle versus Mach number. The optimum wing sweep is zero degrees until the free stream Mach number approaches the drag divergence Mach number of the airfoil section. Thereafter, the optimum sweep angle is defined as that sweep angle for which the section drag curve has a minimum just before the drag divergence. The figure is a locus of the sweep optimum sweep angles for varying Mach numbers generated by plotting points.

The RTJ-303 drag polars for various mission configurations are shown in Figure 27. A comparison of the subsonic and supersonic cruise drag polars shows the relative increase in drag per unit increase in lift for the supersonic case. The subsonic cruise drag polar includes the parasite drag, drag due to lift, and interference drag. The supersonic drag adds the wave drag due to volume and lift at the cruise Mach number to the subsonic drag polar.

The lift to drag ratios for each of the mission configurations, as determined from the drag polars, are summarized in Table 8. The highest lift to drag ratios occur at subsonic cruise. The subsonic cruise L/D is one of the best performance advantages of the variable sweep wing. The restrictions on sonic boom over land require subsonic flight overland. For routes that divert part of the flight over land, the variable sweep HSCT is more efficient than a conventional delta wing. The supersonic cruise L/D is comparable to those for conventional delta wings.

Table 8: RTJ-303 LIFT TO DRAG PERFORMANCE

	L/D
Takeoff	10.1
Climb	13.1
Supersonic Cruise	9.5
Subsonic Cruise	17.5
Landing	7.9

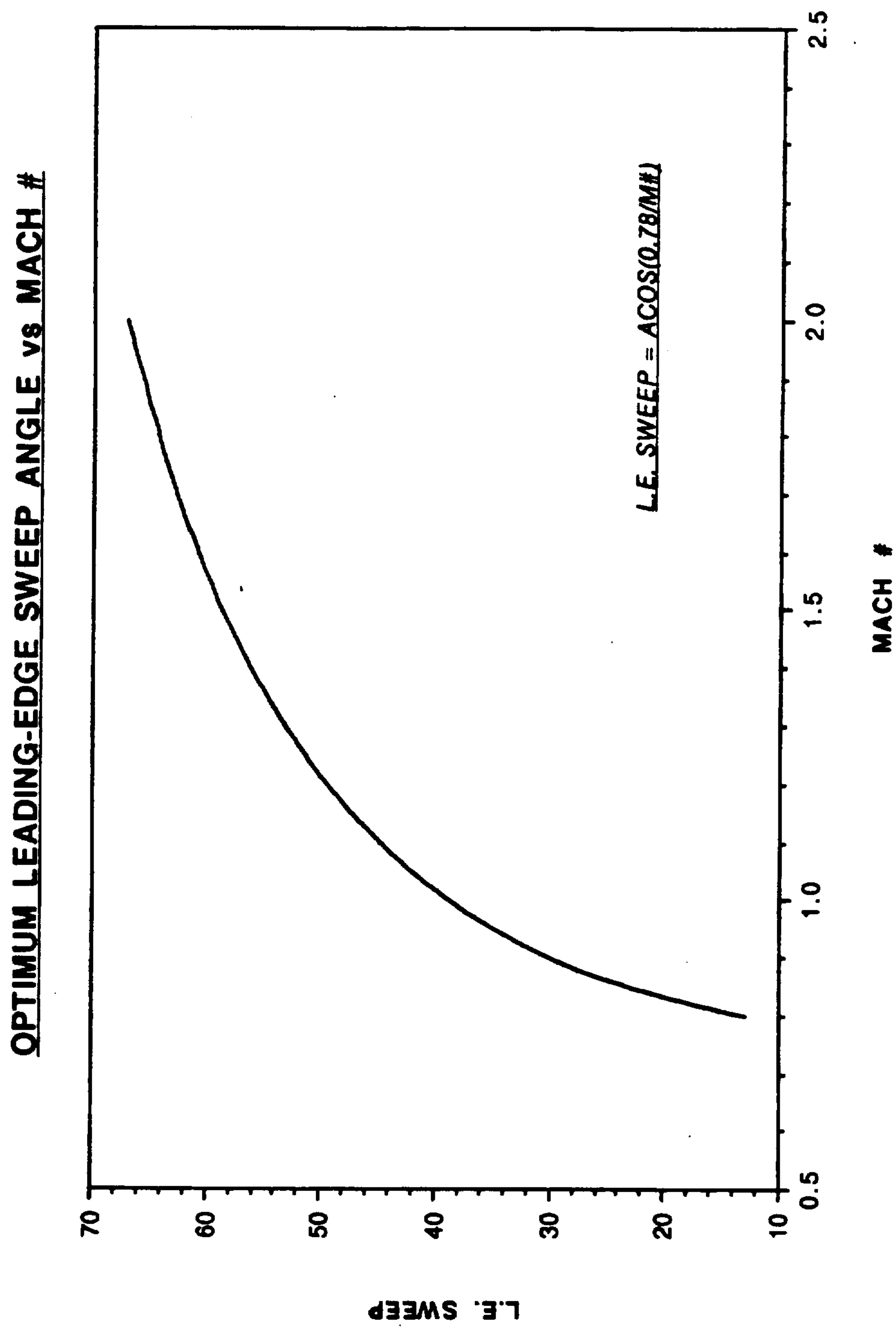


Figure 26: OPTIMUM LEADING EDGE SWEEP ANGLE vs. MACH NUMBER

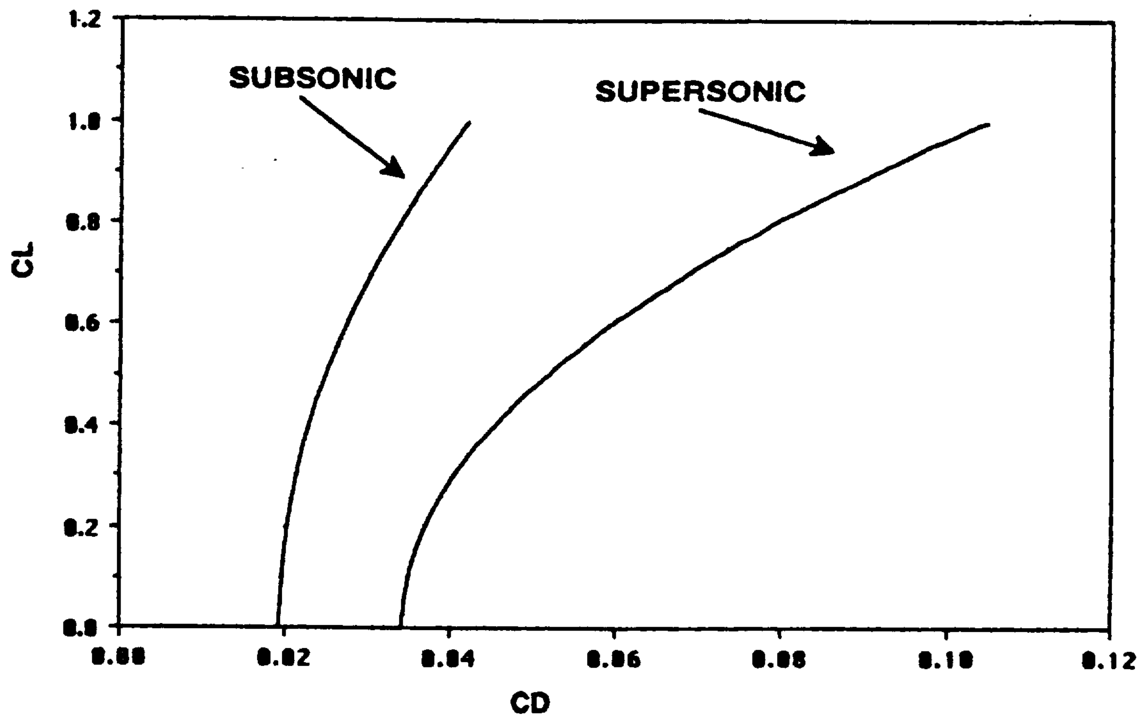


Figure 27a: DRAG POLAR FOR SUBSONIC AND SUPERSONIC CRUISE

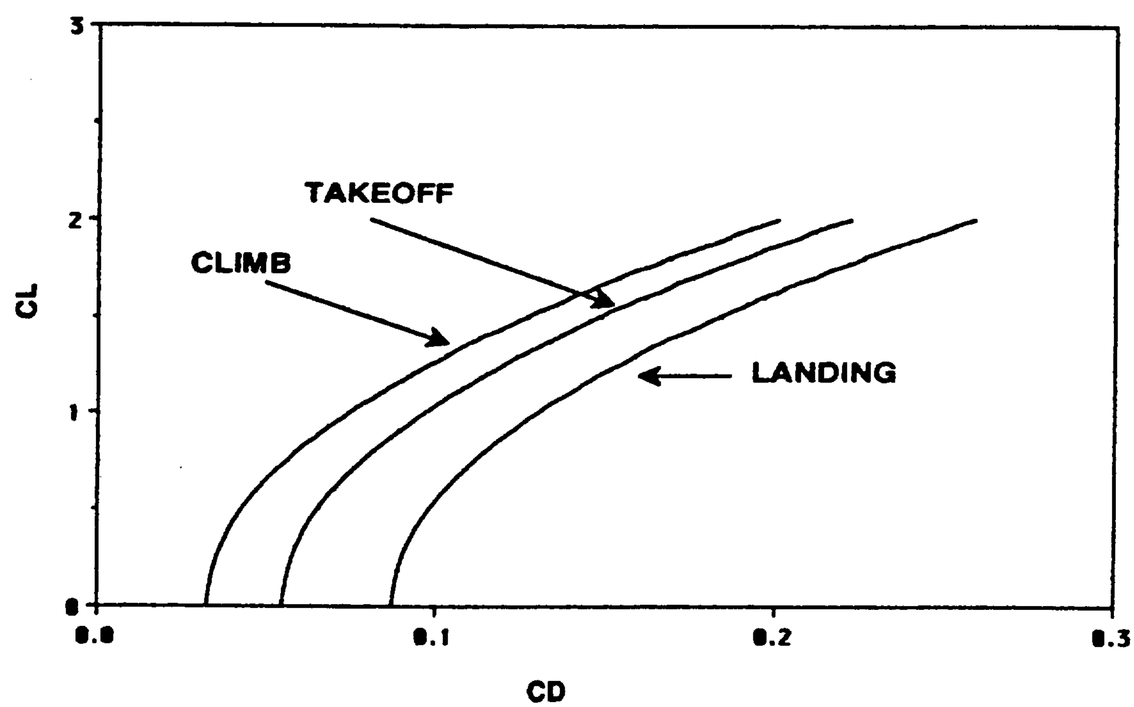


Figure 27b: DRAG POLAR FOR TAKEOFF, CLIMB, AND LANDING

The calculation of wave drag was divided into two parts, one for the wing and another for the fuselage. The fuselage wave drag increment was calculated using the methods of Roskam (reference 15). The wing wave drag increment was calculated separately because of the unique drag reduction achieved with an elliptic skewed wing configuration. The wing wave drag was calculated according to the formulas provided by R.T. Jones. (reference 16).

Takeoff and Landing Performance

Table 9 summarizes the important performance parameters during takeoff and landing. The lift to drag ratios at takeoff and landing are given in the previous section.

Table 9: TAKEOFF AND LANDING PERFORMANCE PARAMETERS

Performance parameters	Takeoff	Landing
wing loading (lb/ft^2)	120	61
speed (knots)	160	130
coefficient of lift	1.59	1.80
flap deflection required (deg)	20	60
rotation angle required (deg)	4	4

The coefficient of lift versus angle of attack curves for the RTJ-303 are shown in Figure 28. The effect of the 20 degree takeoff flap deflection and the 60 degree flap deflection are shown in comparison to the clean wing.

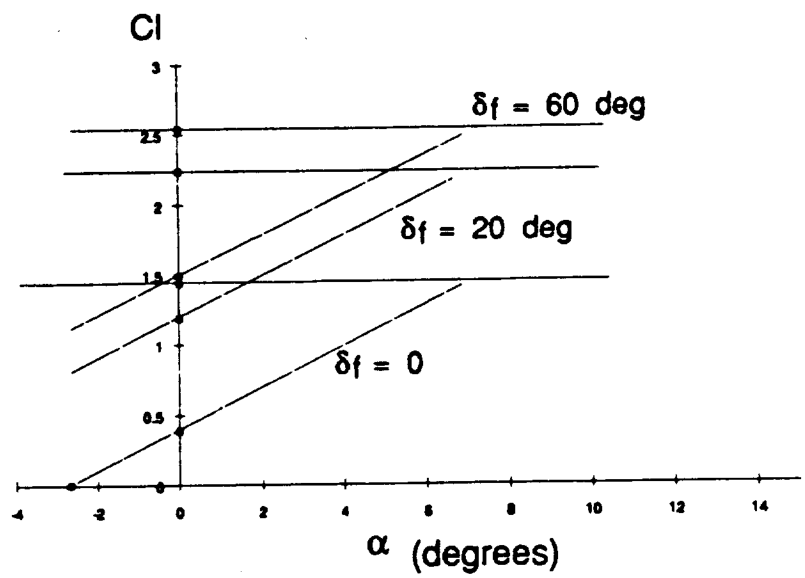


Figure 28: EFFECT OF FLAP DEFLECTION ON LIFT CURVE

STABILITY AND CONTROL

CG Excursion

The RTJ-303 center of gravity excursion diagram is shown in Figure 29. The most aft center of gravity occurs with the plane at operating empty weight. The addition of a full load of passengers moves the CG to the most forward position, and the subsequent addition of fuel moves the CG back three inches. The maximum forward shift due to fuel burn during flight is three inches. On the ground, the maximum variation in center of gravity position is five feet. The landing gear is configured such that this variation falls within the acceptable limits of nose gear loading percentages. The percentages are discussed in the landing gear section of this report.

The aerodynamic center of the aircraft is 101 inches behind the leading edge of the wing. For the fully loaded, maximum passenger, cargo and fuel configuration, the most forward CG is 100 inches behind the wing and the most aft CG is 168 inches behind the leading edge of the wing. Therefore, the aircraft is stable throughout the mission if it is fully loaded with maximum passengers, cargo and fuel. However, the RTJ-303 becomes unstable with fewer passengers. The instability will be handled with a fly-by-wire control and feedback system. Table 10 gives the static margin for several passenger load configurations and the feedback gain required to handle the relative instability (if any.) Reference 17 states that the feedback gain required should be less than 5 degrees per degree. The gain required for the RTJ-303 is well below this limit.

Table 10: STABILITY VARIATIONS WITH PASSENGER LOAD

	100 % PAX, full fuel	70 % PAX, full fuel	No PAX, full fuel
static margin	1/2 % stable	2.3 % unstable	7.7 % unstable
feedback gain	N/A	0.13 deg/deg	0.14 deg/deg

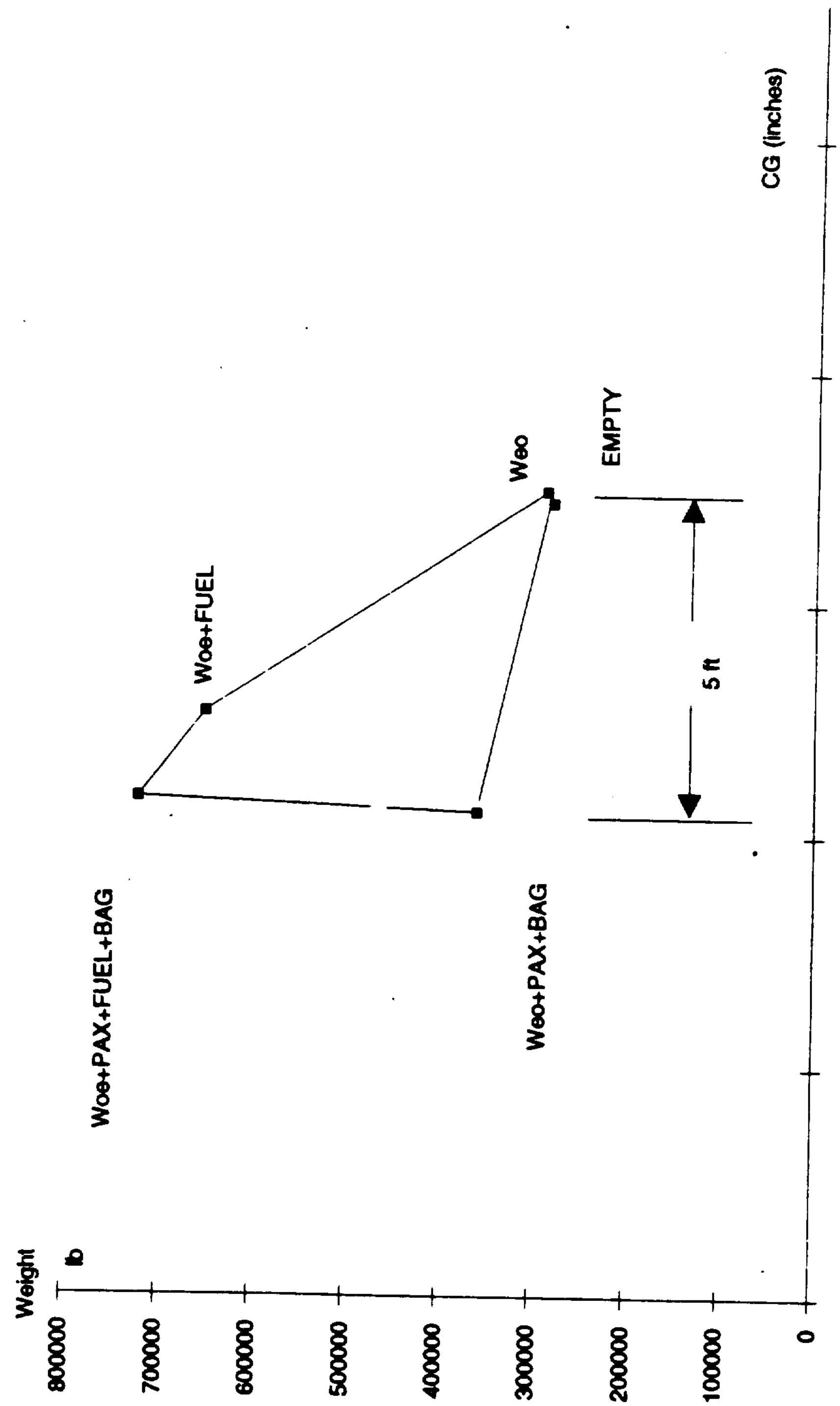


Figure 29: CG EXCURSION

Longitudinal

The aircraft trim diagram for clean subsonic flight is shown in Figure 30. The lift versus angle of attack and lift versus pitching moment curves are given for 10, 0, and -10 degrees of elevator deflection. In Figure 30, the Cm=0 line for the center of gravity position during subsonic cruise with a full load of passengers and fuel is shown as the dashed line slightly right of the most forward CG line.

The highest subsonic cruise coeficient of lift of 0.98 is entered into the trim diagram. This corresponds to the loiter and flight to alternate phases of the mission. The change Cm required for trim is shown at the intersection of a horizontal line through the cruise Cl and the Cm=0 line for the cruise CG position. The change in Cm required is achieved at a maximum elevator deflection of -2 degrees. The average Cl during descent is about 0.71 which corresponds to a trimmed flap deflection of -1.5 degrees.

Determination of Supersonic Trim Deflections

Datcom reference (19) does not adequately represent this type of planform. To estimate the elevator deflections required to trim the RTJ-303 in supersonic flight, wind tunnel data for an oblique wing and body combination at Mach 1.4 was used. This data was presented in reference 18. The data was taken from a wind tunnel test conducted in the NASA-Ames 11- by 11- foot Transonic Wind Tunnel under conditions given in Table 11, which compares the geometry and wind tunnel flight conditions of the NASA aircraft model to those of the RTJ-303.

Table 11: SUPERSONIC CRUISE TRIM GEOMETRY COMPARISON

	Wind Tunnel Model	RTJ-303
GEOMETRY:		
Planform	elliptic	elliptic
Axis ratio	10:1	8:1
Unswept AR	12.7	10.2
t/c	.10	.10
FLIGHT CONDITION:		
Mach number	1.4	1.6
Wing Sweep Angle	60 deg	62 deg
Sideslip angle	0	0
Angle of attack	2 deg	2 deg

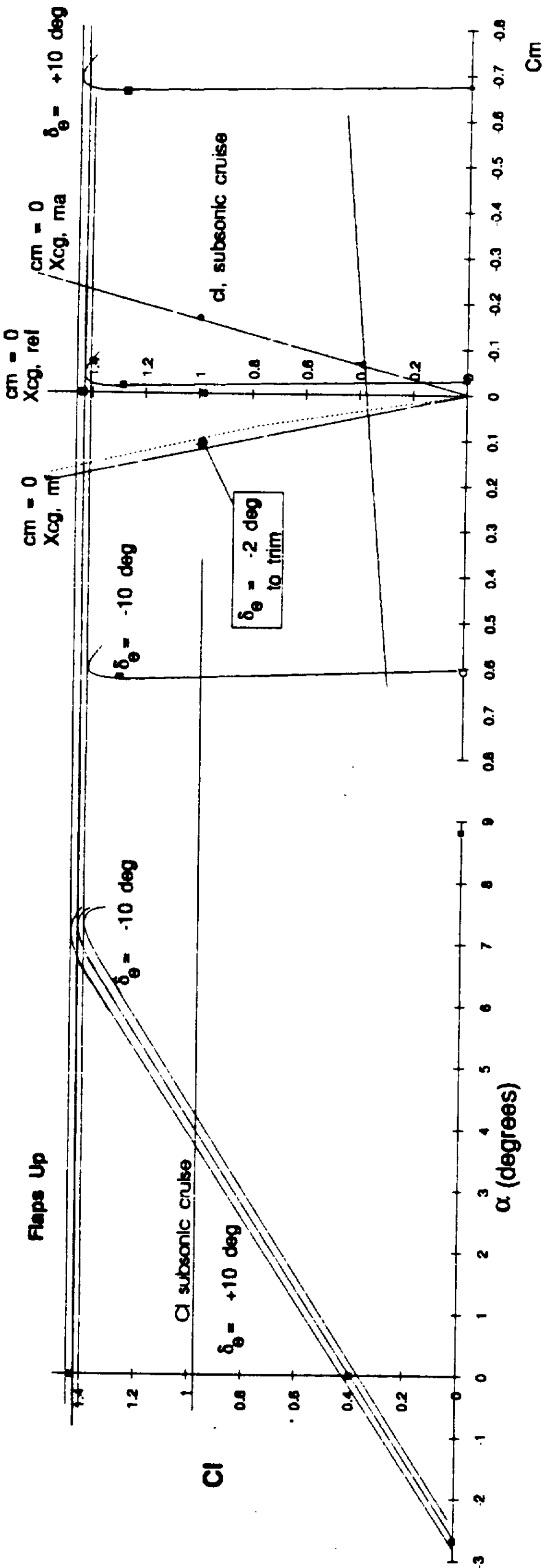


Figure 30: LONGITUDINAL TRIM DIAGRAM

A value for the pitching moment coefficient was selected from the wind tunnel data for an angle of attack of 2 degrees. The resulting value provided the change in pitching moment required to trim the aircraft. To determine the amount of elevator deflection that the RTJ-303 would require to achieve this change in pitching moment coefficient, the elevator control power derivative for the RTJ-303 was re-computed using supersonic data from reference 18 as available and was divided into the desired change in Cm.

The resulting trim deflection is less than 1/2 degree which will not produce too much trim drag in cruise.

Lateral

The solutions of the lateral equations of motion for the RTJ-303 provide the trim surface deflections required and the sideslip angle experienced during a given flight condition or maneuver. The magnitude of the aileron and rudder deflections, and the sideslip angle experienced, must be within acceptable limits to satisfy FAR regulations. These acceptable limits are such that the control surfaces do not stall and the sideslip angle is not so large as to produce a significant increase in drag.

The RTJ-303 required takeoff and landing trim deflections and sideslip angle experienced at sea level and standard day conditions are summarized in Table 12 and compared to typical acceptability limits as given in reference 17.

Table 12: SIDESLIP AND CONTROL DEFLECTIONS (T/O AND LANDING)

	RTJ-303	"Acceptable"
β	2.6 deg	< 5 deg
δa	0.97 deg	< 25 deg
δr	14 deg	< 25 deg

The stability derivatives calculated for the solution of the lateral equations of motion for takeoff and landing conditions are summarized in Table 13 and compared to those of an aircraft representative of the 747-100 (Ref. 15). These derivatives were calculated using chapter 10 of reference 15. Table 13 shows that the general trend is that the RTJ-303 lateral derivatives are somewhat small compared to those of a 747, except for Cl_{β} and $Cl_{\delta a}$ which are larger.

Table 13: LATERAL STABILITY DERIVATIVES FOR TAKEOFF

	RTJ-303	747-100 model
Cy_{β}	-0.116	-1.08
$Cy_{\delta a}$	0	0
$Cy_{\delta r}$	0.119	0.179
Cn_{β}	-0.024	0.184
$Cn_{\delta a}$	0.00907	0.0083
$Cn_{\delta r}$	-0.0462	-0.113
Cl_{β}	-0.3328	-0.281
$Cl_{\delta a}$	0.9005	0.053
$Cl_{\delta r}$	-0.002	0

SYSTEMS LAYOUT

The overall systems layout is shown in Figure 31. The corresponding system schematics were determined using reference 11 and are discussed below.

Flight controls

The RTJ-303 aircraft uses a hydraulic system with electrical signaling for its flight control system. Figure 32 shows the proposed schematic of the primary flight controls for the aircraft system. Redundancy is an important parameter for powered flight controls, therefore, for hydraulically driven systems this means a large number of hydraulic pumps and at least three independent power sources for the hydraulic pumps and redundant actuators. Each system is powered by pumps driven by the engines, as well as an air driven pump which is connected to individual electrical motor pumps for additional power. The third system allows for airplane control if all engines were to fail. Pilot information is fed into input transducers for roll, pitch, and yaw. These signals are sent to their appropriate control surface via electrical inputs and handled by the controllers for the actuators to engage. Note that the signals and actuators are doubled for redundancy in order to obtain the power necessary in the event that the primary hydraulic system for the respective control surface fails.

High lift control systems

Because of the relatively large size of this aircraft, and consequent control forces, mechanized flap deployment provided by hydraulic control is chosen over manual control. Figure 33 shows typical actuator systems for leading and trailing edge flaps. Hydraulic power drive units located at the leading and trailing edge providc the actuating deployment of the flaps. Sensors for flap position are important in order to avoid asymmetric deployment. These travel sensors which are hooked up to logic circuits feed back the deflection angles for comparison and correction of any asymmetries.

Propulsion control systems

Propulsion control is very important for flight safety and performance optimization of the aircraft. The four types of systems needed for this jet aircraft are the ignition control , the starter system, fuel flow (throttle) control, and thrust reverser control. The ignition

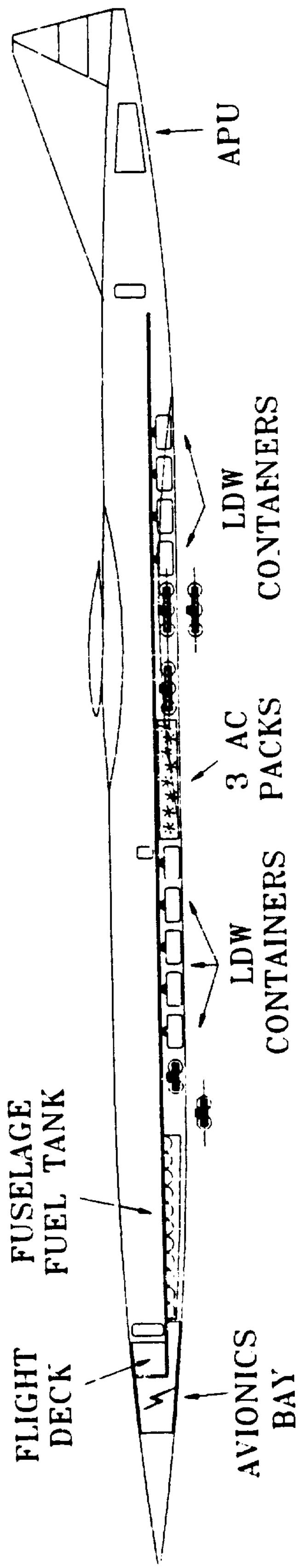


Figure 31: OVERALL SYSTEMS LAYOUT

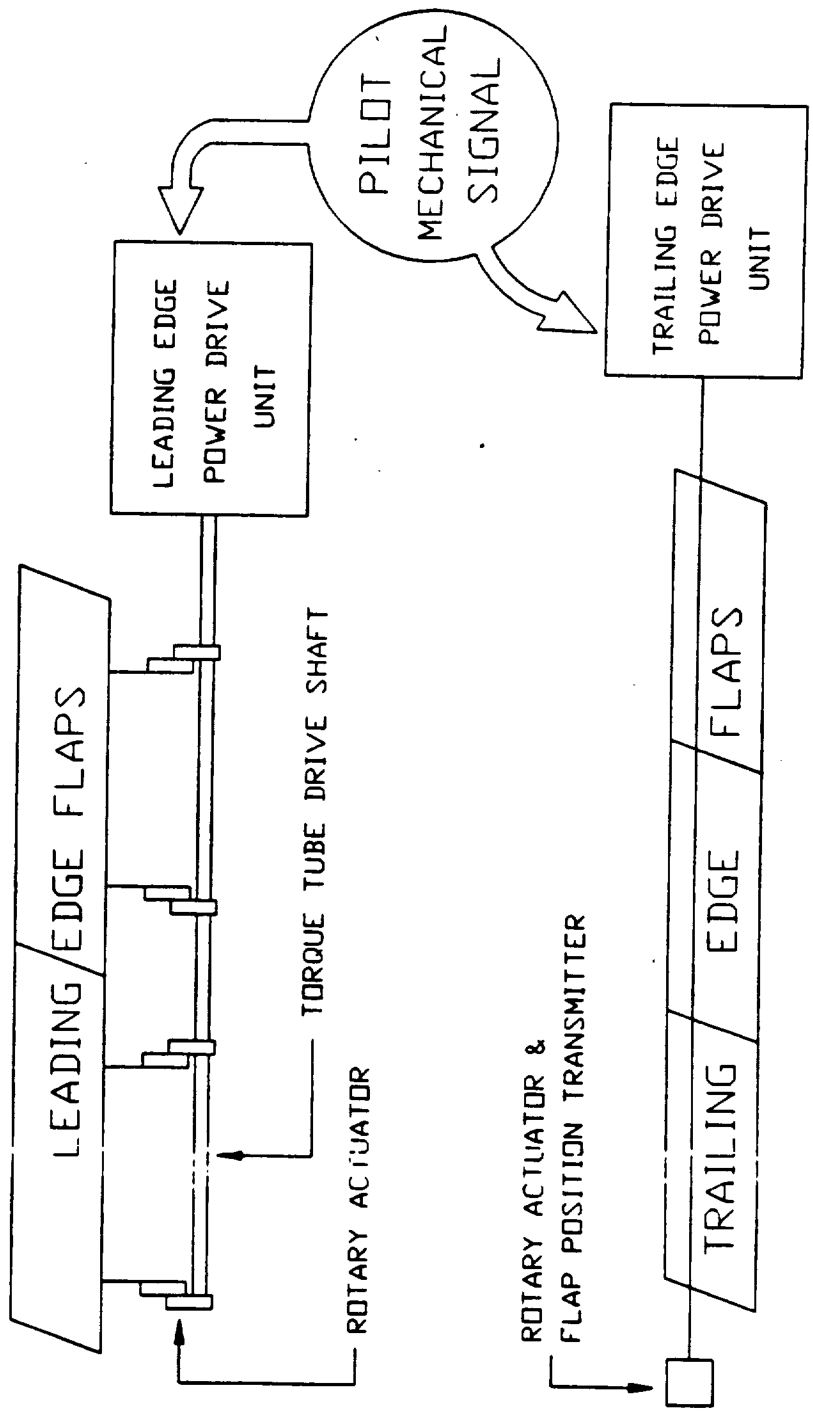


Figure 32: SCHEMATIC FOR FLIGHT CONTROLS SYSTEM

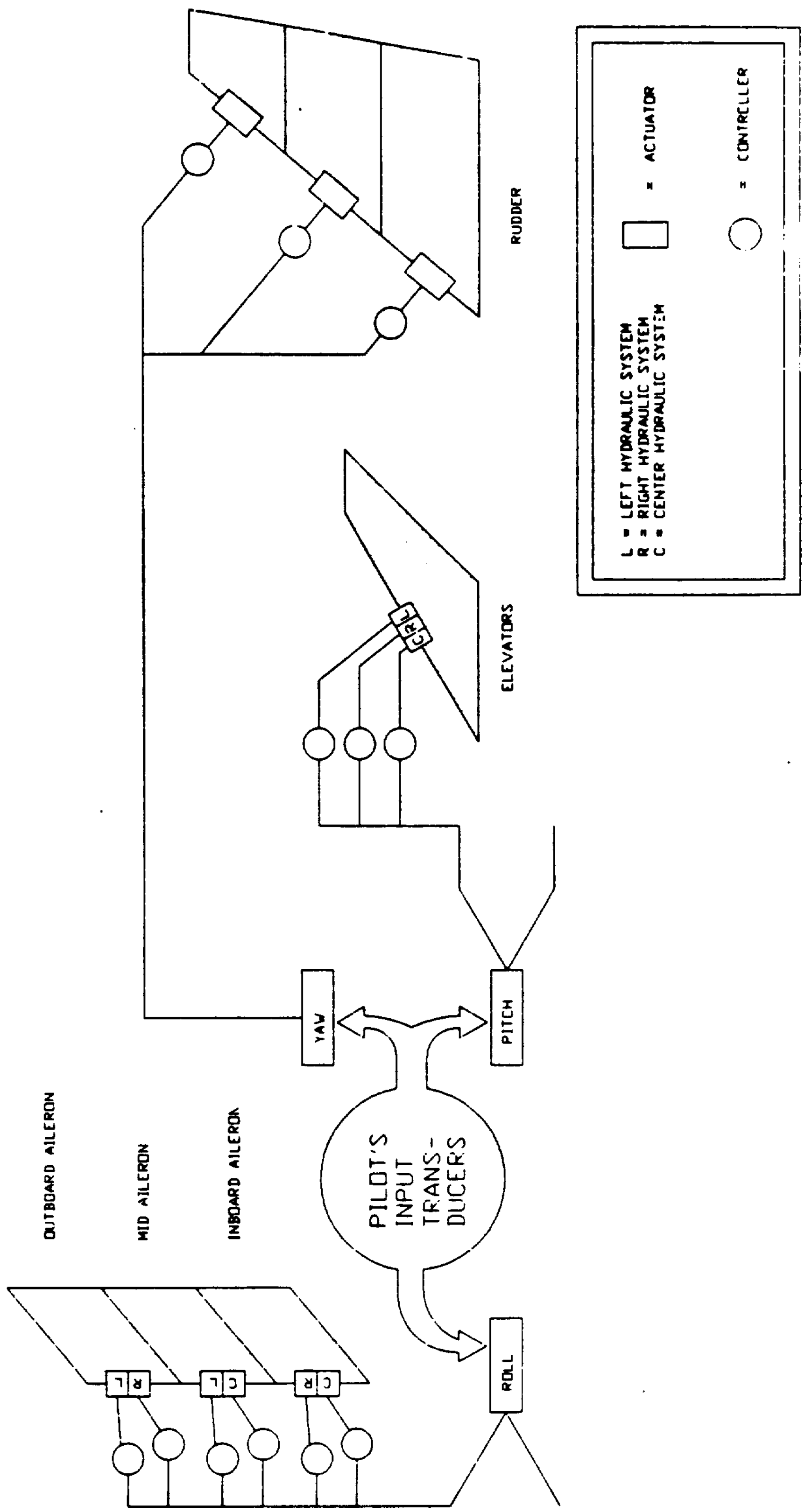


Figure 33: SCHEMATIC FOR HIGH LIFT DEVICES

control is part of the electrical system for start up. The starter system is comprised of a pneumatic starter that is geared to the engine. Fuel flow control allows the pilot to control the power of thrust output with throttles. Thrust reverser control is actuated by hydraulic controls for assisting the deceleration of the aircraft after touchdown.

Fuel system layout

The arrangement of fuel tanks in the RTJ-303 allow for enough fuel volume to cover the design range of the aircraft plus reserves. The wing houses 93% of the total fuel for the aircraft. Fuel lines must run from the wing tanks through the pivot ring before reaching the engines. In order to ensure separation of the critical fuel feed system, flexible fuel lines are routed off center through the pivot ring and into one of two pivot actuator housings (PAH). The right wing's fuel tanks feeds through the right, forward PAH, while the left wing's fuel lines run through the left, rear pivot actuator housing. This separation as well as the staggered engine pod arrangement guards against an uncontained engine failure interrupting the total wing fuel flow. Further redundancy is created by the forward placement of the fuselage fuel tank. While the main function of the fuselage tank is to reduce CG shifts during flight, its forward location provides a fuel source that is completely independent of the wing's fuel system. The fuel management system provides information to the flight crew keeping them aware of fuel levels and of flow regulation between fuel tanks. If an engine becomes inoperative, the fuel management system performs an automatic shut off of fuel flow to that engine and it alerts the crew of the situation. Multiple fueling stations are located along the entire wing to allow for fast and easy refueling.

Hydraulic systems

The hydraulic systems of this aircraft serve many functions. These include actuation of the primary (aileron and elevator) and secondary (high lift device) control surfaces, landing gear braking, steering, retraction, and deployment, as well as control of the thrust reversers. The system is comprised of hydraulic pumps, lines, and flight deck control. Pumps located at the compressor stations of each engine providing the main power for the hydraulic system. Another pump system is run by the auxiliary power unit (APU) in order to provide power to critical flight systems in case of an engine failure. Hydraulic lines run below the cabin floor and along the lower interior perimeter of the fuselage to and from the APU and the appropriate control surface actuators. The wing control surface actuators are fed by lines that run through separate pivot actuator housings. All lines are separated as much as possible to insure redundancy in the event of a single failure. The system pumps are powered by the engines, electric motors, and the APU. In the event of an emergency, the APU and Ram Air Turbine (RAT) are utilized, in that order, to provide backup power to critical control systems.

Electrical system layout

An electrical system power feeds many systems for this aircraft. Such uses for electrical power are lighting of the interior and exterior, flight instruments and avionics, food and beverage heating and cooling systems, and flight controls for electrical signaling to the actuators of primary and secondary control systems, as well as avionics systems. The electric power is provided by two means. The first is the primary power generating system delivered by engine driven generators. The other system is a secondary or stand-by power generating systems in case of failure of the primary system. These include the battery system, APU , and the RAT. All electrical power is fed throughout the aircraft via wire bundles running along the side and top of the fuselage perimeter.

Environmental control systems layout design

Pressurization systems for this aircraft are needed for cabin air pressure during flight at high altitudes for passenger comfort. In the event of a cargo bay door blow out, the differential pressure between the cargo bay and cabin could cause the floor to fail. To avoid this occurrence, pressure relief systems are allotted to engage when the pressure differential is larger than 9 psi.

Pneumatics are needed to supply the air for cabin pressure and air conditioning. The primary source of air is engine compressor bleed air. Secondary source is the APU.

Air conditioning the cabin air requires changing the temperature and humidity for passenger comfort. The air coming from the air-conditioning system is distributed throughout the aircraft through a network of ducts. These air ducts lead to the individualized air outlet installations for the passengers and flight crew and also serve as a cooling system for the flight deck instrument panels, electrical/electronic equipment and especially for the avionics bay. The main ducts are laid out above the passengers and filter along the perimeter of the fuselage to the individual "gaspers". An air-flow rate of 20 cubic feet per minute per passenger is deemed sufficient. Temperature sensors are located throughout the aircraft to monitor the comfort levels. These messages are then fed to the temperature controller logic board for computerization to maintain a specified comfort level for the passengers and flight crew. The air conditioners are located in front of the main wheels and next to the left engine pod. Since the stagnation temperatures are around 130^{o} F (the heat sink temperature will be less), the air-conditioning needs of the RTJ-303 are manageable during the entire flight regime by the environmental control system.

Emergency oxygen systems are required at high altitudes after failure of the cabin pressurization system. This is to ensure the passengers and flight crew have adequate breathing in the event the regular environmental system is unable to supply the required airflow. The oxygen system is supplied by gaseous oxygen for the crew whereas the passenger oxygen is supplied from a chemical source.

Flight deck instrumentation, flight management and avionics system layout design

Flight deck instrumentation layout is designed for pilot visibility and ease of workload demanded upon the pilot. Because of rapid development in instrumentation and aircraft avionics technology, the RTJ-303 utilizes these advancements for fly-by-wire and see-by-wire systems. As was stated earlier, the pilot signals for primary and secondary flight control are sent via electrical signalling to the actuators.

Pilot workload has been lightened with the integration of a flight management system. This system is run by computers with preprogrammed logic circuits for handling qualities. For this long range aircraft, the subsystems available to the flight crew are the auto pilot, automatic landing capabilities, inertial referencing, satellite navigation reference system, flight data acquisition, communication, and advisory systems.

The RTJ-303 will utilize a synthetic vision system (SVS) that provides superior vision at high angles of attack and during poor weather conditions (i.e. fog, stroms, and night flights). The vision system eliminates the need of a droop nose or drag producing wind screen. The flight deck screens give a 180 degree pan of vision for the pilots. The SVS is tri-redundant with a fourth physical periscope redundant system, deployable at transonic and subsonic speeds. A fifth non-vision redundancy is the combination auto pilot and automatic landing capabilities.

The flat viewing screens are at the convenience of the passengers for individual viewing of preselected movies and programs, as well as, views outside of the aircraft. Other options for viewing are stockmarket information, local, and world news.

Maintenance and servicing considerations need to be addressed. A significant amount of electrical power is consumed by the avionics equipment and transformed into heat. Overheating of equipment leads to malfunctioning of the avionics. As was outlined previously in the air conditioning systems, the avionics need to be cooled. A reasonable assumption that avionics equipment fails rather frequently demands a need for accessibility for replacement and maintenance.

Anti-icing and defog systems

One of the expectations for the flight characteristics of this aircraft is to fly in all weather conditions. Conditions throughout the flight may call upon the aircraft to fly in adverse weather. Certain combinations may cause ice accumulation on the wing and poor visibility due to precipitation and/or fogging on the visual replicators. Anti-icing systems are utilized for the wings, tail, and engine inlets. The formation of ice on these surfaces and cause aerodynamics performance penalties. Conventional thermal anti-icing systems are used to employ hot air to heat surfaces where ice is most likely to form. The air is taken from the bleed air manifold of the engine and circulated through places such as the engine inlet cowl and wing leading edge. This system is being used in the McDonnell Douglas DC-10.

Emergency escape systems

The RTJ-303 adequately satisfies the emergency exits and escape system as required for FAR certification. Because the RTJ-303 flies over water, provisions for safety include the need for life jackets and emergency rafts. These items can be located under seats and in overhead stowage bins, respectively. Other items of emergency include fire extinguishers, first aid kits, survival kits, and provisions for radio transmitter. The inflation of emergency slides and rafts are done by compressed gas containers. the evacuation of passengers is possible through all doors which are equipped with self illuminating exit signs.

Layout design of water and waste systems

Water systems for large transport jets normally allow 0.3 US. gallons per passenger (Ref. 15). For the RTJ-303, this totals to 90 US gallons which are stored in stainless steel tanks located below the floor line behind the flight deck area. Initial filling of the aircraft occurs at ports located on the starboard side of the flight deck. The water is transported to the galleys and lavatories via the pneumatic system. Warm water is available by running cold water through electrical heat exchangers.

The waste system is self-contained, consisting of collector tanks and flushing units which mix the waste with chemicals for proper storage. Plumbing lines from the forward lavatories and galleys function on a pressurized system to prevent any clogging as might be encountered in a gravitational system. The collector tanks are located in the aft section of the aircraft where the waste can be serviced after each flight. The service drain locations of both the water and waste systems are heated to prevent any freezing of condensation or fluid leaks. The ice formed may cause blockage of flow and induce subsequent complications of the plumbing or may break off and become ingested by the engines.

AIRPORT OPERATIONS AND MAINTENANCE

In order to fully analyze the feasibility of a supersonic transport, more than just the aircraft needs to be examined. Every time the aircraft arrives at its destination, ground crews and support personnel must service and inspect the RTJ-303. It must be fueled, loaded with passengers and baggage, and, in general, be readied for its next flight. The ground crew must bring the plane up to FAR specified standards before the aircraft is allowed to take off. Overall, airport operations and aircraft maintenance are a major contributor to the Direct Operating Cost of the airplane. This section outlines the ground support equipment and personnel required for airport operations and maintenance.

Figure 34 shows the locations of the major ground support vehicles which must service the aircraft. Like conventional transports, the RTJ-303 will be serviced from the right side and boarded from the left. The RTJ-303, due to its unique pivoting wing is serviced in its most compact (fully-swept) configuration. Since the aircraft is a high-wing, ground support vehicles need not be concerned with wing clearance problems. The fuel truck, carrying standard Jet-A fuel, is positioned under the wing and fuel hoses are attached to fuel ports in the wing. A potable water truck attaches to a water lead at the front of the fuselage (just below the flight deck). Two food trucks attend the RTJ-303. At the location of the forward service door, one food truck is brought in to replace first class food supplies. The other truck services the 8 business and coach class galleys through the aft service door. Baggage carts, carrying LDW containers, come in to load the baggage into the belly of the fuselage at two stations. LDW containers extending from the main landing gear bulkhead to the very end of the plane are loaded from the rear of the plane. The other baggage section, located between the left engine mount and the nose gear bulkhead, is reached by two clamshell doors in the belly of the fuselage between the two engine mounts. One waste disposal truck attaches to the toilet servicing box at the very end of the aircraft. Boarding through the forward door occurs through an enclosed gate whereas the aft boarding door is reached from a portable stairway.

The RTJ-303 was designed with airport compatibility as one of its major driving factors. Preliminary sizing was carried out for a landing field length of 11,000 feet. Due to the high aspect ratio of the RTJ-303 in its unswept landing and takeoff configuration, this common runway length is expected to be more than sufficient for takeoff and approach. Ground noise is furthermore expected to be well below FAR-36 Stage III Noise

Requirements due to the rapid climb-out predicted for the RTJ-303 and the fact that full throttle does not need to be employed for takeoff. Geometrically, the RTJ-303 also is believed to be airport compatible. The largest commercial transport currently flying is the Boeing 747-400. The 747 diagonal allows for a guideline for an HSCT fuselage length of approximately 310 feet. The length of the RTJ-303, although exceeding this length by 15 feet, is believed to be of reasonable length to allow for proper maintenance in existing airport hangars. With a door-sill height of just under 10 feet, the RTJ-303 is well below the maximum 17.5 feet governed by baggage ramps and ground equipment.

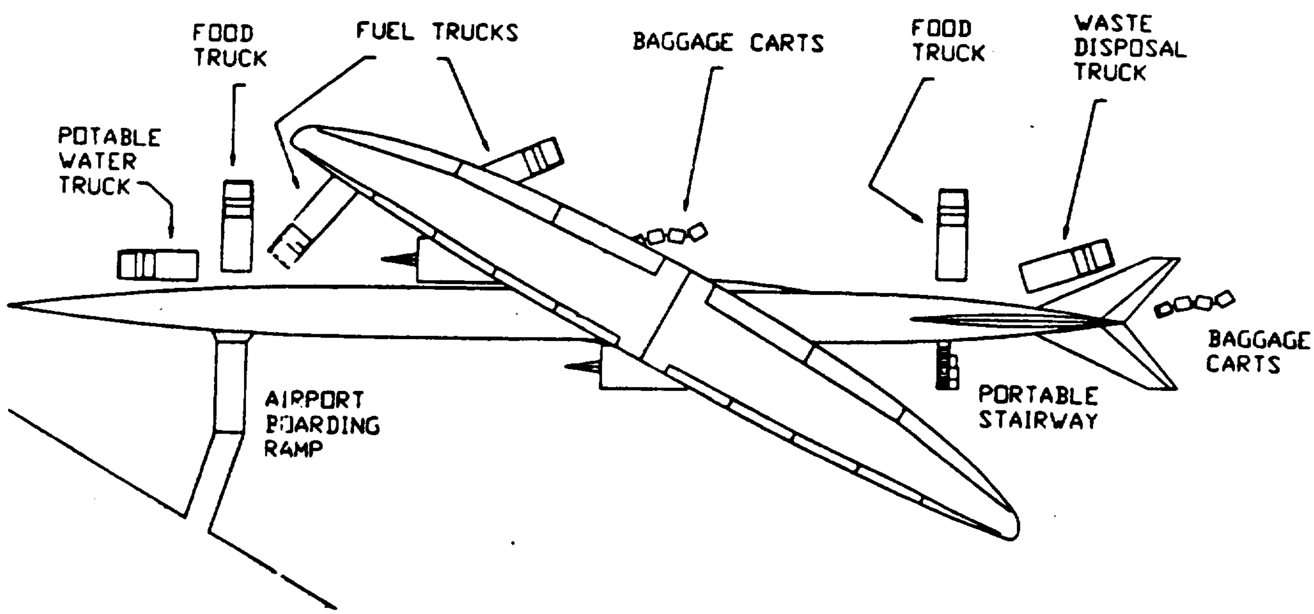


Figure 34: GROUND SUPPORT EQUIPMENT

COST ANALYSIS

Along with technical considerations covered in this report, market study was done to justify the specifications of RTJ-303. These specifications include number of seats, cruise Mach number, and design range. The methods of reference 19 was used to estimate the price per airplane in 1992 US. dollars. The estimated price of each airplane is $183 million '92 US dollars which includes the costs from the initial research and development stage to the end of the production of the aircraft. The Price was estimated for a production run of 300 aircraft which is a very conservative number compared to a 700 aircraft demand expected based on market study from reference 19. A conservative 12% profit was assumed throughout all levels of RTJ-303 cost analysis. Life Cycle Cost (LCC), the cost of an air plane incurred between the airplane's period of conceptual design and disposal, was also estimated to be $2,645 million '92 US dollars using methods of reference 19. The four major components of the Life Cycle Cost (LCC) are listed below:

1. Research, Development, Test and Evaluation (RDTE)
2. Manufacturing and Acquisition (MAC)
3. Operation Cost
4. Disposal Cost

Research Development, Test and Evaluation Cost

The Research Development, Test and Evaluation cost was calculated as suggested by reference 19. In this method, major variables had to be selected. As with the Concorde, four airplanes are needed to be produced for testing and evaluation. The difficulty factor (Fd) which used to determine the airframe engineering and design cost ranges from 1.0 to 2.0 with 1.0 for programs involving fairly conventional type airplanes and 2.0 for programs involving extensive use of advanced technology. 1.6 was selected for the RTJ-303 due to the predicted moderate use of advanced technology which is used on the wing, engines, and systems. The typical production rate of 0.33 units per month was used for RDT&E cost analysis. Table 14 summarizes RDT&E cost in '92 US dollars.

Table 14: SUMMARY OF RDT&E COSTS

	(millions of 1992 US. dollars)
Airframe Engineering and Design (AED) Cost	522
Development Support and Testing (DST) Cost	195
Flight Test Airplanes (FTA) Cost	1784
Flight Test Operations (FTO)Cost	112
Test and Simulation Facilities (TSF)Cost	355
RDTE Profit	427
Finance Cost	356
Total RDTE Cost	**3,753**

The cost of manufacturing Flight Test Airplanes (FTA) is the most dominant cost in RDTE with 47.5%. Figure 35 shows the relative percentage of RDTE components.

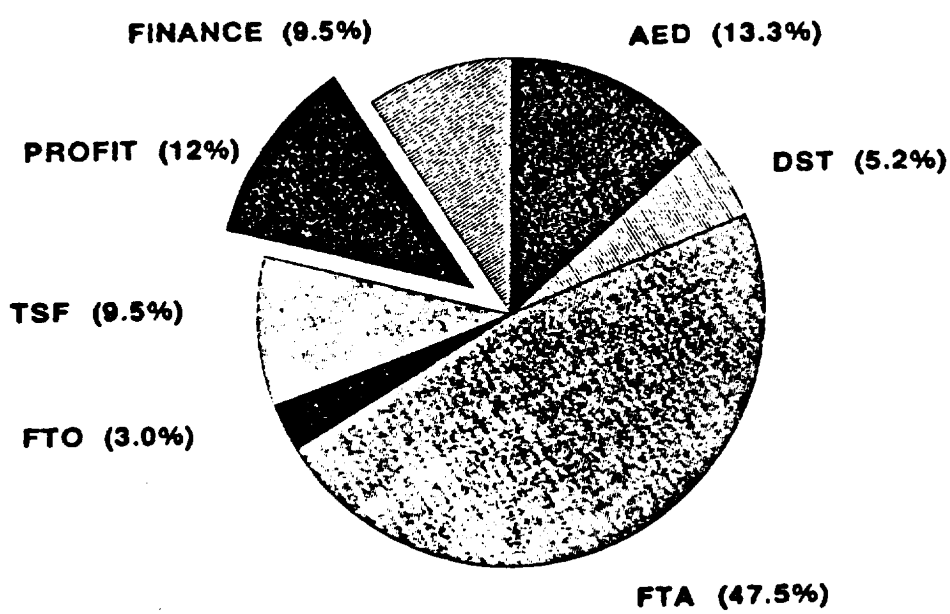


Figure 35: RDT&E COST BREAKDOWN.

Manufacturing and Acquisition (MAC)

Manufacturing and Acquisition cost was estimated based on material composition of 40% carbon fiber and 60% aluminum. Reference 19 suggests a 3.0 judgment factor for a 100% carbon composite aircraft and 1 for conventional aluminum aircraft. For this reason, a judgment factor of 1.7 was used. 300 airplanes will be produced over 10 years, which works out to 10 units every 3 months (2.5 units/month). Table 15 shows the components of Manufacturing and Acquisition cost.

Table 15: SUMMARY OF MANUFACTURING AND ACQUISITION COST

	(millions of 1992 US. dollars)
Airframe Engineering and Design (AED) Cost	4,245
Airplane Production Cost	36,512
Production Flight Test Operations (FTC) Cost	240
Finance Cost	4,555
MAC Profit	5,466
Total MAC Cost	**51,019**

The Airplane Production Cost (APC) is the highest element of manufacturing and acquisition cost with 71%. Figure 36 shows the relative percentage for all elements of Manufacturing and Acquisition Cost.

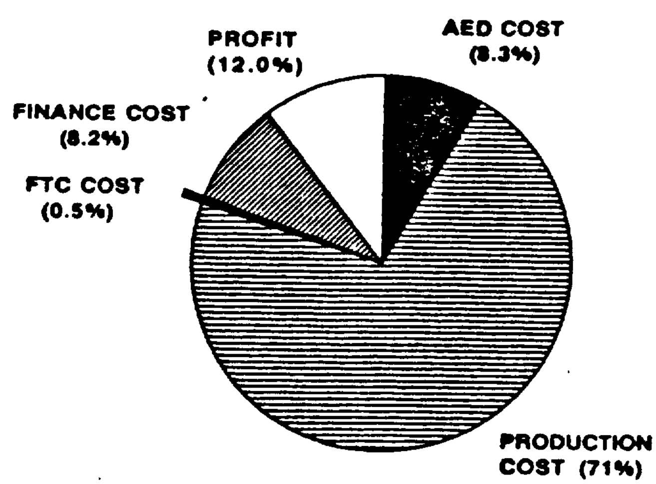


Figure 36: MANUFACTURING AND ACQUISITION COST BREAKDOWN

Operation Cost

The operating cost, broken down into the Direct Operating Cost and the Indirect Operating Cost, was determined using reference 4. The Direct Operating Cost (DOC) was estimated based on 730 hours of utilization per year. The fuel price of $0.16/lb, which is the average recent price for today's fuel standards, was used. The Indirect Operating Cost (IOC) was approximated from a ratio found in reference 4. The IOC was taken to be 47% of the total operation cost. Table 16 shows how the operation cost was broken down.

Table 16: SUMMARY OF OPERATION COST

		(in millions of '92 $)
Direct Operating Cost	Fuel and Oil Costs	215,338
	Flight Crew Costs	57,130
	Maintenance Costs	87,893
	Depreciation	52,735
	Insurance	26,367
	Total DOC	439,465
Indirect Operating Cost		305,391
Total Operating Cost		744,857

Disposal Cost

The Disposal Cost of the RTJ-303 was 6,085 million 1992 US dollars which is 10% of the total RDE&T and manufacturing cost. A disposal cost is a negative cash flow. This implies that the airplane will be worth 10% of its life cycle cost at the end of its service life.

Life Cycle Cost Calculation:

The life cycle cost (LCC) was calculated by summing the four categories calculated above. The results are summarized in Table 17.

Table 17: SUMMARY OF LIFE CYCLE COST

	(in millions of 1992 US. dollars)
RDTE Cost	3,754
Acquisition Cost	51,019
Operation Cost	744,857
Disposal Cost	-6,085
Total Life Cycle Cost	793,544
Life Cycle Cost per RTJ-303	2,645

Figure 37 shows how components of the life cycle cost compared. Since the disposal cost is a negative cash flow, it is not part of these chart. This chart shows the huge relative amount of operation cost compared to the manufacturing cost. The chart also shows high relative amount of manufacturing cost compared with research and development cost.

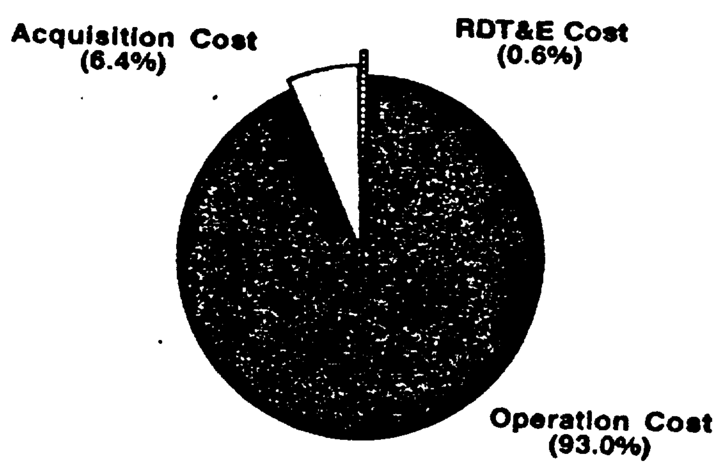


Figure 37: LIFE CYCLE COST BREAKDOWN

Airplane Estimated Price

The airplane's estimated price was calculated from the RDTE and acquisition cost. According to reference 19, it was calculated to be 183 million 1992 US. dollars. This price is very appealing for a supersonic aircraft. Compared with a 140 million '92 US dollars Boeing 747 which seats about 400, RTJ-303 would make a higher profit due to its higher utilization.

CONCLUSIONS AND RECOMMENDATIONS

The RTJ-303 is an interesting alternative to the supersonic transport design goal that warrants further consideration. The possibility for economic savings in the transonic range over subsonic aircraft indicates that further design improvements on the variable sweep wing and pivot should be sought. Another advantage of the oblique swing HSCT is that it has been designed to today's technology and could be put into production almost immediately. It uses an existing engine, existing materials, and standard fuels. The takeoff performance of the RTJ-303 is another bonus of the oblique wing configuration. Lower speeds, better visibility, lower noise profiles, higher wing loading, and a better matching of engine sizing for cruise and takeoff are other plusses of the RTJ-303 design.

Economically, the RTJ-303 is competitive as well. The estimated fly-away price of the RTJ-303 was lower than that projected by McDonnel Douglas and Boeing (Ref. 21, 22) for conventional supersonic transport designs. Further, making the variable geometry oblique wing configuration more attractive to prospective buyers is the fact that its constant fuselage cross-section, not coke-bottled as in most delta designs, allows for easy plugging with changing market demand. Although the flight time is increased over that of conventional delta planforms due to a lower cruise Mach number, this lower speed carries other advantages. For one, the amount of exotic materials necessary for the construction of the HSCT is reduced to nothing more than carbon composites for the wing and control surfaces. Secondly, aerodynamic heating is not a factor with the stagnation temperatures encountered by the RTJ-303 during supersonic cruise. This allows for the use of standard aluminum alloys and also relieves the work of the air conditioning units, which have historically been problematic with the Concorde. Therefore this reduces the cost of manufacturing.

Having such a long list of benefits, one should wonder why supersonic oblique wings are not flying today. The answer to this question would most likely be the fact that industry is reluctant to make large investments in a configuration which has not proven itself yet. Furthermore, real concerns have been brought up in the past regarding the aerodynamic problems and controllability of such an asymmetric design. However, problems previously thought to be insurmountable are believed to be solvable with today's technology. The highly cross-coupled nature of the plane can be easily solved with current fly-by-wire technology. The pilot need never know that he is flying an oblique wing aircraft. An aeroelastically tailored composite wing using unidirectional carbon fibers drastically reduces the problem of aeroelastic twisting and divergence.

The designers of the RTJ-303 believe that the benefits of this configuration would outweigh any passenger (and airline) doubts in this unconventional design. The advent of fly-by-wire and other electronic advances such as fly-by-light, and synthetic vision give us reason to believe that the time for the swing wing has come.

Recommendations for the HSCT design program are that supersonic flight tests be performed and performance characteristics be studied, research into synthetic vision be carried out, and composite wing tailoring be tested for effectiveness of reducing aerodynamic twisting and divergence. Further studies should be made as to the economics of a variable sweep HSCT that carries fewer passengers in order to reduce the overall length and weight of the plane.

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