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An Advanced Medium Size Transport for 2005

JB-300

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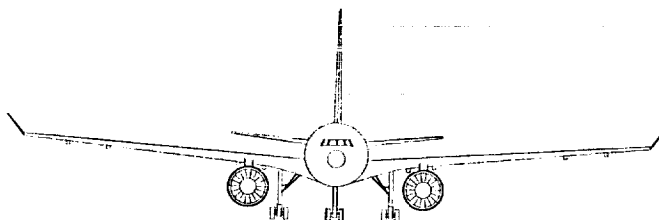
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Abstract

In the fall of 1992, the T.A.C. Team was presented with a Request for Proposal (RFP) for a mid-size (250-350 passenger) commercial transport. The aircraft was to be extremely competitive in the areas of passenger comfort, performance, and economic aspects.

Through the use of supercritical airfoils, a technologically advanced Very High By-pass Ratio (VHBR) turbofan engine, a low overall drag configuration, a comparable interior layout, and mild use of composites the JB-300 offers an economically viable choice to the airlines. The cents per passenger mile of the JB-300 is 1.76 , which is considerably lower than current aircraft in the same range.

Overall, the JB-300 is a technologically advanced aircraft, which will meet the demands of the Twenty-first century.

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Nomenclature

A/C	Air Conditioning
B	Sideslip Angle
Bdot	Rate of Change of Sideslip
c	Chord
cg	Center of Gravity
C	Coefficient
dB	Decibels
D	Drag
ER	Extended Range
ft	Feet
h	Height (ft)
K	Knots
KV	Kilovolts
lb	Pound
L	Lift
m	Minute
M	Moment / Mach Number
nm,NM	Nautical Mile
Psf	Pounds per Square Foot
Psi	Pounds per Square Inch
rpm	Revolutions per Minute
s	Second
SFC	Specific Fuel Consumption
t	Thickness / Time

V	Velocity
W	Weight Fraction / Weight
X	Location / Cross

Subscripts:

a	Angle of Attack / Aileron
b	Maximum Intensity
c	Cruise
d	Delta (Deflection Angle)
d,D	Drag
e	Elevator
eas	Equivalent Air Speed
i	Induced
l	Rolling Moment / Lift
m	Pitching Moment
mc	Minimum Control
n	Yawing Moment / Load Factor
o	Parasite
p	Roll Rate
q	Pitch Rate
r	Yaw Rate / Rudder
s	Stall
y	Side Force

1.0 Introduction

The JB-300 is a commercial transport aircraft that will fit into the mid-size range (250-350 passengers). The design philosophy of the T.A.C. Team, the design team of the JB-300, was to have a technologically advanced aircraft with low operational cost and development risk, that is compatible with technological advancements and restrictions, and economical over the life of the aircraft.

The interior design philosophy of the JB-300 was to provide superior service, safety, comfort, and convenience to everyone involved in the flight, including crew and passengers. The JB-300 offers 4 different configurations, which can accommodate the various needs of the airlines. Many man-hours have been spent ensuring the comfort of the passenger. This, coupled with a technologically advanced aircraft and a lower overall drag configuration, has produced an economically viable choice for the airlines.

The JB-300 was designed to meet all Federal Aviation Requirements (FAR) 25 requirements. It will be capable of entering into service by the year 2005. Without the use of composites, technological risks have been minimized. The Very High By-pass Ratio turbofan that has been incorporated into the design is a high-technology engine that presents a small technology risk because it has been on schedule with all of its testing.

Overall, the JB-300 is a technologically advanced aircraft, which will meet the demands of the Twenty-first century.

2.0 Mission Description

The missile profile is broken up into ten phases:

Phase 1: Engine Start and Warm-up

Phase 2: Taxi

Phase 3: Take-off

Phase 4: Climb to cruise altitude and accelerate to cruise speed

Climb to a cruise altitude of 39,000 feet. Note that 60 NM range credit is taken for the climb.

Phase 5: Cruise

Cruise Mach number is 0.82 and range is approximately 5295 NM.

Phase 6: Descent (1st stage)

Descent range is approximately 73 NM. Note that range credit is taken for descent.

Phase 7: Loiter

Loiter time capability of 45 minutes.

Phase 8: Fly to alternate

The cruise altitude at this phase would be 20,000 feet.

Phase 9: Descent (2nd stage)

Descent for landing. Note that 72 NM range credit is taken for descent.

Phase 10: Landing, Taxi, Shutdown

Note that cruise would be done at an initial altitude of 39,000 ft. then stepping up to 43,000 ft. halfway through the cruise phase. Also note that for this mission type, it was decided that a maximum 45 minute time would be allocated.

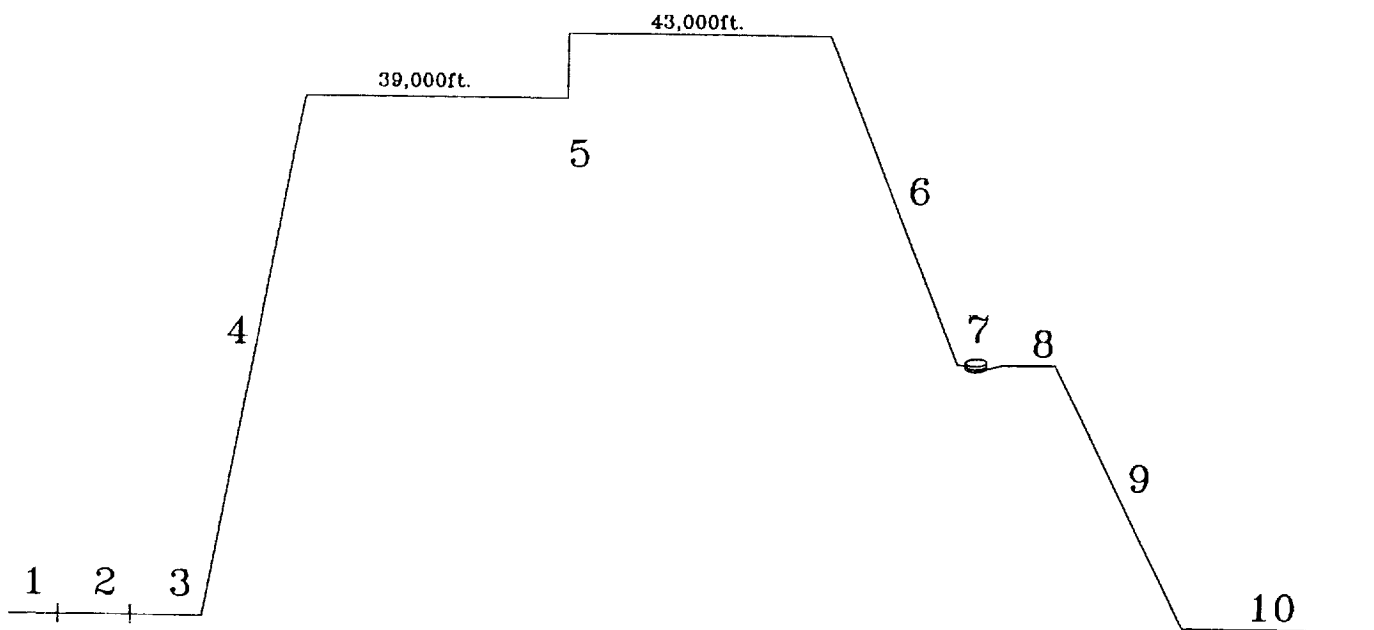


Figure 2.0.1 Mission Profile Diagram

3.0 Preliminary Sizing

The first step in the design process of the JB-300 was to pick a design point. The Design Point diagram was based on the assumption that the aircraft would have a lift to drag ratio of approximately 22, an Oswald efficiency factor of 0.8, and an aspect ratio of approximately 10.5. The most crucial flight parameters in deciding the design point were the direct climb and OEI (one engine inoperative) requirements. When choosing a wing loading, there are many trade-offs to consider. A high wing loading would provide a smoother flight for the passengers and lower manufacturing cost, while a lower wing loading would allow a lower thrust to weight ratio, shorter landing and take-off distances, better growth, and small improvements in L/D (lift to drag ratio). It was decided that a wing loading of 99 pounds per square foot (psf) would provide a good balance of trade-offs. With a wing loading of 99 Psf, the JB-300 is 15% lower than its nearest competitor, the Boeing 767. The lower wing loading will allow us to maximize growth potential. A wing loading of 99 psf also allows for a take-off distance of 6000 feet, which is 5% lower than the nearest competitor, the Airbus A310, and a 40% improvement on the Boeing 767. The last step was to choose a thrust to weight ratio. In order to meet the OEI requirements, a thrust to weight ratio of .30 was chosen. Finally, the design point was set at a thrust to weight ratio of .3 and a wing loading of 99 psf. (See Figure 3.0.1)

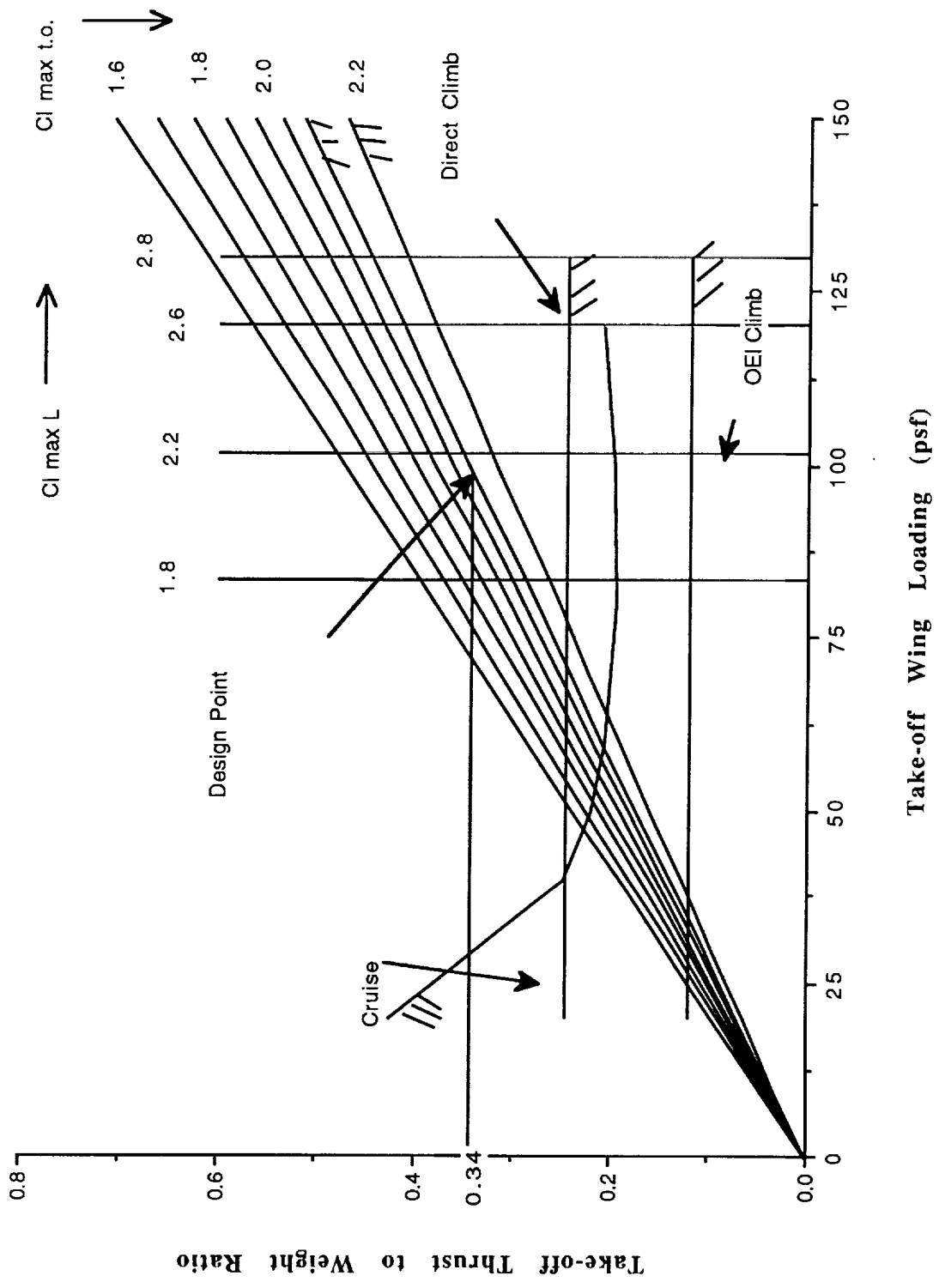


Figure 3.0.1 Design Point

4.0 Aircraft Configuration

The JB-300 employs a conventional configuration yet has a major improvement in performance over current competitors. This is achieved by using new engine technology coupled with low cost, aerodynamic design improvements. The use of fly by wire in the JB-300 is a key factor which allows it to achieve its improved performance. By going from this configuration concept to configuration refinement and using a practical wing, fuselage, and empennage design, this design shows the maximum potential of a design for 2005 using the latest technology and a proven configuration.

4.0.1 Configuration Concept

Midsize aircraft in the 250-350 passenger range have few realistic fuselage configuration options. Most of the possibilities could be broadly classified into two groups: tube-like or span loaded fuselages. Layout of a completely span loaded fuselage(flying wing) is impractical due to geometric constraints. In order to accommodate passengers, an 8 foot (ft) thick wing with a 45 ft. chord would be required. To accommodate enough passengers, the span would only need to be 150 ft., which would yield an aspect ratio of 3. This would still allow a comparable lift to drag ratio of 21. Although it could work, the added cost of development, manufacturing and increased risk would quickly negate any advantages of the flying wing configuration for this size. Variations

from the conventional tube like fuselage, i.e., non-circular cross section, such as a double bubble, provide a potential for reduced fuselage wetted area per passenger by having better volumetric efficiency. This has been found to be as much as ten percent less fuselage wetted area per passenger for the configuration shown in appendix F. However, any gains are quickly offset because of increased structural complexity and added weight.

A conventional fuselage configuration, circular cross section, has several advantages. The circular section allows the pressurization loads to be taken up very efficiently in the form of hoop stresses. This allows a light and simple thin skin, longeron, and frame arrangement to take all the possible loads. Finally, a circular section's lower manufacturing costs follows the original design philosophy to have an economical aircraft throughout its life. For these reasons a conventional circular cross section fuselage configuration was chosen.

Using a conventional fuselage allows for many possible lifting surface arrangements. The Request for Proposal (RFP) required cruise Mach of .82, necessitated swept wings to minimize compressibility drag. Several possible wing configurations were looked at. They include: tandem, swept forward, joined, and a conventional swept aft wing. Existing airport facilities are already designed to accommodate wingspans in the range of 170 to 200 ft. For an aircraft in this weight category a wing span significantly greater than 170 ft is not beneficial due to an increasing structural weight penalty. Therefore, with a single wing configuration, induced drag would be reduced to its lowest practical limit. Compared to

the already low induced drag of a single wing, the joined wing and tandem wing would not provide a significant drag benefit. In addition, they would be more expensive to manufacture. A swept forward wing would cause a large weight penalty offsetting a marginal reduction in induced drag. This is common knowledge in the commercial transport industry. Based on the lesser complexity, it's proven efficiency, and low risk, a single wing arrangement was chosen.

To prevent cabin obstruction, the wing was mounted just below the cabin floor. The 173 foot wing span required 5 degrees of dihedral to allow for wing tip clearance. Next, a landing gear length was determined which would provide a 11.6 degree rotation angle, and adequate engine clearance.

From this fuselage and wing arrangement, the empennage could still be configured in several different ways. A vertical tail is required to satisfy directional stability and control. Longitudinal stability could be satisfied by using either a horizontal tail, canard, or both. Although potentially very efficient, canards were not chosen because of loading, access, and structural interference problems. The location of horizontal stabilizer could be anywhere between the fuselage and the top of the vertical tail. A low, fuselage mounted horizontal tail has the advantages of having less structural weight, and lower trim drag from being more in the wing's down wash. The other extreme of having a T-tail would have the disadvantage of requiring a larger surface area to alleviate deep stall. The T-tails only advantage is providing an area for rear fuselage mounted engines which was decided against in preliminary

design. Therefore, a fuselage mounted horizontal stabilizer was chosen. Figure 4.0.1 shows the resulting configuration which was arrived at with further analysis as described later in this section.

4.0.2 Configuration Refinement

In order to meet or exceed all RFP, FAR, and economic requirements, a special design approach was used which would synergistically meet the conflicting requirements of low noise, low fuel burn, operating and manufacturing cost.

At present, Stage 3 noise requirements are in effect. With an entry to service date of 2005, new noise requirements were anticipated to be 3 EPNdB lower than stage 3 levels. Our RFP required that we meet this anticipated noise requirement. The actual stage 3, and RFP requirements based on the JB-300's Gross Weight are shown in Table 4.0.1 below.

Table 4.0.1: FAR 36-8 and RFP Noise Certification Requirements

	FAR 36-8 Stage 3 (EPNdB)	RFP -Anticipated Stage 4 (EPNdB)
Approach	102.3	99.3
Sideline	99.0	96.0
Takeoff	94.5	91.5

The approach, sideline, and takeoff noise levels are measured as shown in Figure 4.0.2. The lowest noise level requirements, sideline and takeoff, are when engine thrust settings are high. Since

these will be the critical cases, effort was concentrated on reducing their expected noise levels. As can be seen in Figure 4.0.3, exhaust and fan noise are prevalent during takeoff. Reducing required takeoff thrust reduces exhaust gas velocity by a proportional amount. The exhaust noise is proportional to the eighth power of exhaust velocity (Ref. 27). To achieve this affect, the required takeoff thrust was reduced by increasing Lift to Drag ratio at high lift coefficients. This can be achieved by using low drag flaps combined with a low wing loading and minimal wing sweep, and a high aspect ratio wing. As will be shown later this was taken advantage of to decrease noise. In addition, this design approach would also allow the engines to be down-sized, reduce cruise fuel burn, and result in a simpler, economical flap system.

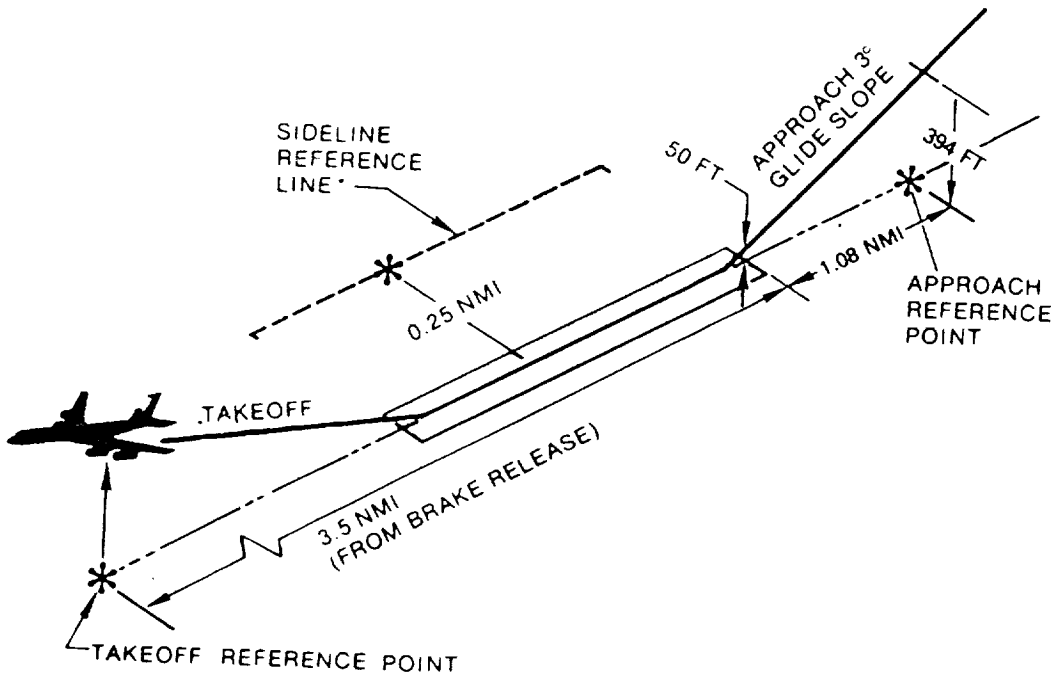
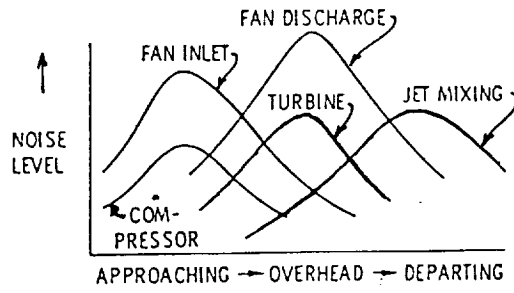
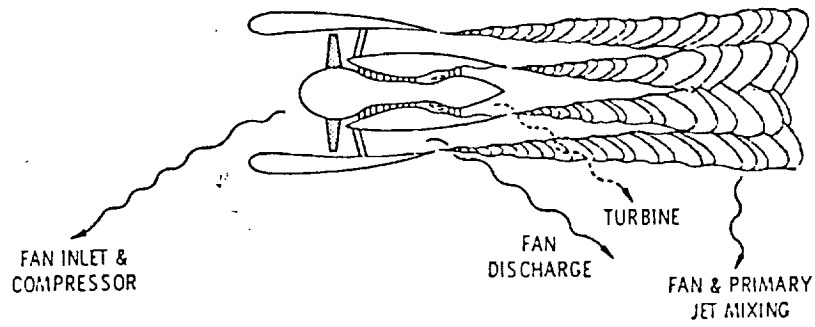
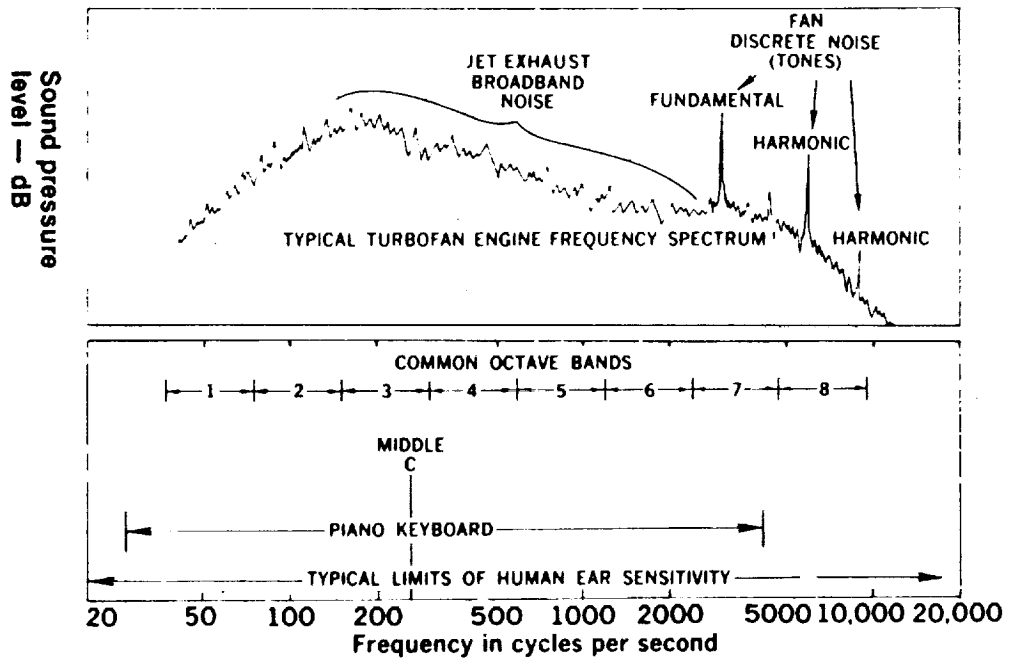


Figure 4.0.2: FAA Noise Measuring Points. Source: Ref. 14



Source: Ref. 13



Source: Ref. 22

Figure 4.0.3: Major Powerplant Noise Sources.

Using these concepts, further optimization of the wing location and dimensions, landing gear location and configuration, and fuselage upsweep was used to improve the design. This required several important design restrictions:

- 1) Carrying fuel only in the wing outboard of the fuselage with the front and rear wing spar fixed, and a slightly variable wing thickness ratio.
- 2) Meet all FAA Part 25 Regulations.
- 3) Use a small Yahodi to minimize compressibility drag with a thick wing root section.
- 4) Use the minimum wing sweep required to allow no more than 10 counts, ($C_{dc}=.001$), of wing compressibility drag during cruise.
- 5) Locate the wing to minimize cruise trim drag to less than 2% (Static Margin=-.15). To get less trim drag, the wing would have to be moved farther forward. When this was tried, other problems arose.
- 6) Provide at least a 5% of gross weight static load on the nose landing gear to allow safe turning ability.
- 7) Change the fuselage upsweep to allow a rotation angle equal to 11.6 degrees to minimize upsweep drag.
- 8) Hold the aspect ratio constant at a 10.5 while changing wing area, and span. A constant aspect ratio of 10.5 was arrived at as a good compromise between wing structural weight and aerodynamic benefit.

Initially while attempting to minimize trim drag without having a large yahodi, several changes were required to prevent

compromising other characteristics. The centerline main landing gear was added and some tilt back on the wing main gear was provided to allow dynamic turning stability. Also, a vertical tail trim tank to carry reserve fuel during cruise was added. Several systems were moved back as far as possible to move the C.G. back.

To facilitate designing with all these restrictions and variables, a design program was used to do all calculations. This program was written in spreadsheet format to maximize flexibility and save time. It was organized as shown below in Figure 4.0.4.

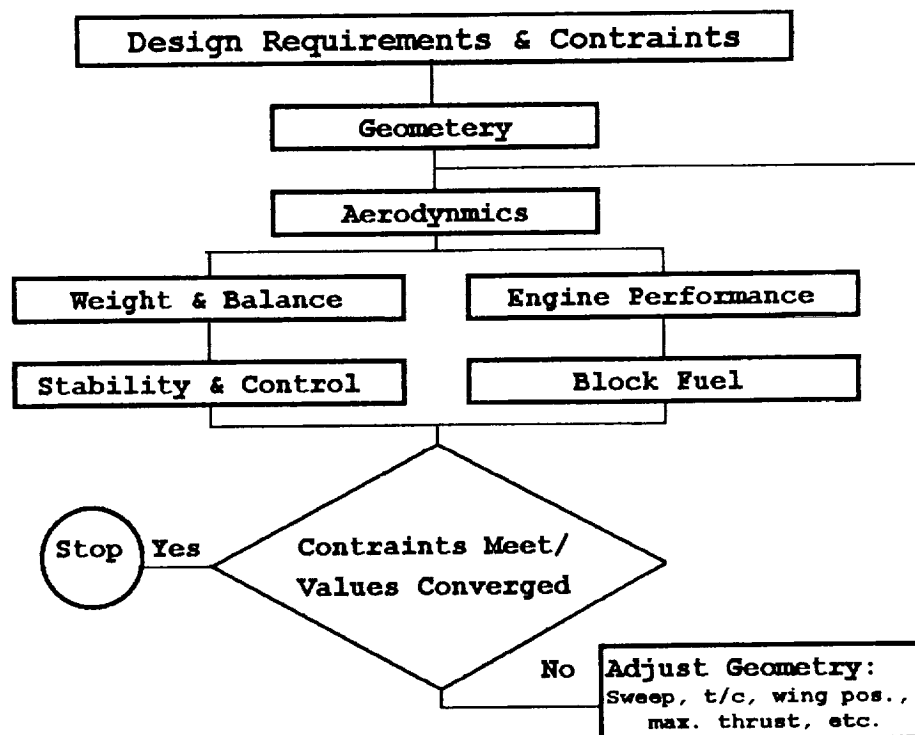


Figure 4.0.4 : Aircraft Sizing Optimization Program.

Using this program, a family of configurations was investigated by changing wing areas and the design point cruising altitude (design cruise lift coefficient). With this data, the best design was found and the design approach was verified. Figure 4.0.5 and 4.0.6 show contours of how gross weight and fuel weight varied as the wing area changed and cruise altitude were varied. A dashed line on Figure 4.0.5 shows the optimum design point for a given wing loading which results in the minimum gross weight. Note that the optimum cruise lift coefficient changes only slightly. Although a near minimum gross weight can be achieved anywhere along this dashed line, fuel weight, Figure 4.0.6, can be significantly reduced by going to the low wing loading side. The lowest wing loading which would provide the lowest fuel consumption, noise, and operating cost, yet still adequately meet gust requirements is marked on each Figure as about 99 pounds per square foot

Performance of a higher wing loading case, 122 psf, was compared with this design point to verify the improvement. Fuel burn at conditions other than minimum fuel consumption cruise altitude is shown in Figure 4.0.7 for both cases. This shows that there is a large fuel savings at all altitudes. In addition, the higher wing loading case required 5 degrees more sweep, full span slats, and double slotted flaps. The expected takeoff and approach exhaust noise also increased as shown in Figure 4.0.8 for the higher wing loading. Based on these findings, with noise and cost as the primary considerations, the low wing loading case was chosen as the design point.

FOLDOUT FRAME 1.

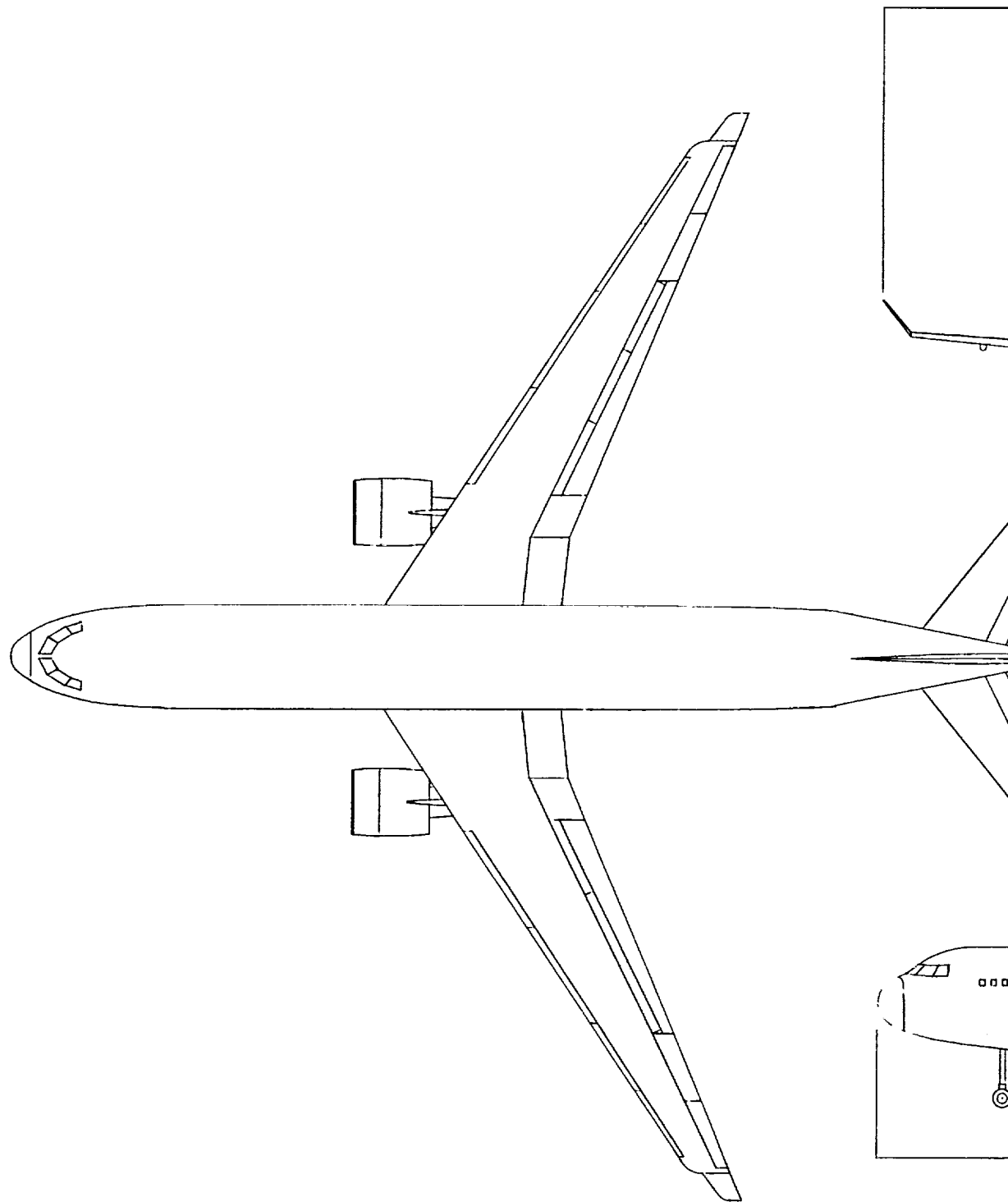
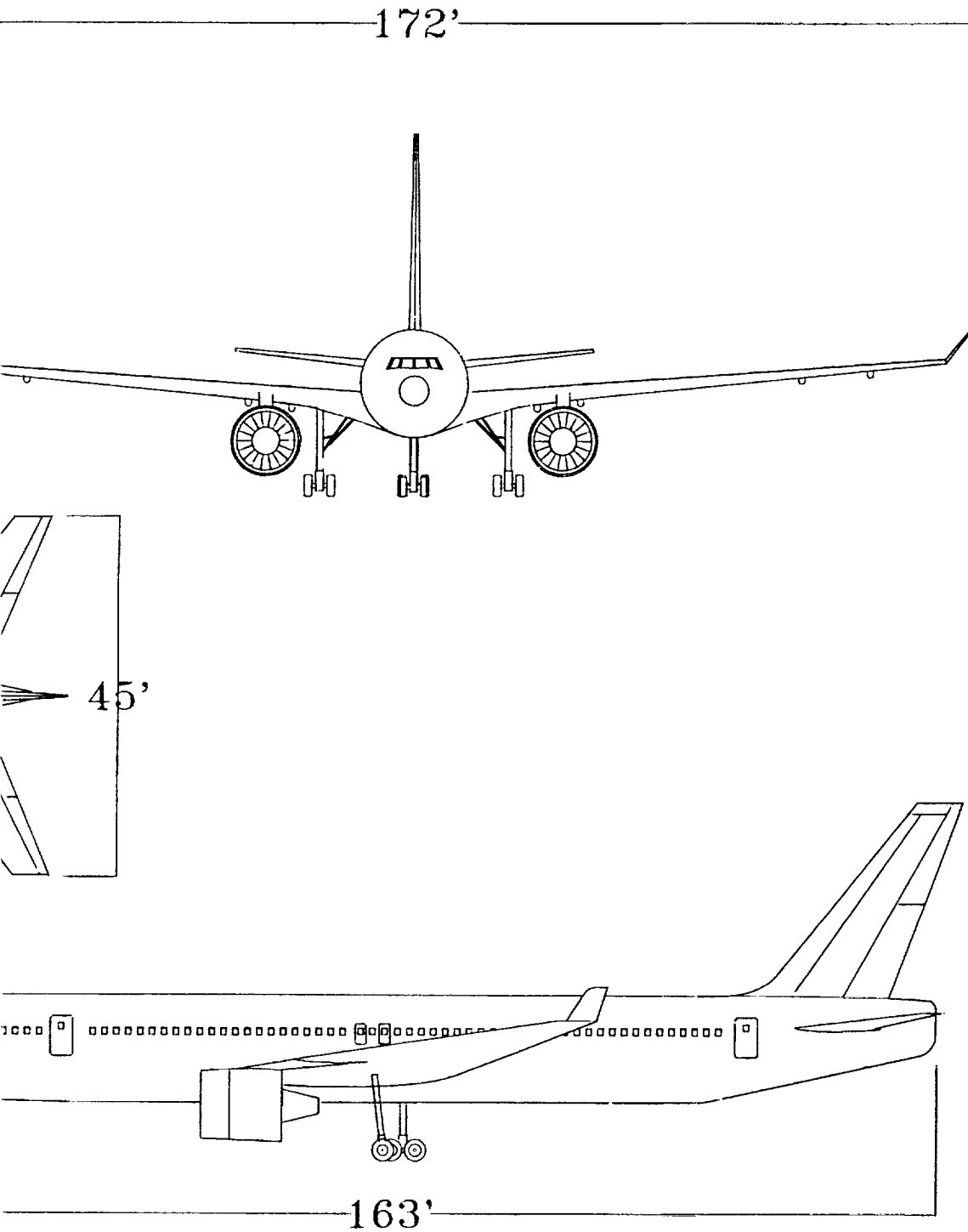


Figure 4.0.1 Three-view of

FOLDOUT FRAME

2



the JB-300

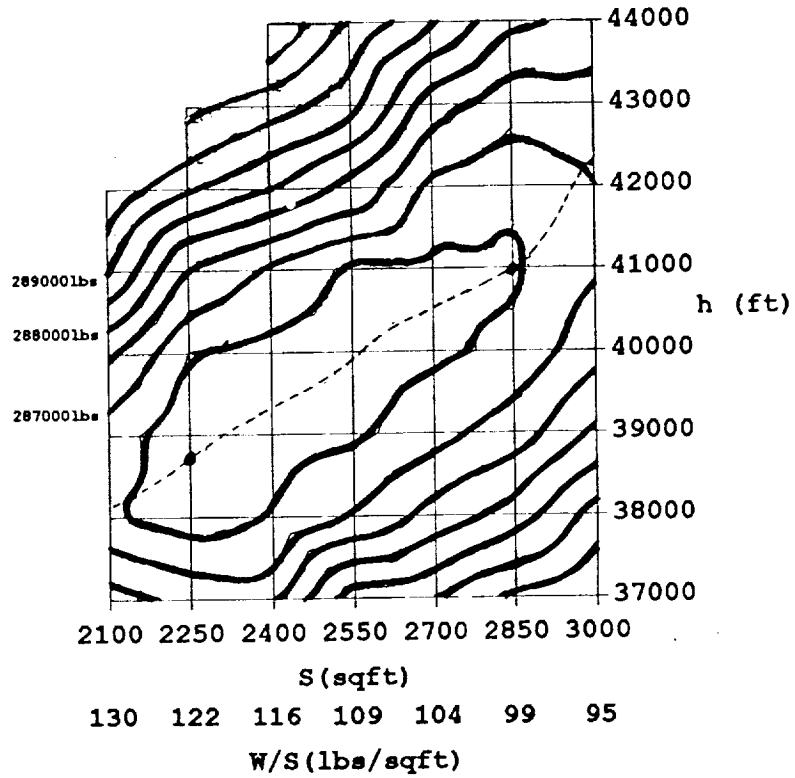


Figure 4.0.5: Gross Weight Contours vs Wing Loading vs Altitude

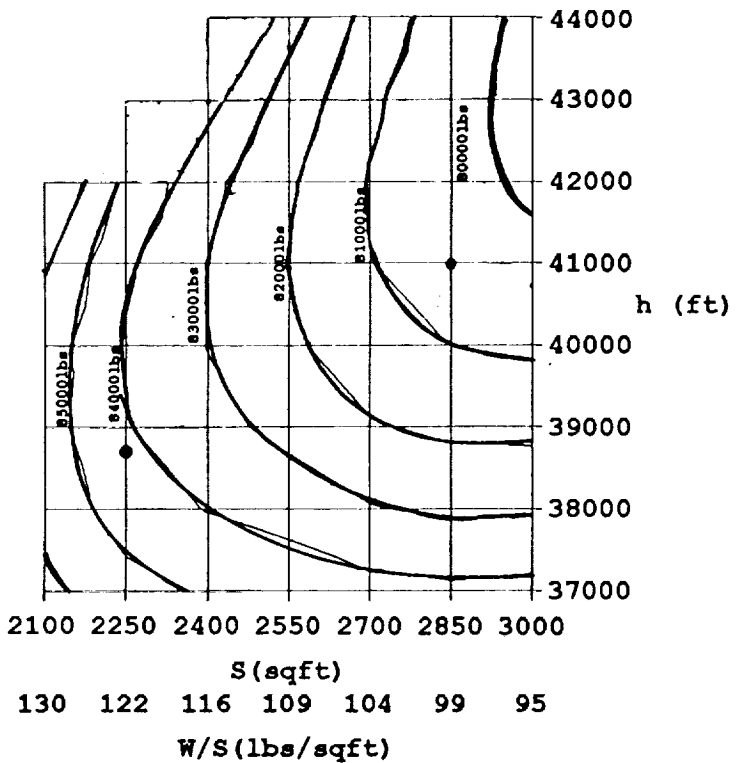


Figure 4.0.6: Fuel Weight Contours vs Wing Loading vs Altitude

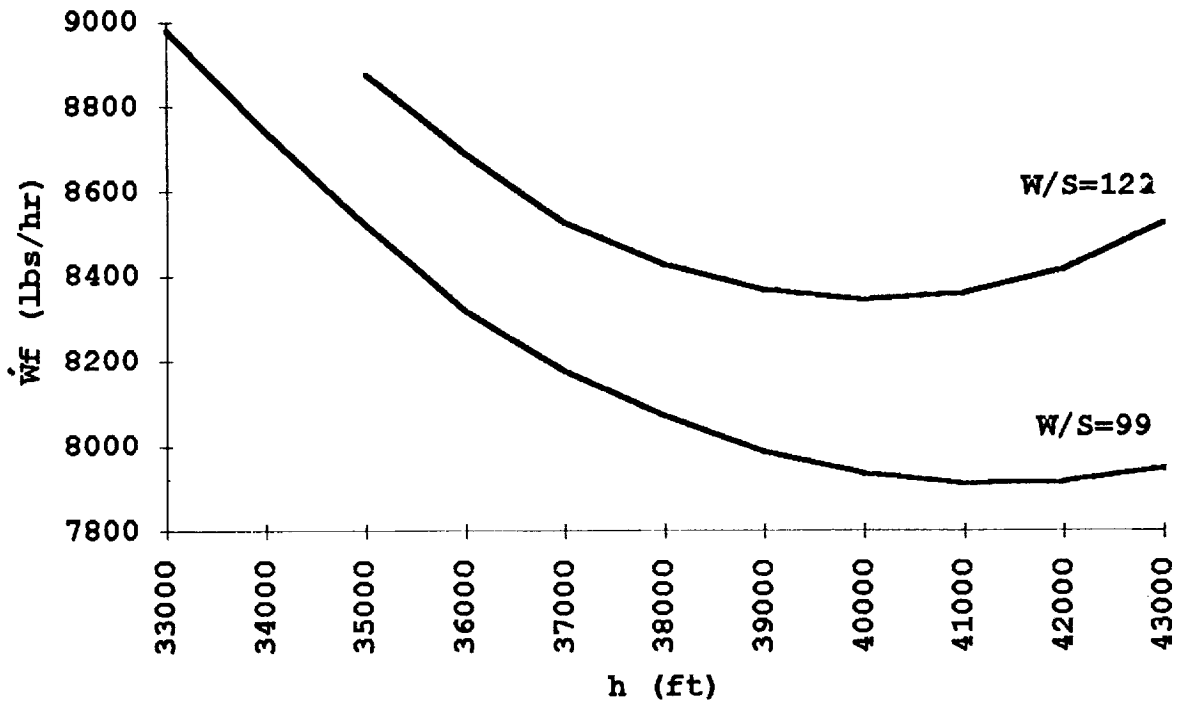


Figure 4.0.7: Fuel Burn vs Altitude

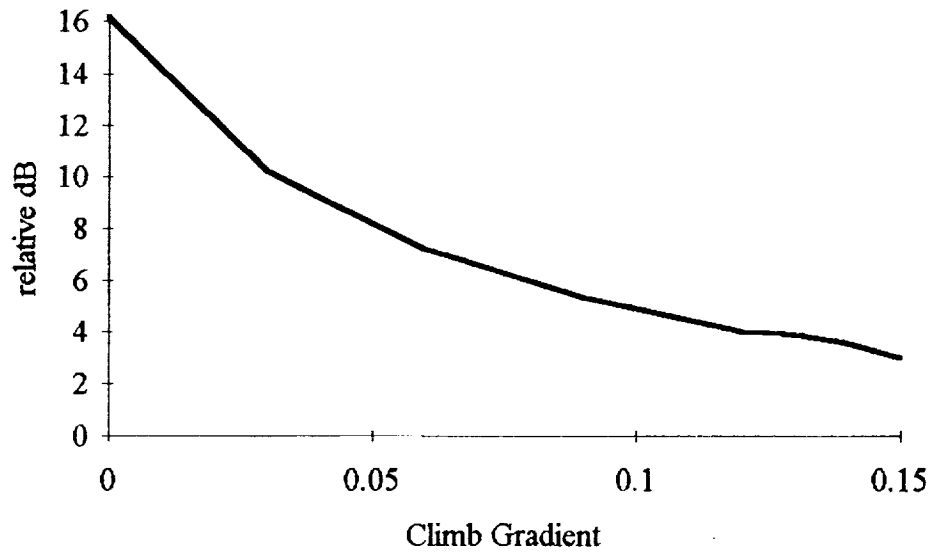


Figure 4.0.8 : Exhaust (Jet) Noise Difference Between High and Low Wing Loading Design

4.1 Wing Design

In designing the wing, the two main objectives were to lower weight and drag. To accomplish better performance than the JB-300's counterparts, a supercritical wing with minimal sweep, an aspect ratio of 10.5, and winglets were used.

4.1.1 Airfoil

The airfoil chosen for the wing design consists of a spanwise variation of thickness ratio and lift coefficient. At the root, the airfoil has the greatest thickness ratio of 14 percent. It is then reduced and maintained at 10 percent around mid-span (See Table 4.1.1). Taking compressibility drag into account, a compromise between thickness and structural weight was considered. Also the variation in lift coefficient forces stall to initiate along the inboard section of the wing.

In addition, the lift coefficient varies from .4 at the root to .7 near the tip. Maximum controllability is a result of the larger lift coefficients chosen in front of the ailerons. Also, because the inboard section of the wing is designed to stall first, controllability is maintained even after the wing has started stall; and its not until after the entire wing stalls when lift and controllability is lost.

The following table gives the airfoil designation at the various spanwise positions. At locations between these positions interpolated shapes will be used.

Table 4.1.1 Airfoil Designations

Most inboard section	SC(2) - 0414
Inboard/center	SC(2) - 0412
Center	SC(2) - 0410
Outboard/center	SC(2) - 0610
Most outboard section	SC(2) - 0710
Winglet	SC(2) - 1010

By using a supercritical airfoil with winglets, both design objectives of low weight and low drag are accomplished.

Since the drag divergent Mach number is larger with a supercritical airfoil when compared to non supercritical airfoils, a smaller wing sweep angle was used. This allowed for reduced structural weight. At 31 degrees of sweep the JB-300 can cruise at the required Mach number of .82 and not be penalized with a large increase in compressibility drag.

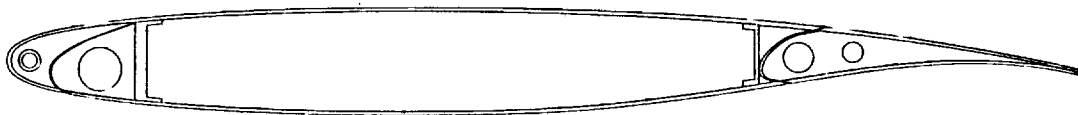


Figure 4.1.1 Airfoil Cross-section

Another way the JB-300's airfoil reduces weight is through the allowance of a large torsion box. Figure 4.1.1(airfoil cross-section)

is a cross-section of the airfoil with the structural torsion box shown. The large torsion box reduces weight by requiring smaller main and rear spars. Also, a large fuel volume can be handled with a large torsion box. Maximum flexibility of fuel placement is essential to reducing the center of gravity excursion through fuel burn. Trim and control surfaces were allowed to be kept small. Also, for expansion reasons, the large volume available for fuel storage can be fully utilized if range is to be added later.

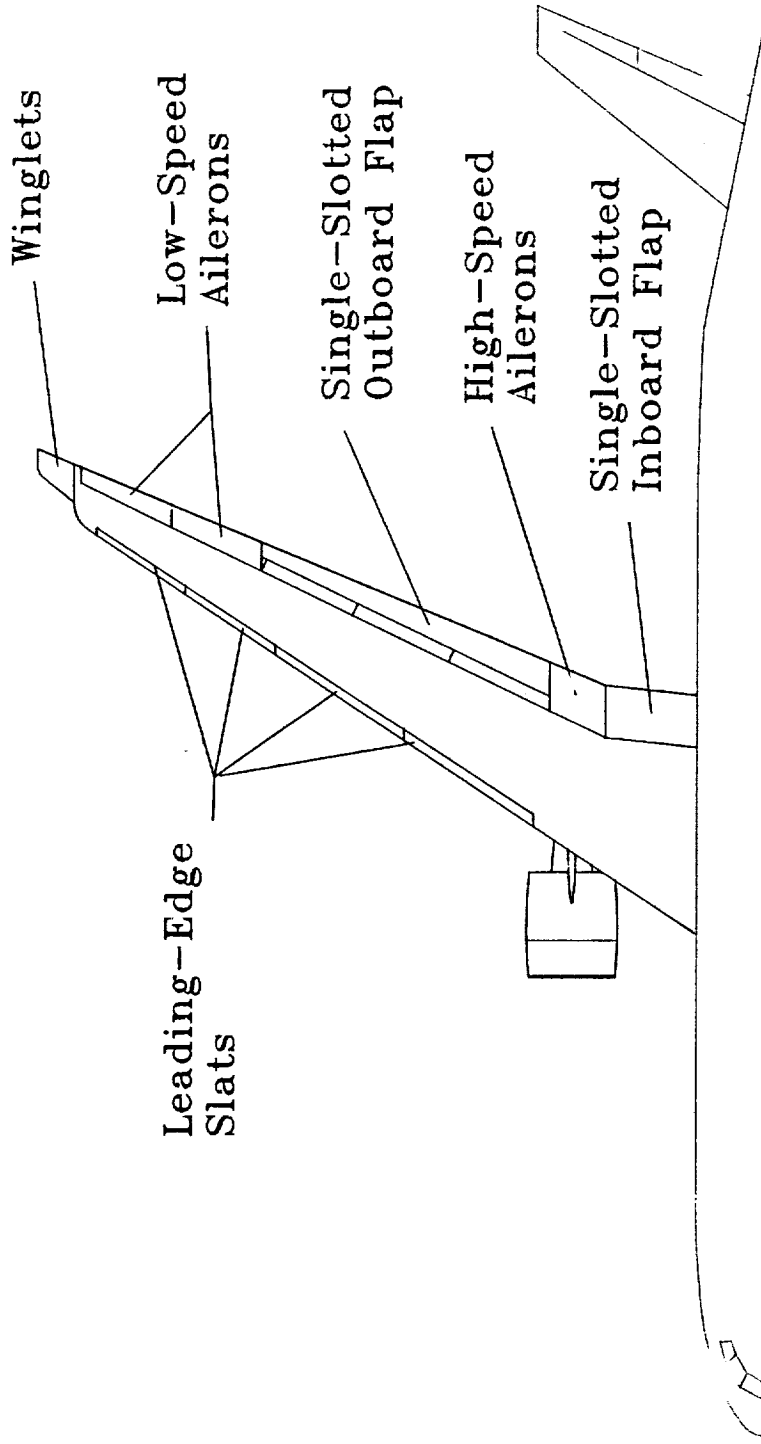
4.1.2 High Lift Systems

In the design of the JB-300, the high lift devices were chosen to minimize complexity while still obtaining the required lift enhancement. The needed increase in lift coefficient for both take-off and landing was determined to be .6. When compared to other airplanes of the same size, .6 is small. This is because of the low wing loading designed for. Connected to the trailing edge, single slotted flaps were chosen because they provide the needed lift increase; they are also simple to design, easy to maintain, and cheap to build. Figure 4.1.2 shows the placement of the high lift devices. The inboard and outboard sections both require a 12 degree deflection at take-off and a 24 degree deflection at landing. This small deflection angle was designed for because of the possibility of future growth to the aircraft. If the aircraft is someday expanded, for example, the deflection angle of the flap needs only to be changed. A whole new flap system may not have to be designed.

A leading edge slat is used on the outboard portion of the wing for a leading edge high lift device. Though the slat is not needed for additional lift at take-off, it is used for landing and to control the section of the wing that stalls first. This is also a great benefit for future expansion of the airplane when larger lift increases are needed from the high lift systems.

4.2 Interior Design

The basic three class configuration consists of a 20 passenger, First class section, a 62 seat Business class, and Tourist class that holds 176 passengers (See Figure 4.2.1). This class breakdown is based on the increase in demand for the Business class passenger. This increase is supported by the January 15th edition of the USA Today which conducted research to see who is utilizing the airlines today. As compared to the Boeing 767-322, the Business class is 5% larger with respect to the total passengers. The Tourist class suffers a 5% decrease due to current load factors of less than 60% in this class. The First class section has a 40 in. seat pitch and seats 5 across. The Business class has a 35 in. seat pitch and seats 6 across, while the Tourist class seats 8 across with a 31 in. seat pitch. All classes have two aisles, overhead and underseat storage, at least one shadeable, elliptical window, as well as individual reading lamps and cabin ventilations, with forward to aft passive circulation. There are 7 lavatories and 3 galley complexes, as well as 2 large screen projection televisions, 4 sixteen inch monitors and individual First class monitors for movie viewing. The emergency exits to the



7
Figure 4.1.2 High Lift Systems

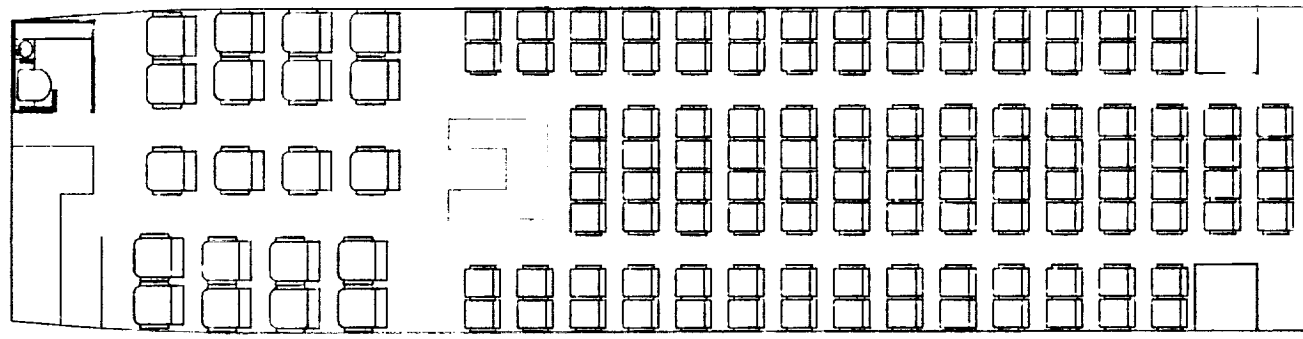
JB-300 consist of 2 Type A doors and a Type I door per side (in the 3-class configuration) of the aircraft, with the main passenger loading door located behind the First class seating area. Additional safety features include individual air masks, seat cushion floatation devices and emergency egress inflatable slides (See Figure 4.2.2).

4.2.1 First Class

The First class of the JB-300 offers many advantages over the current aircraft, e.g., the Boeing 757 and 767 and the Airbus A300 and 310. The first benefit is the main passenger loading doors are located aft of the First class section. This allows for the First class passengers to enjoy more privacy during boarding and deplaning, and especially in stopover situations. Normally, this convenience is only reserved for larger aircraft, such as the Boeing 747. These forward doors are Federal Aviation Administration (FAA) Type A, plug-type doors, and are located on both sides of the cabin. The required flight attendants' chairs and the cross aisle are located near these doors. The cross aisle is capable of handling two lines of passengers. These doors are also equipped with an under the floor, dual lane inflatable, emergency egress slide, which can also be used as a raft in water egress (See Figure 4.2.2).

The seats of the First class are built to provide more comfort than current aircraft. The seat pitch of 40 inches exceeds the standard 38 inch seat pitch in the Boeing 767-200, Boeing 757, Airbus A300, and the Airbus A310. The JB-300 seat is 23 inches wide and 50 inches from floor to top of seat with individual 2.5 inch armrests (See Figure 4.2.3.a). The left armrest offers a

1.
FOLDOUT FRAME



— Lavatory

Galley

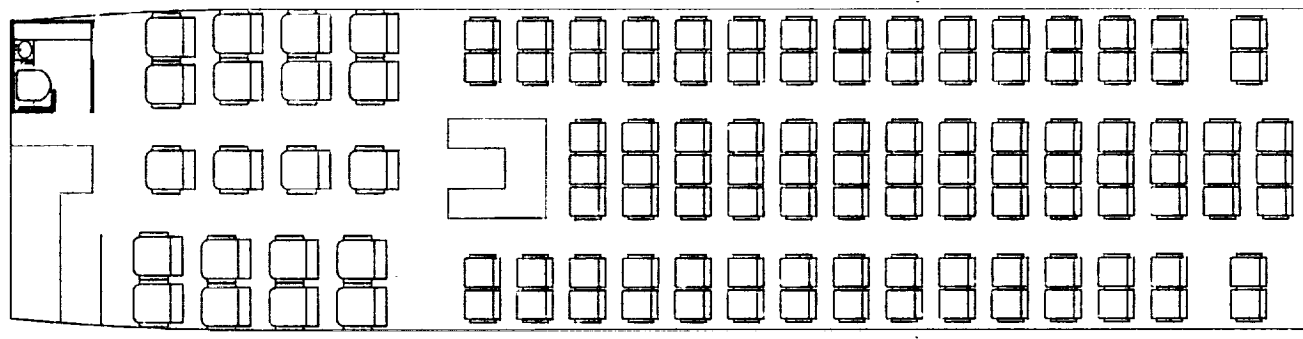
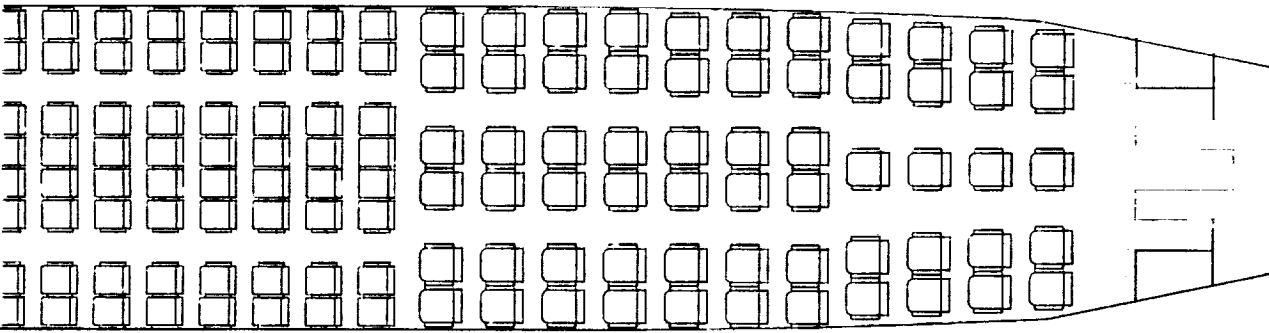


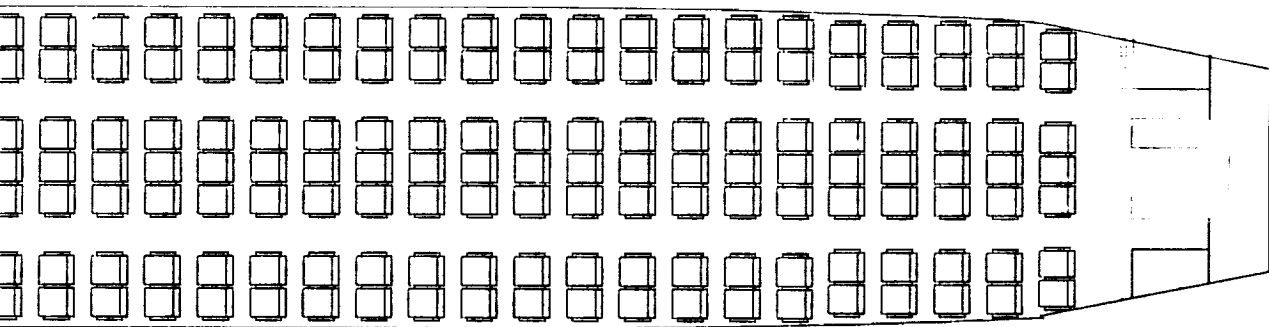
Figure 4.2.1 Interior Layout

2.

FOLDOUT FRAME



Attendant's Seat



1

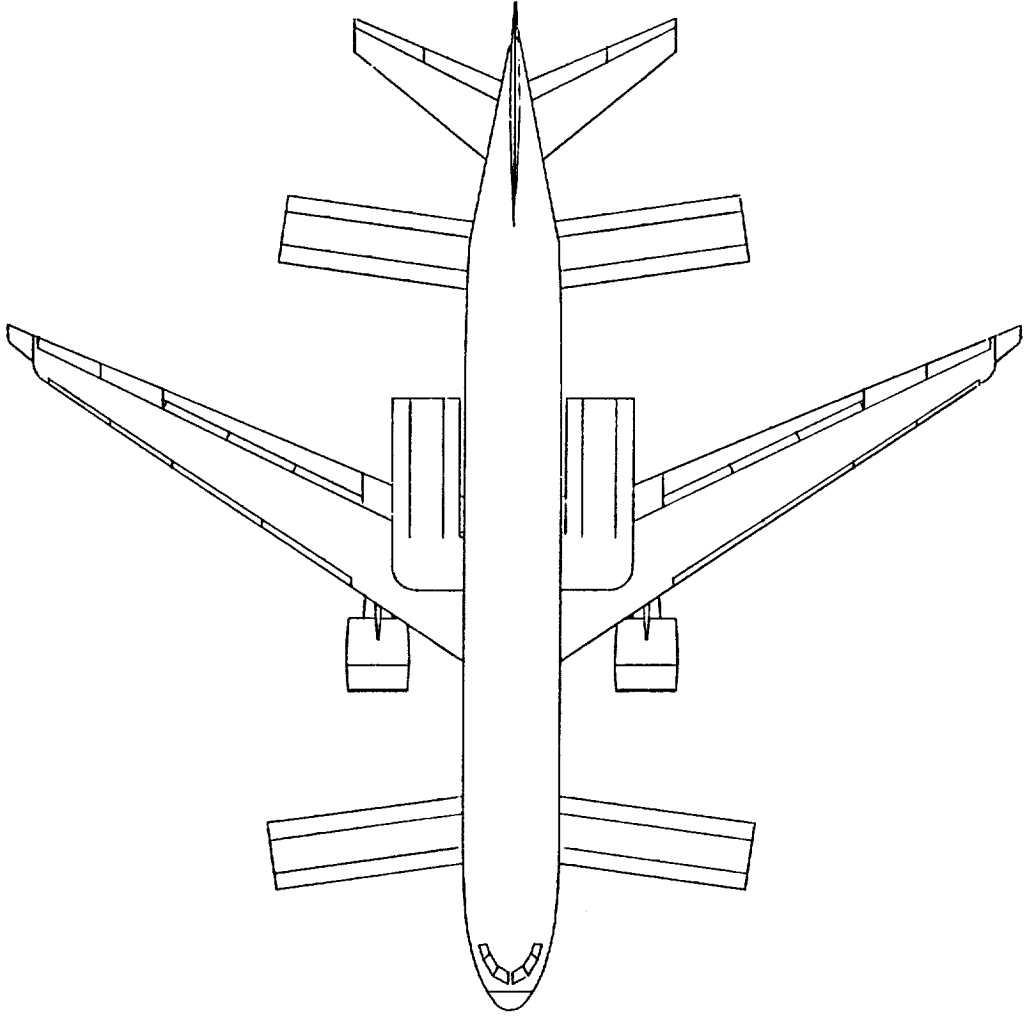
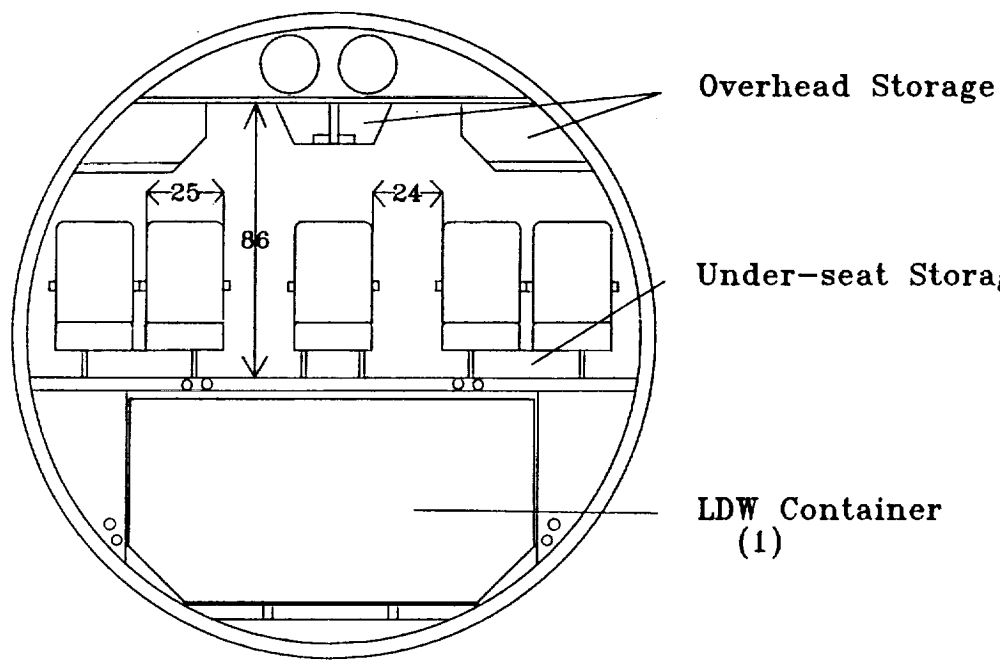


Figure 4.2.2 Emergency Egress

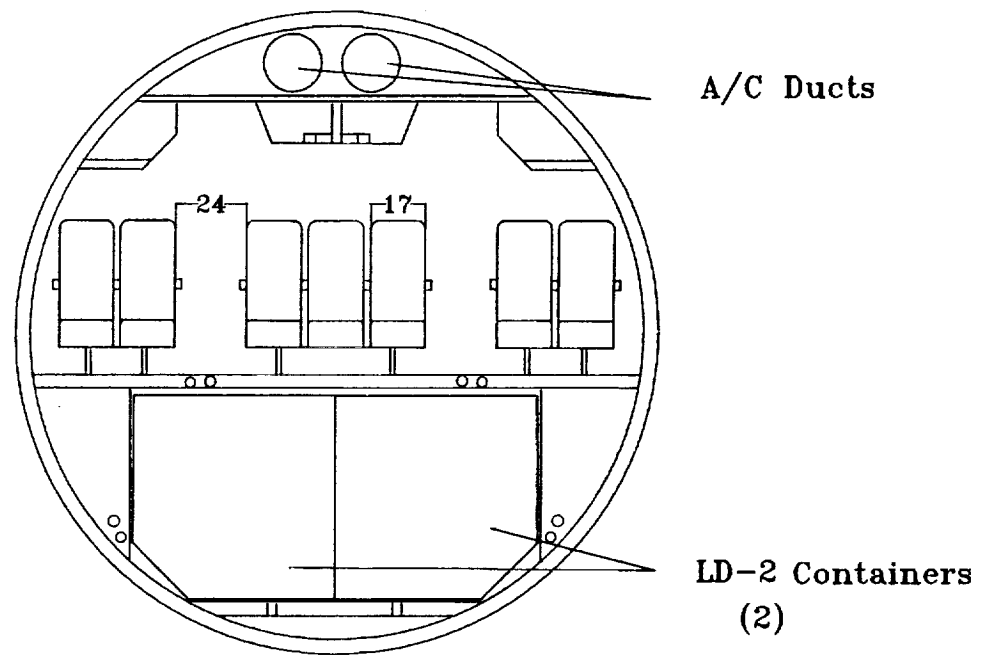
compartment for a fold-out food service or work table, while the right armrest has a personal monitor, earphones, power outlet, and a cellular phone. This size seat in the 2-1-2 seating configuration has two aisles of a width of 24 inches from armrest to armrest. This leaves ample room for a food service cart and a person of average size to pass simultaneously. The ceiling height at the aisle is 84 inches. This can accommodate over 98% of the world's population comfortably without the need for ducking while walking through the aircraft.

The overhead bins of the JB-300 have a higher capacity per passenger than all aircraft in this range. There are two sets of stationary top-hinged bins above each of the two abreast seats with a pull-down storage bin located over the center seat (Fig 4.2.3.a). This pull-down type bin allows for 6 feet of height from the floor to the bottom of the bin and leaves sufficient room for a garment bag. This center bin leaves approximately 22 inches of head room. The side bins are designed to leave over 63 inches of room between the floor and the bins, which leaves over 13 inches of headroom. This gives 5.7 cubic feet per passenger. Our nearest competitor, the Airbus A310-300, has only 5.4 cubic feet per passenger. The seat orientation in the fuselage leaves no interference in passenger head and shoulder room. This large overhead storage capacity is complimented by the underseat storage capacity, which is 1.9 cubic feet per passenger. In addition to the overhead and underseat storage, there is also availability for an optional hanging bag closet near the passenger boarding door between the First class and

FOLDOUT FRAME



a) FIRST CLASS

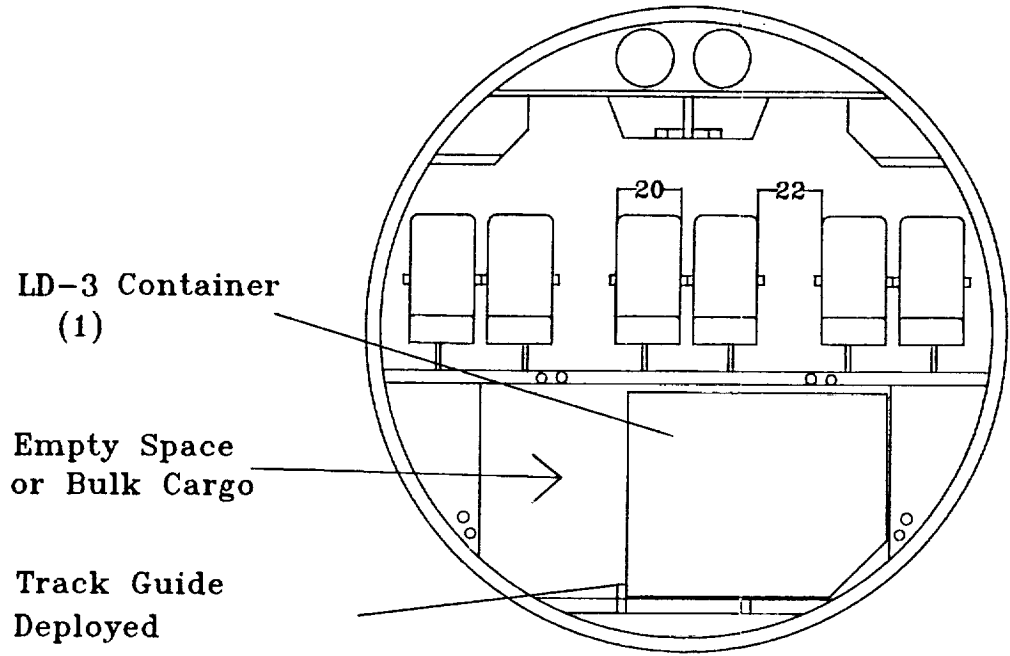


c) ECONOMY CLASS

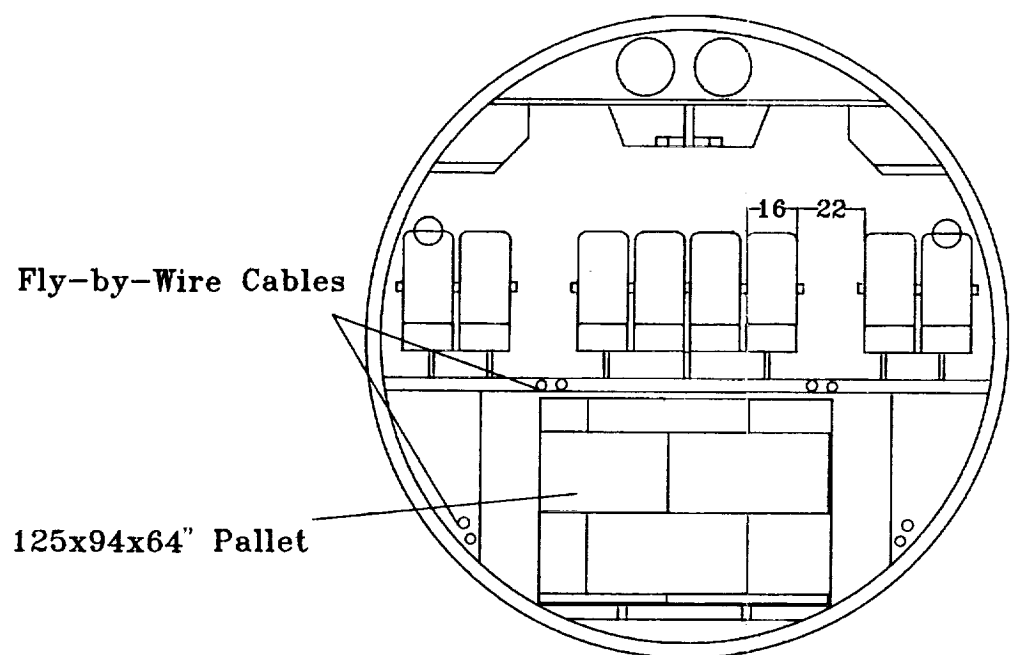
Figure 4.2.3 In

2.

FOLDOUT FRAME



b) BUSINESS CLASS



d) TOURIST CLASS

terior Cross-Section

Tourist class sections. This closet can accommodate an additional 45 cubic feet of carry-on baggage or coats.

There is one lavatory in the First class section and it exceeds current aircraft lavatory standards. This lavatory is provided for the comfort of the First class passengers and is also specially designed for the physically disabled (See Figure 4.2.4). The lavatory is over 4 feet by 4 feet in planform dimensions and is large enough to allow

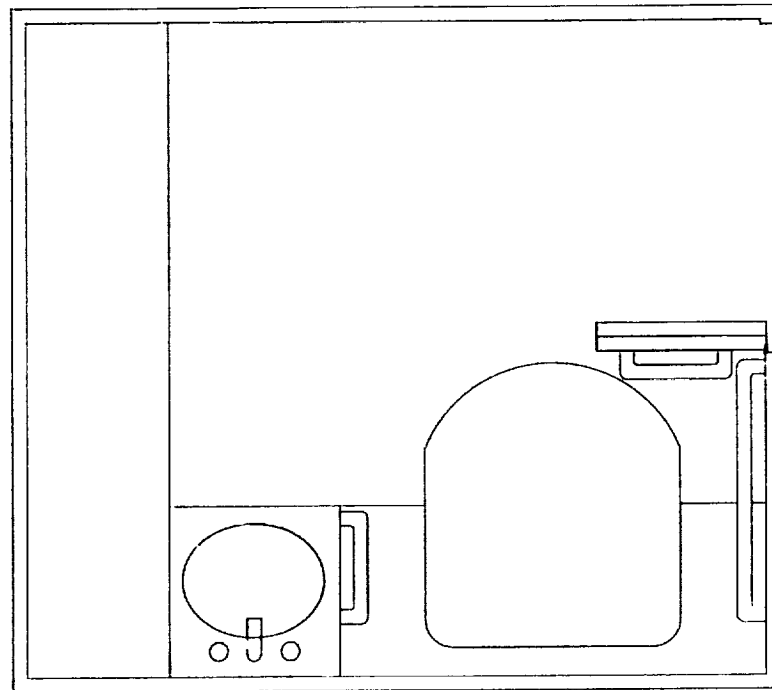


Figure 4.2.4 First class (Handicapped) Lavatory

an airline wheel chair to turn around. Special bars along the walls also add access to physically disabled passengers. While other aircraft, like the Boeing 767-322, merely add bars to the walls and call these lavatories handicapped, the JB-300 goes the extra mile to ensure the accessibility for the physically disabled passengers to the entire aircraft including the lavatories. Accessibility is also insured

by the FAA minimum aisle widths as well as the widened passenger loading door.

The JB-300 is equipped to handle seating for two First class attendants at the Type A doors, who would manage the galley at the front of the First class section (See Figure 4.2.1). This galley has an unconventional shape, but it effectively uses the tapered area in the front of the aircraft. The JB-300 also offers a larger galley size than our nearest competitor, the Boeing 767-300, with 7.4 cubic feet per passenger compared to 5.1 cubic feet per passenger. The increase in size of the galley increases the volume of storage space for food. The weight cost of this additional service depends on the airline service philosophy. This space could be used to increase meal selection at a cost of approximately 1 pound per extra meal carried by the flight or could be used to increase passenger and crew safety by providing more fire extinguishers, extra life vests and portable oxygen at variable weight penalties. If the extra meals are chosen, the passengers are able to have more choices, and because there are more oven capability in larger galley, they will be served faster.

All of these provisions make the First class section of the JB-300 superior to all current aircraft in its size range. With many options available to the airline customer, such as a 60 inch seat pitch, a 5 across seat configuration with Weber First class sleeper seats, extra front aisle, or extra closet space, the JB-300 can meet the needs of any First class passenger.

4.2.2 Business Class

The JB-300 reserves 25% of its seating capacity for a Business class section to provide maximum comfort for the increasing demands of the business world on the airlines. Many of the features of the First class have been incorporated into the Business class such as aisle height, windows, air flow and closet space. Another feature of the First class incorporated into the Business class is the privacy. The business class of the JB-300 is located in the rear of the aircraft. The advantages to this configuration are: privacy, closer proximity to the four lavatories in the rear and two in the mid section and the efficient use of the tapered interior of the rear of the fuselage. The disadvantages involved in this unconventional configuration do not seem to effect the opinion of the business class passenger. In a TAC Team survey of business class travelers in both the San Luis Obispo Municipal and Los Angeles International Airport there was only a 5% dissension to the proposed idea. When the disadvantages of possible excess engine noise, the longer walk to the seat and the use of a 2-1-2 configuration in the rear of the cabin were shown to the survey participants there was a great response to the countermeasures used to combat the problems. The passengers enjoyed the privacy, individual earphones, and proximity to the rear galley and lavatories.

In the 2-2-2 configuration, the JB-300 offers a 20 inch wide Weber Business class seats with a 35 inch pitch (See Figure 4.2.3.b). The Business class passenger will enjoy a 22" aisle, 2.57 cubic foot per passenger(ft^3/PAX) of galley space, and 4.22 ft^3/PAX of

overhead storage space. The increase in galley space allows for increase in Business class passenger service or can be transferred to the tourist class at the airline's option. Each individual armrest offers airphone outlets with airphones available upon request. Depending on the airline choice, there are provisions for a 48" by 48" video screen and projection television or personal video monitors. There are 2 lavatories forward of the Business class section and provisions for 4 attendants to service the Business class with their seats at the rear exits and galley.

4.2.3 Tourist Class

The tourist class of the JB-300 accounts for 68% of the total seating capacity with similar standard features of the other classes (See Figure 4.2.3.d). In the 2-4-2 configuration, the JB-300 offers a 16" wide seat with a 31" seat pitch and a 20" aisle. Although this is not superior to the competition, such as the Boeing 767-322ER with a 31" seat pitch, it is competitive. This provides the airlines a revenue generating, tourist class with a competitive seat pitch. The tourist passenger is guaranteed at least 3 ft³ of overhead storage space and 1.44 ft³ of galley space. An inherent benefit to the galley configuration besides the increase in customer service is the modularity of the galleys in the fore, middle and aft sections of the fuselage. During manufacturing, only four different galley sections need to be manufactured, a U-shaped section (used mid and aft), a small extension section (used fore and aft) and the fore section that follows the curvature of the fuselage.

For entertainment, the tourist passengers are provided with a 48" by 48" video screen and projection television and two 16" monitors for aft seat viewing. There are also 2 portable airphones available. It is possible to seat 4 to 6 flight attendants with 4 at the aft exit doors and 2 at the galleys. There are 4 lavatories located in the aft section of the aircraft to minimize waiting time. For emergency egress there is one Type A exit on each side of the aircraft equipped with double aisle inflatable egress slides which serve as rafts in water egress. Also, aft of the Tourist class lavatories, there is a Type I emergency exit on each side of the aircraft for emergency egress (See Figure 4.2.2) with rear wing fairing, inflatable egress slide and/or raft.

4.2.4 Class Options

The JB-300 is capable of just about any internal class configuration desired by the airline customer from use of seat track as well as standard galley and lavatory modules to reduce manufacturing costs and number of parts. Other class options analyzed for the airlines are the 2 class(269 PAX), high comfort configuration, the single class, all economy(286 PAX) configuration, and the high density(324 PAX), all tourist configuration. (See Figure 4.2.1) Our sizing of the aircraft was optimized at the all-economy configuration of 286 PAX which incurs no performance penalties from an increase in weight. In the high density configuration the range is compromised by having less fuel because of the increase in PAX. This option causes the range to decrease by only about 100 nautical miles if the extra bags and cargo requirements are dropped.

This should not present a problem because a tour aircraft is usually very baggage controlled. If the baggage and cargo requirements are still desired from a tour operator then a range penalty of an additional 450 nautical miles will be observed. The high density configuration would also require the two overwing Type III exits to be converted to Type II exits to comply with FAA restrictions on egress.

The Request for Proposal (RFP) for our aircraft calls for a minimum cargo requirement that is three-fold. This includes passenger bags, 20% overage in baggage, and 5000 pounds in bulk cargo. The compartment must fit a standard cargo container and possibly provide for a bulk cargo area in the aft compartment, all of which have to be ventilated, temperature controlled, and have a slope of no more than 2° during ground loading.

4.2.5 Cargo

The cargo area of the JB-300 (See Figure 4.2.5) meets these requirements and is competitive with current aircraft. The cargo volume in the JB-300 is 4000 ft³ as compared to the Boeing 767-300 at 4030 ft³. As seen in Figure 4.2.2, the cargo compartment holds the standard LD2 or LDW container (See Figures 4.2.3.a & c). As an added feature, when cargo transfers occur from larger aircraft that utilize the LD3 containers, the JB-300 can accommodate these in place of 2 LD2's with the track guide in the upright position (See Figure 4.2.3.b). Standard bulk cargo pallets of dimensions 94" by 125" by 64" or smaller can also be easily handled in either the fore

or aft compartment with the aid of fully mechanized, floor roller system (See Figure 4.2.3.d).

An oversized cargo compartment is advantageous in several ways. First, when using the LD3 container, there is some wasted space on one side of the container. This would require extra length of the compartment to satisfy the cargo requirement if the extra space is not used for bulk cargo. Secondly, additional aircraft parts, such as an engine core or electronic equipment that don't efficiently use the cargo compartment can be handled. This allows delivery of parts to be carried out on routine flights, saving thousands of dollars in delivery costs for special flights from Maintenance Operations Centers to grounded aircraft throughout the globe. Thirdly, additional cargo volume translates to additional revenue with effective airline marketing of such service. With passenger load factors of 60%, the airline could convert wasted space into revenue by adding cargo business without adding costly convertible aircraft to their fleet. Even though cargo is not as profitable to the airlines as passengers, in low load factor flights this could be a valuable offset to the loss of passenger revenue.

Loading of the JB-300 is done through two 130" by 69" starboard cargo doors fore and aft which are of sufficient width to handle pallets. These doors when closed and fastened will carry the loads that are normally carried by the structure that is compromised by using such a large cargo door. For bulk cargo loading, such as live animals, skis, bicycles and any other non-containerized cargo, a 38" by 45" port side cargo door is located in the aft section of the rear cargo hold.

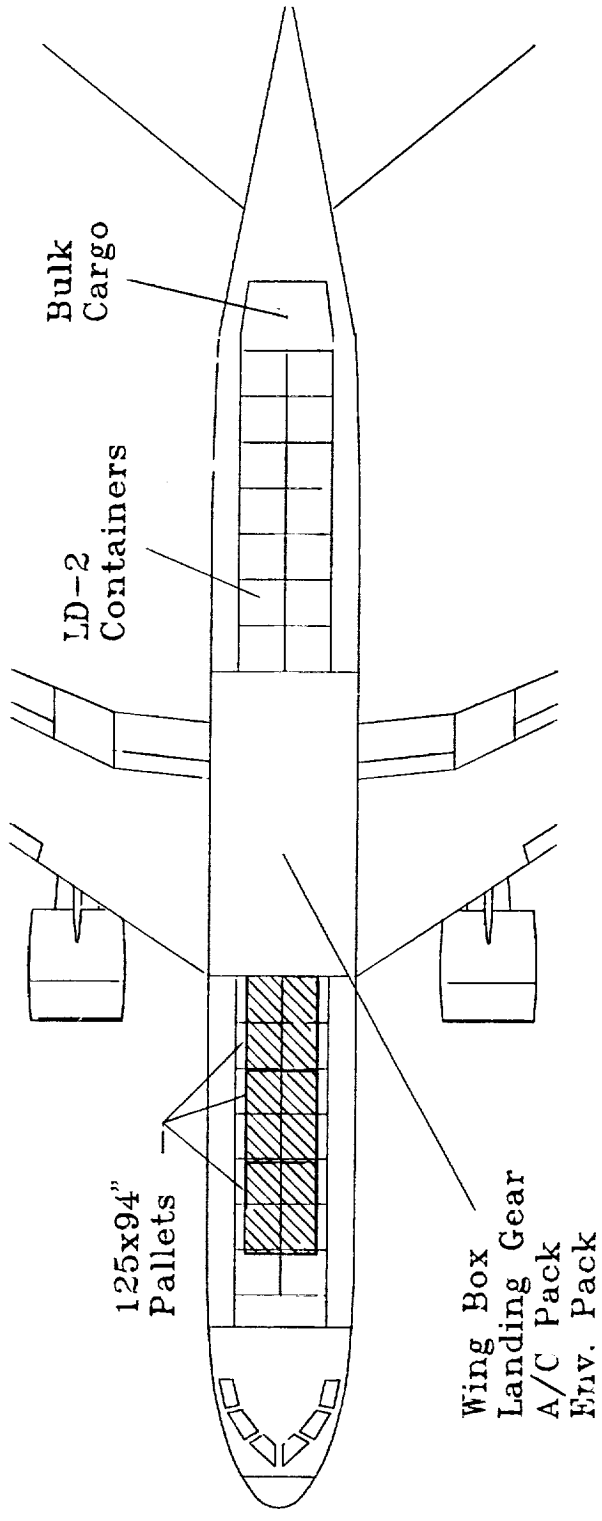


Figure 4.2.5 Cargo Layout

4.3 Design

The JB-300 has implemented a conventional configuration in its design (See Figure 4.3.1 and 4.3.2). The horizontal and vertical tail are mounted far aft on the fuselage. Note that in sizing the vertical tail, the following engine-out conditions were taken into consideration: engine-out yawing moments, drag induced yawing moment due to the inoperative engine, maximum allowable V_{mc} (minimum control speed), rudder deflection required to hold engine out condition at V_{mc} , and vertical tail area. After calculating the volume coefficients, and having determined the moment arms, the tail areas were then computed. SC(2)-0010 symmetrical-supercritical airfoils were used for both the horizontal and vertical tails in order to have a lighter structure since these airfoils would allow for a reduced sweep angle, and therefore less structure. Note that a 35° tail sweeps were used to allow for a higher vertical Mach number and thereby increasing controllability in case of inadvertent dives with Mach numbers of 0.95 . (See Table 4.3.1)

Table 4.3.1 Basic Data

	Horizontal Tail	Vertical Tail
Tail Area (sq. ft.)	550.16	225.3
Tail Volume Coefficient	0.64	0.072
Span (ft.)	45	26
t/c	0.09	0.09
Aspect Ratio	2.66	3.0
Taper Ratio	0.35	0.35
Mean Aerodynamic Chord (ft.)	14.16	9.32
Root Chord (ft.)	19.47	12.82
Tip Chord (ft.)	6.81	4.49
Dihedral Angle (deg.)	5°	90°
Incidence Angle (deg.)	variable	0°
Sweep Angle (deg.)	35°	35°
Airfoil Type	0010	0010

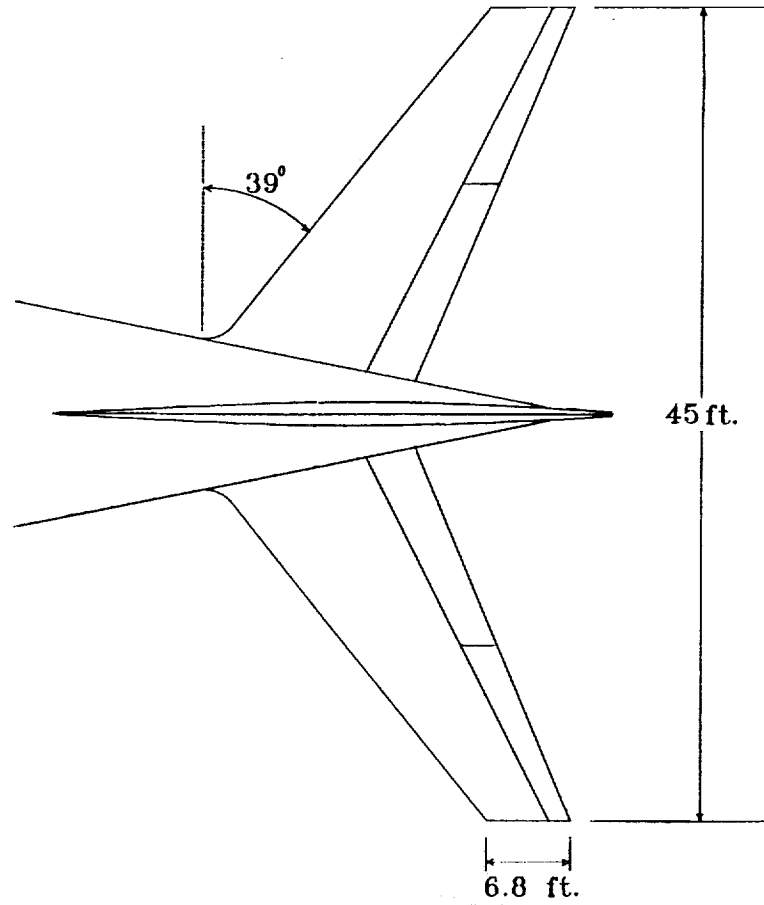


Figure 4.3.1 Horizontal Tail Section

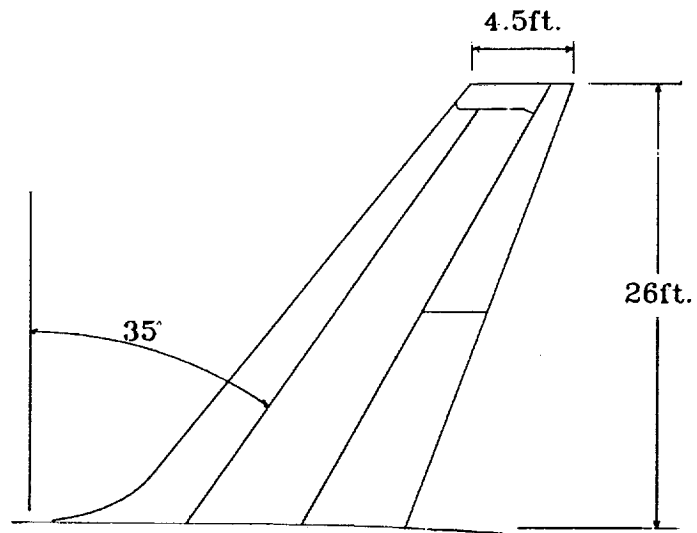


Figure 4.3.2 Vertical Tail Section

5.0 Propulsion Systems

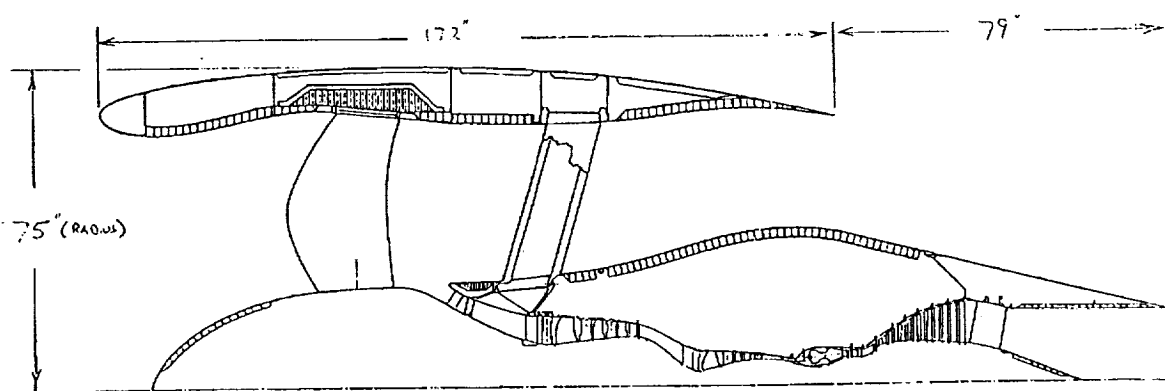
Part of the original TAC team goal was to use an engine with an SFC as low as .45 lbs/lbhr. This value of Specific Fuel Consumption (SFC) was used to do preliminary sizing. This original goal was met with little compromise. The engine type was selected based on thrust, efficiency, and noise requirements. It was then sized in conjunction with the configuration optimization to get the best performance, noise, and low cost.

5.1 Propulsion System Selection

The primary driving factors used to decide on a propulsion system were the Request for Proposal (RFP) cruise Mach of .82, Stage 4 noise requirements, low SFC requirements, and expected engine availability. Under wing engine maintenance requires the least support equipment. The engine was to meet these requirements by an RFP service entry date of 2005. The cruise Mach of .82 restricted the type of propulsion system to turbojet, turbofan, and Very High By-Pass (VHBR) turbofan. The anticipated stage 4 noise requirement eliminated the turbojet as a possibility, and made the VHBR turbofan a preference over the turbofan. The initial design goal of using an engine with an SFC of .45 also favored the VHBR turbofan. To displace development cost, an engine from one of the major turbine engine manufacturers, General Electric, Pratt & Whitney, or Rolls-Royce, would be preferred.

These manufacturers were consulted to see what kind of research and development programs they had in progress. Based on this information there were two choices. The first choice, offered by General Electric and Rolls-Royce, was to use a conventionally configured turbofan with a bypass ratio pushed to the limit, but this would not provide the desired SFC improvement. The second choice, offered by Pratt & Whitney, is a true VHBR turbofan. It is known as the ADP (Advanced Ducted Propulsion). This engine is expected to meet all the initial requirements, and do so with little penalty to other engine characteristics. A cross section of the fully developed version is shown in Figure 5.1.1.

100 OPR IN-LINE ENGINE STS970A



- 130 inch fan diameter
- Variable pitch fan
- Blade pitch thrust reverse
- Gear driven fan
- Dirt separating inlet

ALL DIMENSIONS IN INCHES

Figure 5.1.1: Pratt & Whitney ADP Cross Section Source: Ref. 14

The major differences between this engine and conventional turbofans are a thin cowling, and a variable and reversible pitch geared fan. Instead of using thrust reversing doors, the fans pitch is reversed. If this thrust reversing mechanism works as well as a turboprop's, then it could be much more effective than conventional systems. Similarly, the maintenance cost is expected to be lower. Although this engine has a thrust specific weight 14% higher than conventional turbofans, this extra weight is more than offset by reduced fuel weight for the JB-300. The 22% lower fuel burn would also reduce operating cost.

The only area of concern is the fan drive gear system shown in figure 5.1.2. This compact gear box is one of the key factors which allow this engine to have lower noise output and fuel consumption. Although it has reached efficiencies in excess of 99%, its operational reliability still needs to be proved.

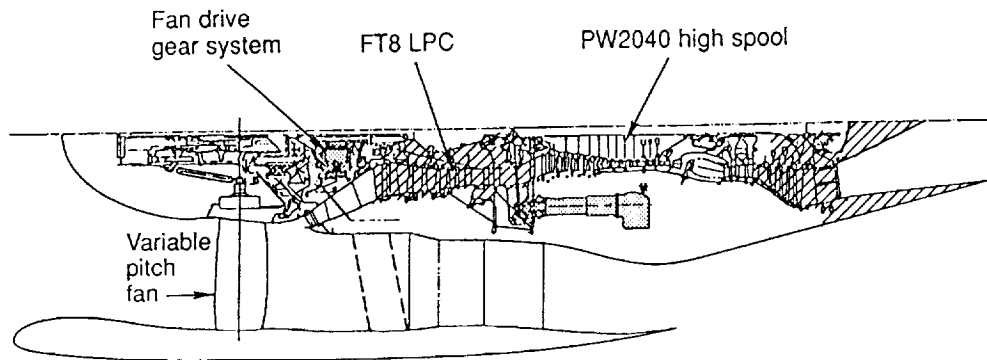
A major development advantage is that this engine can be developed from existing turbine engine core with minor modifications according to Pratt & Whitney Engineers. A prototype, Figure 5.1.3, has already proved several design goals, and is being further tested. Based on the expected performance data supplied by the manufacturer, Appendix A, the Pratt & Whitney ADP was selected.

5.2 Propulsion System Sizing

The data provided in Appendix B and C allowed for engine scaling up or down from the 62,000 lbs model. Using rubber engine



Figure 5.1.2: Pratt & Whitney ADP Fan Drive Gear System
Source: Ref. 14



Source: Ref. 14

Figure 5.1.3: Pratt & Whitney ADP Prototype Cross Section

sizing methods, this would allow the aircraft designer to size the engine for a particular size of aircraft.

To have a rubber engine requires that parametric equations for maximum operating thrust, SFC, engine weight, engine size, and cowl drag are scaled to the required maximum thrust. Using the data provided combined with a momentum theory method outlined in Ref. 12, an equation for the maximum operating thrust at any velocity and altitude (pressure ratio) was found. This is plotted in Figure 5.2.1 for a 46,000 lb maximum thrust engine. The cruise SFC as a function of corrected thrust, and ambient air temperature ratio is shown in Figure 5.2.2. The performance data also shows how SFC varies with Mach number, Figure 5.2.3. The cowl drag was also scaled according to changes in engine size.

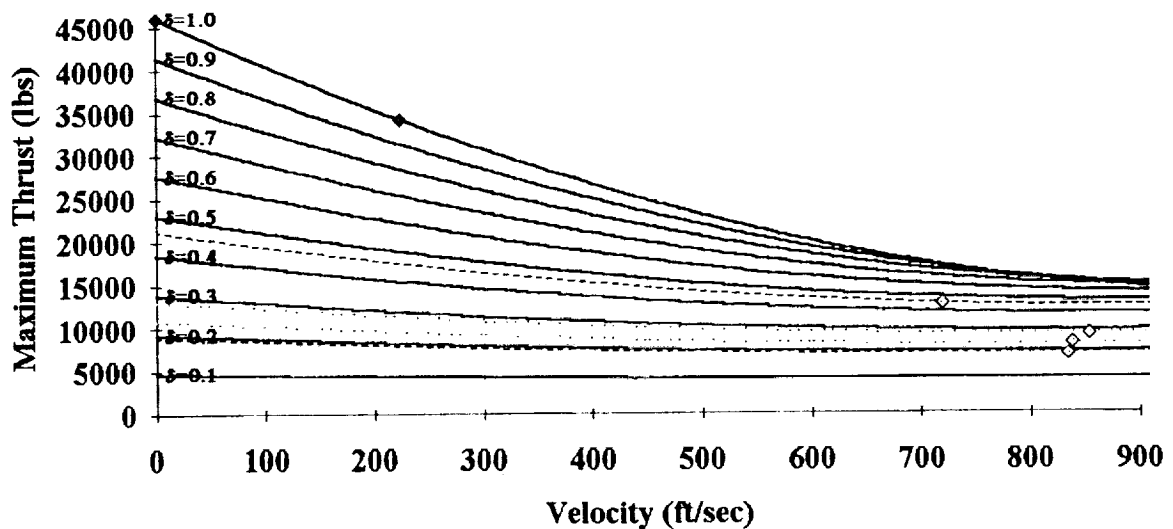


Figure 5.2.1 : Maximum Thrust vs Velocity and Atmospheric Pressure Ratio

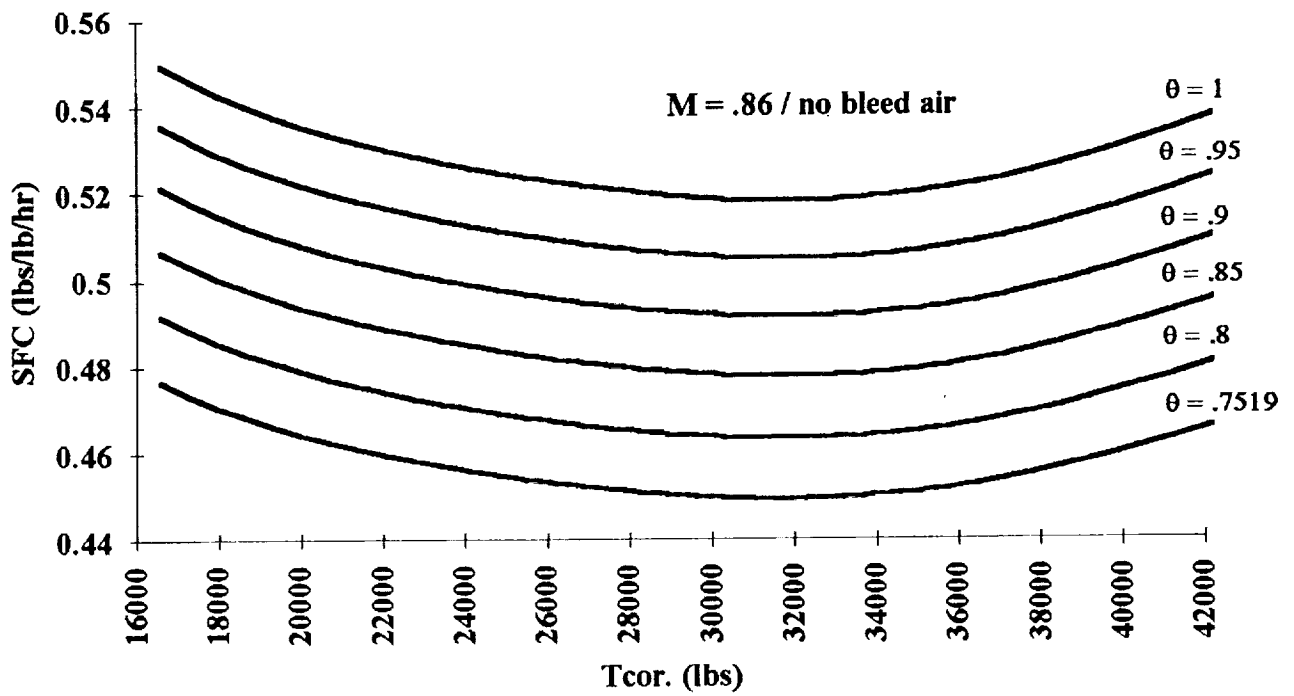


Figure 5.2.2 : SFC vs S.S.L. Corrected Thrust and Temperature Ratio

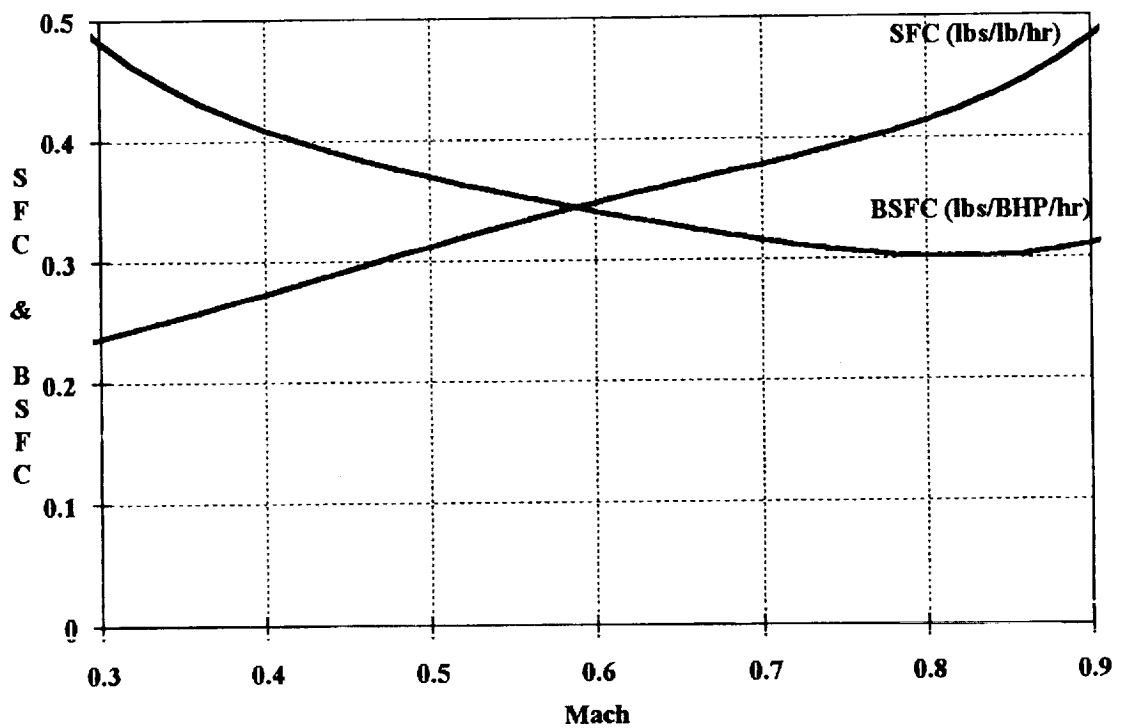


Figure 5.2.3: ADP Fuel Consumption vs Mach Number

After refining the configuration with the engine sized to meet minimum FAR and cruise SFC requirements, the result was an engine with 46,000 lb. of thrust. Based on this desired maximum thrust, Pratt & Whitney would be solicited to go into full scale production if the JB-300 reached production approval. With this size engines, cruising at the minimum fuel efficiency altitude causes the engines to operate past the bottom of the SFC loop. This resulted in a 3% SFC penalty with a cruise SFC of .457 lb/lbhr including bleed and power requirements.

Considering that these engines are expected to have a higher than originally anticipated specific thrust, an investigation was performed to see if the added weight of larger engines would more than offset the resulting improvement in cruise SFC. Two options were studied, a 10% engine size increase to get the minimum fuel burn, and a 30% size increase to get the minimum SFC. The resulting effect on SFC and weights is shown in Table 5.2.1. This confirms that the best engine size is near the minimum size required to meet FAR OEI requirements.

Table 5.2.1: Engine Sizing Study

Current Design:	2 x 46000 lbt	(meets OEI/takeoff requirement's)
Option 1:	2 x 51000 lbt	
effects:	cruise SFC -2.0%	Empty Weight +0.5% <u>Fuel Weight</u> -0.2% Takeoff Weight +0.3%
Option 2:	2 x 60000 lbt	
effects:	cruise SFC -3.0%	Empty Weight +1.5% <u>Fuel Weight</u> +0.1% Takeoff Weight +1.6%

6.0 Landing Gear

The JB-300 has incorporated a modified, tricycle configuration landing gear. The original design contained a conventional tricycle gear configuration, but to take full advantage of the super-critical wing and to decrease the trim drag it was necessary to make the main gear smaller and add a body gear. (See Figure 6.0.1)

The modified, retractable, tricycle gear configuration has provided many benefits for the JB-300:

- 1) Good visibility over the nose during ground operation
- 2) Good steering characteristics
- 3) Low aerodynamic drag
- 4) Level floor while on ground

All of these are important to a commercial transport; the most significant being the level floor. A level floor allows ease of loading and unloading cargo and passengers. It also makes the service carts easy to push down the aisles.

The landing gear for the JB-300 was designed to operate from major airports. The load classification number (LCN) was calculated to be 80, so operation on runways from Load Classification Groups Type 1 and 2 will be possible. Type 1 and Type 2 runways make up most of the major airports' runways. (Ref. 28)

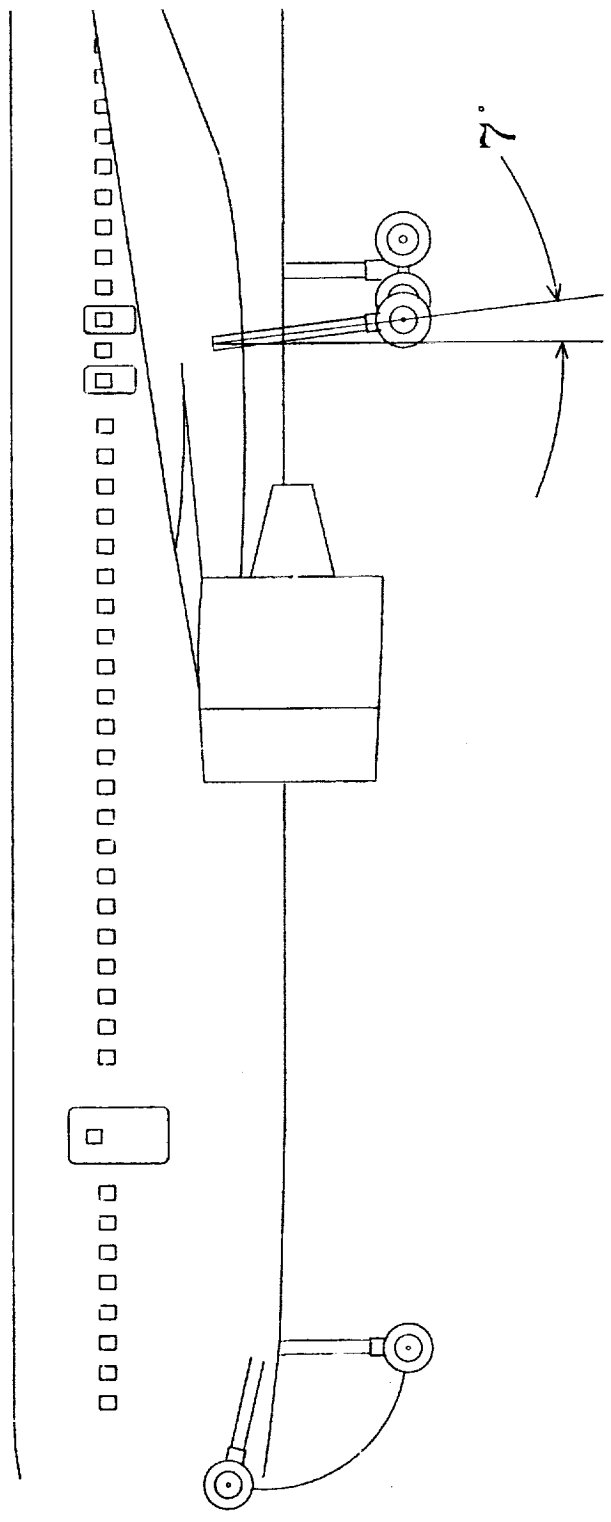


Figure 6.0.1 Landing Gear Configuration

6.1 Nose Landing Gear

The nose landing gear (NLG) is located 20.3 feet behind the nose of the aircraft. From Class II weight sizing, the maximum static load was found to be 24,800 pounds, while the maximum dynamic load was found to be 33,150 lbs. When selecting a tire size, the larger load was used. The NLG was designed to be able to hold this maximum dynamic load, which is approximately 11.5%. Since the NLG consists of two tires, a tire that could support a 16,600 pound load was needed. The tire chosen was a Type VII, size 39" x 13". (See Table 6.1.1)

Table 6.1.1 Nose Gear Data

Location	20.3 feet
Weight	1721 pounds
Maximum Static Load	24,800 pounds
Maximum Dynamic Load	33,150 pounds
Tire Size	39" x 13"
Tire pressure	115 psi
Tire Type	VII

The NLG will consist of one strut and two wheels in a dual pattern which retract forward into the fuselage. A feature of the dual pattern is increased steering control, and in the case of a tire failure, the single wheel can still maintain steering control.

For safety reasons, in the unlikely event of a tire failure, the NLG was designed to be stowed behind the cockpit, . In an emergency, the NLG can be manually dropped with the free stream dynamic pressure being used as a means for lock down.

6.2 Main Landing Gear

The main landing gear (MLG) is attached to the wing, just behind the center of gravity. To satisfy longitudinal tip-over criterion, the MLG needs to be rotated 7° (See Figure 6.0.1). When the MLG is making contact with the ground it is located 84.1 feet behind the nose. The reason behind the need to rotate the MLG was that the position of the wing was moved forward. The wing was moved forward to shift the center of gravity closer to the aerodynamic center of the wing in order to take advantage of our supercritical wing and to decrease our trim drag. Along with the wing being moved forward, the yahodi was decreased, and the two coupled together caused the MLG to be decreased in size so it could fit into the fuselage (See Figure 6.2.1). The JB-300's ability to stow the MLG in the fuselage is a great advantage because interference drag is reduced.

From Class II weight sizing (Ref. 18), the maximum static load per strut was found to be 92,000 pounds. The MLG consists of two, double bogies that will support 48% of the aircraft. It was calculated that two tires be used so that the same size tire could be used on both the MLG and the body landing gear. When selecting a

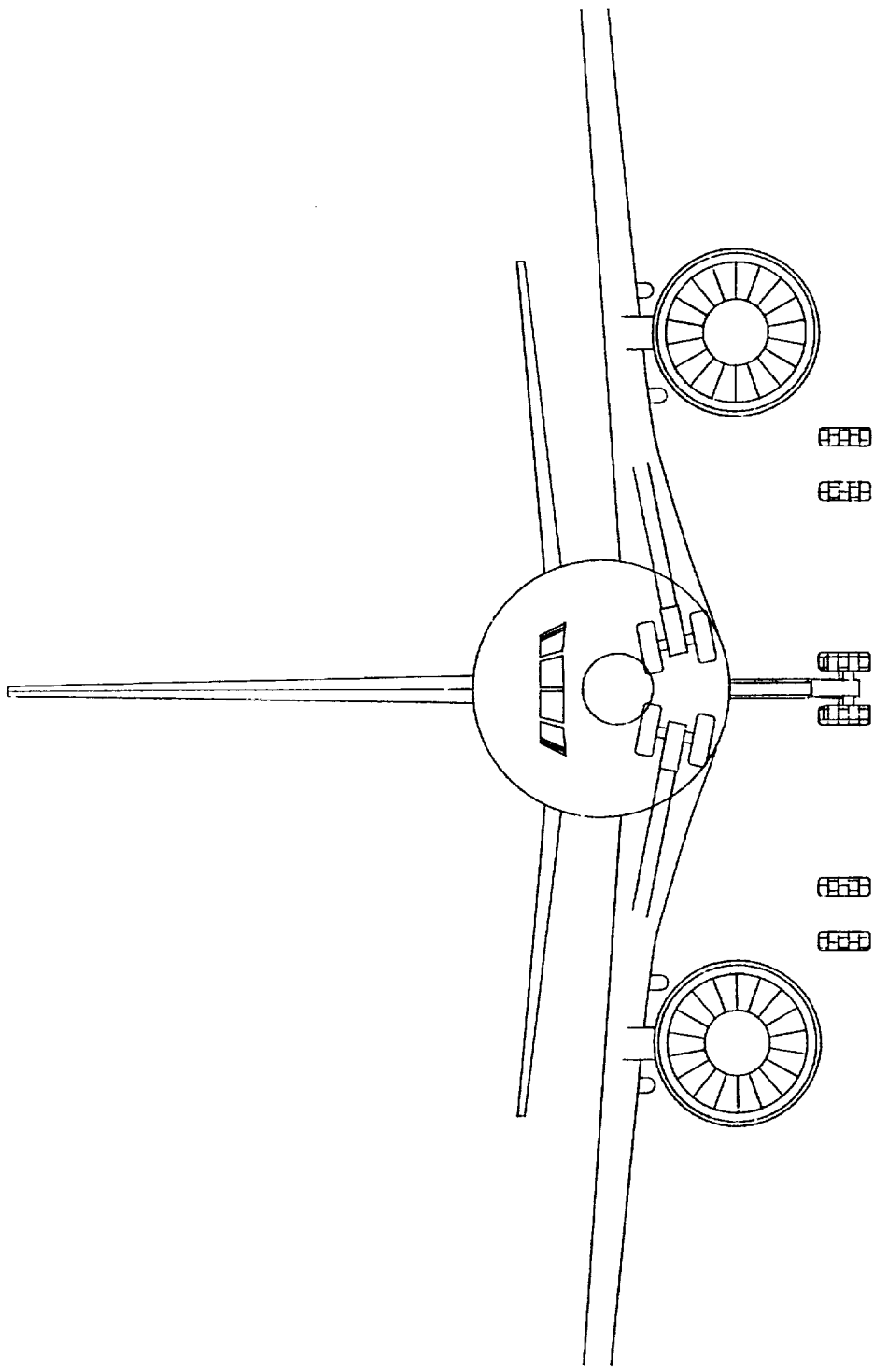


Figure 6.2.1 Landing Gear Retraction

tire size, a tire that could support a 46,000 pound load was needed. The tire selected was a Type VII, size 49" x 17". (See Table 6.2.1)

Table 6.2.1 Main Gear Data

Location	84.1 feet
Weight	5968 pounds
Maximum Static Load/Strut	92,000 pounds
Tire Size	49" x 17"
Tire Pressure	195 psi
Tire Type	VII

6.3 Body Landing Gear

The body landing gear (BLG) will consist of one, four wheel bogie. The BLG is needed because of the decreased size of the MLG. Another landing gear is needed to support the weight of the aircraft. The BLG is designed to support 47% of the aircraft. The BLG is located 85.4 feet behind the nose and will be forward retracting (See Figure 6.0). From Class II weight sizing, the maximum static load was found to be 182,000 pounds. It was decided that four wheels be used so that the same size tire could be used on the MLG and BLG. When selecting a tire size, a tire that could support a 45,500 pound load was needed. The tire selected was a Type VII, size 49" x 17". (See Table 6.3.1)

Table 6.3.1 Body Gear Data

Location	85.4 feet
Weight	5994 pounds
Maximum Static Load/Strut	182,000 pounds
Tire Size	49" x 17"
Tire Pressure	195 psi
Tire Type	VII

7.0 Structures

7.1 V-n Diagram

The V-n diagram locates the envelope that the JB-300 can maneuver in while remaining free from the major effects of gust winds. The diagram (Fig. 7.1.1) shows that at a cruise altitude of 41,500 feet the JB-300 is not gust critical. The JB-300 is gust critical at altitudes of 20,000 feet (Fig. 7.1.2) and below due to the high aspect ratio wing.

The maximum stall velocity calculated was 128.24 keas. This corresponded to a maximum cruise velocity and dive velocity of 239 keas and 298.75 keas respectively.

7.2 Material Selection

Due to aluminum's economic advantages and proven reliability, it was used as the primary material in the structure of the JB-300. The costs associated with tooling, processing, and material acquisition are lower for aluminum than for a comparable composite structure, and this results in a reduced manufacturing cost for the JB-300.

Another reason for the JB-300's extensive use of aluminum is that structural analysis has been more thoroughly developed and tested for this material than for composites. Past experience in the aircraft industry has shown that aluminum is safe and reliable, while, at the same time, the use of major composite structures has

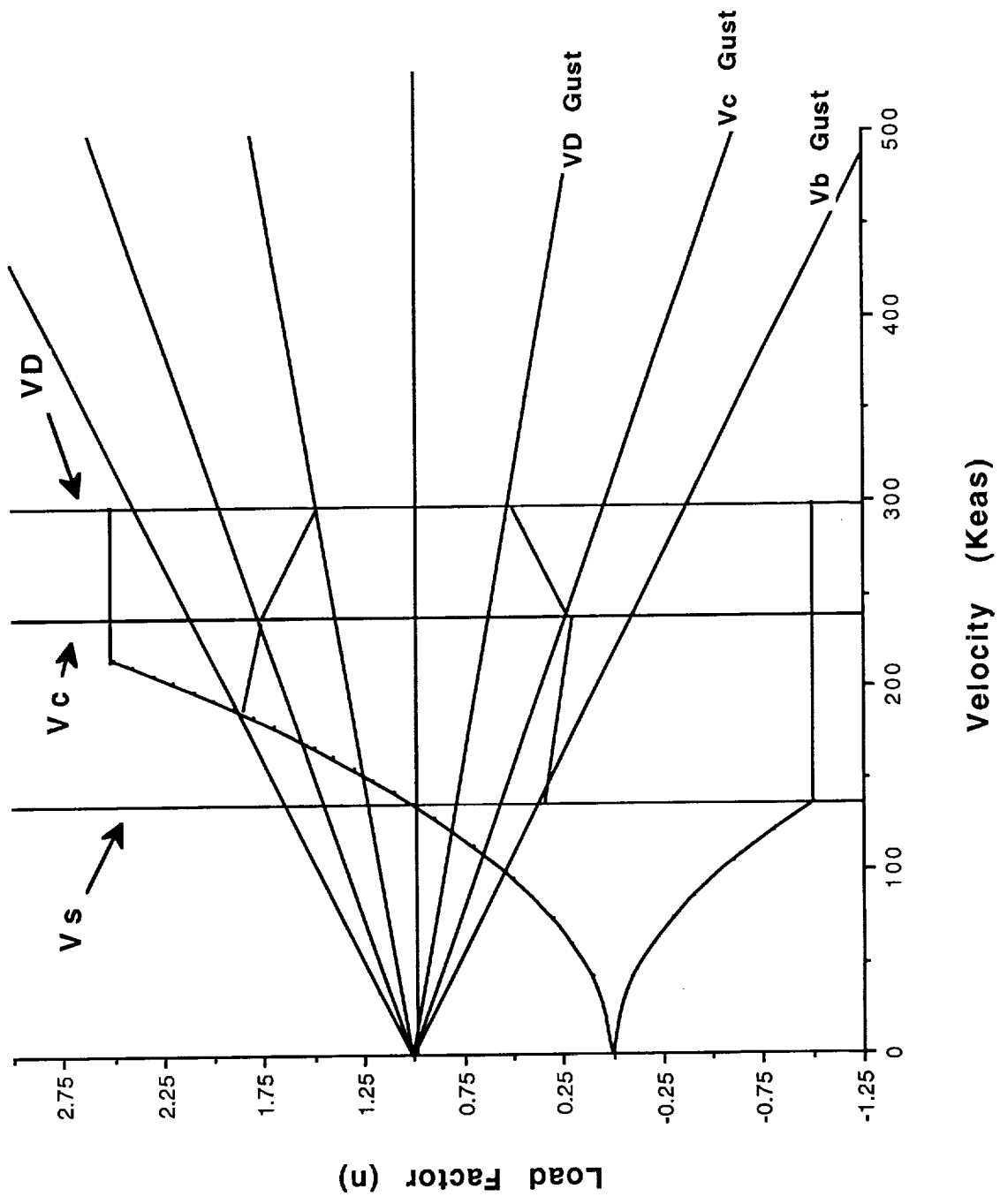


Figure 7.1.1 Manuever & Gust Diagram for 41,500

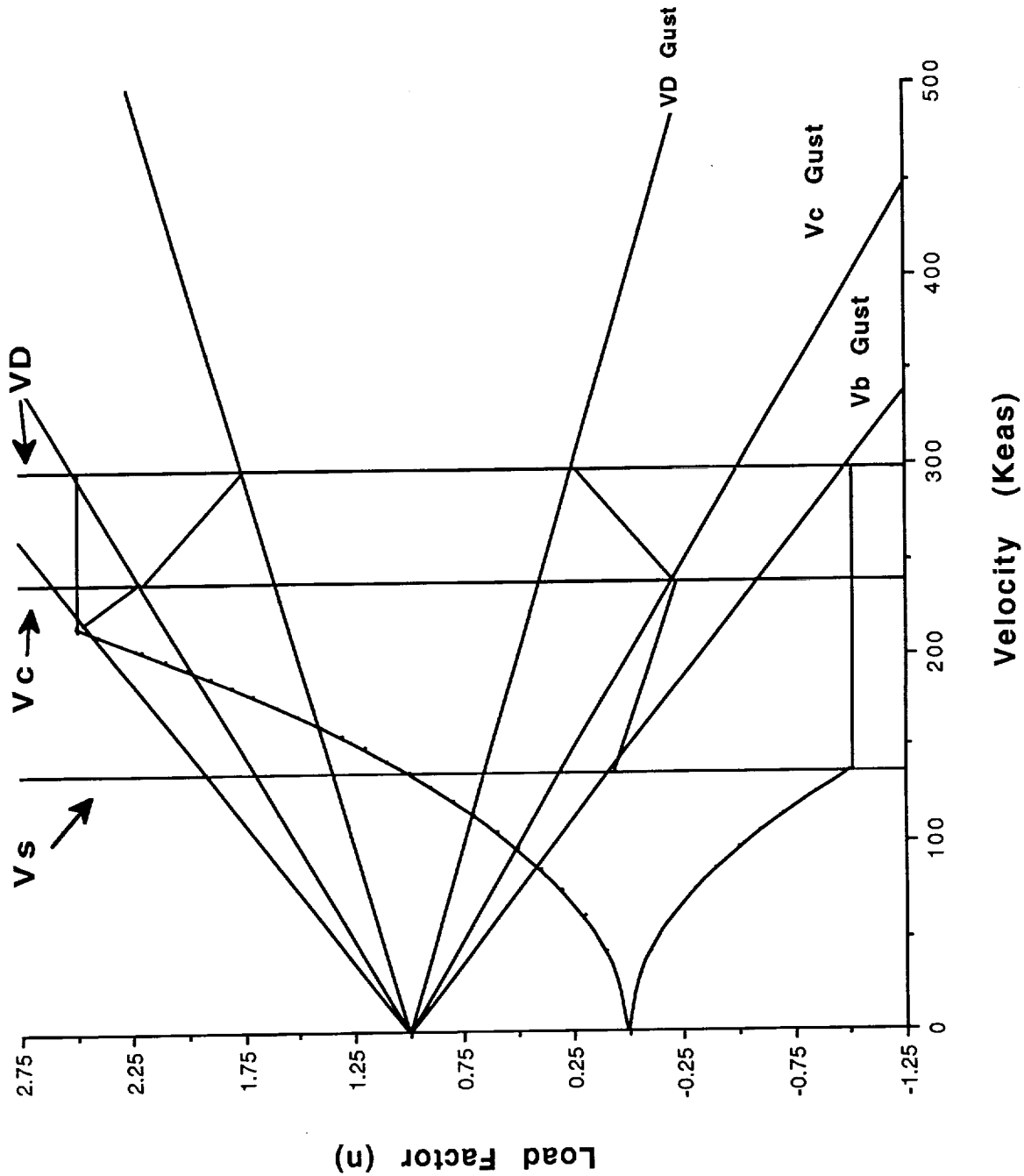


Figure 7.1.2 Maneuver and Gust Diagram for 20,000 ft

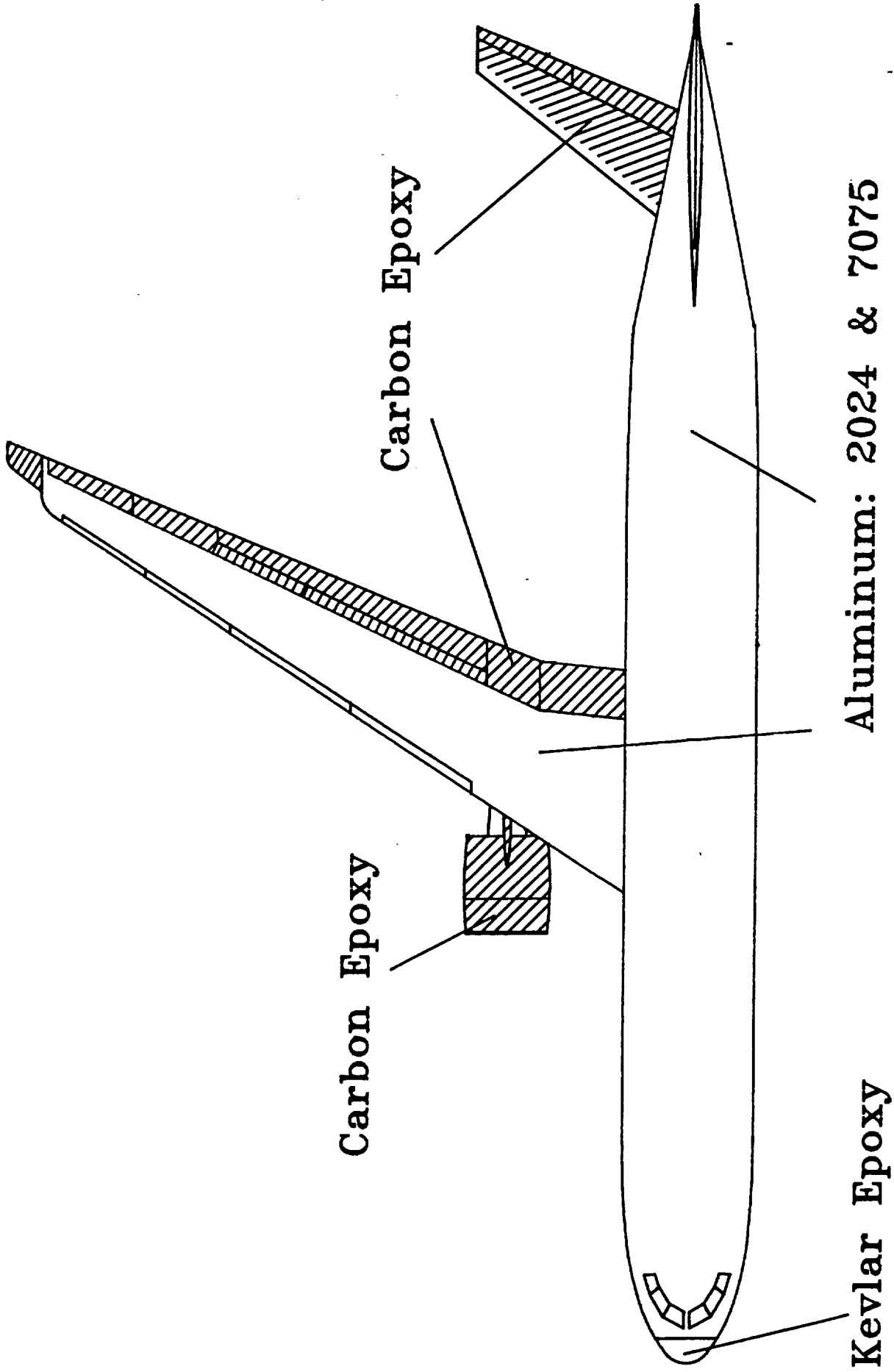


Figure 7.2.1 Material Layout

remained relatively untested in commercial aviation. Two significant concerns that arise in the use of composites are the detection of cracks and the prevention of rapid crack growth. For these economic and safety reasons, there is only limited use of composites in the JB-300.

Composites were used in the nacelle, nose, tail section, control surfaces, and interior layout of the JB-300 in an effort to reduce the weight of the aircraft. The use of composites in these areas has already been widely established by existing aircraft. Vehicles such as the Boeing 767 and Airbus 320 have proven that composites can be cost effective and safe in these limited regions.

7.3 Shear and Bending Moment

The bending moment diagram (Fig. 7.3.1) for the JB-300 was developed in order to determine the required strength of the wing structure. For this reason, the analysis was done at the most critical flight condition that could be reasonably anticipated. The lift distribution was determined for stall at a load factor of 3.75. Loading relief was taken for the weight of the wing and engine, but the fuel tanks were assumed to be empty. This resulted in a maximum bending moment of 9000000 ft-lbs which occurs at the wing root.

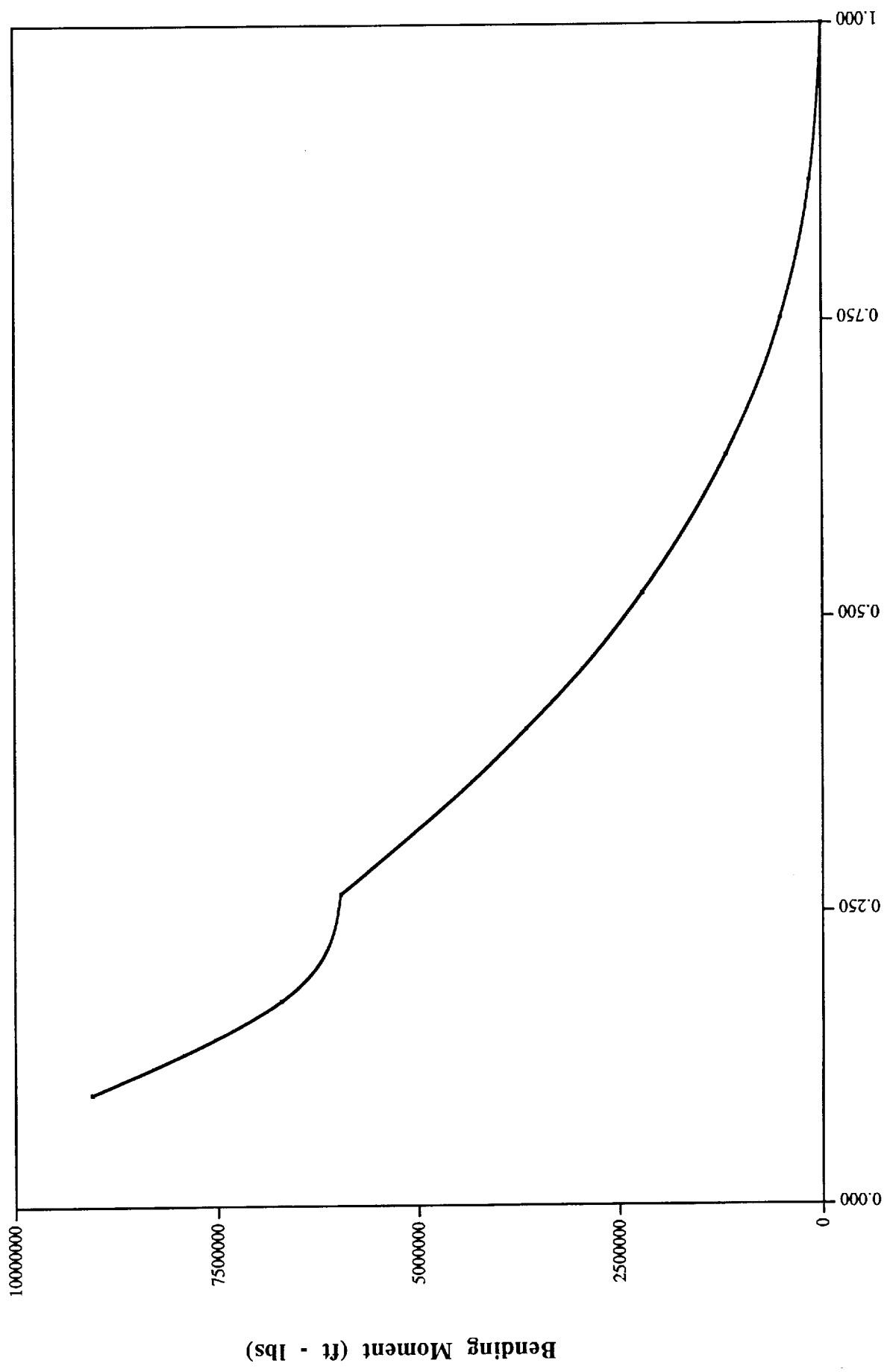


Figure 7.3.1 Percent Wing Span Bending Moment Diagram

8.0 Performance

8.1 Drag Polars

Comparing the JB-300 drag polar, Figure 8.1.1, with a drag polar for an older generation transport, Figure 8.1.2, shows how the design's high efficiency was obtained. The older generation transport drag polar (Boeing 707) is very similar to a 767 drag polar. The 767 only has a 6% reduction in induced drag. The JB-300 drag polars do not include compressibility drag. The compressibility drag increases similarly with Mach number as it does with current aircraft. The .7 Mach number drag polar in Figure 8.1.2 has negligible compressibility drag. So the Boeing 707 drag polar is useful as a comparison to one of the JB-300's primary competitors, the Boeing 767.

The main difference between these two drag polars is a reduction in induced drag. The JB-300 has only 68% of the induced drag of Boeing 767 at the same lift coefficient. This is due to the 17 ft larger wing span of the JB-300. The profile drag coefficient of the JB-300 is approximately equal to that of the 767. A 20% lower wing loading and a higher design cruise lift coefficient allows cruising at 20,000 ft higher altitude. The net effect is a reduction in profile drag with little increase in induced drag. The cruise drag breakdown of the JB-300 compared to that of the 767 is shown in figure 8.1.3. Due to differences in the way some drag components are classified, an exact comparison is difficult. But a significant difference in addition to the reduction in wing induced drag is a

reduction in tail profile drag. This reduced profile drag was achieved by having 32% less tail plane area.

In addition to the cruise configuration drag polar, the takeoff and landing configuration drag polars are also shown in Figure 8.1.1. Going from the cruise to takeoff configuration results in 56% more profile drag and 15% more induced drag at any lift coefficient. The increase in profile drag is not very significant because this configuration is flown where induced drag is prevalent. Going from the cruise to landing configuration, causes a 270% increase in profile drag and a 18% increase in induced drag.

Although these drag increments seem high, the over takeoff and landing drag increments and total drag is still lower than that of a Boeing 767. The Boeing 767 uses double slotted flaps inboard, and has more slat area than the JB-300. These two required differences produce higher drag during takeoff and landing. If double slotted flaps were used on the JB-300, the profile drag increment would be 30% higher.

The JB-300 has a lower wing loading than all current transports in this size range. This allows a low drag configuration during cruise to be used more during climb out and decent than current transports. Overall, the JB-300 has the potential to have less drag in each configuration and lower drag at certain flight speeds.

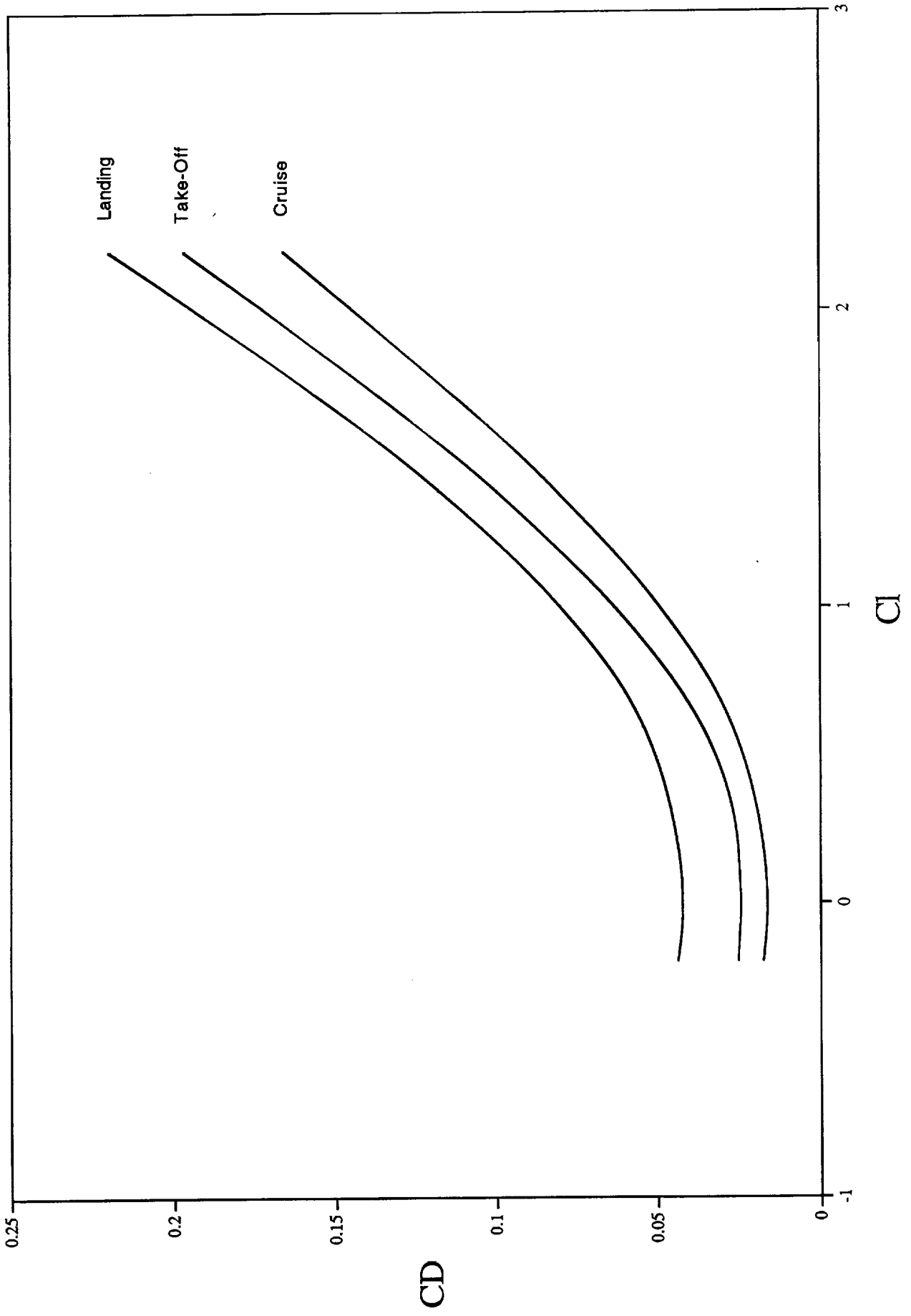


Figure 8.1.1 Drag Polars

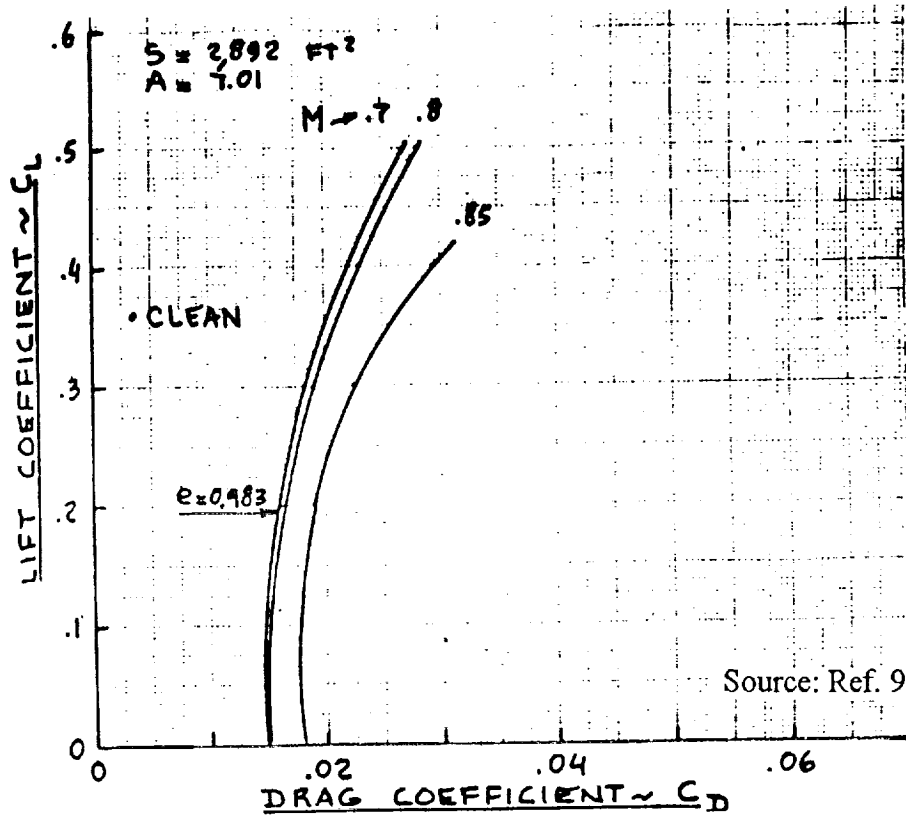


Figure 8.1.2: Boeing 707-320B Drag Polars

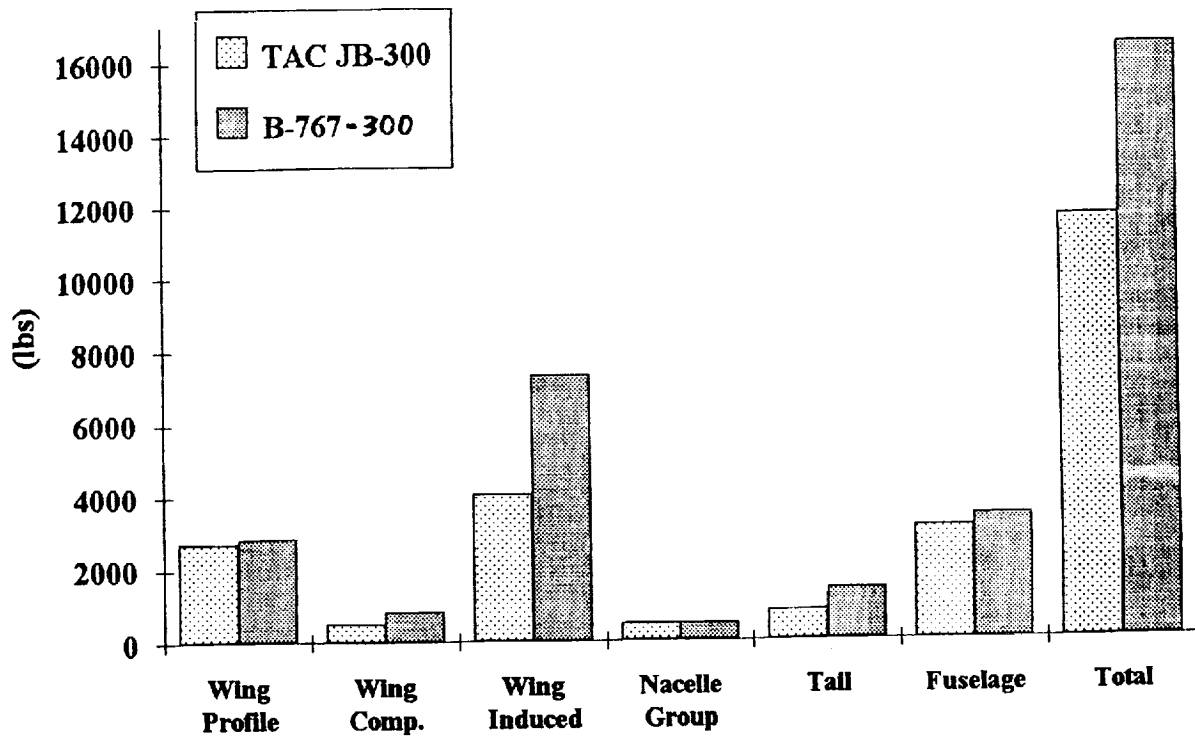


Figure 8.1.3: Drag Breakdown Comparison

8.1.1 Methods of Drag Calculations

All known component drags for this configuration were calculated based on equations from Ref. 1 through Ref. 14. An equation for each type of drag component was taken from a reference or created from the data (graphs) given using numerical methods. Typically, polynomials were fitted for each graph. This method of parameterizing all equations facilitated design changes. This led to trade studies which helped refine the design. Additionally, the overall accuracy of this program was tested by inputting all the dimensions of the Boeing 767 to see how the predicted performance compared to the known performance. The major drag types can be classified into four types: profile, interference, induced, and compressibility. The drag polars are shown in Fig. 8.1.1 for landing, take-off, and cruise conditions.

8.1.2 Profile Drag

The primary method used to find the profile drag for each component was employing a standard equation found in almost all related texts. The component drag coefficient was found to be the product of the form factor, friction coefficient, and area ratio. In some cases, such as fuselage upsweep drag, more specialized techniques were used as detailed in the references. These components were then summed to get the total profile drag coefficient.

8.1.3 Interference Drag

The interference drag coefficient from the intersection of airfoils with other airfoils or with bodies was the most difficult to calculate. It was also the greatest source of uncertainty. It was primarily found using the methods from Hoerner (Ref. 4) as a function of the length of the intersection, the airfoil thickness, and the thickness ratio. This rough estimate was compared with available data and added to the profile drag coefficient.

8.1.4 Induced Drag

The components of induced drag coefficient came from several sources: wing induced drag due to lift and trim, trim drag, fuselage induced, and one engine inoperative vertical tail induced. The wing induced drag, the most significant portion of induced drag, was calculated based on a method outlined in Shevell (Ref. 11) combined with the theoretical wing-only efficiency factor from the Theory of Wing Sections (Ref. 1).

8.1.5 Compressibility Drag

The compressibility drag was determined from equations derived from empirical data. All parts of the aircraft contribute to this type of drag, however, the wing's portion is the largest. It was determined using a method outlined in Shevell (Ref. 11), and is a function of quarter chord sweep angle, average thickness ratio, Mach number, lift coefficient, and supercritical airfoil corrections.

The compressibility drag coefficient is shown in Table 8.1.1 for various velocities.

Table 8.1.1 Compressibility Drag

M	C_{Dc}
.80	.00076
.82	.00104
.84	.00152
.86	.00254

8.2 Takeoff and Landing Performance

The mission requirements for the JB-300 specified a 8,000 ft. runway (See Appendix A). The takeoff and landing characteristics of the JB-300 were estimated with the methods presented in Ref. 15. Using this process, the takeoff ground run was calculated to be 3,421 ft. The takeoff distance to obtain the 35 ft clearance requirement is 4,559 ft., and the balanced field length is 6,050 ft. (Fig. 8.2.1). The landing distance is significantly shorter than the takeoff, even without utilizing thrust reversers, requiring only 4,470 ft. on dry asphalt . Although this short landing distance indicates that thrust reversers are not necessary, the ADP engine has the capability integrated into its variable pitch fan. The variable pitch fan is required for VHBR engines, so the ability to use thrust reversers is provided for without incurring additional weight or cost

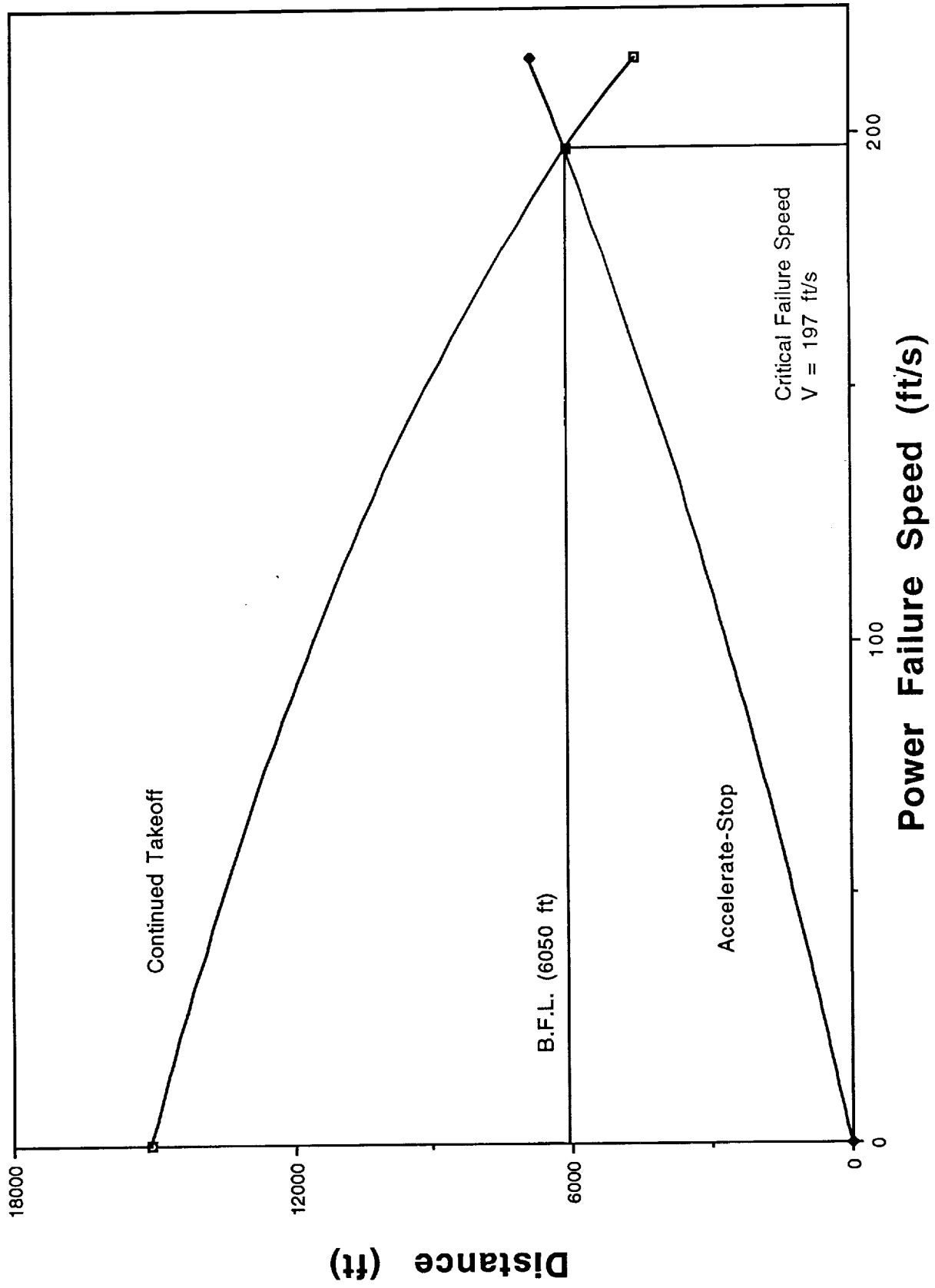


Figure 8.2.1 Balanced Field Length

penalties. These takeoff and landing distances will allow the JB-300 to be compatible with the facilities currently used by the competition.

8.3 Range Vs. Payload

The RFP for the JB-300 stated that with a fully loaded aircraft, a range of 3,500 NM was required (See Appendix A). In order to be competitive with other aircraft of our size, the range was increased to 5,500 NM. This gives the JB-300 a distinct advantage over the Airbus 310 and Boeing 767-300, the JB-300's primary competition, who have a range of 3820 and 4020 NM respectively (Fig 8.3.1). This advantage is even more significant considering that the JB-300 is capable of carrying approximately 20 additional passengers (Fig. 8.3.2). The extended range version of the Boeing 767-300, the Boeing 767-300ER has a 560 NM range advantage over the JB-300, however, the JB-300 is capable of carrying 76 more passengers than this version of the 767.

At the expense of 2,692 pounds (from 65,350 to 62,658 pounds) of cargo, the JB-300 can obtain a maximum fuel loading and increase its range to 6029 NM. This is approximately equivalent to the loss of 14 passengers. The ferry range is 8369 NM. The Payload Vs. Range diagram is shown in Fig. 8.3.3.

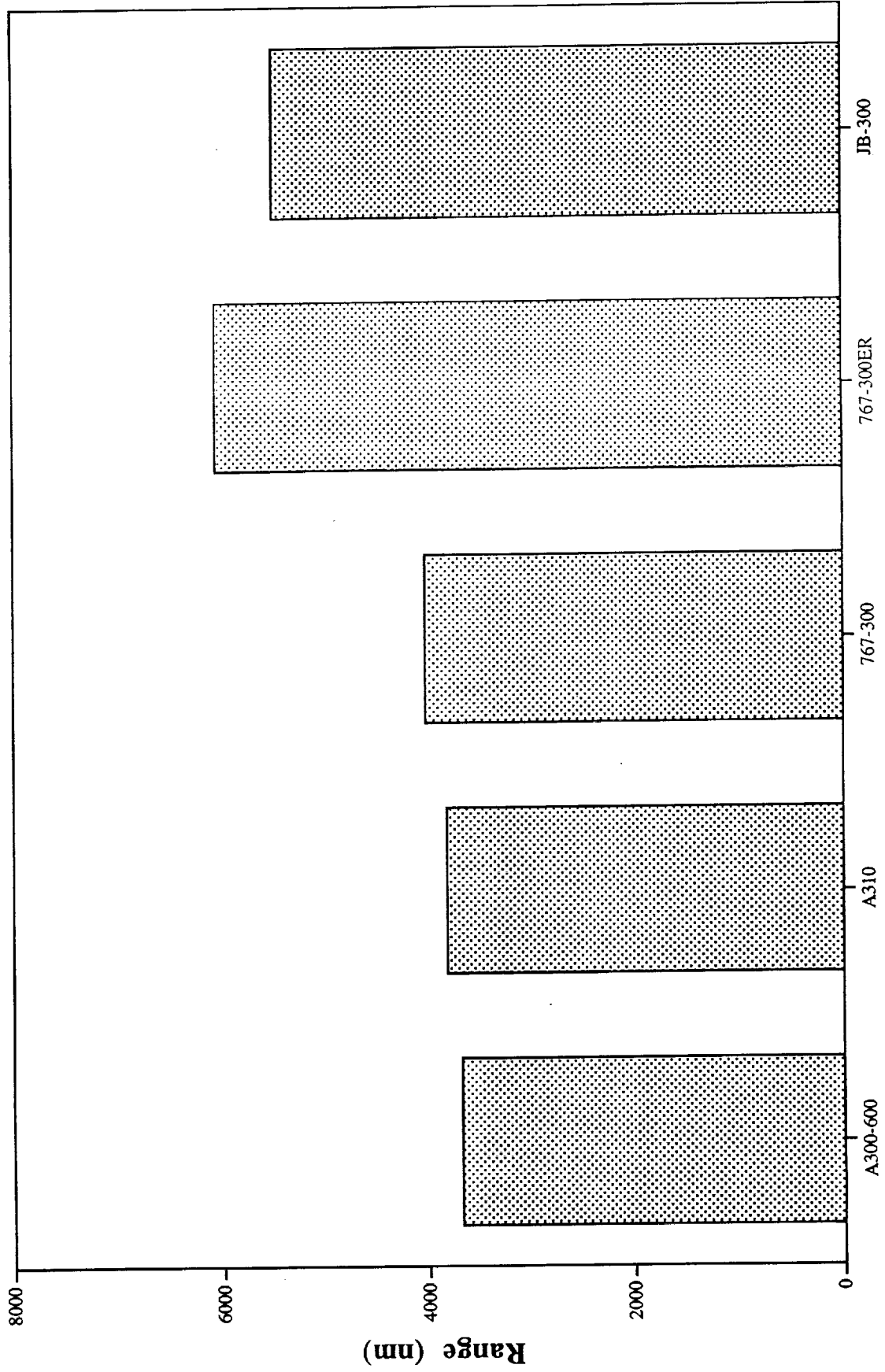


Figure 8.3.1 Range Comparison

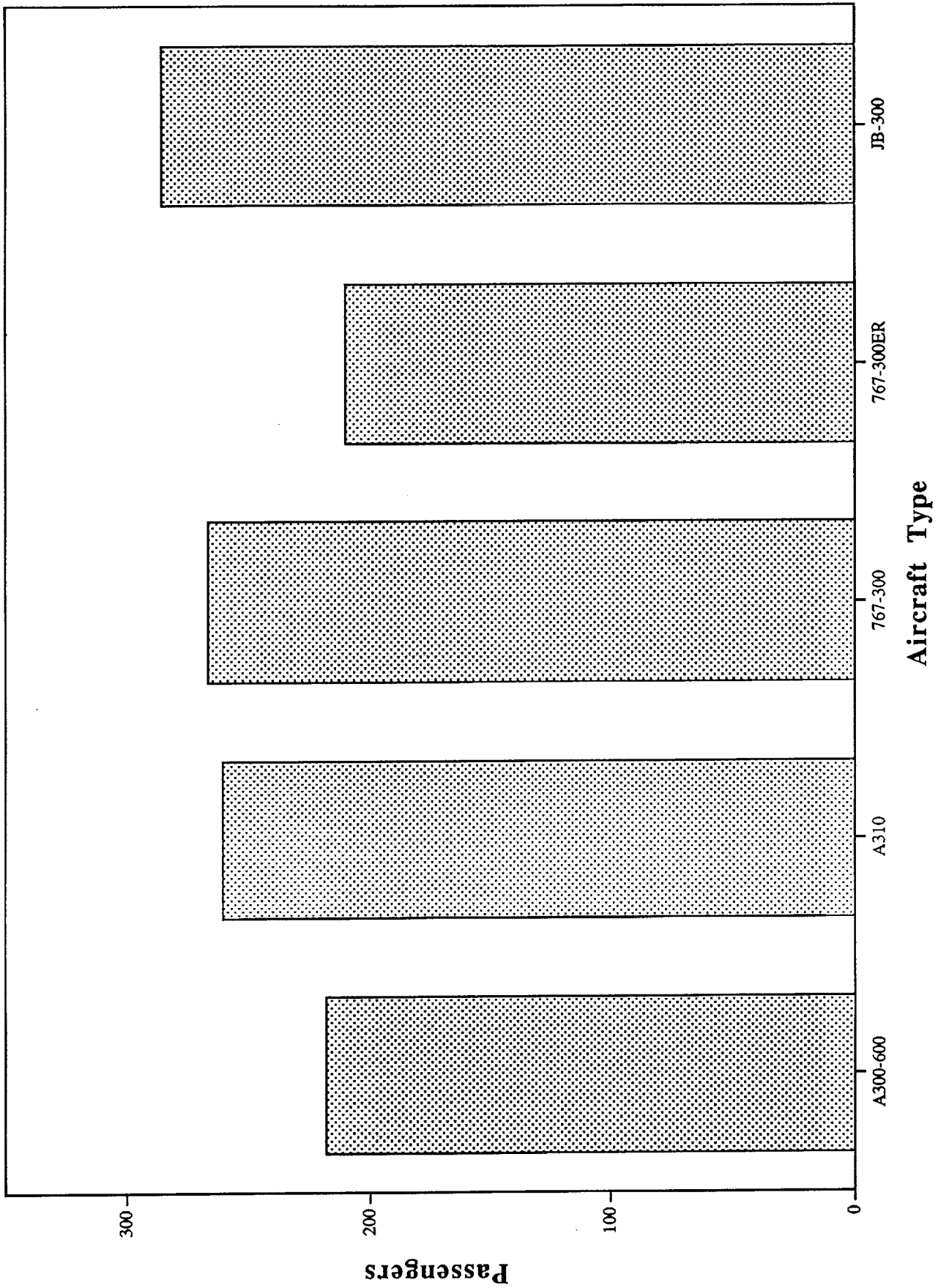


Figure 8.3.2 Passenger Capacity Comparison

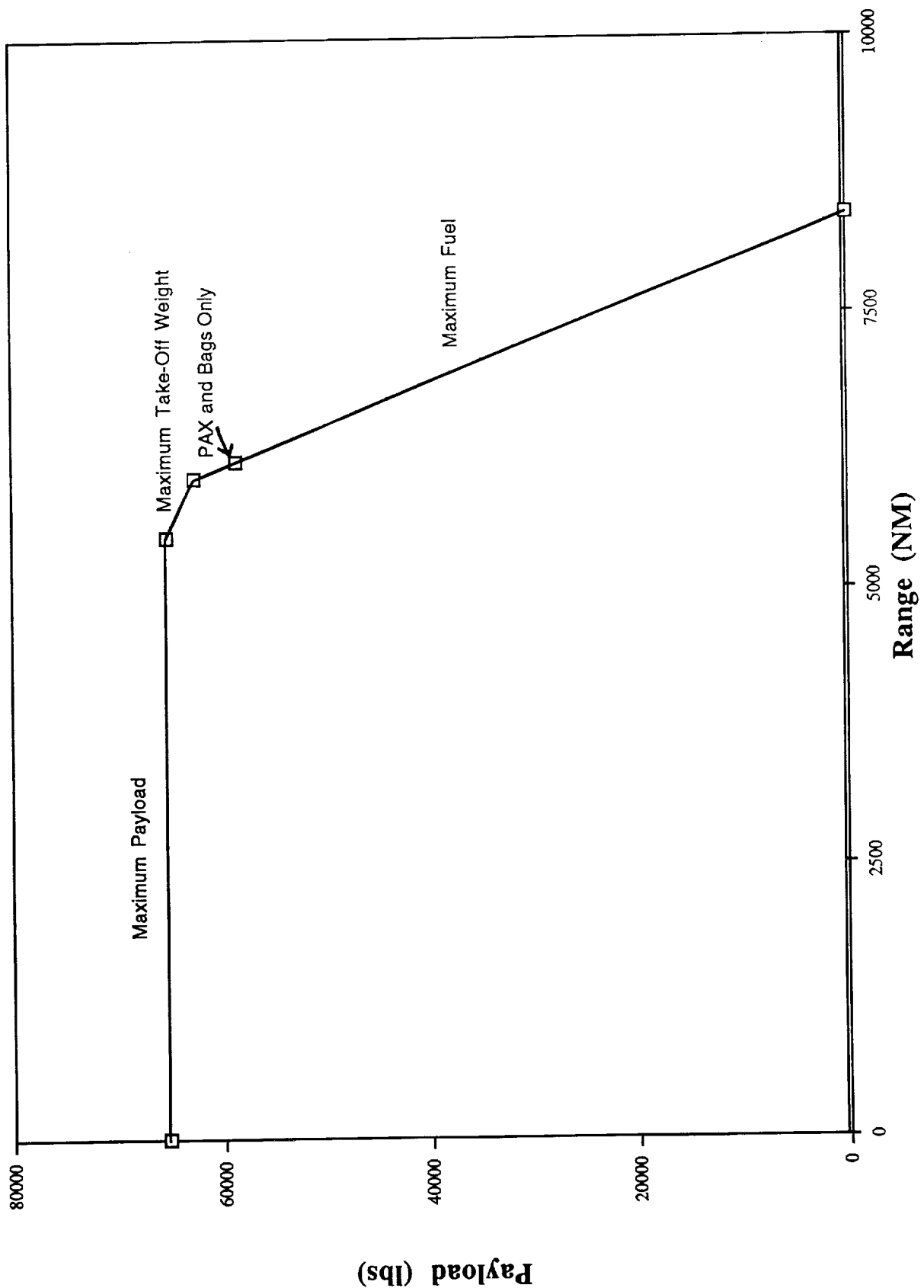


Figure 8.3.3 Payload Vs Range Diagram

8.4 Optimum Flight Conditions

A fully loaded JB-300 achieves optimum efficiency when flying between 39,000 and 43,000 feet. At this altitude, the lift to drag ratio is maximum and the specific fuel consumption is near its minimum. Initial cruise altitude would be 39,000 feet, but as weight decreases from fuel burn, a 43,00 ft. altitude would become desirable. A cruise Mach number of .82 was chosen after considering flight time, drag, and engine performance. Obviously, customers prefer a shorter flight time, and this is achievable with a faster cruise velocity. A faster cruise speed, however, decreases engine efficiency and increases drag. At Mach numbers greater than .8 the JB-300 begins to experience a dramatic increase in compressibility drag. In order to provide a reasonable balance between flight time and price per passenger seat mile, a cruise velocity of Mach .82 was chosen based on the additional costs that would be incurred by fuel consumption.

8.5 Rate of Climb

There are several FAR regulations regarding rates of climb (ROC) that the JB-300 must adhere to. Five flight conditions are defined, along with a corresponding minimum allowable ROC. These requirements are primarily concerned with one engine inoperative situations. The flight configuration, minimum climb gradient, and JB-300 climb gradient are shown in Table 8.5.1. This demonstrates

compliance with FAR, and the JB-300's exceptional climbing characteristics. These large climb gradients are a result of the high aspect ratio wing, which significantly lowers the induced drag experienced during a climb. This quick climb rate is desirable for safety reasons in one-engine-inoperative or emergency conditions. Also shown in Fig. 8.5.1. is a graph of the JB-300's maximum rate of Climb Vs. Altitude. These values were developed at the velocity where the maximum lift to drag ratio is obtained.

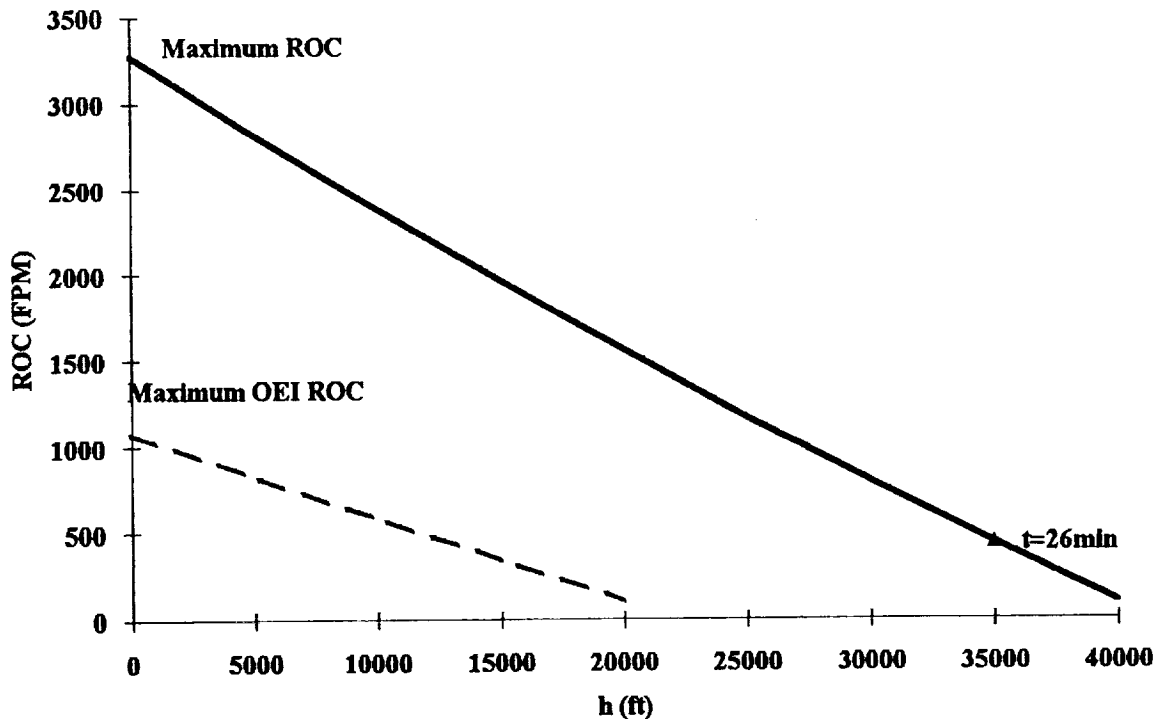


Figure 8.5.1: Rate of Climb vs Altitude

Table 8.5.1 Climb Gradient

Configuration			Flight Speed	Required Climb Gradient	Climb Gradient
Flaps	Landing Gear	Engine			
Take-Off	Down	OEI	Lift Off	Positive	0.9 %
Take-Off	Up	OEI	V ₂	2.4 %	3.3 %
En-Route	Up	OEI	=> 1.25 V _s	1.2 %	3.9 %
Approach	Up	OEI	<= 1.5 V _s	2.1 %	4.7 %
Landing	Down	All Op.	<= 1.3 V _s	3.2 %	17.5 %

9.0 Stability and Control

The primary objectives during the analysis of the stability and control of the JB-300 were to: assure the mission requirements were satisfied, assure FAR part 25 regulations were met, and assure an acceptable ride quality for the pilots, crew, and passengers. Longitudinal, lateral and directional control, and trimmability will be discussed.

9.1 Weight and Balance

The center of gravity for the JB-300 was determined by the method described in Ref. 16. The weight of each component of the airplane was estimated (Table 9.1.1). This was accomplished with the use of two different systems of equations from Ref. 16 and Ref. 17. This was done to ensure that the results were reliable. Next, where available data permitted, the actual weight components of similar aircraft were examined in order to verify that they were comparable to the JB-300's estimates.

The weights were then multiplied by the distance between an arbitrary axis and the component's location on the airplane. These moment arms were totaled, and then divided by the airplane's total weight. This gives the coordinates for the airplane's center of gravity on the arbitrary axis system. Different configurations were analyzed similarly, to determine the cg. location for various loading conditions. The JB-300's shift in cg. is about 3.3 ft., which is equivalent to 20.15% of the mean aerodynamic chord. This is

Table 9.1.1 Component Weights

Components	Weight (lbs.)	X (ft.)	Z (ft.)
Structural			
Wing	40457	84.6	15.9
V. Tail	1186	153	35.9
H. Tail	1574	158	18.6
Fuselage	27455	76.6	19
Belly Gear	5994	85.4	9
Nose Gear	1721	21	9
Main Gear	5968	82.7	9
Power plant			
Engines	18567	62	8.7
Fuel System	1099	84.6	15
Engine Controls	155	69	8.7
Start & Ign.	219	67	8.7
Pylons	1896	69	8.7
Fixed Equip.			
Flight Controls	2782	94.6	19.2
Electrical Sys.	2113	79.9	11.8
Avionics	2156	5	19
AC/Pres./Ice	4228	87.4	16
Oxygen	726	75	21.1
APU	1140	160	17
Furnishings	14422	84.8	18
Cargo Hand.	1660	104.3	18
Aux. Gear	1410	72	18
Paint	1290	81.5	17.5
Miscellaneous			
Crew	1640	55	18
Passengers	50050	81.5	18.6
Cargo	15300	81.5	18.6
Fuel	80248	83.6	15
Trapped Fuel	1146	72.4	13.1.3
Total	286601		

illustrated on the excursion diagram (Fig 9.1.1). Ref. 16 indicates that this cg. fluctuation lies within the standard acceptable range for aircraft of this size. An unusual characteristic of the JB-300 is that the OEW cg. is the most forward condition, and as passengers or fuel are added the cg. shifts toward the back of the airplane. This distinct excursion diagram occurs because the cg was designed to be close to the aerodynamic center in order to decrease trim drag.

9.2 Moments of Inertia

The moments of inertia were an important factor in determining the stability, control, and handling of this aircraft. The data obtained from the cg. analysis, about the magnitude and location of each mass in our airplane, made it possible for a preliminary calculation of some moments of inertia to be done. This was accomplished according to the methods presented in Ref. 5. Empirical data taken from existing aircraft (Ref. 10), verify that these are reasonable results for an aircraft of this weight.

9.3 Control and Maneuverability

The following objectives were looked at in determining the compliance of the control and maneuverability of the JB-300 in the lateral, directional and longitudinal directions:

1. Trimmable in all flight conditions.
2. Acceptable stick forces in all flight situations.
3. Maneuverable between any two flight conditions.

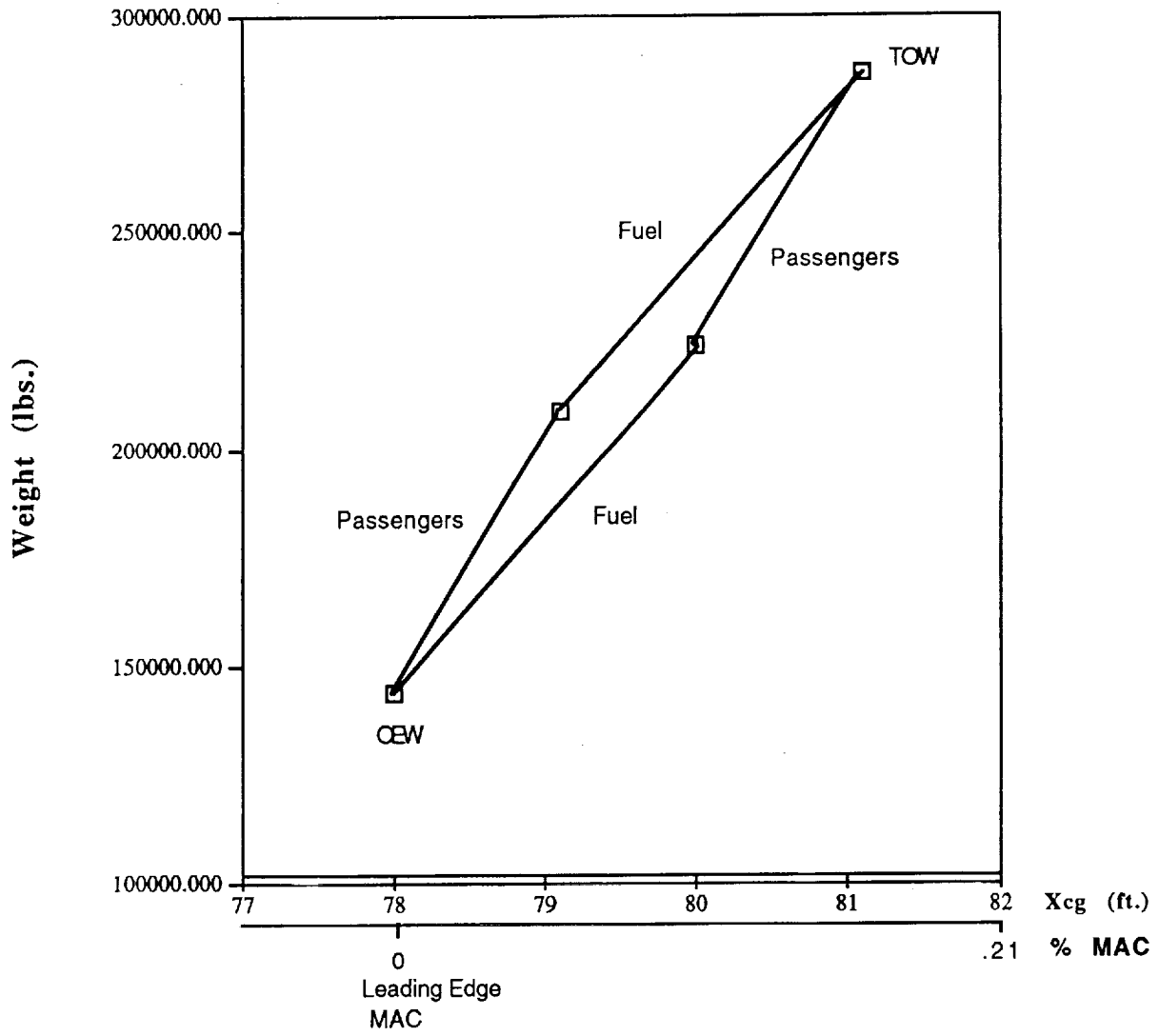


Figure 9.1.1 Excursion Diagram

Longitudinal

The configuration of the longitudinal control surface incorporates two main functions: to trim the pitch of the airplane and provide adequate pitch control. For trim, a fully rotatable horizontal aft surface is used because of the large pitching moment induced by the airfoil. For control, a control surface located at the aft edge of the horizontal tail surface is used. Control is obtained through deflections of plus and minus 20 degrees.

Figure 9.3.1 is a trim diagram for the JB-300. From this diagram any flight condition can be analyzed to assure trimmability to zero stick force. The critical flight conditions looked at were cruise, climb and descent conditions with the following loading:

1. Operating empty weight.
2. Take-off weight.
3. Operating empty weight with fuel.
4. Operating empty weight with passengers.

The results obtained resulted in a plus and minus 6 degree rotation of the horizontal tail incidence.

Because the JB-300 utilizes a fly-by-wire system the stick force will be acceptable without having to design for it. This is only one benefit of a fly-by-wire system. The primary advantage for using a fly-by-wire control system was the ability to design an unstable aircraft configuration. This achieves a savings in tail area.

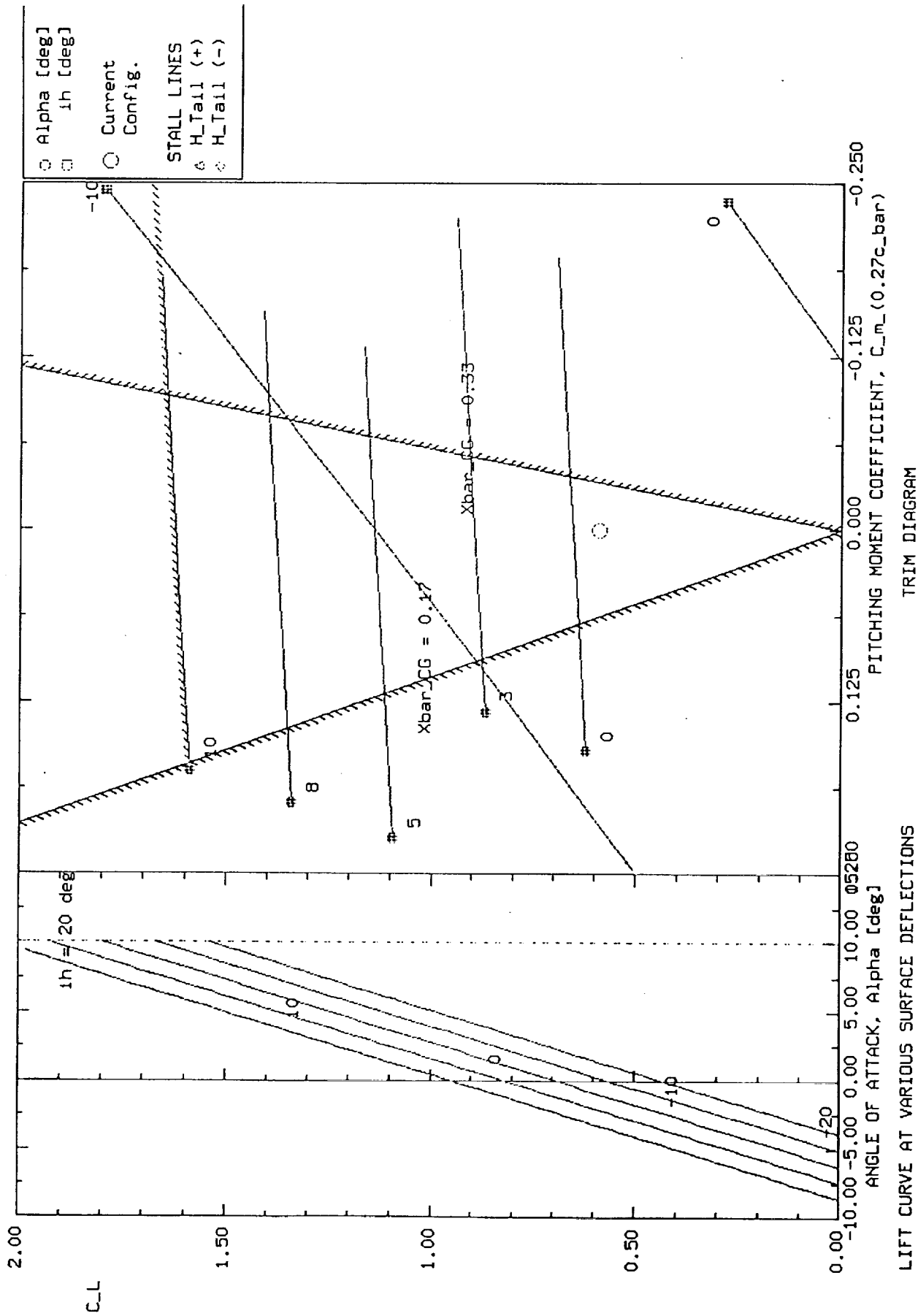


Figure 9.3.1 Trim Diagram

Consequently weight and drag were decreased from the smaller areas.

Lateral and Directional

The two design objectives stated previously were accomplished when designing the lateral and directional flight surfaces. First, when trimmed, the plane is still able to turn with one-engine-out. Second, heading changes can be made without rolling the airplane. Also, by meeting the first two objectives the additional regulations prescribed in section 25 of the FAR's were met with no special design. Compromises were made between surface deflections, surface location, and surface size. Consequently, the rudder was designed with a single hinge capable of 25 degree deflections. The ailerons were designed with 20 degree deflection angles. Both the rudder and ailerons are divided into two redundant sections. This is done for safety.

For the additional FAR requirements, static lateral and direction stability regulations are shown to be met if three criteria are passed: The direction stability derivative must be positive, the rolling moment due to side slip derivative must be negative, and the stick free directional stability derivative must be positive. A positive directional stability derivative indicates that when the airplane is put into a side slip condition, it will have the tendency to return to a zero side slip condition. A negative rolling moment derivative shows that when the airplane is subjected to a positive side slip, it will have the tendency to raise the right wing. A positive stick free directional stability derivative verifies that the rudder pedal force needed to initiate a side slip condition is such that the pedal-force-

gradient does not reverse its sign. The JB-300 meets these requirements.

Stability Derivatives

Stability derivatives for the JB-300 were calculated with Ref. 25. These longitudinal and lateral derivatives are listed in Table 9.4. Analysis of them indicates that FAR one-engine-inoperative requirements have been satisfied. In addition, all other regulations are also satisfied. Since the FAR requirements for the frequency, damping, and time constant characteristics of the roll, dutch roll, and spiral modes are vague, the JB-300 was designed to meet the military requirements which is recommended in Ref. 15. Using the military's criteria, the JB-300 meets all Class 1 designations for these modes.

Table 9.3.1 Stability Derivatives (Cruise)

Longitudinal:

CDu	.0164	CLu	.5749	Cmu	.2054
CDa	.3489	CLa	6.3381	Cma	-2.5845
CDq	0 ¹	CLq	7.8882	Cmq	-33.0274
CDde	.0013	CLde	.2016	Cmde	-.9712

Lateral:

CyB	-.944	CIB	-.2574	CnB	.2062
CyB dot	-.0067	CIB dot	-.0008	CnB dot	-.0028
Cyp	-.1685	Clp	-.5647	Cnp	-.0832
Cyr	.6047	Clr	.3839	Cnr	-.2626
Cyda	0 ²	Clda	.2995	Cnda	-.0309
Cydr	.1721	Cldr	.0223	Cndr	-.0802

1 For small angles of attack the value is considered to be zero.

2 In preliminary design this stability derivative is assumed to be negligible.

10.0 Systems

The systems used in the JB-300 are designed primarily for simplicity by the use of existing layouts that have already been proven to be reliable. The layouts were designed for low cost, maintainability, and accessibility.

10.1 Flight Control System

The JB-300 has a fully digital fly-by-wire control system. This system is based on the Airbus A320 flight control system, however, it also includes a fly-by-wire rudder. Fly-by-wire was chosen primarily because of its weight reduction, reduced complexity, and allows for a de facto stability. Another benefit derived from fly-by-wire is that it has the ability to automatically compensate control power under one engine out situations. The system has miniature sidesticks that will control command pitch and side attitudes. The sticks are centered by simple springs providing return to neutral forces independent of speed or attitude. Each pilot will have their own sidestick, mounted on the side console.

The JB-300 has integrated the flight management system and the flight control system into a single computer unit. The aim is to reduce complexity, expand the use of the management system, and reduce fuel consumption.

The system will include triple redundancy with the control wires running through the floor and on both sides of the aircraft.

10.2 Fuel System

The JB-300 stores all of its fuel in the wing (Fig. 10.2.1) in a layout similar to that presented in Ref. 18. There are three fuel tanks in each of the wings that hold a total of approximately 90,000 lbs. of fuel. The fuel is pumped from the outer tanks into the engines located beneath the wings.

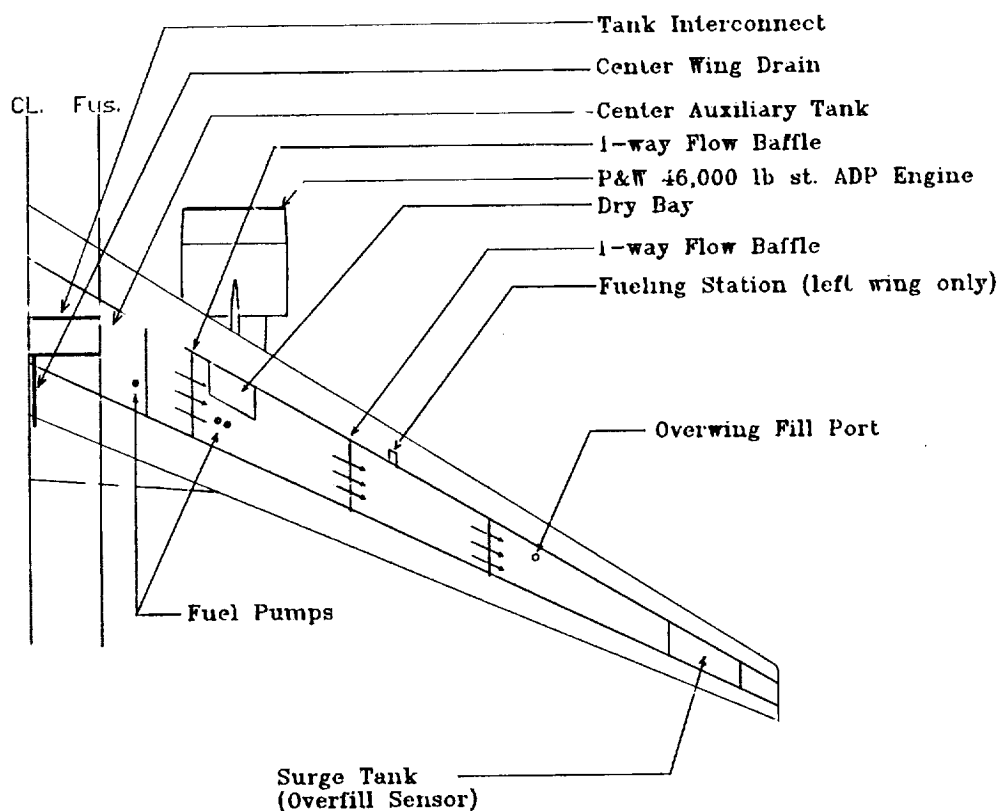


Figure 10.2.1 Fuel System Layout

10.3 Hydraulic System

The JB-300 requires the use of hydraulics for landing gear operations , however, does not require a traditional hydraulic system for the flight controls . This is due to the use of electrohydrostatic actuators with the fly-by-wire flight control system. These actuators were chosen primarily for a weight reduction, because they do not require an airplane hydraulic system. They have their own hydraulic system that includes a pump and electric motor which drives the pump. Electrohydrostatic actuators are supplied by electricity, so that in the case of an engine failure the control surfaces can still be used.

10.4 Electrical Power System

The controls and displays used to manage the electrical power are located on the overhead panel in the flight crew stations. The APU used to drive the electrical power is the GTCP 331-200. The GTCP 331-200 can produce a generator output shaft speed of 12,000 rpm with an overspeed limit of 107% rpm. Its dimensions are 61 X 31 X 30 inches, and it has a dry weight of 518 lbs. This along with the engines will provide all the electric power needed, approximately 150 KV during climb, for normal operations.

Two generators which are driven by the engines are also used on the JB-300 . These generators and the APU are used to start the engines. The JB-300 is also equipped with a battery located in the

nose that can operate the flight control system for a short period of time in the unlikely event of a total electrical system failure .

10.5 Air-Conditioning System

The air-conditioning ducts for the JB-300 consist of two ducts that are 1.5 ft. in diameter. A double duct system was chosen over a single larger duct system in order to provide the air circulation needed while minimizing the overhead space it consumed. A single duct would require the ceiling to be dropped and take away from the passenger head room.

The air-conditioning pack is located behind the wing box along with the environmental mixing bay. The air-conditioning pack that the JB-300 uses requires 26 hp and provides 35 lb/min of air flow. The total weight for the pack is 138 lbs.

10.6 Oxygen System

The JB-300 uses a plumbed gaseous oxygen system for the crew and chemical oxygen generators which provide the oxygen supply for the passengers in case of an emergency. The chemical oxygen is located over the passengers head and the generator is automatically started with the use of one mask.

11.0 Maintenance

The JB-300 was designed with maintenance and accessibility as a major concern. It is compatible with existing ground servicing equipment, and Fig. 11.0.1 shows how ground vehicles can operate on the JB-300 simultaneously. This includes the loading of passengers and cargo, refueling, cleaning, restocking of food and beverages, replenishing the water supply, and servicing of lavatories.

The JB-300's engines are positioned beneath the wing making them only 2.8 feet off the ground. This makes the engines easily accessible for inspections and repairs, which will shorten the time required for maintenance.

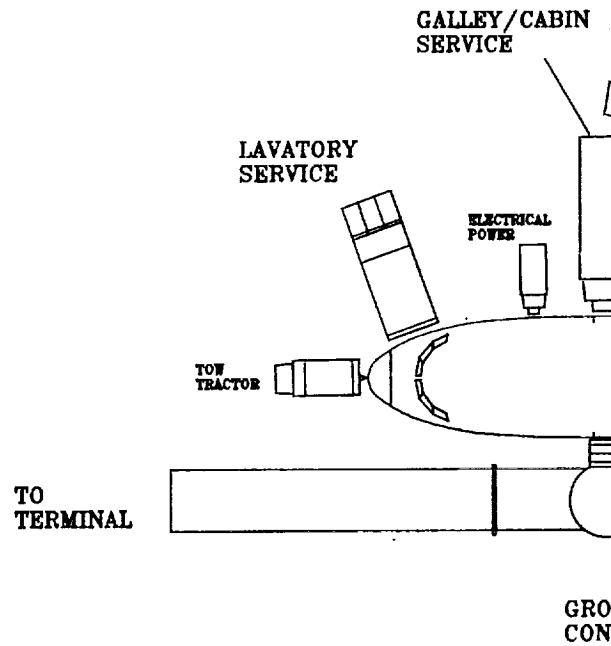
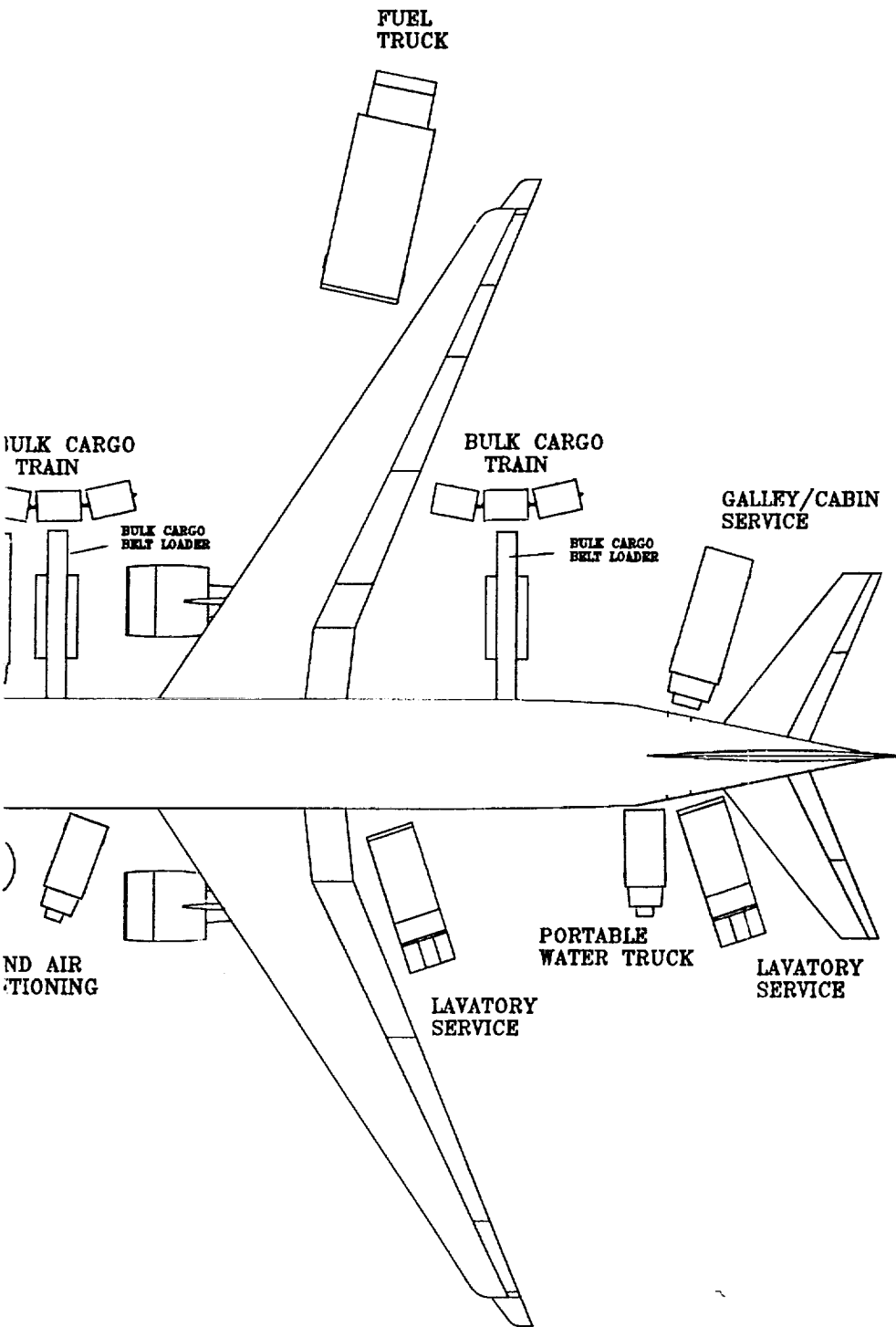


Figure 11.0.1 Ma



Maintenance and Accessibility

12.0 Manufacturing

The manufacturing of the JB-300 was broken up into several primary components as shown in Fig. 12.0.1. This breakdown is similar to that done for the Boeing 777. Components can be concurrently produced at remote facilities, and then shipped elsewhere for final assembly. This is particularly advantageous in the current market because it allows for international cooperation in the manufacture of the various components. The JB-300 breakdown also allows for future growth in the fuselage sections that lie in front of and behind the wing.

The JB-300 has an almost entirely aluminum structure, which will help to keep tooling, manufacturing, and material costs to a minimum. The small sections that are made of composite materials are already widely used in the aviation industry, and have been proven reliable and cost effective.

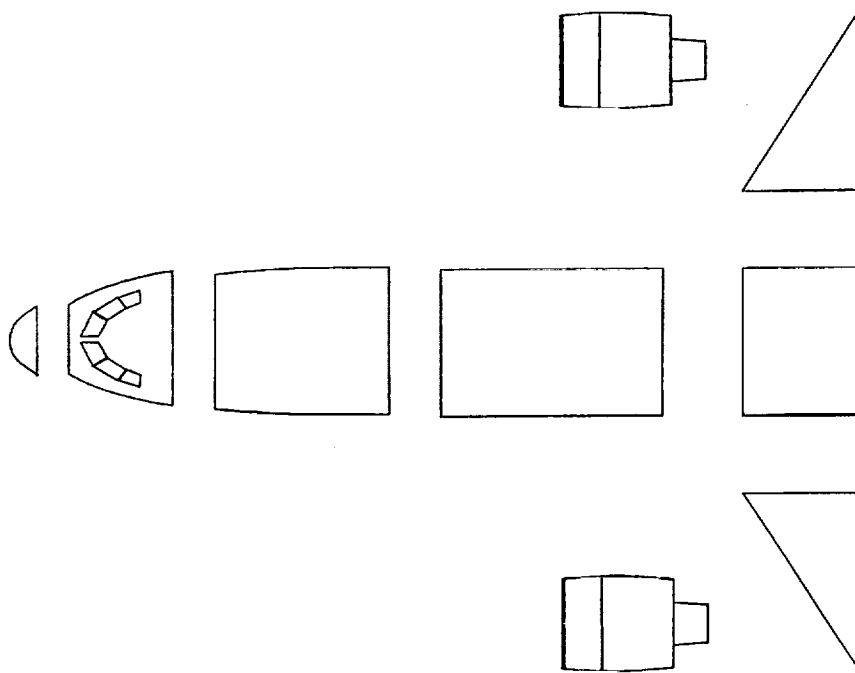
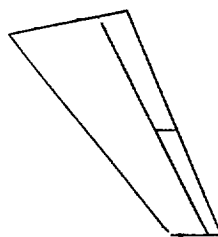
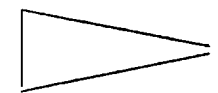
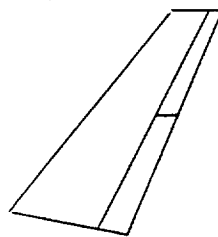
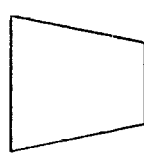
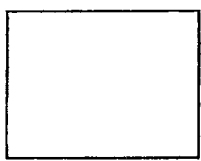
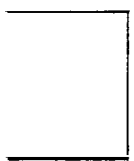
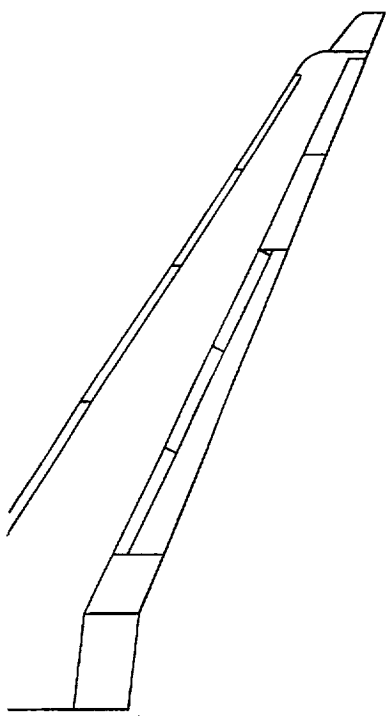


Figure 12.0.1 Manufacturing Bro

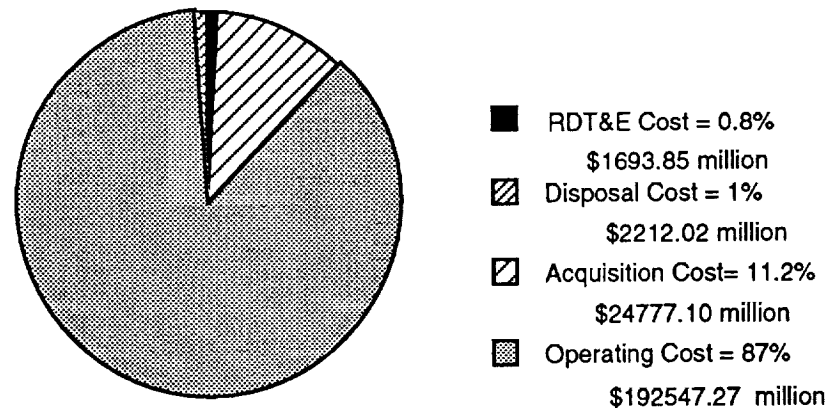


breakdown

13.0 Cost Analysis

The JB-300 was designed from the need for a lower cost mid-size commercial transport. The leading competitors in this field are Boeing 757/767 and Airbus 310/320. In order to capture this market from Boeing and Airbus, the JB-300 had to be able to perform up to and surpass the ability of its competitors and still maintain a lower cost.

The unit cost for JB-300 was calculated to be \$53 million. The process for cost estimation was based on the methods presented in Ref. 19 and 1993 dollars. The cost analysis of our aircraft was broken up into four main categories: research and development cost, acquisition cost, operating cost, and disposal cost (Figure 13.0.1).



Total Life Cycle Cost = \$221202.375 Million
For 505 JB-300

Figure 13.0.1 LIFE CYCLE COST FOR JB-3

The acquisition cost for the JB-300 includes the manufacturing labor cost and the profit for the manufacturing phase. The total cost for this phase is \$25 billion. This amount is based on the assumption that 500 planes will be manufactured at a rate of 3.5 per month. This yields a Research, Development, Testing and Evaluation (RDT&E) cost for each aircraft to be \$49.6 million.

The research and development cost includes airframe engineering cost, development cost, flight test cost, cost of new facilities, and finance cost for this phase (Table 13.0.1). The total RTDE cost for the JB-300 was calculated to be \$1.69 billion. The research and development phase was based on the assumption that five test planes would be used. Two of the aircraft would be used in static testing, while the other three would be reserved for dynamic testing. These planes, once the program is approved by the FAA, would be sold after all five planes were brought up to standards..

Table 13.0.1 RDT&E Costs

RDT&E Cost Break Down	1993 US. Dollars (Millions)
Airframe Engineering and Design Cost	155.83
Development Support and Testing Cost	45.14
Flight Test Operations Cost	25.96
Test and Simulations Facilities	169.39
RDT&E Profit	169.39
RDT&E Finance Cost	169.38
Sub-total	1693.85

JB-300's operating cost was obtained by calculating the program operating cost, direct operating cost, and the indirect operating cost (Table 13.0.2). The direct operating cost was the highest of all three operating cost. The total operating cost was determined to be \$193 billion.

Table 13.0.2 Operating Costs

Operating Cost Breakdown	US. Dollars in Millions
Direct Operating Cost	125000
Indirect Operating Cost	70000
Sub-Total	193000

The last phase involved in estimating the life cycle cost is obtaining the disposal cost. This was calculated to be 2.21 billion. This yielded a total life cycle cost for the JB-300 to be \$22.1 billion for a twenty year life cycle.

14.0 Conclusions and Recommendations

14.1 Conclusions

The JB-300 is a technologically advanced aircraft which will meet the demands of the 21st century markets. The JB-300 has several distinct advantages that make it more efficient and cost effective than the competition.

First, the JB-300 design allowed for the integration of the very-high-bypass-ratio engines that are currently being developed. These engines are up to 24% more fuel efficient than those used on the competition (Ref. 14), and the engine's large diameter also prevents them from being incorporated by current aircraft at a later time.

Second, the JB-300 has an aerodynamic design that is superior to the competition, resulting in a lower overall drag configuration. Some of the specific drag reduction techniques used were: decreasing induced drag by using a high aspect ratio wing at low wing loading, minimizing trim drag by designing the center of gravity and aerodynamic center to be close to one another, and keeping compressibility drag at a reasonable level by choosing a supercritical airfoil, a 31 degree sweep angle, and a cruise velocity of Mach .82.

When these advantages were coupled together it resulted in a lower weight aircraft that did not rely heavily on composites. The design superiority of the JB-300 will be passed on to the airlines in the form of reduced DOC costs. This is demonstrated by the JB-300's 1.85 cents per seat mile calculation.

14.2 Recommendations

If further analysis were to be done on the JB-300 the following recommendations should be considered:

1. Wind tunnel tests should be conducted to verify the data for stability and control, aerodynamics, and structures.
2. The SFC. Vs. thrust loop of the ADP should be optimized to get better cruise SFC at higher altitudes.

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