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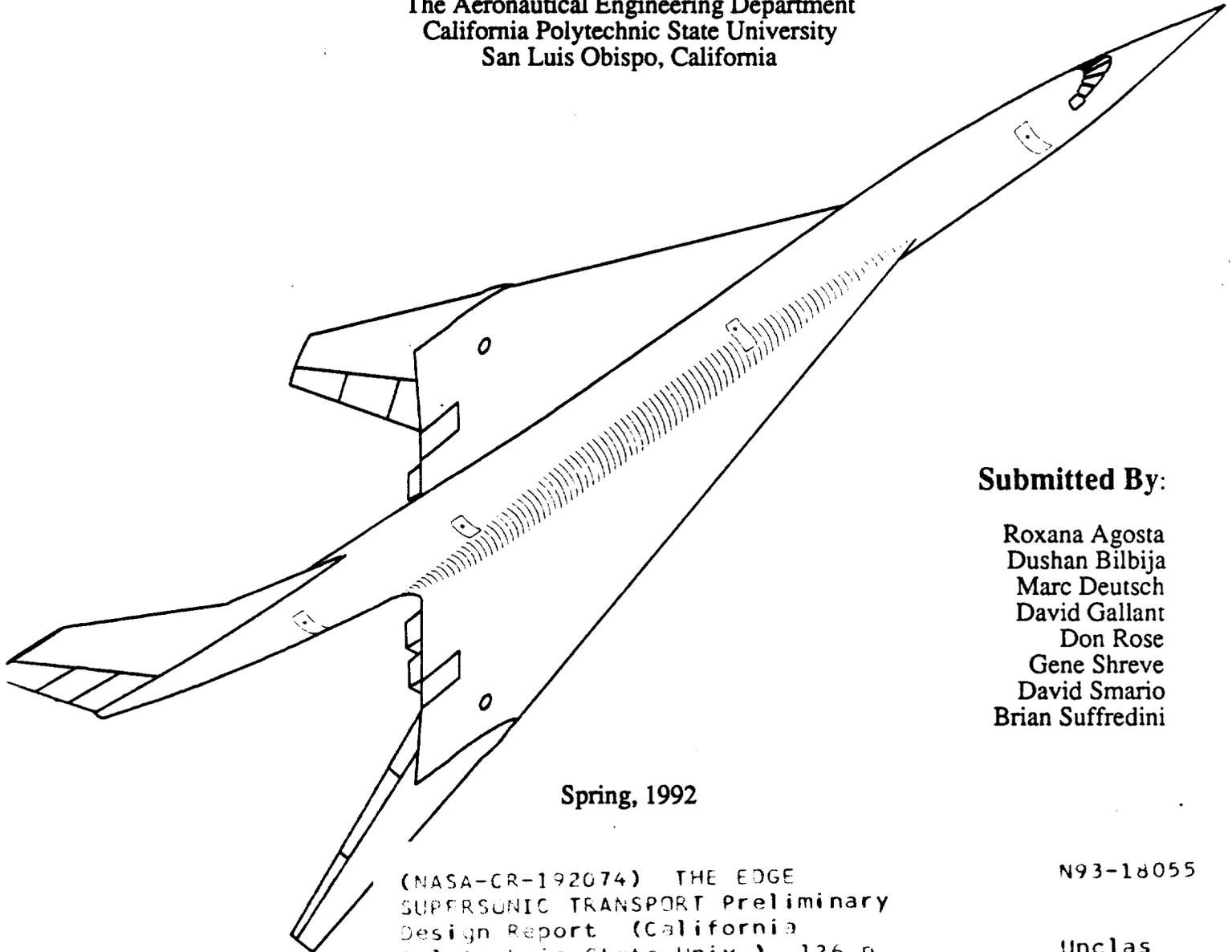
# THE EDGE

# SUPERSONIC TRANSPORT

A Preliminary Design Report

Presented to

The Aeronautical Engineering Department  
California Polytechnic State University  
San Luis Obispo, California



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## Abstract

As intercontinental business and tourism volumes continue their rapid expansion, the need to reduce travel times becomes increasingly acute. *The Edge* Supersonic Transport Aircraft is designed to meet this demand by the year 2015. With a maximum range of 5750 nm, a payload of 294 passengers and a cruising speed of  $M = 2.4$ , *The Edge* will cut current international flight durations in half, while maintaining competitive first class, business class, and economy class comfort levels. Moreover, this transport will render a minimal impact upon the environment, and will meet all Federal Aviation Administration Part 36, Stage III noise requirements.

The cornerstone of *The Edge's* superior flight performance is its aerodynamically efficient, dual-configuration design incorporating variable-geometry wingtips. This arrangement combines the benefits of a high aspect ratio wing at takeoff and low cruising speeds with the high performance of an arrow-wing in supersonic cruise. And while the structural weight concerns relating to swinging wingtips are substantial, *The Edge* looks to ever-advancing material technologies to further increase its viability.

Heeding well the lessons of the past, *The Edge* design holds economic feasibility as its primary focus. Therefore, in addition to its inherently superior aerodynamic performance, *The Edge* uses a lightweight, largely windowless configuration, relying on a synthetic vision system for outside viewing by both pilot and passengers. Additionally, a fly-by-light flight control system is incorporated to address aircraft supersonic cruise instability.

*The Edge* will be produced at an estimated volume of 400 aircraft and will be offered to airlines in 2015 at \$167 million per transport (1992 dollars).

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## Nomenclature

AC	Aerodynamic Center
AEMPR	Aeronautical Engineering Manufacturing Planning Report
AIAA	American Institute of Aeronautics and Astronautics
AOA	Aircraft Angle of Attack
APU	Auxiliary Power Unit
ATC	Air Traffic Control
BFL	Balance Field Length
BPR	By-Pass Ratio
$C_D$	Drag Coefficient
CEF	Cost Escalation Factor
CET	Combustion Chamber Exit Temperature
CG	Center of Gravity
$C_L$	Lift Coefficient
$C_T$	Wing Root Coefficient
$C_{VT}$	Vertical Volume Coefficient
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FOD	Foreign Object Damage
HSCT	High Speed Civil Transport
HUD	Head-Up Display
lbs	Pounds
LCC	Life Cycle Cost
LCD	Liquid Crystal Display
L/D	Lift-to-Drag Ratio
LE	Leading Edge
LCN	Load Concentration Number
ft	Feet
M	Mach
MFTF	Mixed Flow Turbofan
NASA	National Aeronautics and Space Administration
RAT	Ram Air Turbine

SAS	Stability Augmentation System
SFC	Specific Fuel Consumption
SST	Supersonic Transport
TE	Trailing Edge
TO	Takeoff
$x_{AC}$	Aerodynamic Center as a Percentage of the Wing Root Chord
$x_{CG}$	Center of Gravity as a Percentage of the Wing Root Chord

### Greek Symbols

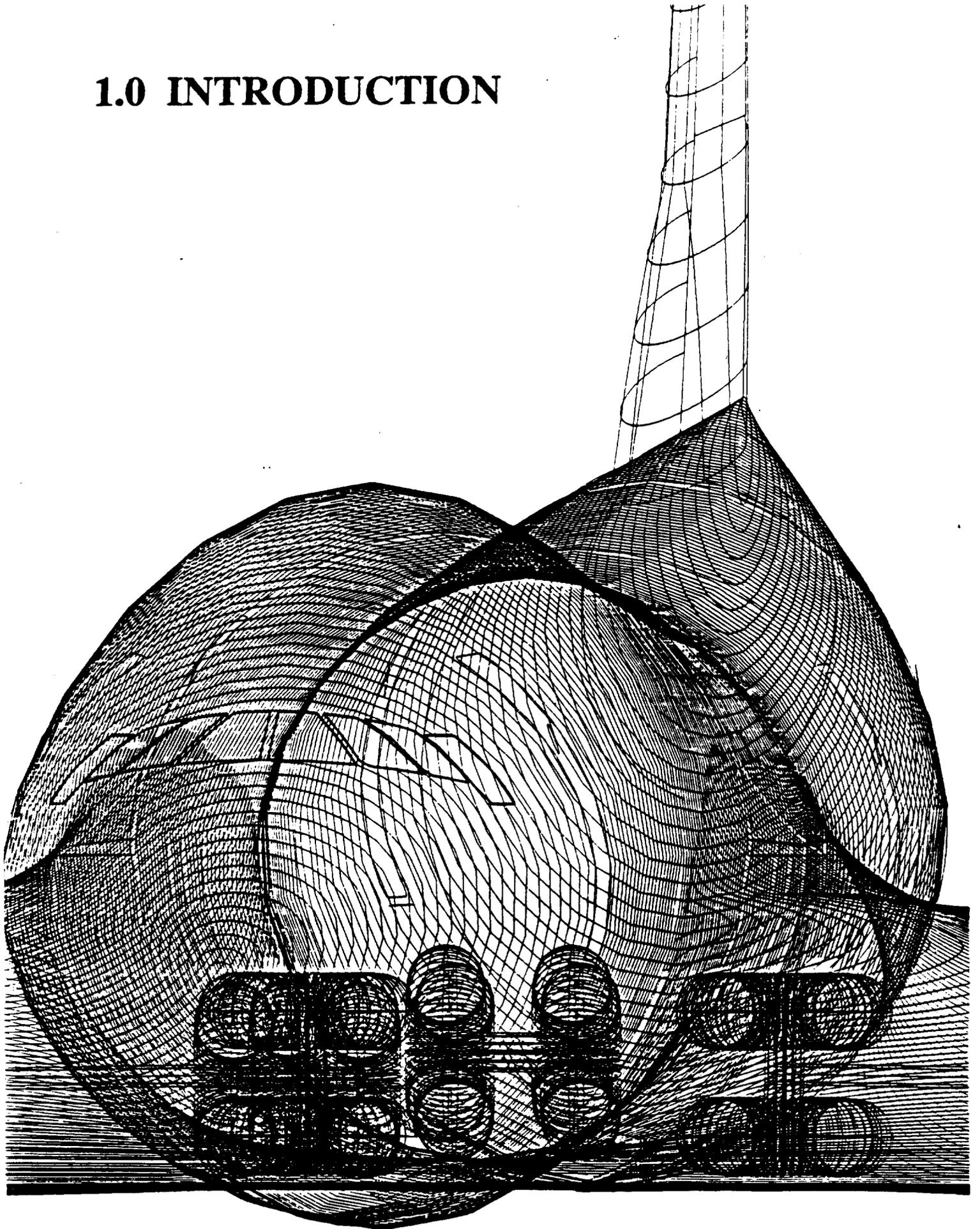
$\alpha$	Aircraft Angle of Attack
$\beta$	Aircraft Sideslip Angle
$\delta_a$	Aileron Deflection
$\delta_e$	Elevon Deflection
$\delta_r$	Rudder Deflection
$K_\alpha$	Aircraft Angle of Attack Feedback Loop Gain
$K_\beta$	Aircraft Sideslip Angle Feedback Loop Gain
$\omega_p$	Phugoid Natural Frequency
$\omega_{sp}$	Short Period Natural Frequency
$\zeta_p$	Phugoid Damping Ratio
$\zeta_{sp}$	Short Period Damping Ratio

### Stability Derivatives

$C_{m\alpha}$	Variation of Pitching Moment Coefficient with Angle of Attack
$C_{mq}$	Variation of Pitching Moment Coefficient with Pitch Rate
$C_{mu}$	Variation of Pitching Moment Coefficient with Speed
$C_{L\alpha}$	Aircraft Lift Curve Slope
$C_{Dq}$	Variation of Drag Coefficient with Pitch Rate
$C_{Du}$	Variation of Drag Coefficient with Speed
$C_{L\delta_e}$	Variation of Lift Coefficient with Elevon Deflection
$C_{D\delta_e}$	Variation of Drag Coefficient with Elevon Deflection

$C_{M\delta_e}$	Variation of Pitching Moment Coefficient with Elevon Deflection
$C_{l\beta}$	Variation of Rolling Moment Coefficient with Sideslip Angle
$C_{lp}$	Variation of Rolling Moment Coefficient with Rolling Rate
$C_{l\delta_A}$	Variation of Rolling Moment Coefficient with Aileron Deflection
$C_{l\delta_R}$	Variation of Rolling Moment Coefficient with Rudder Deflection
$C_{n\beta}$	Variation of Yawing Moment Coefficient with Sideslip Angle
$C_{np}$	Variation of Yawing Moment Coefficient with Rolling Rate
$C_{n\delta_A}$	Variation of Yawing Moment Coefficient with Aileron Deflection
$C_{n\delta_R}$	Variation of Yawing Moment Coefficient with Rudder Deflection
$C_{y\beta}$	Variation of Sideforce Coefficient with Sideslip Angle
$C_{yp}$	Variation of Sideforce Coefficient with Rolling Rate
$C_{yr}$	Variation of Sideforce Coefficient with Yaw Rate
$C_{y\delta_A}$	Variation of Side Force Coefficient with Aileron Deflection
$C_{y\delta_R}$	Variation of Sideforce Coefficient with Rudder Deflection

# 1.0 INTRODUCTION



## 1.0 Introduction

Progress in aviation feeds on itself, with each new triumph a stepping stone for the next. For example, it is the dawn of the commercial airline industry that has truly connected vast continents, and indeed, the world; from this, international tourism and business have flourished, and the demand on the air transport industry is ever growing.

Current global air traffic is estimated to continue to grow at an annual rate of 3.6% well into the next century. This would mean an increase from approximately 986 million passengers today, to about 2,086 million in 2010, generating approximately 2.5 billion revenue-passenger-miles per year. Even more encouraging is that all market areas are charted for healthy growth, especially the Pacific market.<sup>5</sup> It is regions such as this where the need for a supersonic transport (SST) will be felt most acutely.

This demand is driven largely by international business, an area where the time wasted on seemingly endless transcontinental flights is far more costly than airfare itself. The popular flight from Los Angeles to Sidney, for example, takes nearly fifteen hours. Several contemporary studies have shown that whether on vacation or on business, most people would certainly pay a premium to cut this time in half.<sup>5</sup> A supersonic commercial transport is ideally suited to this task.

The Concorde is the only example of such a vehicle now in use. It is a great technological achievement, flying at twice the speed of sound and nearly twice the altitude of the average commercial transport. However, the Concorde burns four times as much fuel per passenger mile as a jumbo jet, violates all airport noise requirements, and cannot fly efficiently over land.<sup>1</sup> Additionally, this aircraft has clearly demonstrated that reasonable development costs and market capture will be the mother's milk of the next generation SST.

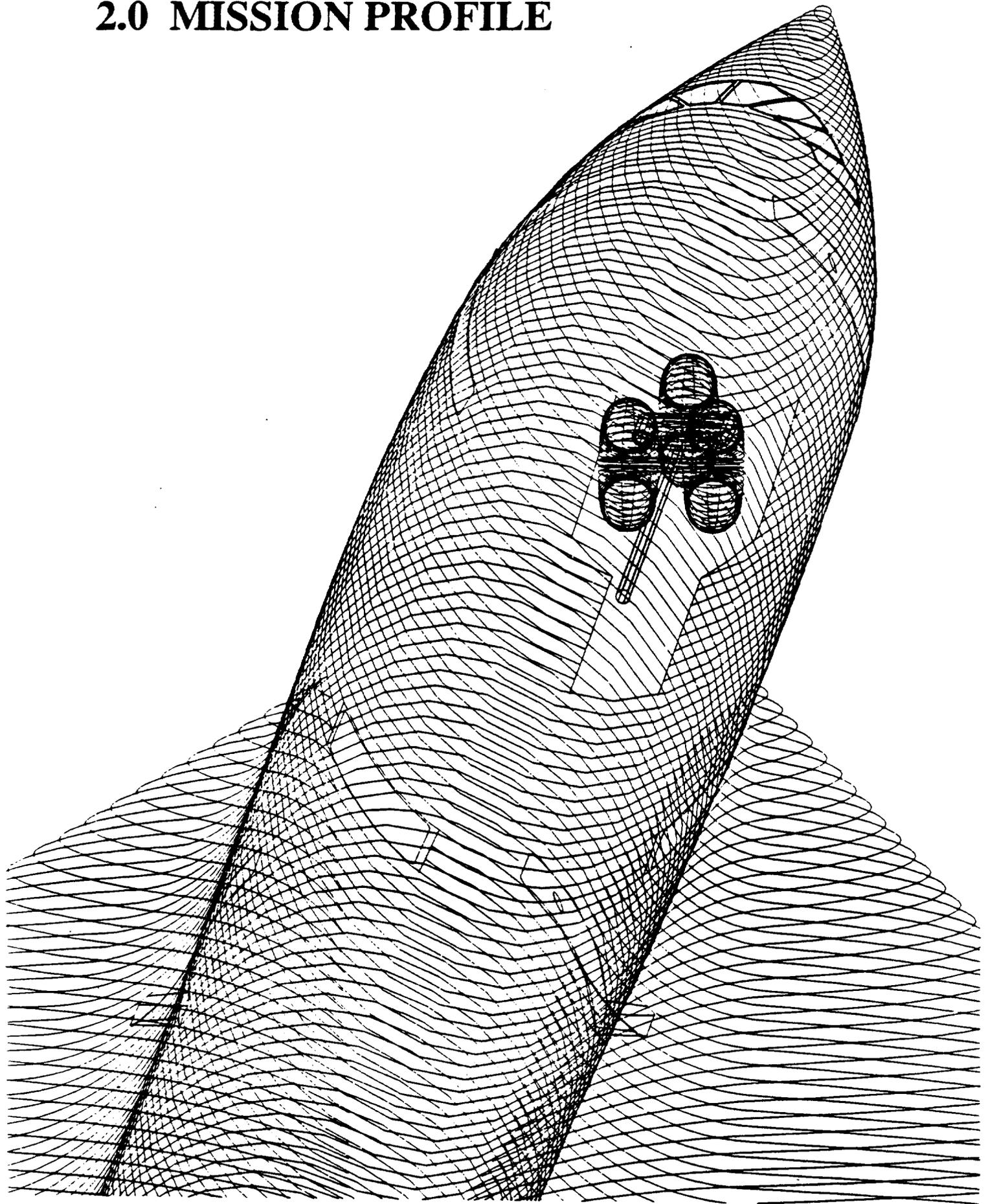
These lessons are well heeded; in striving to meet the demand for a fleet of new SSTs, *The Edge* designers have duly shifted design goals from those of mere technological prowess, to those of economic credibility. This means ensuring developmental practicability, environmental compatibility, and a significant market base.

*The Edge* will accommodate 294 passengers comfortably at a supersonic cruise speed of Mach 2.4 . In the interests of serving the widest range of current and emerging markets, it has a capability of flying 5750 nm non-stop. *The Edge* meets all federal aviation noise requirements, and will satisfy all environmental emissions standards by its market entry in the year 2015. Addressing itself to use, maintenance and servicing concerns, *The Edge* has been designed to be completely compatible with all major airports.

Some of *The Edge's* key technical features include the elimination of a horizontal tail, the use of advanced technology mixed-flow turbofan engines, the implementation of a see-by-wire flight and passenger vision system, and the utilization of an arrow-wing design for efficient supersonic flight, incorporating swinging wingtips which act to provide remarkable economy in subsonic cruise. A highly flexible cabin design is also featured, as well as a wide assortment of passenger amenities including video screens at every economy class seat and telephone, FAX, and computer capabilities throughout the first class and business compartments.

*The Edge* is expected to cost \$167 million per transport (in 1992 dollars), and to provide 10% return on investment over its service life.

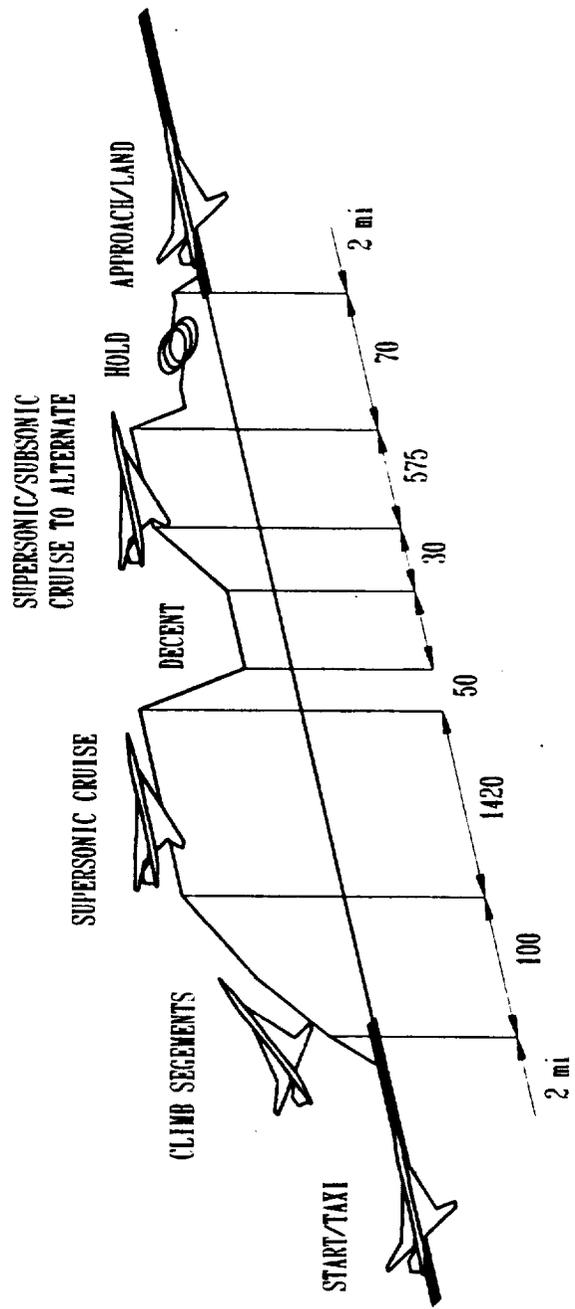
## 2.0 MISSION PROFILE



## 2.0 Mission Profile

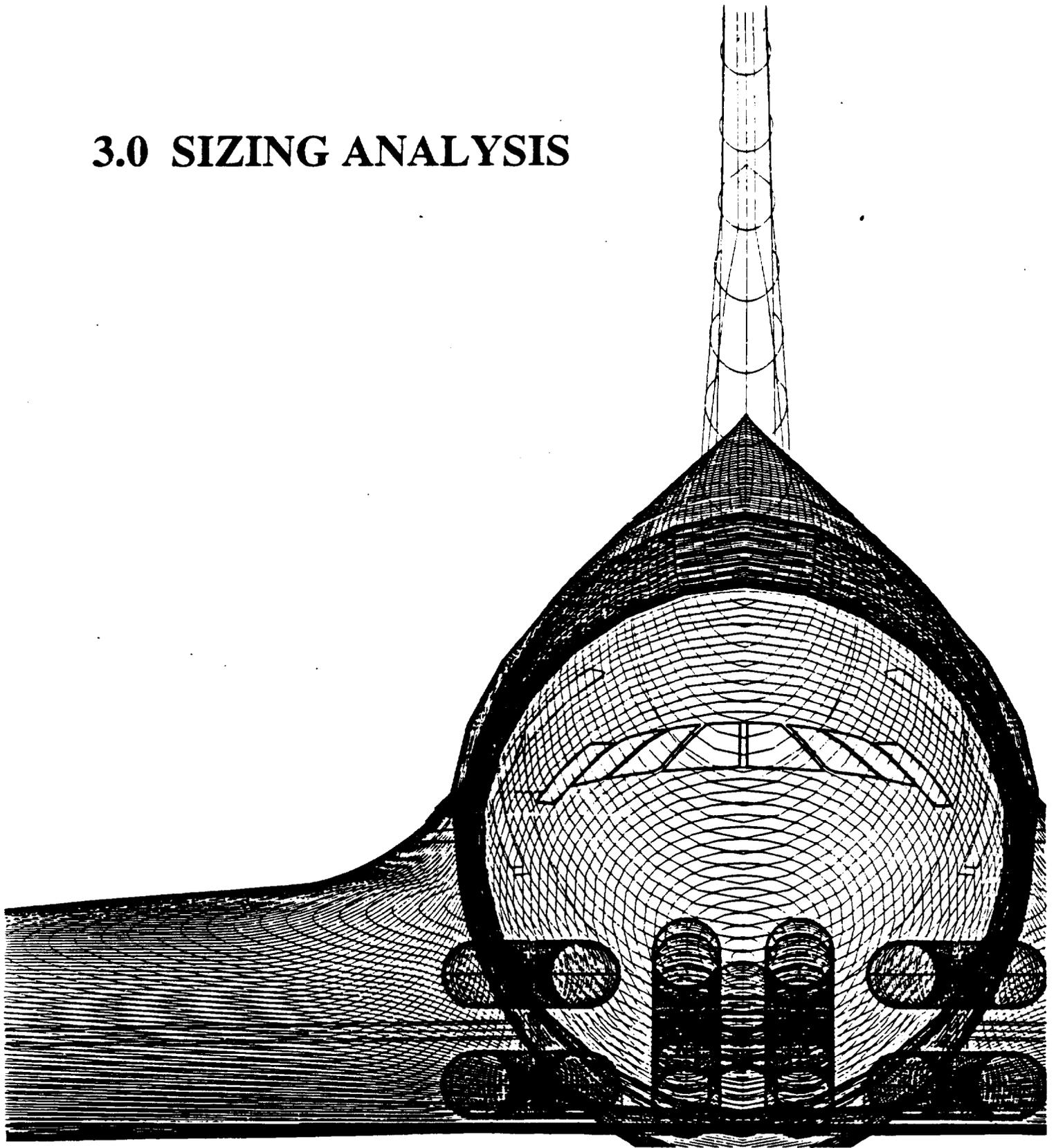
The mission profile, as illustrated in Figure 2.1, will allow compliance with all Federal Aviation Regulations (FARs), Air Traffic Control (ATC) rules, environmental, performance, and safety concerns. *The Edge* was designed to these criteria with the understanding that certain flight requirements may require an airline to deviate from this profile.<sup>8</sup>

1. **Start/Taxi:** Approximately 15 minutes.
2. **T.O./Climb:** Takeoff includes climb to 35 ft from a 12,000 ft runway at sea level standard conditions. Maximum rate initial climb will be performed to 1500 ft at which point a more gradual climb rate may be used for noise abatement over populated areas.
3. **Climb:** Maximum efficiency climb to 10,000 ft under 250 knots.
4. **Climb/Accelerate** - Maximum efficiency climb and accelerate to 60,000 ft (*The Edge* is also designed to fly efficiently at subsonic cruise speed of  $M = 0.7.$ ), and Mach 2.4 or comply with ATC procedures.
5. **Cruise** at Mach 2.4 to destination.
6. **Decelerate and Descend:** Maximum efficiency decent to 1500 ft.
7. **Hold:** Hold time of 1/2 hr at 1500 ft.
8. **Approach/Land:** Hold for 8 minutes at 1500 ft. Land on 12,000 ft runway.
9. **Taxi/Shutdown:** 8 minutes to taxi and shut down.
10. **Alternate:** 10% of flight distance plus distance to alternate or 45 minutes reserves to be allowed for alternate airport, which ever is greater.



**Figure 2.1**  
*The Edge Mission Profile*

### 3.0 SIZING ANALYSIS



### 3.0 Sizing Analysis

#### 3.1 Preliminary Sizing

An iterative design procedure was used to produce an initial design point for *The Edge*.<sup>8</sup> The requirements which determined this design point were those regarding takeoff and landing performance. The design point as shown in Figure 3.1 produces a thrust to weight ratio and wing loading of 0.34 and 87, respectively. These are the values which were chosen for designing *The Edge*.

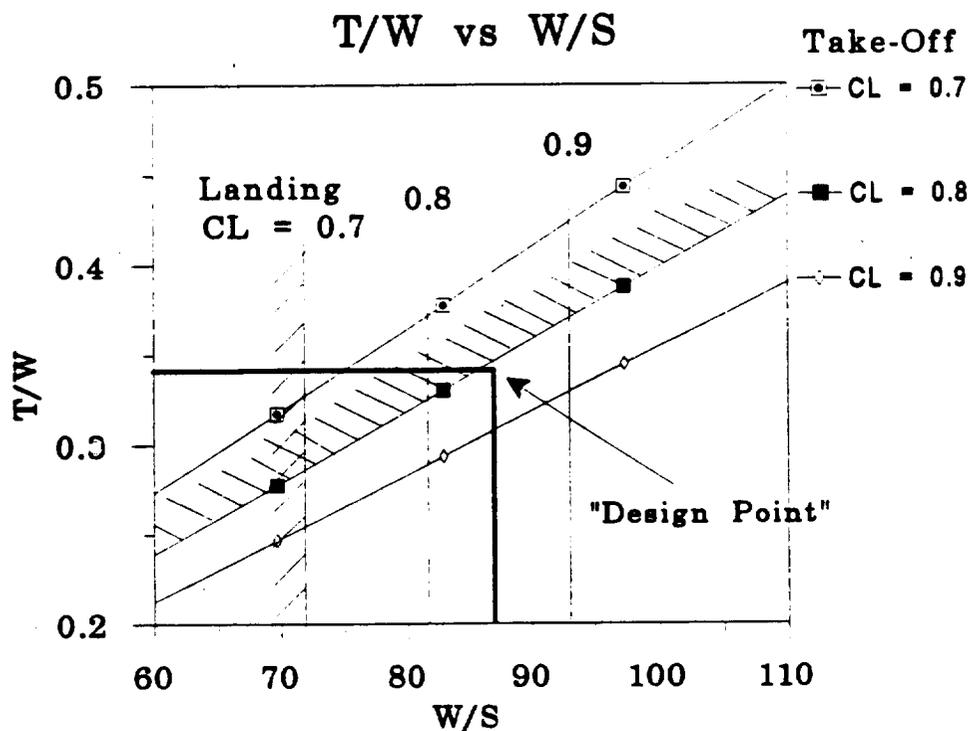


Figure 3.1  
*The Edge* Design Point For Preliminary Sizing

#### 3.2 Weight Estimation

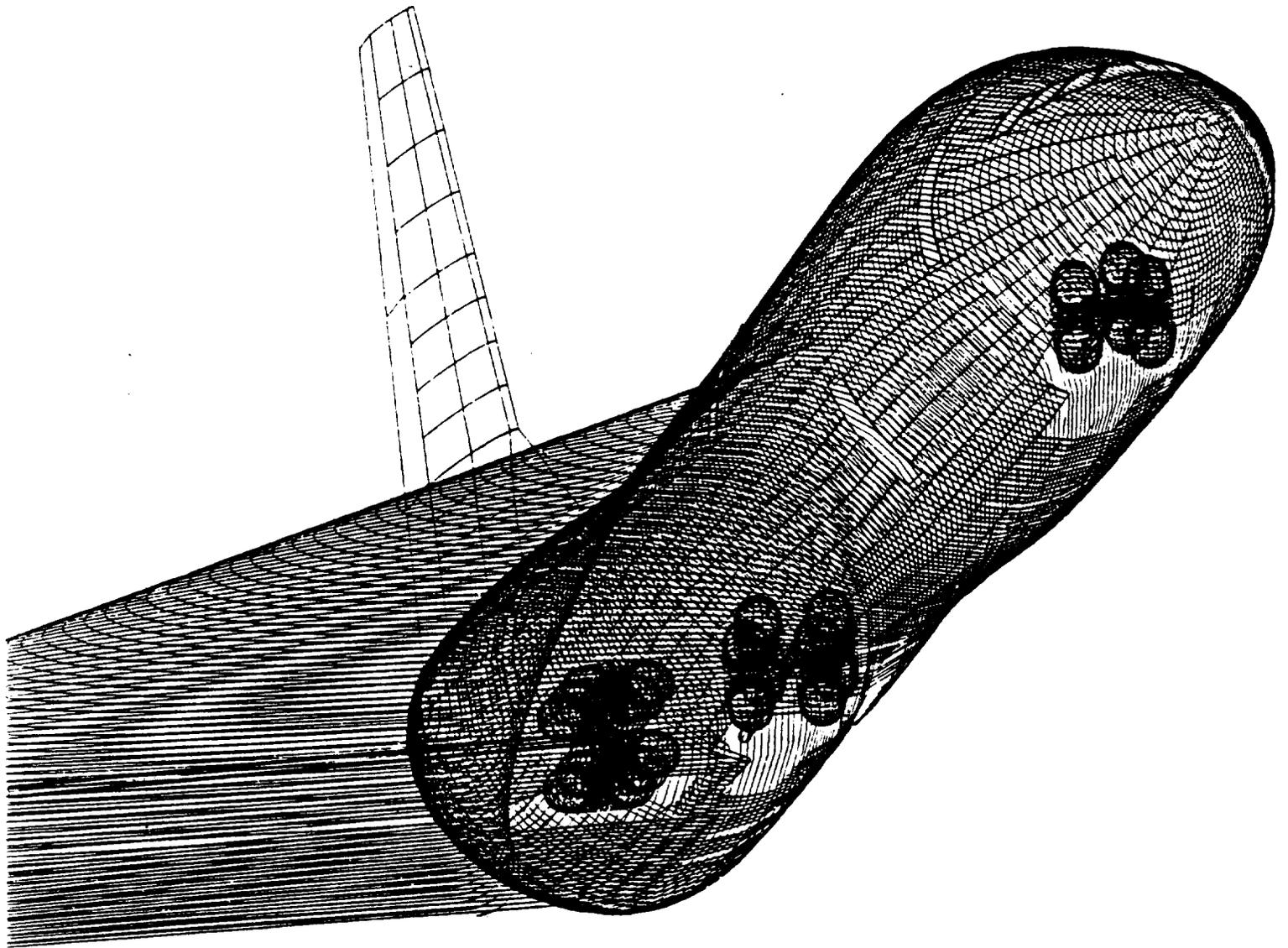
The minimum airplane weight and the fuel weight needed to accomplish *The Edge*'s mission were predicted using the method from Reference 8. The takeoff gross weight is comprised of the following: the aircraft's operating empty weight, the mission

fuel weight, and the payload weight. The operating empty weight consists of the aircraft's empty weight (structure and interiors), trapped (unusable) fuel and oil, and the weight of the crew required to operate the aircraft<sup>8</sup>. The fuel weight is determined by the specific fuel consumption and the range. These various weights are summarized in Table 3.1.

**Table 3.1**  
***The Edge Aircraft Weight Summary***

Takeoff Weight	832000 lbs
Empty Weight	309037 lbs
Fuel Weight	429000 lbs

# 4.0 AIRCRAFT CONFIGURATION



## 4.0 Aircraft Configuration

### 4.1 Design Considerations

Many considerations combined to generate the final configuration of *The Edge* SST. Among them, the driving concerns were the ability to achieve high performance at supersonic and subsonic cruise, passenger comfort levels competitive with the Boeing 747-400, and the lowest possible overall cost for the airline/customer. Preliminary research in these areas was performed for oblique-wing, double delta, and full wing-sweeping aircraft.

Oblique-wing designs, while offering substantial subsonic and supersonic efficiencies as well as a largely self-area-ruling capability, are undoubtedly high-risk configurations. Structural weight and packaging problems inherent to their wing sweep mechanisms are major concerns, as are the insufficiently researched control/attitude nuances of such configurations, and intangible considerations such as the passenger appeal and comfort of an oblique-wing transport. For these reasons, an oblique-wing configuration was not chosen.

Double-delta planform designs have the benefit of the largest database support extending from the Concorde development to the cost and configurations research currently underway at NASA, Boeing, and McDonnell Douglas. And while they clearly can be tailored for passenger comfort considerations, they are a compromise design, yielding fair though less than ideal subsonic and supersonic performance. *The Edge* design group desired to formulate a design with superior performance in both cruise regimes.

Full wing-sweeping designs provide excellent subsonic cruise and supersonic cruise performance, high passenger comfort capabilities, and cost practicability, as well as the added benefits of low takeoff and landing speeds, and a good database of technical data. However, since fuel is usually placed in the sweeping wings, center of gravity shifts have substantial effects on stability and control. Although these effects may be addressed with the use of fuel pumping or increased tail down-loading, a more perplexing concern regarding a full wing-sweep aircraft is that which Boeing designers faced in the 1960's: the possibility that the weight addition incurred to sweep the wings and support the load transfers may indeed outpace the aerodynamic benefits in terms of overall cost. In addition, a full wing sweep design would most likely demand potential cabin space for the packaging of the sweep mechanism; and since the design goal is to

carry approximately 300 passengers within 310 feet of fuselage length, this would certainly pose problems. It is largely in light of these considerations that *The Edge* supersonic transport was not designed in a typical full wing-sweep configuration.

## 4.2 Configuration Description

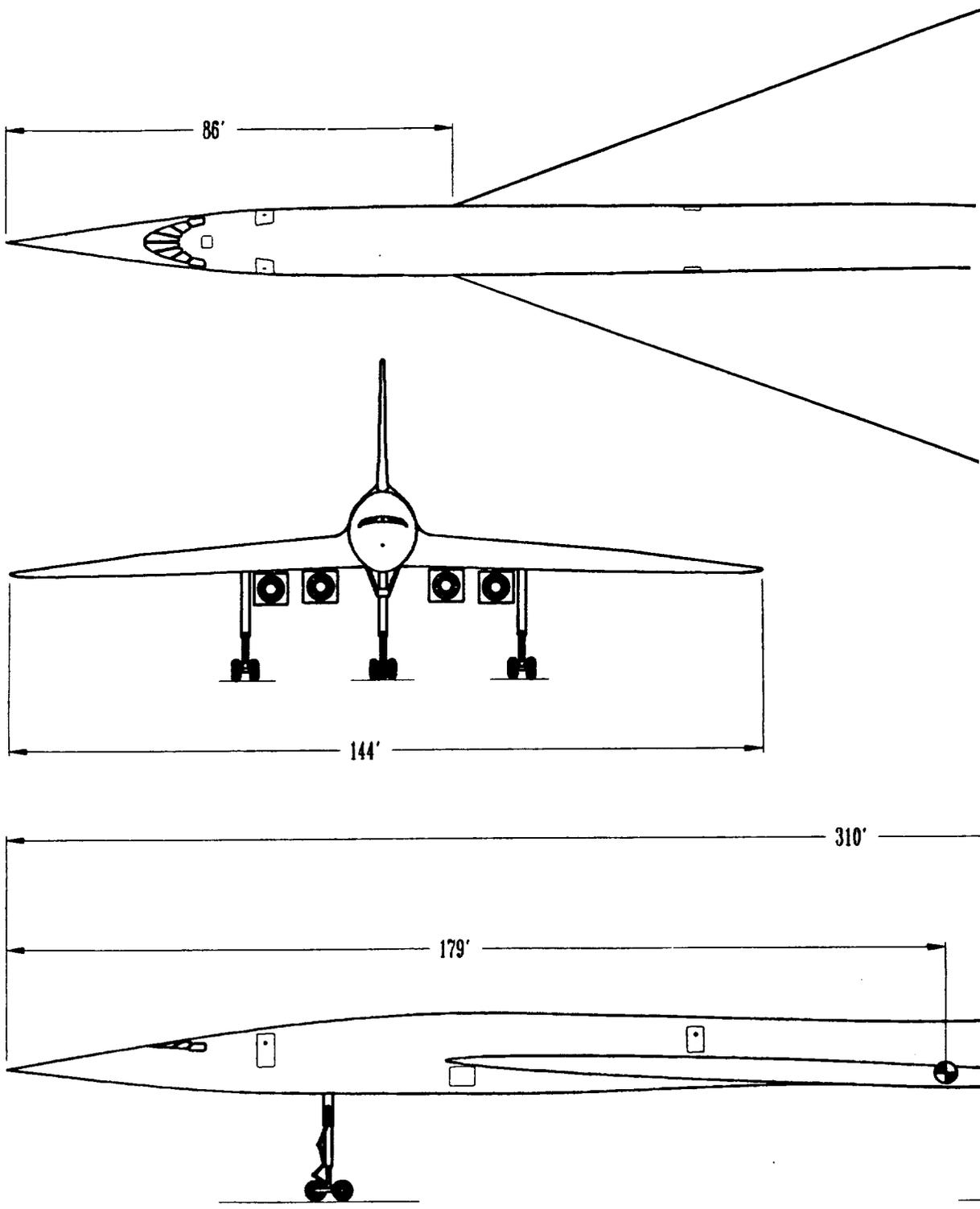
Figure 4.1 illustrates *The Edge* in a three view format. Through the use of wingtips able to swing from 70° to 20° aft, *The Edge* SST combines the high efficiency of a low aspect ratio arrow-wing in supersonic cruise with the benefits of a relatively high aspect ratio wing in subsonic cruise. Naturally, there are trade-offs. It is significant that since the wingtips are relatively small and lightweight in comparison to the main wing, center of gravity shifts due to wingtip sweeping are extremely small. However, while the main wing root chord has a thickness ratio of only 3%, the outboard section of the main wing has an abnormally large 12% thickness ratio (with wing tips unswept) to accommodate the pivot mechanism. This thickness becomes 11% in the swept configuration which incurs a supersonic drag decrement, but which also provides substantial takeoff and subsonic cruise benefits. Additionally, although the wingtip sweep mechanisms do not require the use of valuable cabin space as would likely be the case for a full wing sweep configuration, the structural weight of the wingtip load transfer structures is substantial (approximately 4% of the aircraft empty weight)<sup>9</sup>. Sections 11.0 and 12.0 of this report discuss these considerations in detail.

The incorporation of an area-ruled fuselage and a highly blended wing-fuselage integration contributes significantly to overall supersonic and subsonic flight performance. As well, the exclusive use of elevons for longitudinal control allows the elimination of a horizontal tail and its inherent weight and drag inefficiencies.

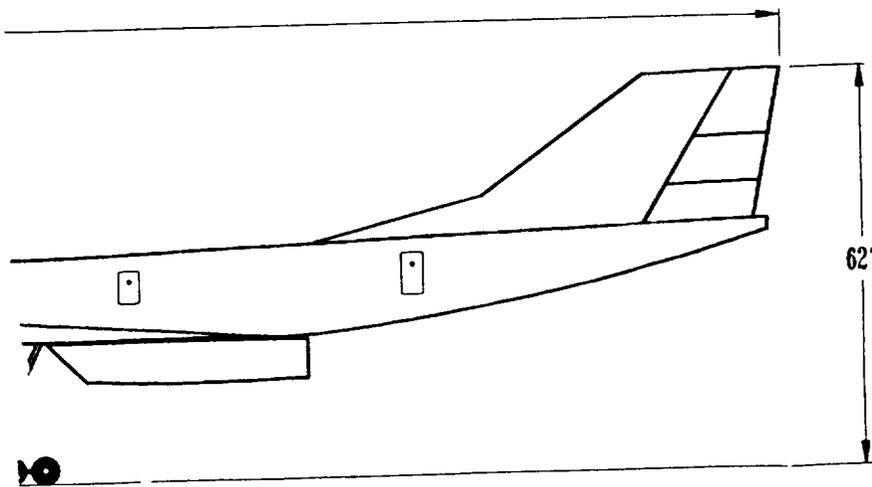
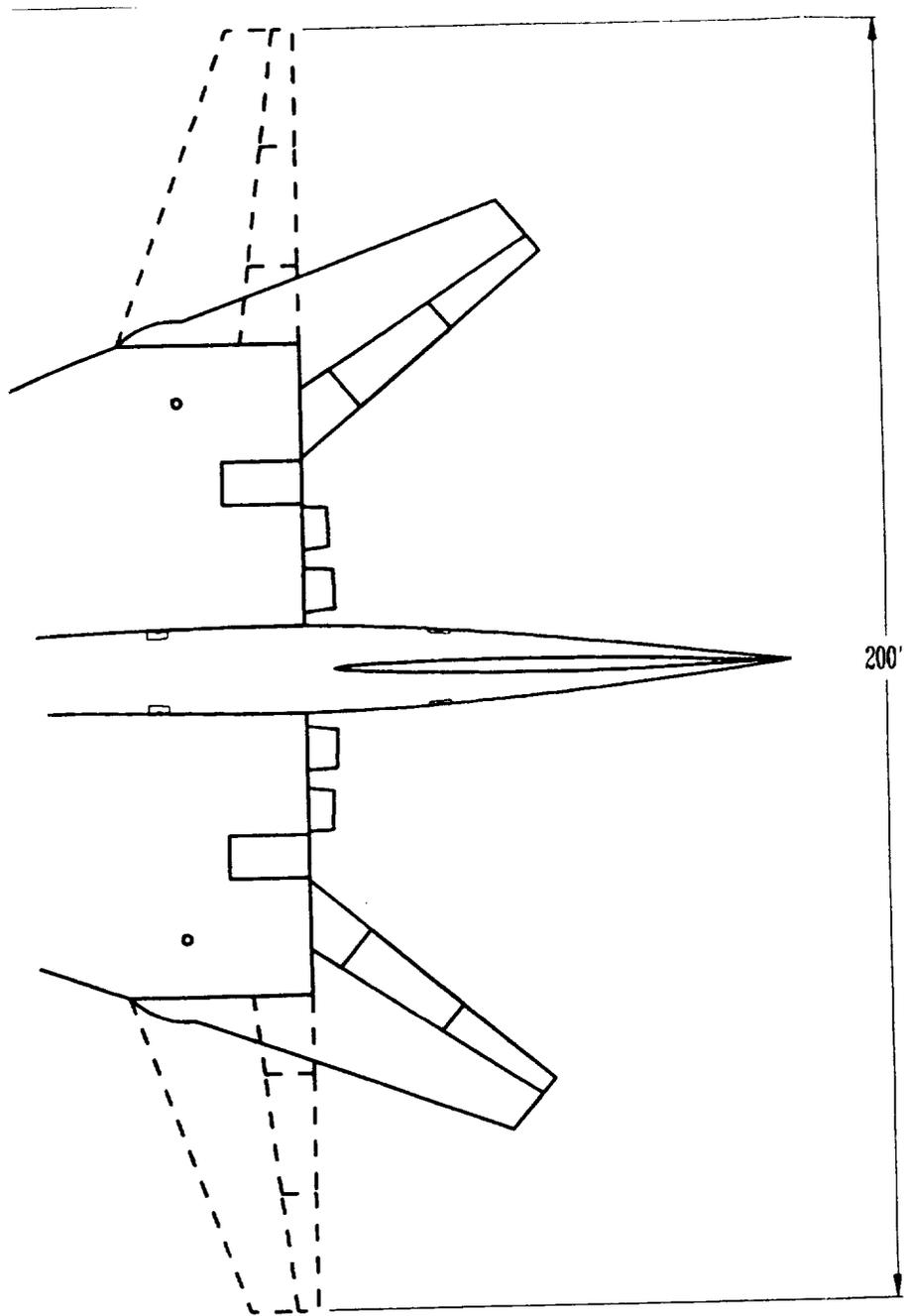
*The Edge's* four mixed flow turbofan engines placed below and aft on the main wing will meet all environmental pollution requirements, and are expected to meet FAR Part 36, Stage III noise levels at takeoff through the use of mixed ejectors with integral noise suppression (see Section 9.0 of this report)<sup>6,12</sup>.

Other salient features illustrated in Figure 4.1 include a main-wing sweep of 70° which places the wing behind the supersonic Mach cone, allowing the use of relatively thick, subsonic airfoils; and a largely windowless design, promoting a significant reduction in aircraft structural weight.

FOLDOUT FRAME /

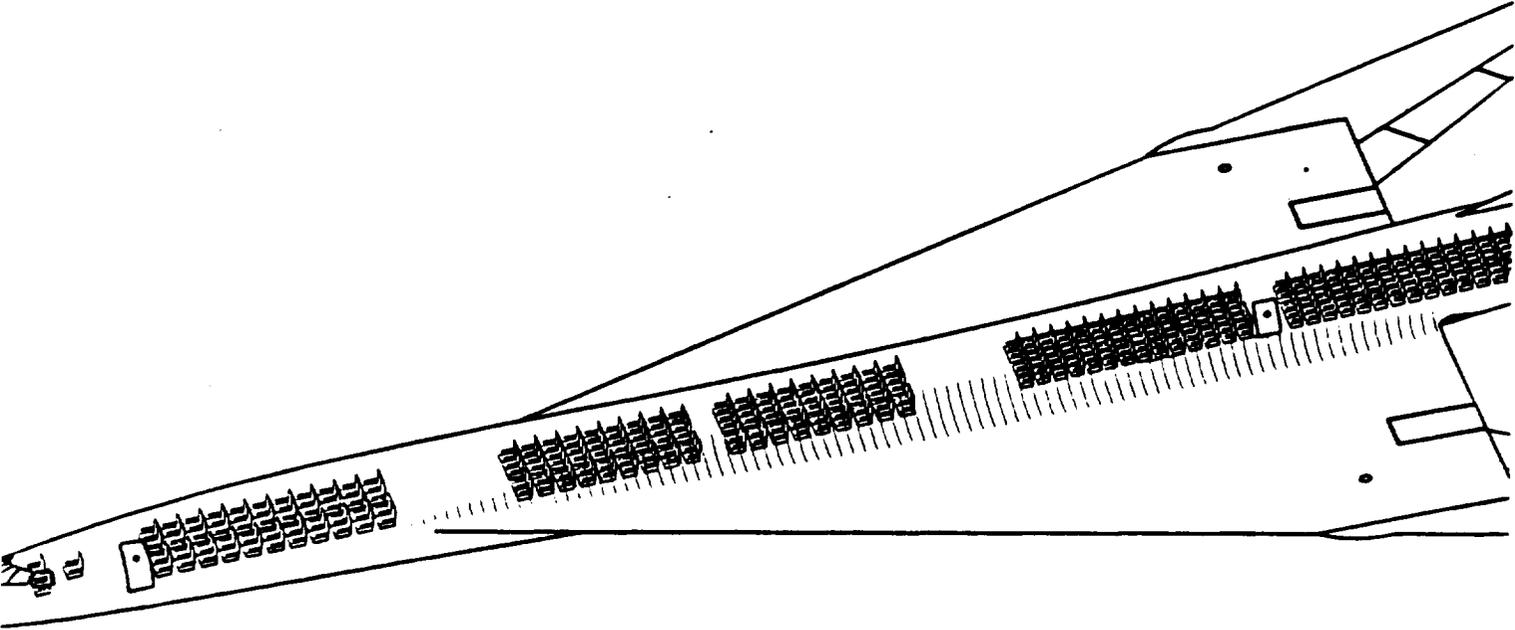


POLOUT FRAME 2



**Figure 4.1**  
*The Edge Supersonic Transport*

# 5.0 ERGONOMICS



## 5.0 Ergonomics

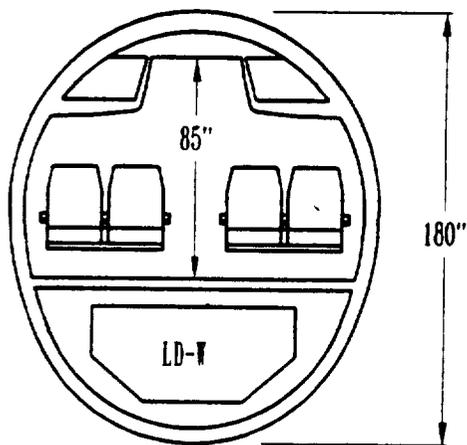
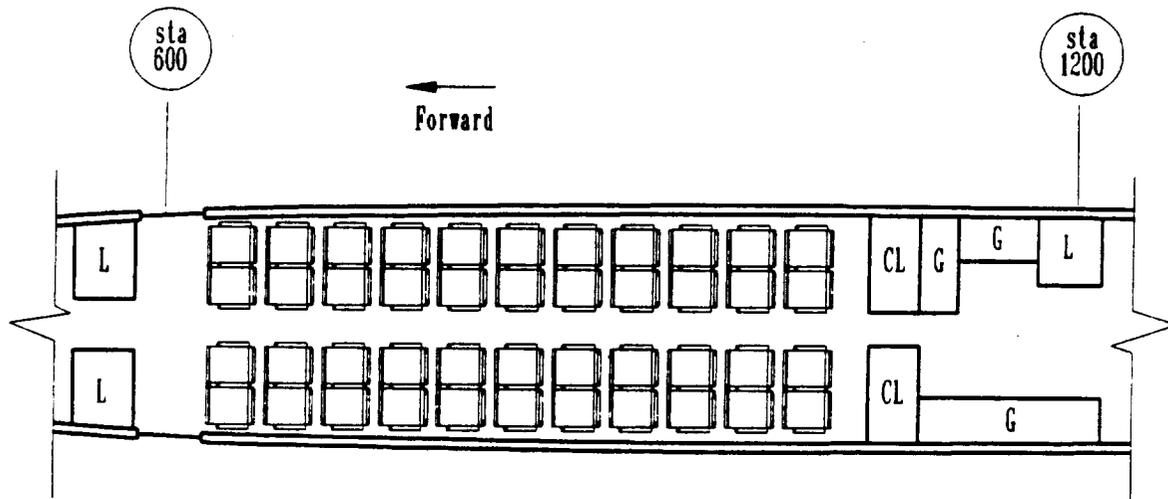
*The Edge* aircraft firmly adheres to the notion that ergonomic features are some of the most important considerations relating to passenger comfort. For this reason, *The Edge* designers have developed the interior of the aircraft to a high level of comfort and pleasure for an enjoyable flight. Even though *The Edge* is a supersonic transport which will reduce current flight times enormously, the passenger comfort levels will be comparable to contemporary comfort provisions. In addition to typical overhead and underseat stowage space, *The Edge* supplies many special amenities such as an LCD display and headphone jacks at every seat, generous food and beverage stowage space, computer and telephone outlets, and FAX machine links.

### 5.1 First Class

*The Edge's* first class contains 44 seats and is located forward of the main entrance door and as such it is separated from the remainder of the cabin, keeping privacy at a maximum. To allow for a spacious environment, the first class seats are arranged in two-by-two seating pairs as shown in Figure 5.1. This cross-section also shows that head room is generous, as is the aisle width of 22 inches which adds to the roomy first class appeal. This section has two private lavatories (see Figure 5.1) located aft of the cockpit.

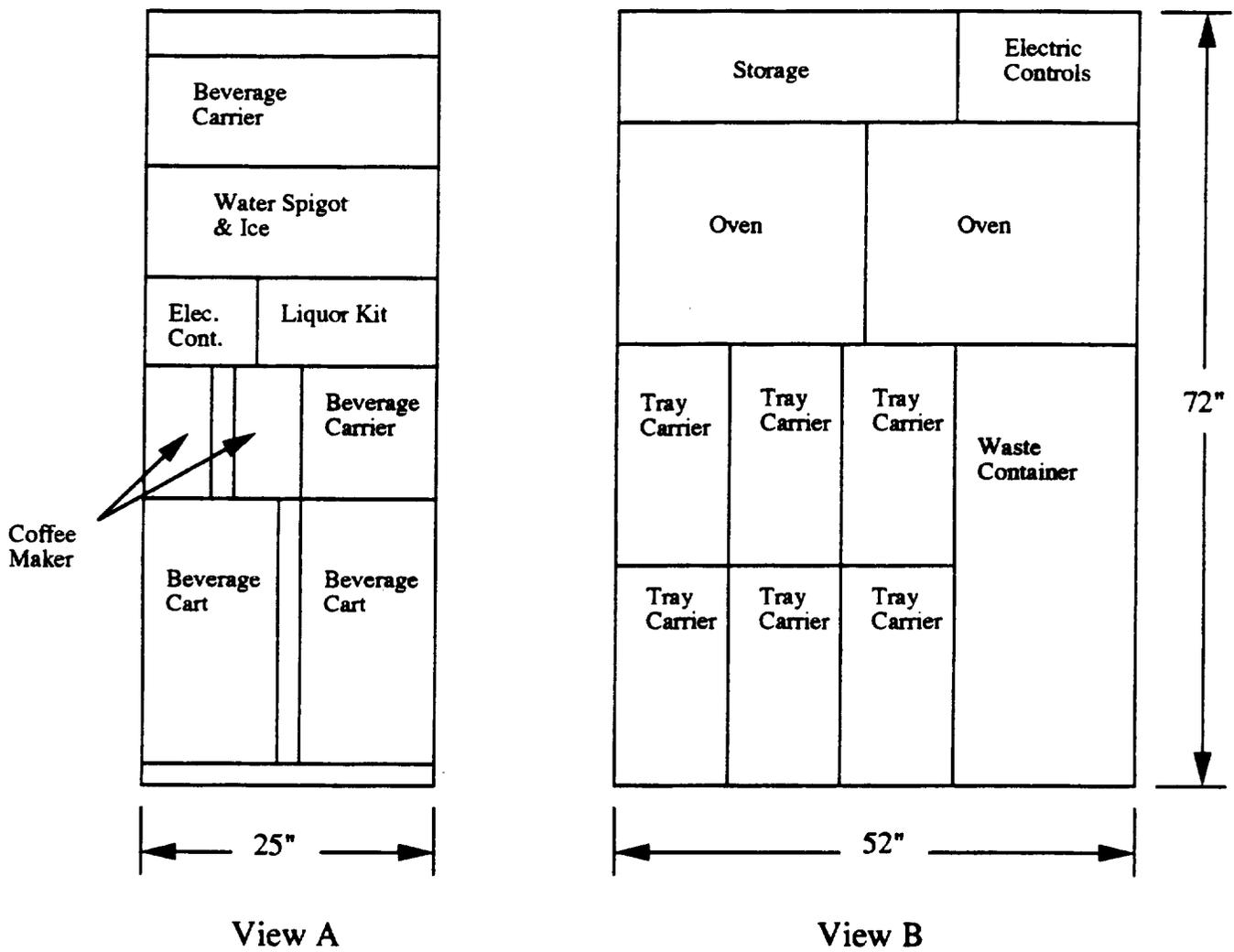
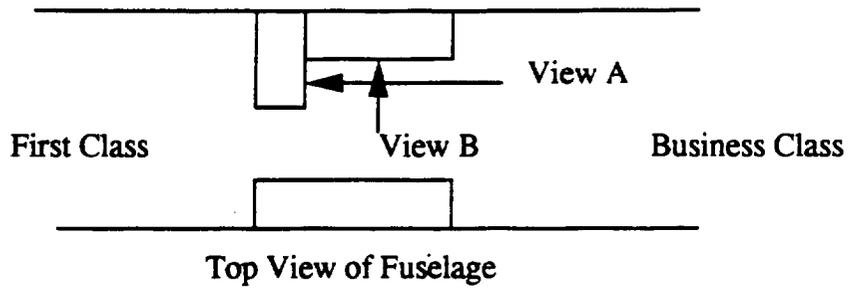
For all three classes, the lavatories provide the following: mirror, sink, soap, electrical outlets, and paper supply. The first class closets allow each passenger an average of 2 inches of closet space for hanging clothes. In addition, they will also be provided a nominal 1.8 in<sup>3</sup> of overhead storage for personal belongings. The galleys for the first class are located aft of the main entrance door and are combined with the business-class galleys, as shown in to Figure 5.1. Figure 5.1 also notes the galley volumes for each section. The spatial arrangement of the galleys gives the most working space possible for the flight attendants. The first class galleys are illustrated fully in Figure 5.2.

In addition to LCD displays, headphone, computer and telephone jacks at every seat, *The Edge* will also provide the first class section with one jack location for a FAX machine.



Seat Pitch	38"
Seat Width	24"
Isle Width	22"
Closet/Pax	1.5"
Overhead Stowage	1.81 ft <sup>3</sup>
Gally Vol./Pax	5 ft <sup>3</sup>
Pax/Lavatory	23

**Figure 5.1**  
**The Edge First Class Layout**



**Figure 5.2**  
***The Edge Forward Galleys (First Class Section)***

## 5.2 Business Class

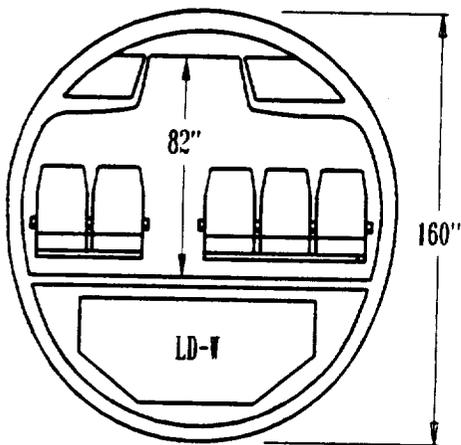
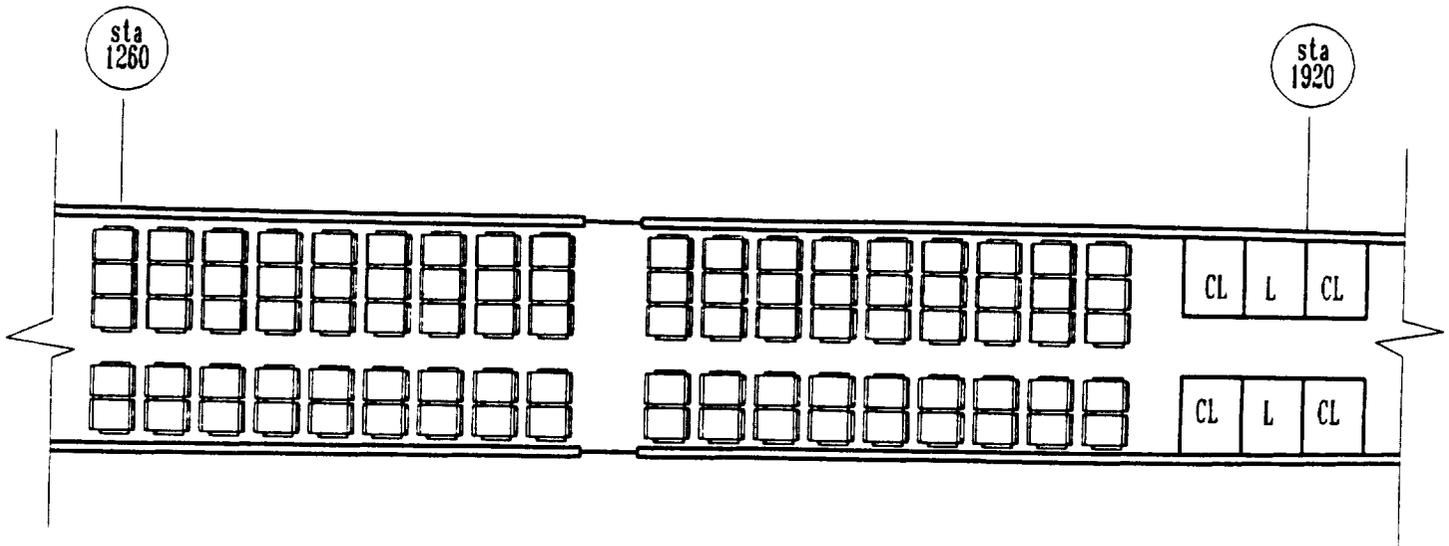
The business class is designed for a pleasant working environment which allows the passengers space to work and/or relax. The class seats 90 passengers comfortably in a two-by-three seating arrangement. The cross-section allows the generous space expected by business travelers. Figure 5.3 shows seat dimensions, as well as the overall scheme of the business class. The two lavatories for the business class are placed aft of the business seats, with closets attached in front of these. The lavatories (Figure 5.3) are essentially the same as those described for the first class section. Each passenger has 1.75 inches of closet space and 1.8 in<sup>3</sup> of overhead storage for their personal belongings. The galleys for business class are shown in Figure 5.4.

The business class will provide similar amenities to those of the first class, with the addition of an extra FAX machine link.

## 5.3 Economy Class

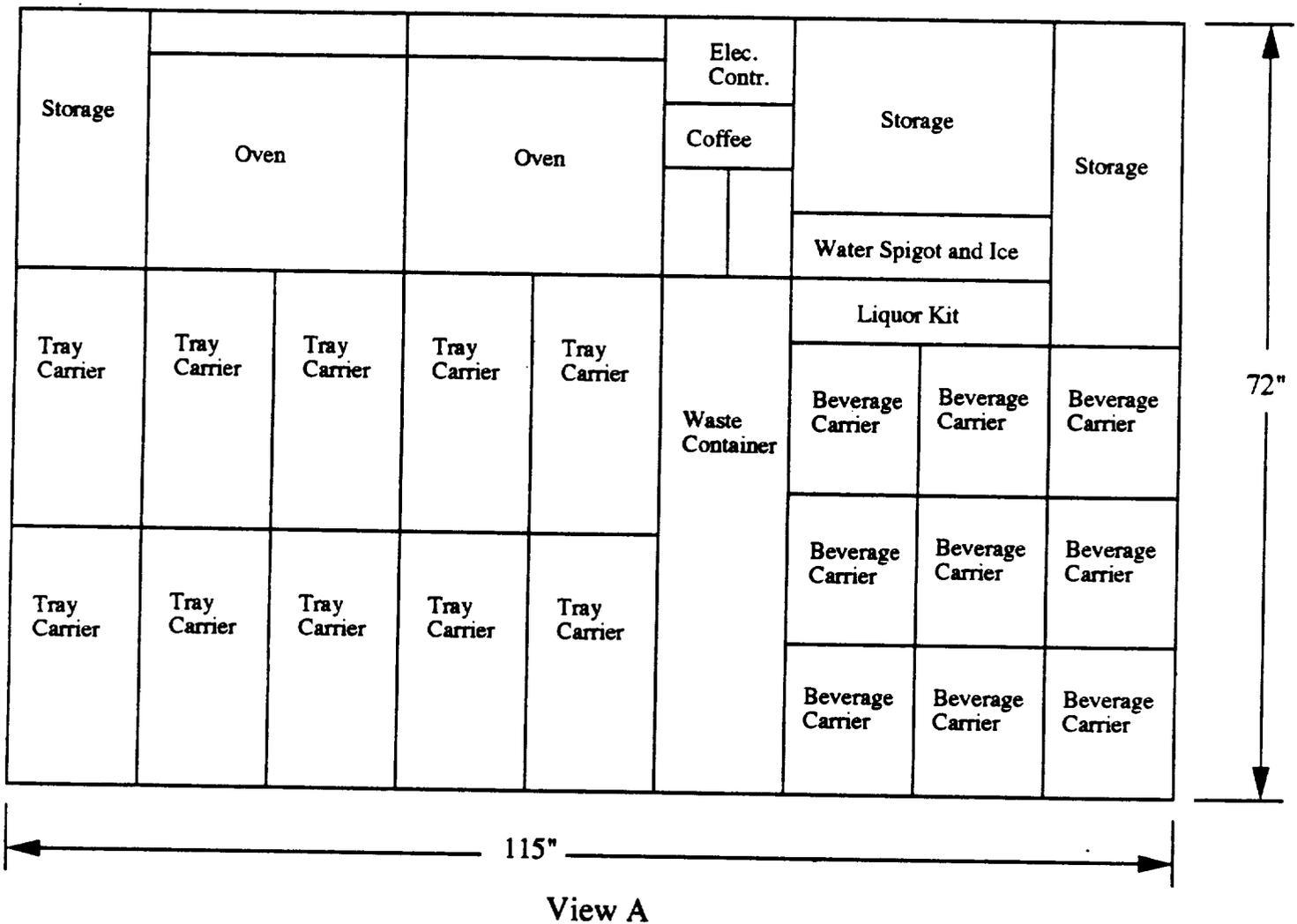
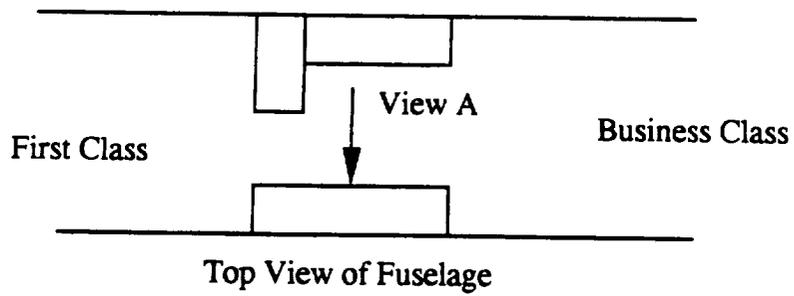
*The Edge* aircraft will make the economy passengers pleased with their decision not to take the long route aboard a Boeing 747. There are 160 seats available for the economy class, which is located directly aft of the business class section. Figure 5.5 shows the economy class layout. The seating arrangement is similar to the aforementioned business class in that it is a two-by-three configuration. The lavatories are located forward and aft of the seats splitting this large class into two smaller sections. Lavatories identical to those described in the first class description are also used for the economy class. There are three lavatories available for the economy passengers. The closets are designed to give each passenger an average of 1.5 inches of garment space; additionally, 1.8 in<sup>3</sup> of overhead storage is available. As shown in Figure 5.5, the galleys are located aft of the lavatories. Figure 5.6 illustrates that these galleys contain carts for serving the hot meals, snacks, and beverages to the economy section.

The economy class will be provided with headphone jacks and LCD displays at every seat, enabling the viewing of videotaped entertainment and allowing pilot's eye viewing through a direct link with synthetic flight vision system.

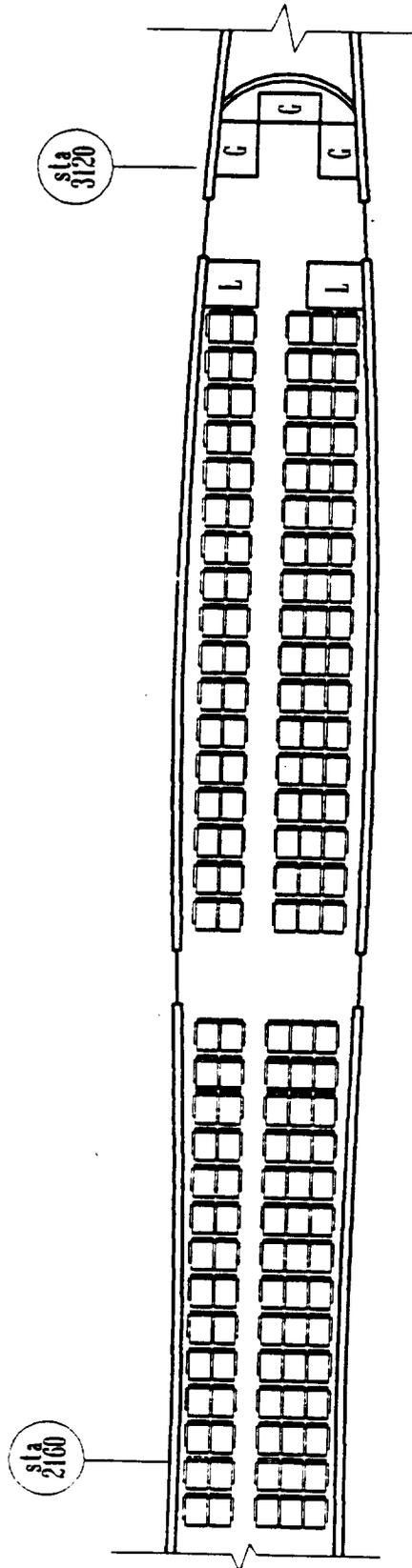


Seat Pitch	36"
Seat Width	20"
Isle Width	20"
Closet/Pax	1.25"
Overhead Stowage	1.81 ft <sup>3</sup>
Gally Vol./Pax	4 ft <sup>3</sup>
Pax/Lavatory	45

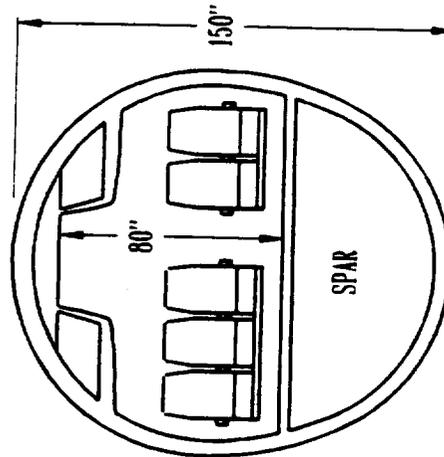
**Figure 5.3**  
**The Edge Business Class Layout**



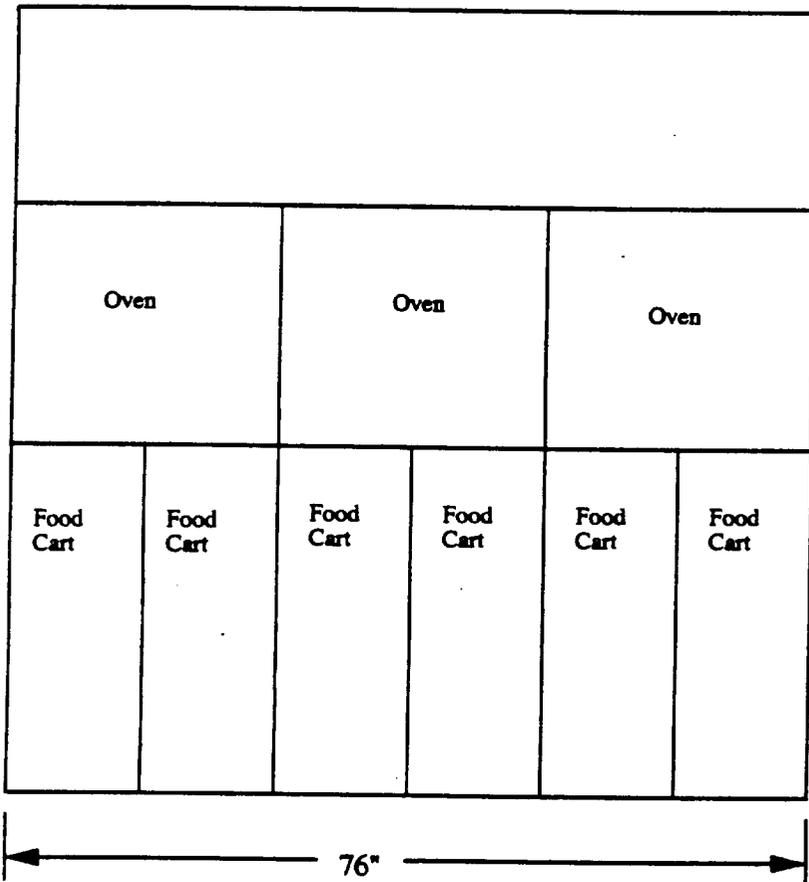
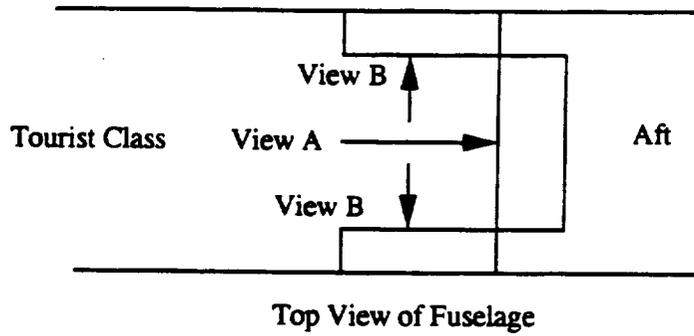
**Figure 5.4**  
*The Edge Forward Galleys (Business Class)*



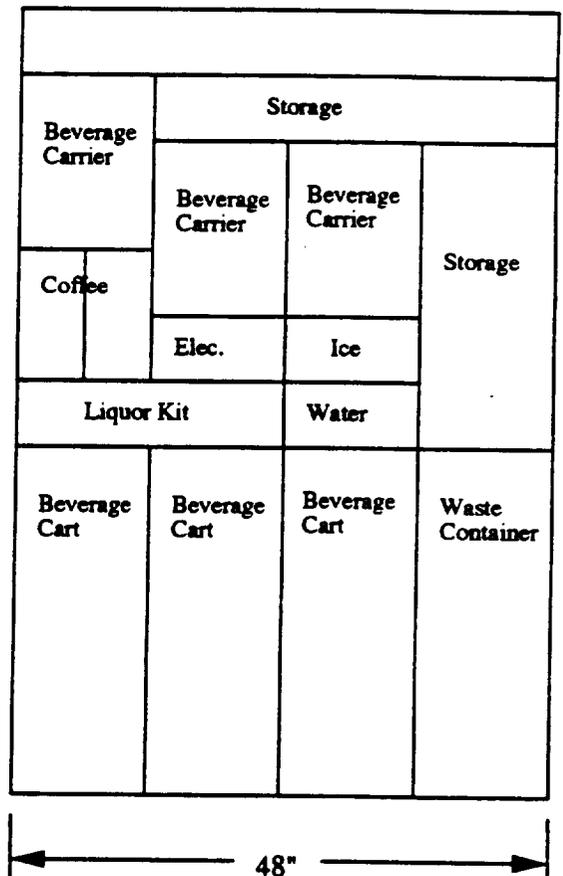
Seat Pitch	32"
Seat Width	18"
Isle Width	18"
Closet/Pax	1"
Overhead Storage	1.81 ft <sup>3</sup>
Gally Vol./Pax	3 ft <sup>3</sup>
Pax/Lavatory	83



**Figure 5.5**  
*The Edge Economy Class Layout*



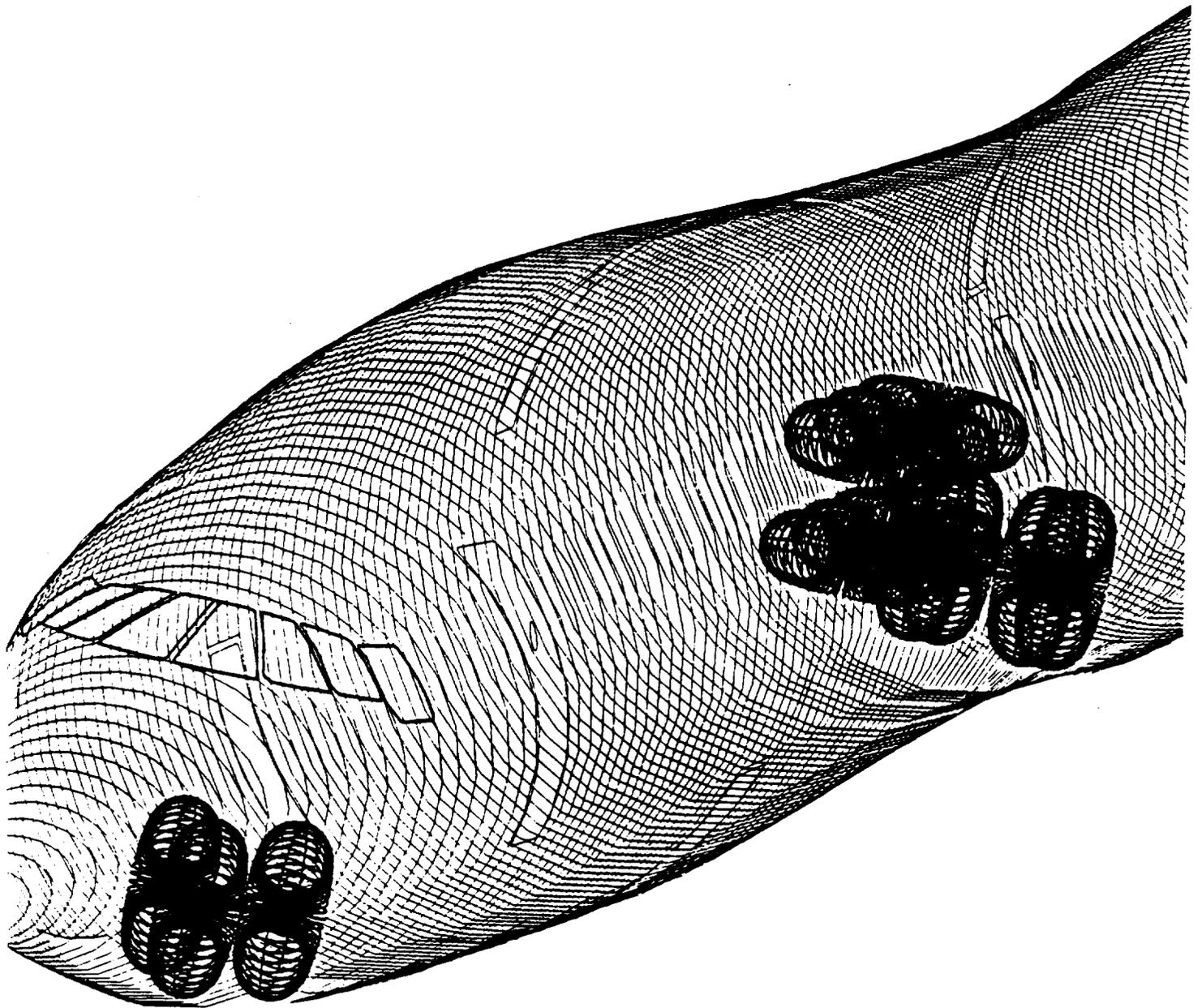
View A



View B

Figure 5.6  
The Edge Aft Galleys (Economy Class)

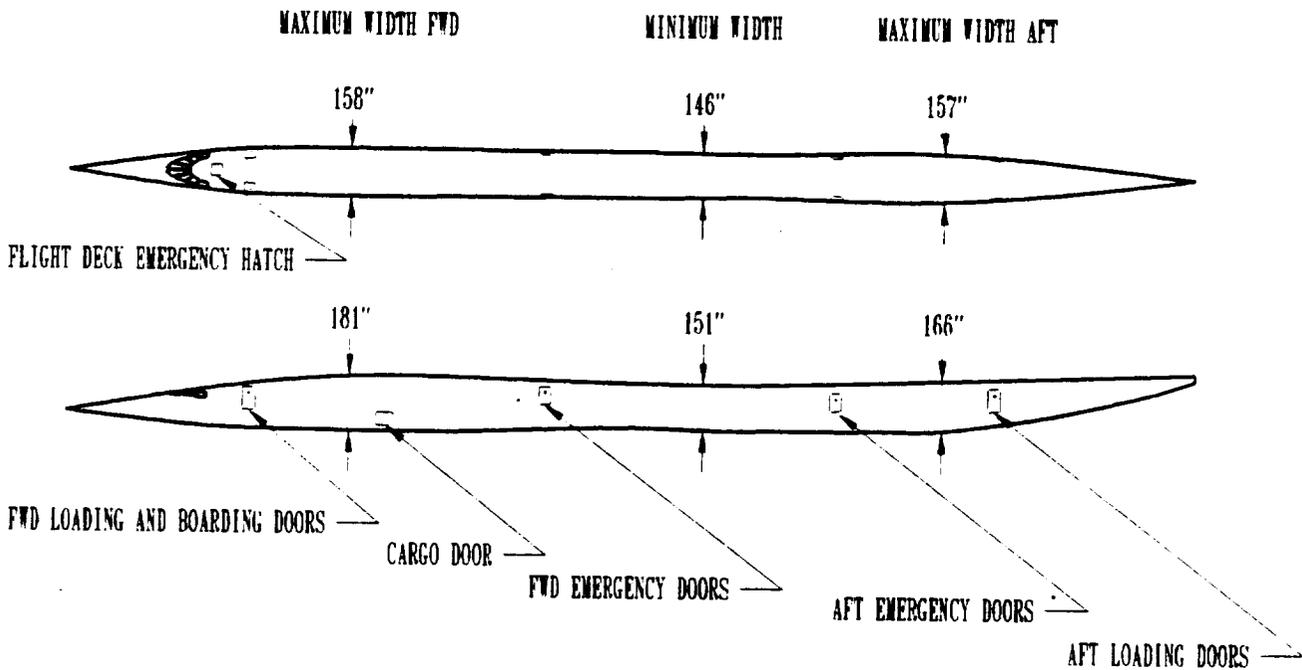
# 6.0 FUSELAGE DESIGN



## 6.0 Fuselage Design

*The Edge* fuselage as shown in Figure 6.1 was developed iteratively using various criteria including: passenger comfort, LD-W baggage container storage, aircraft length, cross-sectional (flat-plate) drag area, and area ruling for performance considerations<sup>9</sup>. For example, the minimum cross sectional area required for maintaining high customer satisfaction was determined for each passenger class section (see Ergonomics section 5.0), and the maximum length of 310 feet was determined with airport compatibility in mind, using the diagonal length of a Boeing 747-400 as the limiting condition<sup>10</sup>.

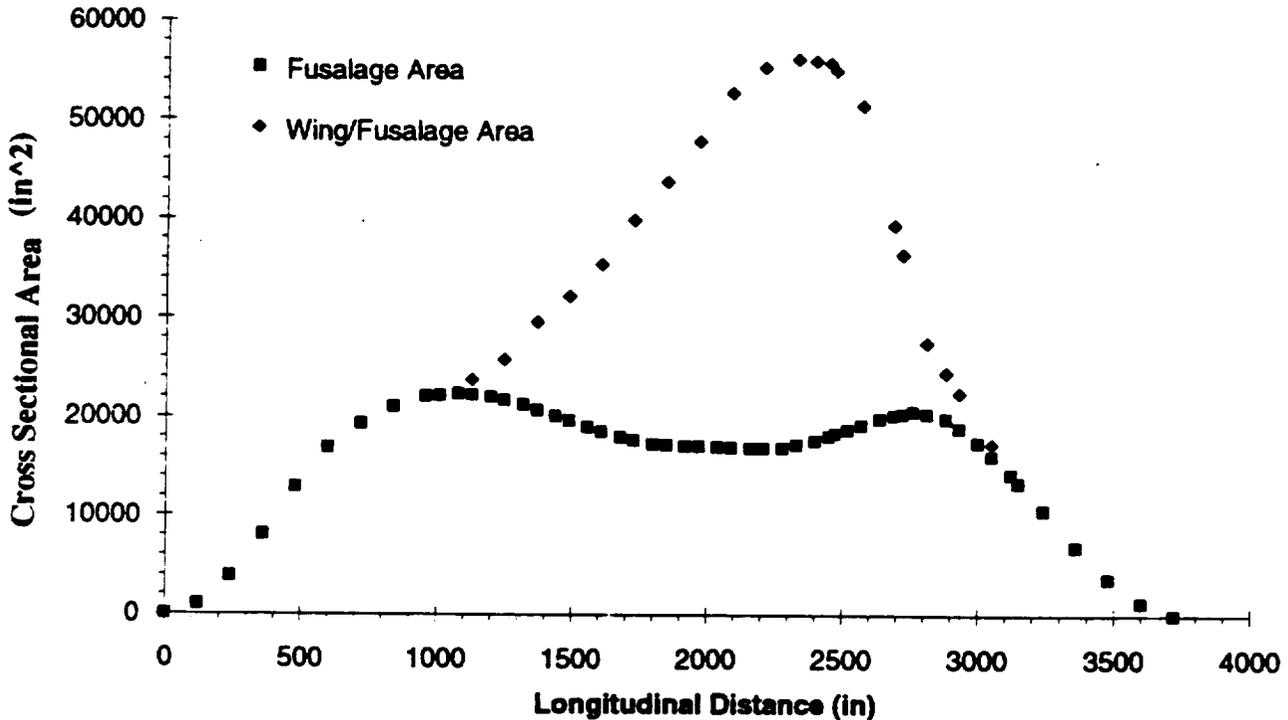
From this, a basic body which included underfloor room for baggage containers or carry-through spars was drawn as the base fuselage. The nose of *The Edge* is designed with a half angle of  $8^\circ$ ; this effectively minimizes the wave drag carried by the aircraft, and induces a Mach cone such that the entire wing experiences subsonic flow at an aircraft cruise speed of Mach 2.4. This allows *The Edge* to utilize relatively thick, subsonic airfoils in its outboard wing design which enhances subsonic aerodynamic performance (refer to Section 12.0). The boat-tail of the empennage is designed with a half angle of  $8^\circ$  to minimize flow separation.



**Figure 6.1**  
***The Edge* Fuselage**

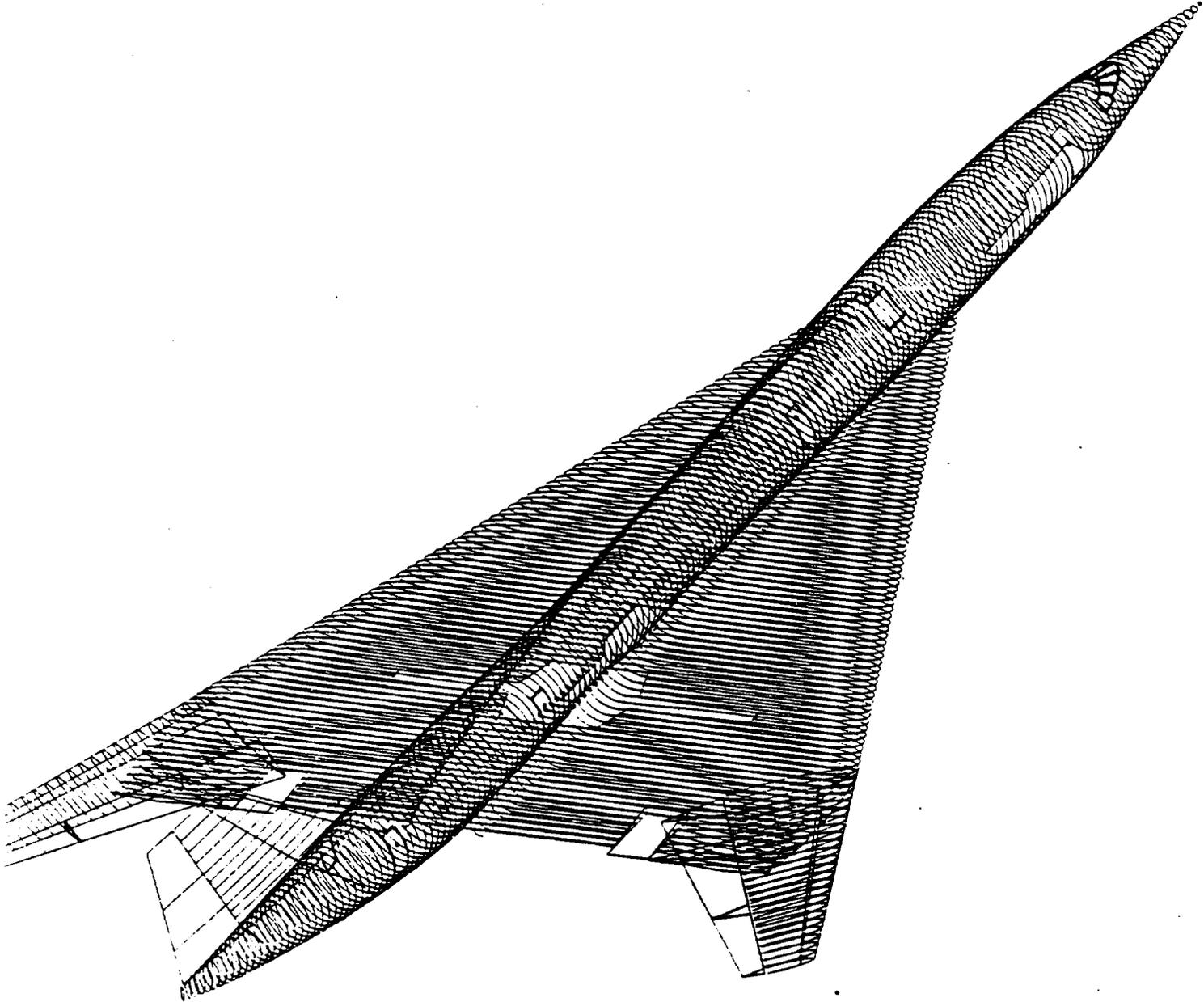
The fuselage was refined using the Sears-Haack area ruling method to minimize supersonic wave drag. Figure 6.2 illustrates *The Edge* area ruling distribution. Typically, a well desinged supersonic aircraft will have a wave drag of less than twice that of the Sears-Haack value, and the distribution of Figure 6.2 is indeed within this range.

In considering sonic boom requirements, over-pressure values sufficient to introduce the possibility of overland supersonic flight were not obtained. Substantial revisions in aircraft geometry must clearly be made to effect such a result; however, such modifications would result in a decrement of overall aerodynamics performance<sup>34</sup>. Considering that the majority of the routes of *The Edge* are 80 to 90 percent over water, it was deemed implausible to attempt supersonic over land.



**Figure 6.2**  
***The Edge* Area Ruling Distribution**

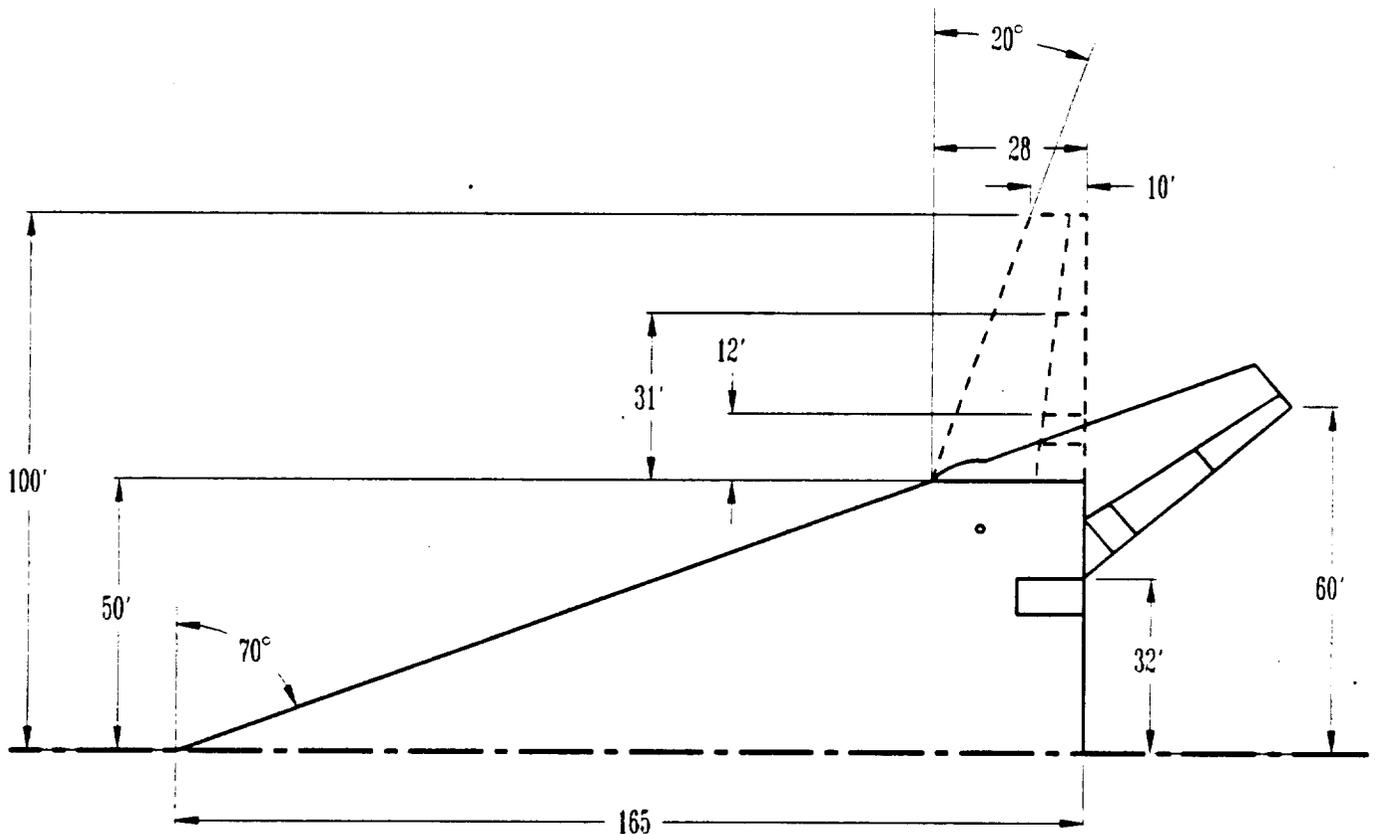
# 7.0 WING DESIGN



## 7.0 Wing Design

### 7.1 Selection And Justification

It is noted in Section 4.0 of this report that a major consideration in *The Edge* design is the attainment of high subsonic as well as supersonic performance. This is especially important since supersonic flight overland is and will remain largely infeasible until the problem of excessive sonic boom over-pressures can be solved<sup>34</sup>. Greater subsonic capability will enable a supersonic transport to incorporate overland flights into their flight schedules, thereby increasing the usability and profitability of the aircraft. This is the driving reason why *The Edge* wing design is that of an arrow wing with sweeping, high aspect ratio wingtips, as can be seen below in Figure 7.1.



**Figure 7.1**  
***The Edge* Wing Planform Layout**

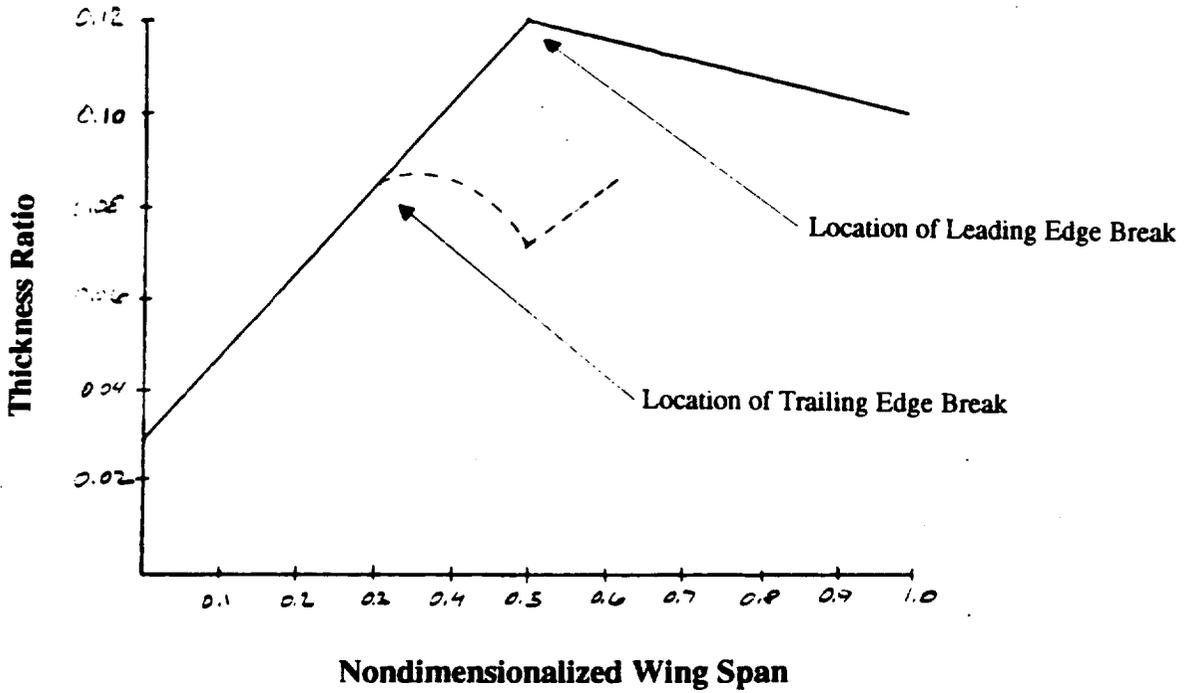
Using available technical references, a trade study was performed involving several potential wing designs, including a delta wing, double delta, and a variable-sweep wing. While each of these provide efficient supersonic cruise performance, it is in subsonic performance that they differ. The delta wing is the poorest of the three, as it cannot provide sufficient rotation power for *The Edge* without the addition of a canard surface<sup>9</sup>. A full, variable-sweep wing provides a low aspect ratio planform for supersonic cruise and a high aspect ratio planform for subsonic flight, which at the outset seems to afford exceptional possibilities in all regimes. However, the wing-sweep mechanism is likely to require the use of valuable cabin space for structures, its weight is typically high, and the additional implications of center-of-gravity shifts on flight stability and control are worrisome<sup>9,33</sup>. The double delta wing, on the other hand, is a composite planform with high speed and low speed wing sections melded together, though not without a compromise in performance within both flight regimes; surely, this compromise has been demonstrated to be a fair one in the designs of both the Boeing and McDonnell Douglas corporations, but it has the primary intent of *The Edge* design team to explore an alternative solution in search of a better compromise.

## **7.2 *The Edge* Planform Advantages and Compromises**

Several advantages are realized from only sweeping the outboard section of the wing. First, a large fixed portion of the wing is preserved, allowing room for landing gear stowage, fuel tanks, and other related systems. Second, the wing-pivot mechanisms are contained within the fixed portion of the wing, allowing a continuous fuselage cabin which would be difficult to achieve with a typical swing-wing arrangement. Third, substantial aerodynamic benefits are derived from *The Edge's* arrow wing in supersonic cruise, and from a significant increase in aspect ratio in subsonic flight (AR = 3.6 in subsonic cruise as compared to 1.9 in supersonic cruise) . These benefits are quantitatively detailed in Section 12.0 of this report.

Unfortunately, the wing thickness distribution required to package the wingtip mechanism and structures induces a drag decrement in supersonic cruise. Although this drawback is discussed in detail in Section 12.0 of this report, its presence can be readily inferred from Figure 7.2 which shows the wing thickness ratios ( $t/c$ ) in subsonic (unswept wing) and supersonic (swept wing) flight as a percentage of span. A 3% thick root chord provides the minimum thickness which will allow the stowage of the main landing gear, whereas the 10% thick tip chord aids in generating high subsonic lift and allows for adequate structural stiffening of the highly loaded wingtips. It is evident that

when the wings sweeps back into the arrow wing configuration, the outboard thickness ratios are lessened, yielding a maximum thickness of approximately 11%. Since typical supersonic aircraft designs utilize wings of 2%-7%  $t/c$ , it is clear that an 11%  $t/c$  will result in a supersonic drag penalty<sup>9</sup>. However, *The Edge* is still able to maintain good supersonic performance regardless of this drawback<sup>29</sup>.



**Figure 7.2**  
***The Edge* Supersonic and Subsonic**  
**Wing Thickness Ratio Distributions**

By utilizing a variable sweep wing with highly loaded wingtips (40% of takeoff lift is generated on the wingtips), *The Edge* essentially trades an aerodynamics challenge for a structural one; that is, while it provides good aerodynamic performance in both subsonic and supersonic flight, *The Edge* must grapple with the structural weight of its wing tip mechanisms, and with the weight of tip-load transferring structures. These disadvantages are discussed in further depth in Sections 11.0 and 12.0 of this report.

### 7.3 Airfoil Selection

The NACA 66 series airfoil was selected for its ability to delay the onset of drag divergence until relatively high subsonic Mach numbers<sup>28</sup>. As the inboard panel is to carry much of the lift in supersonic flight, low ranges of thickness ratio are used, resulting in a thin inboard wing. The outboard panel when unswept will carry a large portion of the load in subsonic flight, thereby requiring a relatively high thickness ratio for efficiency. As previously noted, Figure 7.2 provides a spanwise representation of *The Edge's* wing thickness distribution.

### 7.4 High Lift Systems

As shown in Table 7.1, the lift coefficients required for take-off and landing are 0.84 and 0.71, respectively.<sup>32</sup> These coefficients are obtained with 20% chord, double slotted flaps deflected 20°, and 15% chord leading edge flaps deflected 10°<sup>9</sup>. The increase in section lift coefficient due to these high lift devices is 0.91. The maximum lift coefficient for *The Edge* without high lift devices is 0.74 at an angle of attack of 16.4°. With the addition of the high lift devices the maximum lift coefficient is 1.10, an increase of 0.36, at a 16.4° angle of attack<sup>29</sup>.

**Table 7.1**  
***The Edge* High Lift Aerodynamic Data**

Required Lift Values			
AOA (deg)	CL (Takeoff)	CL (Landing)	
11.6	0.84	0.71	

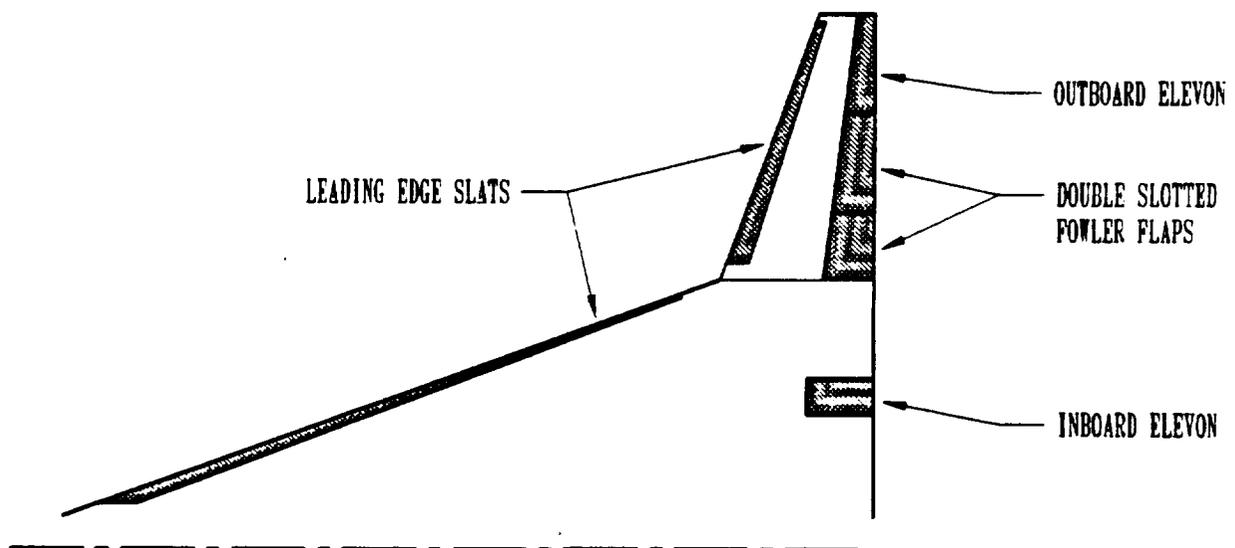
  

Maximum Lift Values			
AOA (deg)	CL <sub>max</sub> (Clean)	CL <sub>max</sub> (High Lift)	ΔCL
16.4	0.74	1.10	0.36

These results are achieved under the influence of two wing design challenges which are particularly acute during takeoff for a supersonic transport aircraft: a difficulty in keeping the flow attached over a thin, symmetric airfoil at increasing angles of attack, and the need for high lift systems in generating the takeoff lift<sup>18</sup>.

The first problem is solved with the use of leading edge slats on the inboard and outboard wing panels, as can be seen in Figure 7.3. The slats detract from the overall lift, but provide the critical function of keeping the flow attached at takeoff angles of attack, effecting an overall increase in L/D.

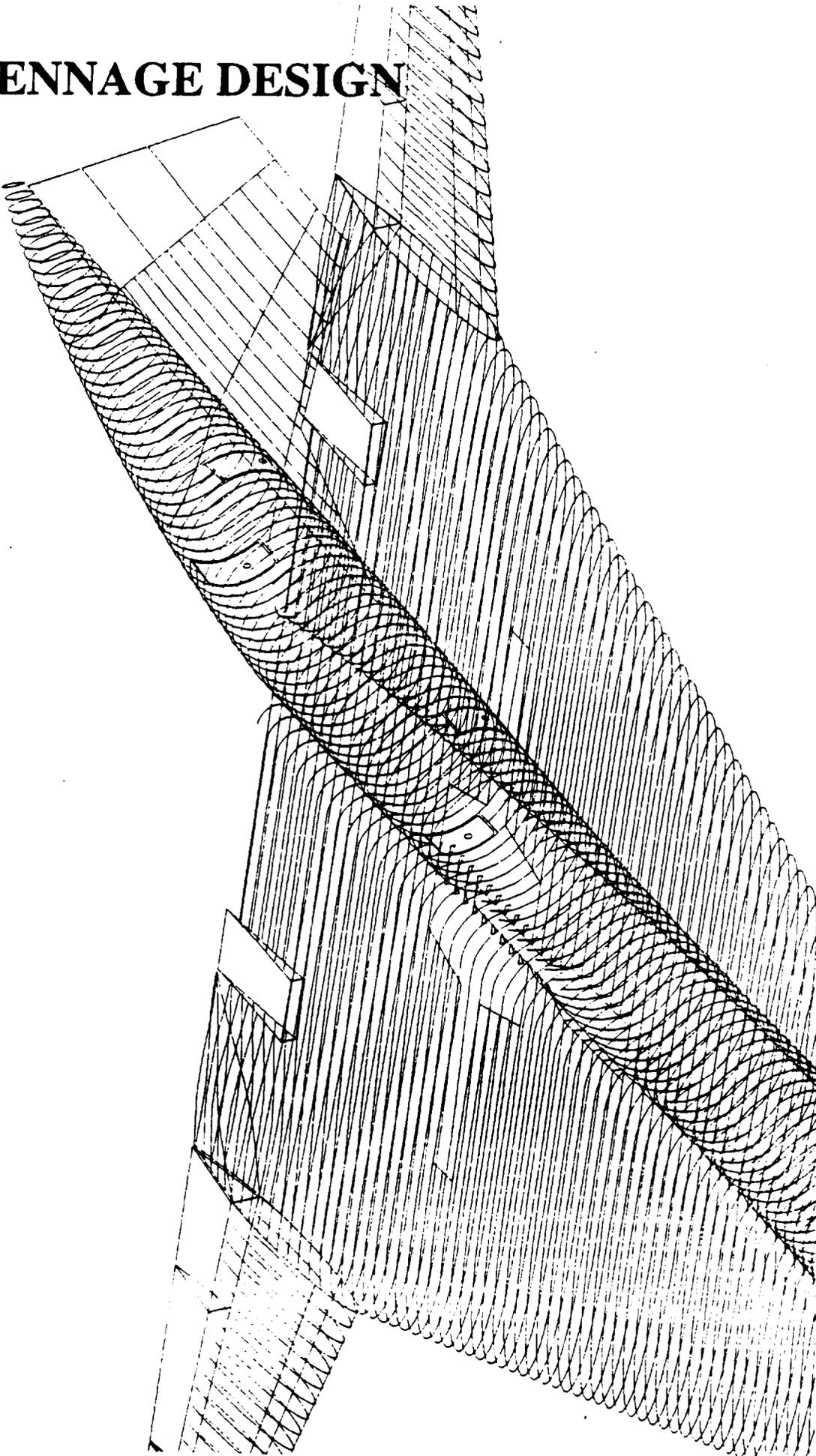
The second problem is solved using double slotted flaps on the wing outboard panels, as shown in Figure 7.3. Since the inboard panels provide a low flap to chord ratio and thus an inadequate increase in lift, the flaps were restricted to the outboard panels. The outboard tip was divided into three sections for high lift systems, with the flaps taking the inner two of these panels, and the elevons using the outer sections. It is notable that although more advanced internally blown flaps would yield greater increases in lift, they are a poor compromise for several reasons; the necessary pressure chamber would be likely be located in the outboard wing or wing tip, competing for space with structural supports. Furthermore, there is both a weight and cost penalty for the internally blown flaps, as well as an unwanted increase in complexity of the overall high lift system.<sup>9</sup>



**Figure 7.3**  
***The Edge High Lift Devices***

It can be seen from Figure 7.3 that once swept, *The Edge* wing no longer has use of approximately 60% of its inboard double-slotted flaps, since they are recessed into the main wing trailing edge. However, this occurs only in supersonic cruise, where high lift devices are not required. In the scenario of an emergency landing while in this swept configuration, on the other hand, an important safety concern becomes apparent. Namely, does it have enough lift to land? The answer is yes. One critical requirement in the initial wing design was to provide enough surface area to generate adequate lift for landing in the swept configuration. This landing would be performed at 180 knots and approximately 15 ° angle of attack. This situation is discussed further in Section 12.0 of this report.

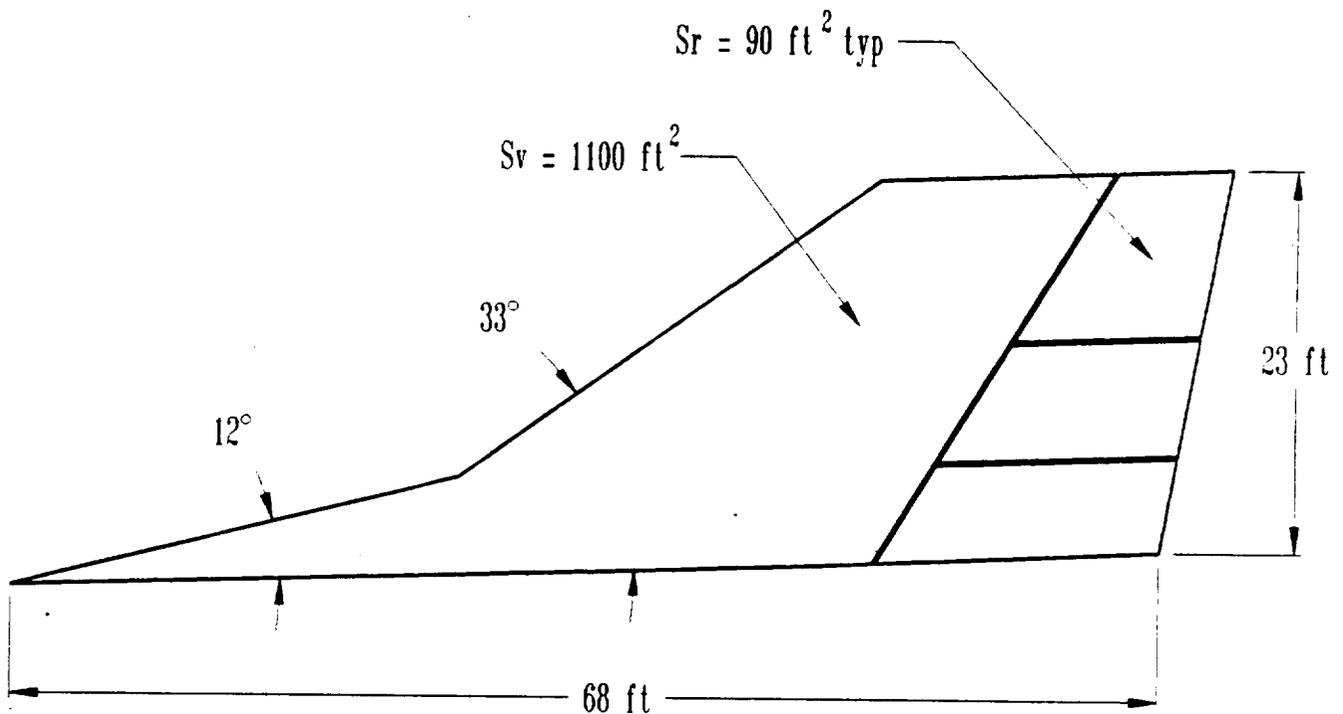
# 8.0 EMPENNAGE DESIGN



## 8.0 Empennage Design

Preliminary sizing of *The Edge* vertical tail was performed by means of a comparative study involving existing supersonic transports and development projects; the Aerospatiale/BAC Concorde, Tupolev TU-144, Convair B58 and a Boeing SST study project served as the cornerstones of this analysis<sup>10</sup>. A tail volume coefficient of  $C_{vt} = .034$  was chosen for the initial tail sizing calculation, which was performed with the unswept wing configuration used in the control-critical regime of subsonic flight<sup>9</sup>.

Subsequent lateral-directional control analysis dictated a 19% increase in overall vertical tail area from that originally calculated (refer to appendix), resulting in the 1,100 ft<sup>2</sup> tail illustrated in Figure 8.1, offering improved low speed controllability. Salient features of this final vertical tail are detailed below; it is notable that the vertical tail strake and sweep were designed as such through a balance of structural and aesthetic considerations.



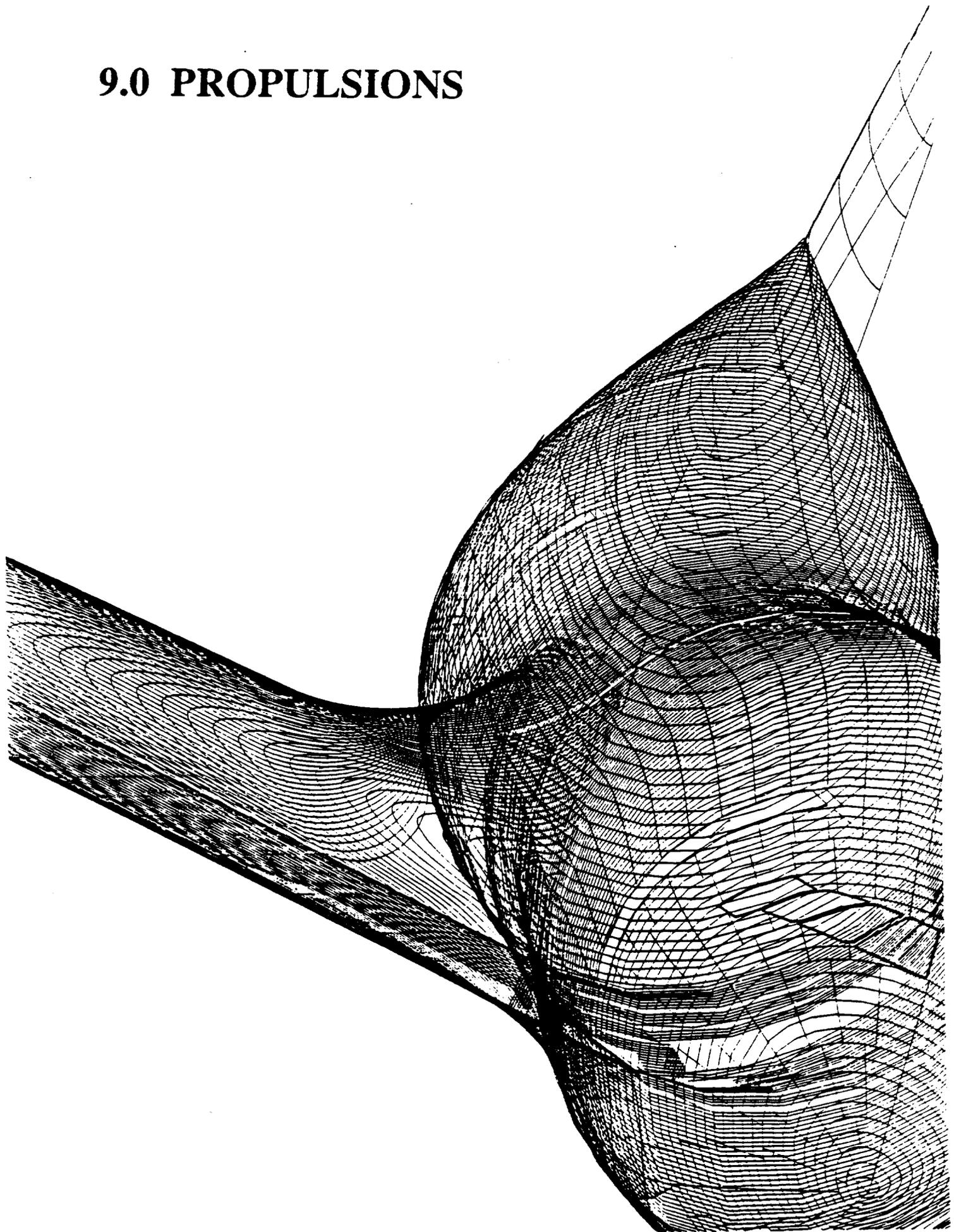
**Figure 8.1**  
***The Edge* Vertical Tail**

The rudder control surfaces were initially sized using data available from other supersonic transport designs<sup>11</sup>. Control analysis varied the results only slightly, yielding a 33% chord, full span rudder. The rudder is split into three equivalent surfaces as part of *The Edge's* triple-redundant flight control system, as discussed in Section 13.0.

In order to fully exploit the large root chord of *The Edge* wing, elevons were designed and placed at the wing trailing edge for longitudinal control, allowing the elimination of a horizontal tail surface. Although this approach was inherently challenging from a longitudinal control standpoint, the promise of structural weight savings was a great encouragement; moreover, supersonic transports such as the Aerospatiale/BAC Concorde and Tupolev TU-144 have demonstrated the practicability of such a configuration.

Elevon sizing is discussed in Section 13.2, Longitudinal Controls and Controllability.

# 9.0 PROPULSIONS



## 9.0 Propulsion System

The propulsion system is clearly one of the key challenges for a supersonic transport (SST). It must meet stringent noise requirements, have a low specific fuel consumption (SFC), yet provide the thrust required to takeoff from existing runways and cruise at supersonic speeds.

### 9.1 Engine Selection

There are a great variety of engines being produced today, including the piston engine, propfan, turboprop, turbofan, turbojet, variable cycle engines, and the ram jet. The piston, propfan, and turboprop were not chosen for *The Edge* because of their inability to operate at supersonic speeds; the ram jet, on the other hand, cannot operate below supersonic conditions. Therefore, the engines which were considered were the variable cycle, the turbojet, and a derivative of the turbofan called a mixed flow turbofan (MFTF).

The turbojet is inherently noisier than the other two, and the SFC of the variable cycle engine requires greater advances in technology than are realistic by 2015, in addition to the fact that its database is only complete up to Mach 2.0<sup>16</sup>. The MFTF, however, holds several significant benefits: a satisfactory SFC, compatibility with FAR 36 Part III noise regulations, and a broad database up to Mach 2.4. Consequently, *The Edge* will use four rubberized MFTF engines, an example of which is shown in Figure 9.1.

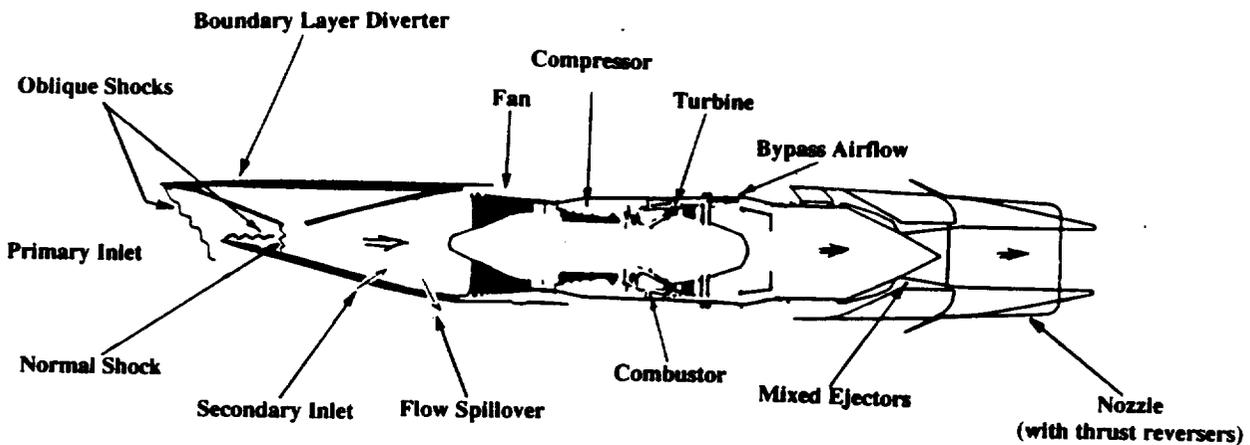


Figure 9.1  
Illustration of a Mixed Flow Turbofan Engine for *The Edge*

The MFTF is a twin spool engine with variable primary and secondary inlet areas, providing greater cycle flexibility. The core and bypass streams mix before entering the nozzle; and while the primary and secondary inlet areas are allowed to vary to achieve peak performance, a constant total area is maintained. The engine throttle ratio (the ratio of maximum combustion chamber exit temperature (CET) to a sea level CET) increases to keep the fan's corrected airflow and pressure ratio near their designed maximum values. Once the maximum CET is achieved (at Mach 2.4), the throttle ratio is held constant by forcing the low spool speed to decrease and the thrust to lapse<sup>14,15</sup>.

Since the available engine data was accurate for a maximum thrust of 58,882 lbs at take-off, the engine was scaled for projected technological advances by 2015 to meet *The Edge's* thrust requirement of 75,300 lbs; this requirement comes from a one engine inoperative (OEI) condition at take-off, with a thrust to weight ratio of 36%. The estimated supersonic cruise SFC attainable with this engine is 1.0, as shown comparatively in Table 9.1<sup>9,14</sup>. According to current trends noted by NASA and the Society of Automotive Engineers (SAE), a 10% to 15% SFC reduction is achievable by the year 2005<sup>1,16</sup>. In light of this, and according to projections by engine manufacturers, it is reasonable to expect that further technological improvements may result in an SFC of 1.0 by 2015<sup>13</sup>. The Edge also assumes a 10% reduction in engine weight<sup>16</sup>.

By the time this engine begins production, advances in technology and particularly in cleaner burning combustors will allow drastic reductions in pollutants and nitric oxide (NOx) emissions.<sup>2</sup> General Electric and Pratt & Whitney are currently working in cooperation with NASA on advanced combustor designs which are projected to meet a goal of 3 to 8 grams NOx per kilogram of fuel burned<sup>1</sup>. Such improvements, which are scheduled to be completed by 2005, will translate into as much as a 90% improvement over the NOx emissions of current aircraft engines.<sup>11</sup> Therefore, since *The Edge* is not slated for market entry until the year 2015, it is expected that *The Edge* will be able to meet the projected 2015 requirement of a 90% reduction from current NOx levels<sup>12,13,16</sup>.

**Table 9.1**  
**Change in MFTF Engine Parameters with Altitude for *The Edge***

Alt (ft)	Mach No.	SFC Inst.	Thrust (lbs)	Prea. Recovery	BPR
0	0.0	0.63	67832	94.3	0.64
0	0.3	0.72	65282	96.3	0.62
0	0.6	0.78	75296	97.0	0.62
10000	0.6	0.74	51620	97.0	0.62
35000	0.9	0.78	20649	96.0	0.62
35000	2.0	0.98	58005	93.0	0.78
50000	2.4	1.00	34717	93.0	0.91
60000	2.4	1.00	21450	93.0	0.92

## 9.2 Engine Placement

Two potential placements were considered for the propulsion system; one was above the wing and the other below. An advantage of placing the system above the wing is a slight increase in lift<sup>11</sup>. This is not a feasible solution for an SST, however, since air needs to be siphoned from the nozzle and directed over the trailing edge to produce the lift increase. Such a situation is difficult to achieve for the following reason. In satisfying FAR requirements regarding disk failure situations, the turbine of the engine must be placed clear of any major structural components; this invariably forces the nozzle to extend beyond the wing trailing edge, thus eliminating the possibility of a lift increase by means of nozzle blowing<sup>11</sup>.

Another advantage for an overwing engine placement is the wing's inherent ability to act as a noise shield<sup>11</sup>. The unavoidable nozzle overhang problem also devastates the utility of this concept, however, since the greater portion of engine noise is from the nozzle, which would be clear of the wing's insulating properties. Other problems with an overwing position exist, such as the possibility of the engine ingesting a vortex formed on the wing leading edge, especially while flying at high angles of attack. In this event, the inlet would become very noisy, further aggravating cabin noise insulation problems.

One of the advantages of an underwing engine placement is easy access for engine maintenance: the housings may be quickly lowered, the engines serviced, and easily raised back into place. Also, the engines in this placement would receive relatively undisturbed air in flight. Of course, one of the disadvantages of having the

engines below the wing is the possibility of foreign object damage (FOD) during takeoff and landing. However, *The Edge* should not have a problem with FOD because of the height of the landing gear, placing the engines several inlet diameters above the ground. Therefore, *The Edge* engines have been placed below the wing.

The center of the inboard engine is positioned 11.7 ft from the centerline of the fuselage, and 9.6 ft from the center of the outboard engine. Many considerations were balanced in reaching this configuration, including landing gear placement, high lift surface accommodation on the wing trailing edge, and overall aerodynamic benefits. The nacelles are canted two degrees inboard in an effort to align the engines with the airflow beneath the wing, and are situated parallel to the flight attitude of the fuselage<sup>9</sup>. It is notable that the engines are not contained in a dual pod. Separating the engines avoids potential hazards such as following: shock waves created by the physical geometry of one engine may be ingested by the other; aerodynamic interference may result in a loss of thrust; a catastrophic failure in one engine may affect the performance of the partner engine<sup>11,13</sup>.

### 9.3 Engine Inlet Selection

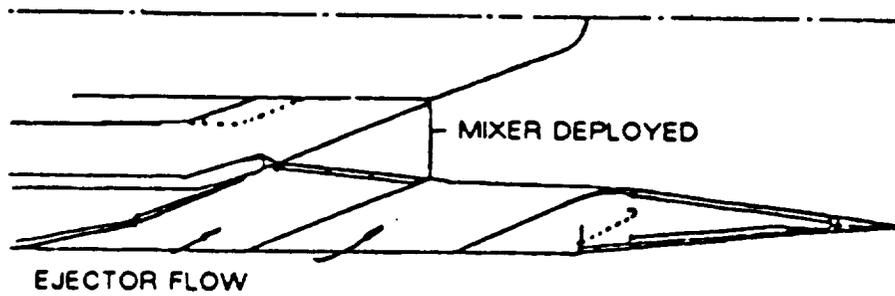
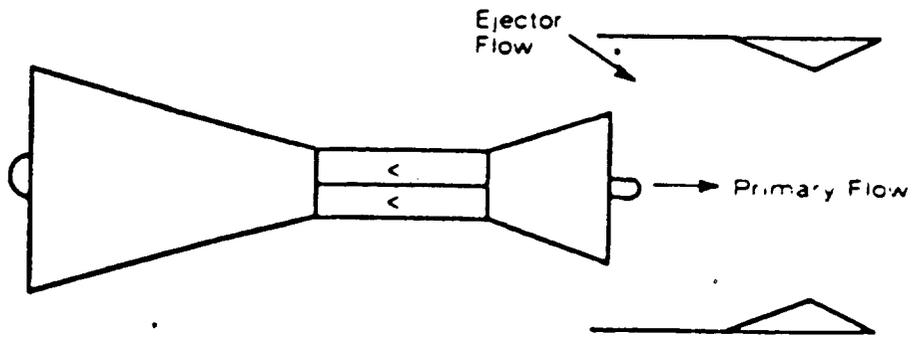
Two different types of inlets were seriously considered: the conical (spike) inlet and the 2-D ramp inlet. The spike inlet exploits the shock patterns of the flow passing over a cone, while a 2-D inlet uses flow over a wedge. The advantages of the spiked inlet are that it is lighter, and has approximately 1.5% better pressure recovery<sup>9</sup>. The disadvantages include high cowl drag and complicated mechanisms for effecting the variable geometry. The advantages of the 2-D inlet are that it is simple to operate, it diverts the boundary layer exceptionally well, and it has low cowl drag. The disadvantage is that it is somewhat heavier than a spike inlet. On balance, however, a 2-D inlet appears to be the best choice for *The Edge*, largely in light of its simplicity.

It is notable that the inlet pressure recovery for a 2-dimensional inlet at supersonic cruise is 93%<sup>11,12</sup>, and results from using three shocks (two obliques and one normal shock).

#### 9.4 Engine Nozzle Selection

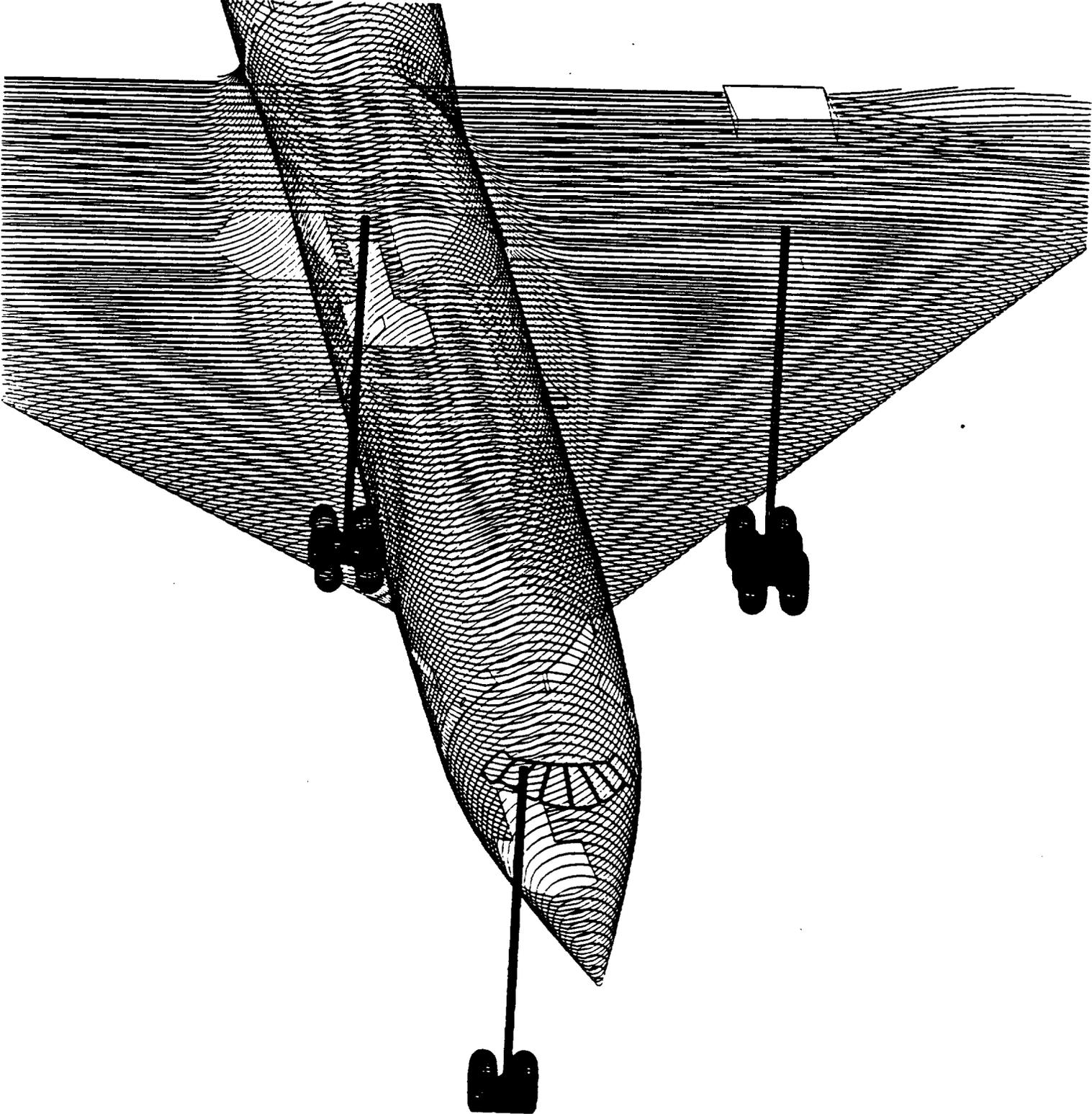
The nozzle is one of the most important parts of the propulsion system. To meet FAR 36, Stage III, mixed ejectors as shown in Figure 9.2 are incorporated into *The Edge's* nozzle. These ejectors have external doors which open and deploy mixer and ejector chutes into the core (primary) flow. As the flow moves through the chutes, it is accelerated so that the static pressure at the mixer exit is greatly reduced. This results in large quantities of ejector (secondary) flow entering the nozzle. For example, shortly after takeoff (1000 ft altitude, and speed of Mach 0.3), the secondary flow is 116% of the primary flow, and the two flows are mixed yielding an exhaust velocity of 1450 ft/s<sup>12,15</sup>.

This mixed ejector nozzle is projected to reduce noise levels sufficiently to meet the 107 EPNdB takeoff, 103 EPNdB sideline, and 105 EPNdB approach requirements as set forth in FAR 36, Stage III. By the year 2015, however, a Stage IV noise requirement is probable, which would further lower the allowable noise levels<sup>17</sup>. According to research performed by NASA, advancements in engine materials will lower engine weights, allowing *The Edge's* engines to be oversized<sup>11</sup>. This oversizing would enable engine throttling at takeoff, thus further reducing noise production in this noise-critical regime. In addition to the use of mixed ejector nozzles, this benefit may aid *The Edge* in complying with a Stage IV requirement<sup>15</sup>. Unfortunately, engine manufacturers are not optimistic that compliance with a Stage IV requirement reducing noise levels by an additional 4 EPNdb is as yet clearly foreseeable by 2015<sup>13</sup>. *The Edge* appendix may be referenced for excerpts of the sources cited herein.

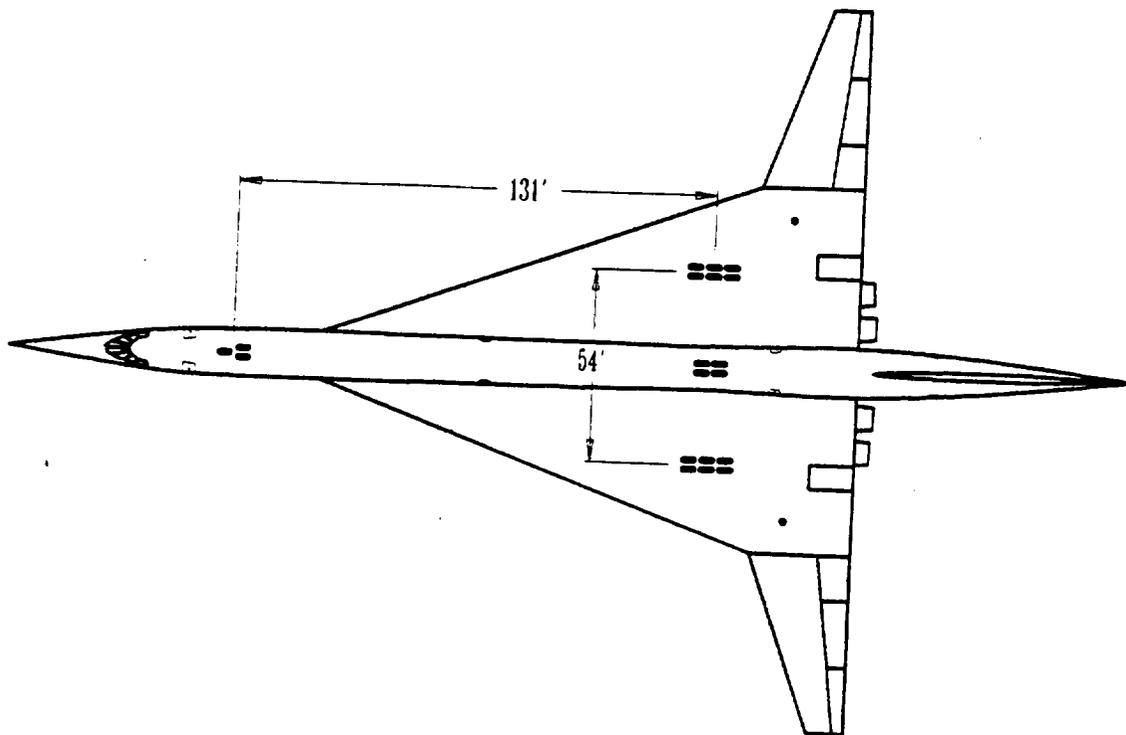


**Figure 9.2**  
**Representations of *The Edge* MFTF Engines with Mixed Ejectors**

# 10.0 LANDING GEAR



## 10.0 Landing Gear

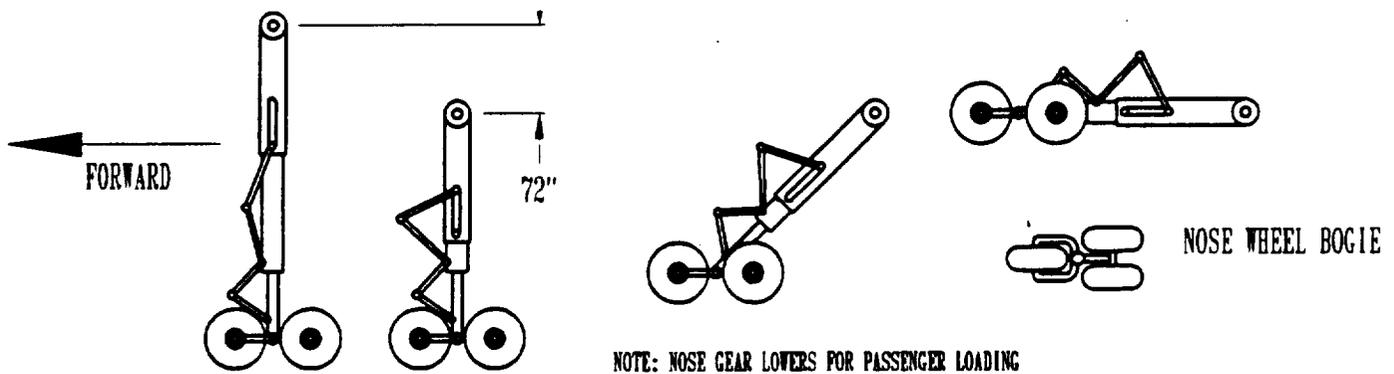


**Figure 10.1**  
***The Edge Landing Gear Arrangement***

*The Edge* landing gear is comprised of a three-wheel nose gear, two six-wheel main gear trucks, and a single four-wheel truck as shown in Figure 10.1. This arrangement provides several benefits, including a good runway and taxi way load distribution; the resulting load concentration number (LCN) is 88. This compares well with the Boeing 747 which has a LCN of 92<sup>21</sup>. Hydraulic actuators retract the landing gear after takeoff. Both nose gear and the center main gear are retracted into the fuselage, and the two six-wheel tracks are retracted into the wing. The landing gear struts will be composed of steel 300m for its high strength, pending improvements in technology.

## 10.1 Nose Gear

The *Edge* nose gear design is a tricycle arrangement as shown in Figure 10.2, providing good ground maneuvering for the large supersonic transport. The nose gear will handle a maximum of 15% of the take-off weight. The three-wheels and strut are retracted forward into the fuselage just aft of the cockpit. Emergency extension will be accomplished by free-fall of the gear into a self-locking position. Table 10.1 shows the data for the nose gear tire and strut loadings.

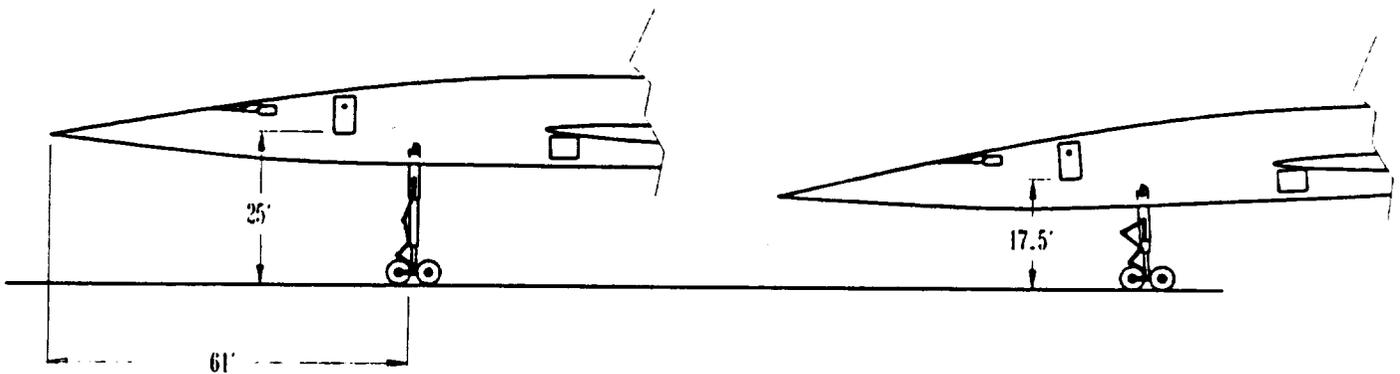


**Figure 10.2**  
**The Edge Nose Gear Configuration**

**Table 10.1**  
**The Edge Nose Gear Data**

NOSE GEAR	
Maximum Loading per Tire (lb)	50400
Tire Height (in)	49
Tire Diameter (in)	17
Pressure (psi)	195
Max Strut Loading (lb)	39771

The standard boarding sill height (the distance from the ground to the loading doors) is 17.5', as can be seen in Figure 10.3. *The Edge's* sill height is 25' with its nose gear fully extended. To solve this problem, the aircraft nose will be lowered vertically 8.4' by use of a hydraulic cylinder functioning essentially as the main nose gear strut. As the result of this, the floor slope during passenger loading will be a mild 4° incidence (note that the cabin floor is designed at a fixed 0.5° incidence relative to the fuselage centerline)<sup>18</sup>.

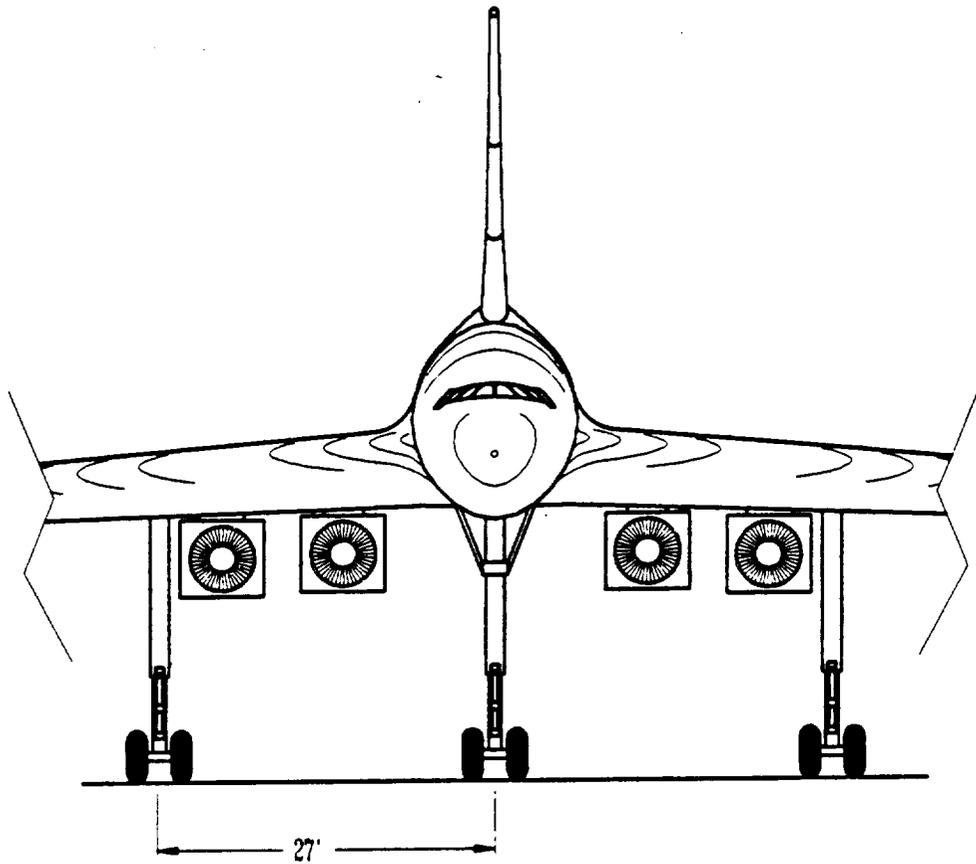


**Figure 10.3**

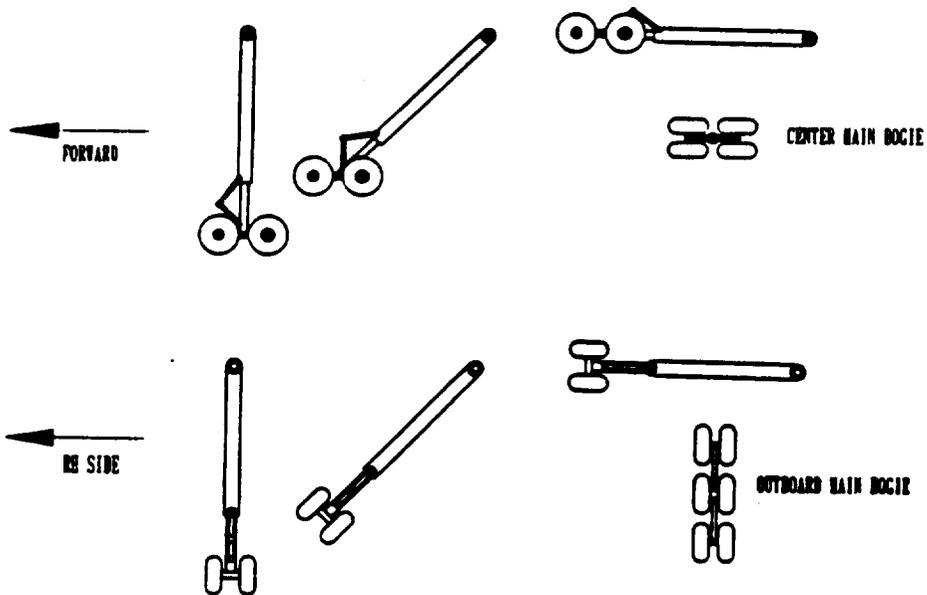
***The Edge* Sill Height and Collapsible Nose Gear Strut**

**10.2 Main Gear**

As illustrated in Figures 10.4 and 10.7, the main gear consist of two six-wheel trucks mounted on the inboard wing, forward and outboard of the engines, and a center gear, which consists of a conventional four-wheel truck located under the fuselage. Retraction paths of the main gear are illustrated in Figure 10.5. The main gear will be able to accept up to 90% of the aircraft takeoff weight. The six-wheel trucks will be retracted into the wing laterally inboard, whereas the center four-wheel truck will retract into the fuselage longitudinally forward. In case of emergency, the main gear will be able to deploy and lock in place under their own weight.



**Figure 10.4**  
*The Edge* Outboard and Center Gear Configurations



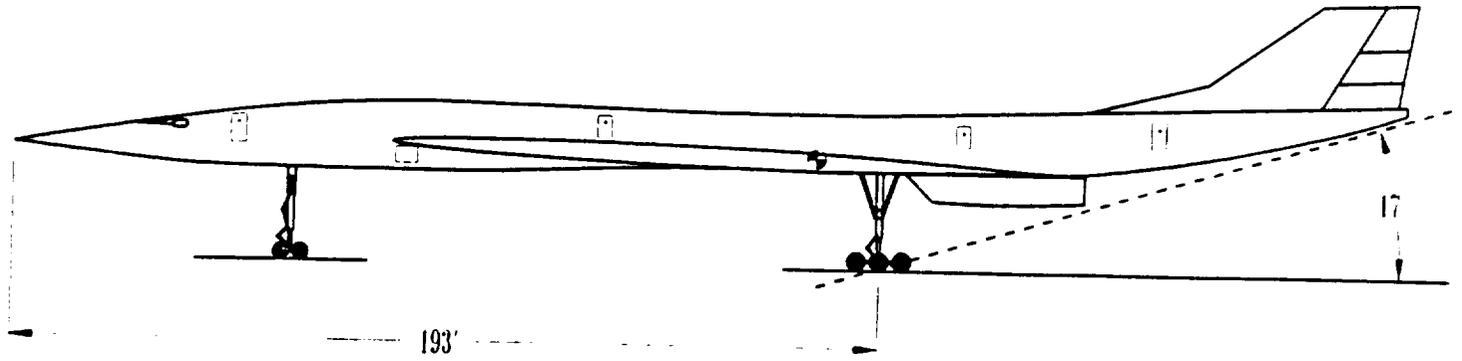
**Figure 10.5**  
*The Edge* Main Gear Retraction Methods

The advantages of having three bogeys for the main gear are threefold: to better distribute the weight on the ground and on the strut, to decrease the gear stowage volume required in the wing, and to better distribute the airframe structural stress. The data for the main gear tire and strut loadings are shown in Table 10.2.

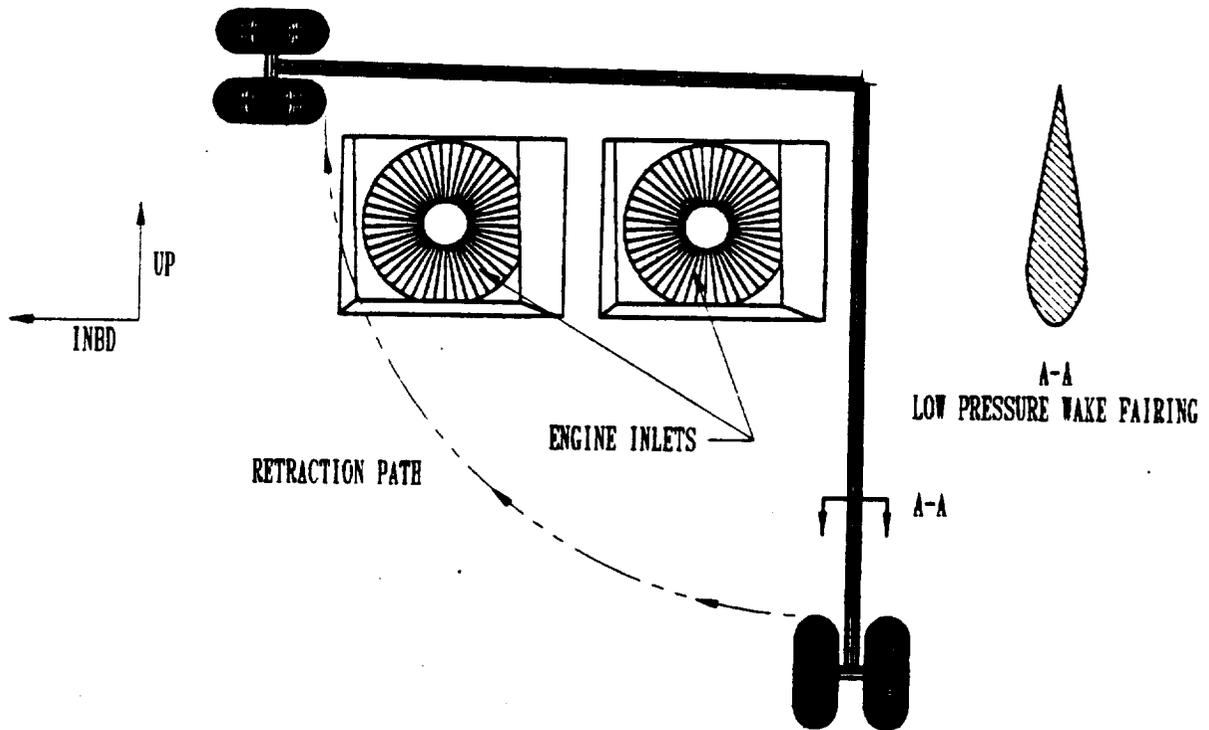
**Table 10.2**  
***The Edge* Main Gear Data**

<b>MAIN GEAR</b>	
<b>Maximum Loading per Tire (lb)</b>	<b>51900</b>
<b>Tire Height (in)</b>	<b>49</b>
<b>Tire Diameter (in)</b>	<b>19</b>
<b>Pressure (psi)</b>	<b>195</b>
<b>Max Strut Loading (lb)</b>	<b>38656</b>

The placement of the main gear allows *The Edge* a maximum rotation angle of approximately 17°, although the aircraft requires only 13° to takeoff, as shown in Figure 10.6. At the outset, it might appear that this excessive allowable rotation capability could translate into a shorter gear length; however, this is not the case, for the following reason: since *The Edge* is a supersonic transport requiring larger engines than conventional aircraft and due to the unavoidable placement of the main landing gear forward and outboard of the engines, the landing gear must be lengthened so that its tires will not pass in front of the engine inlets during retraction. Figure 10.7 illustrates the retraction path of the outboard gear; if positioned incorrectly, the tires could cause high degrees of turbulence to be ingested by the engines. With *The Edge* design arrangement, the main landing gear will retract with minimal affects to the engine inlet flow. Additionally, an aerodynamic fairing in the shape of a symmetrical airfoil will be installed around the outboard gear struts, in a further effort to reduce turbulent flow wakes.



**Figure 10.6**  
*The Edge Rotation Angle*



**Figure 10.7**  
*The Edge Outboard Gear Retraction Path*

### 10.3 Gear Geometry Balance Affects

As shown in Figure 10.8(a), *The Edge* has an overturn angle of  $48.51^\circ$  which is within established limits<sup>10</sup>. This is a particularly important consideration for *The Edge*, since it requires exceptionally long gear to provide the necessary rotation angle at takeoff. Figure 10.8(b) shows a tipback angle of  $19^\circ$ , which is greater than *The Edge* maximum rotation angle of  $17^\circ$ , as is required<sup>9</sup>.

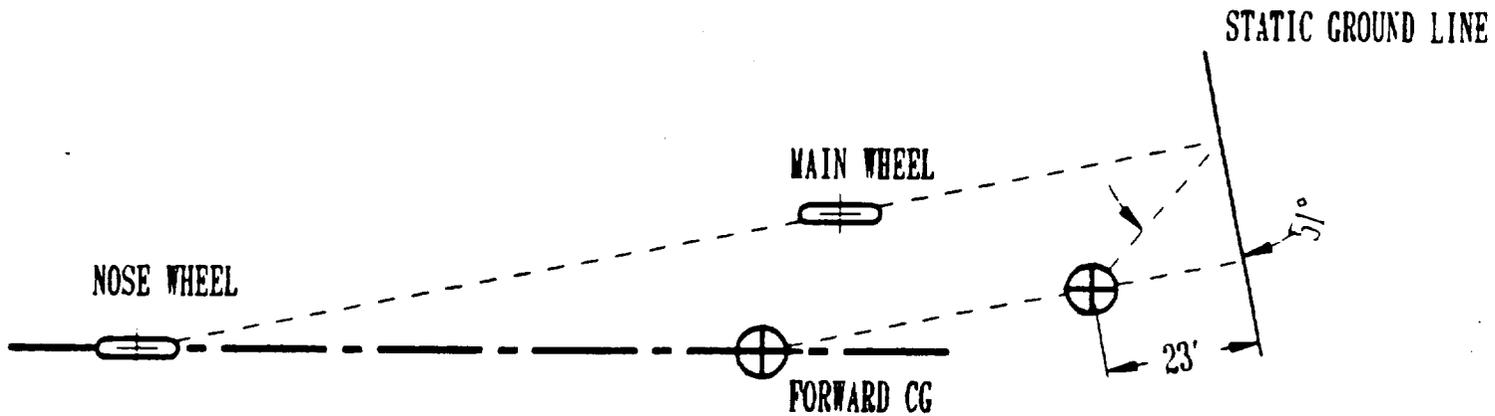


Figure 10.8 (a)  
*The Edge* Overturn Angle

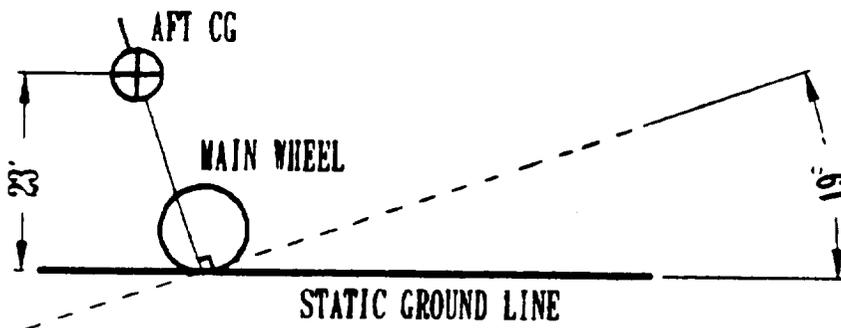
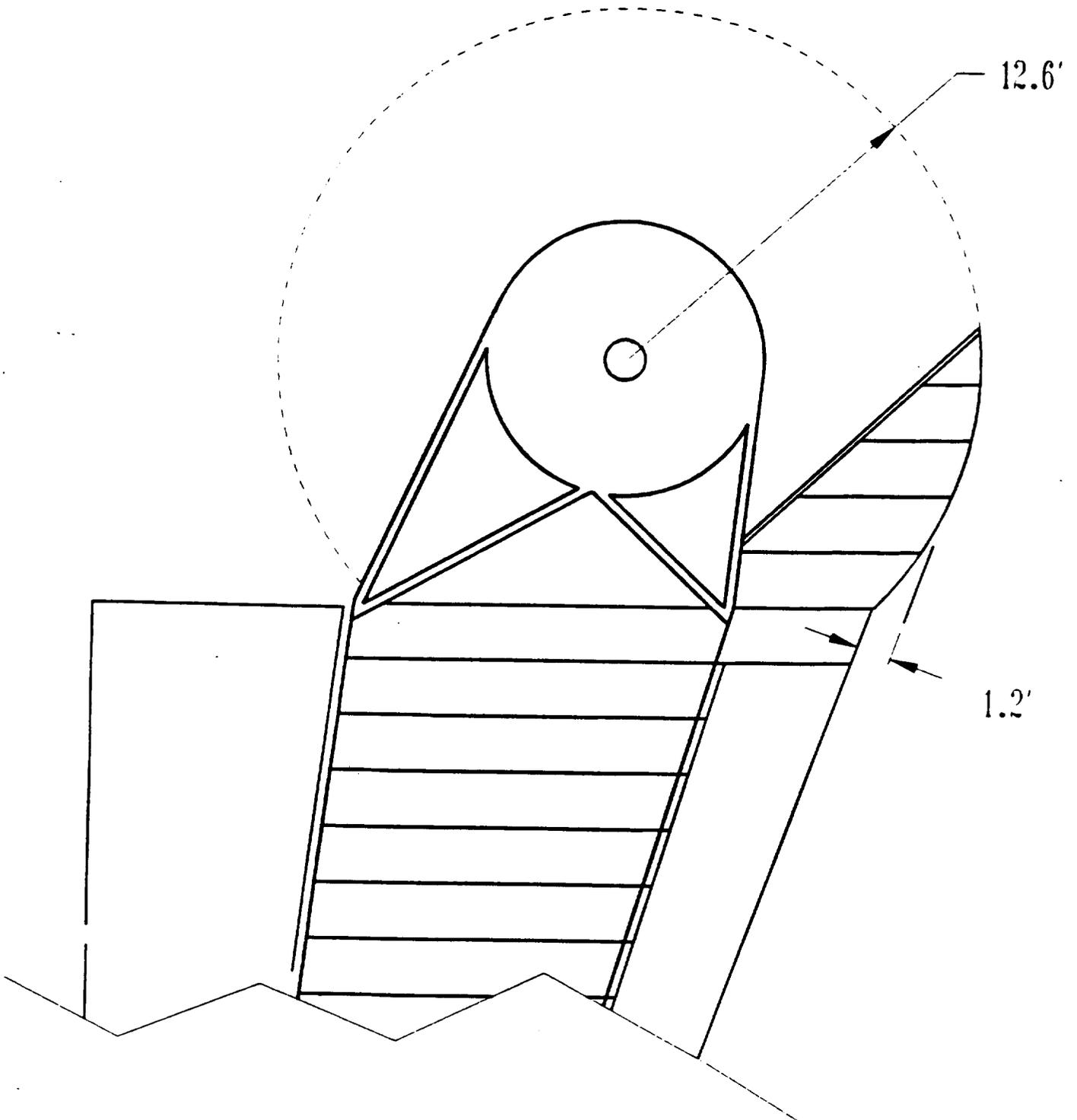


Figure 10.8 (b)  
*The Edge* Tipback Angle

# 11.0 AIRCRAFT STRUCTURES



## 11.0 Structures

### 11.1 V-n Diagram

The V-n diagram depicts the aircraft limit load factor as a function of equivalent airspeed<sup>9</sup>. The design limit and design ultimate load factors as well as the corresponding speeds for *The Edge* aircraft structural limits are presented in Figure 11.1 for the design-critical supersonic flight regime. The load factor versus the velocity diagram was constructed using FAR 25 requirements<sup>9</sup>. The positive limit load factor is 2.5 and the negative limit load factor is -1.0. It is determined from the V-n diagram that *The Edge* is indeed a maneuver-sensitive aircraft with regards to structural loading.

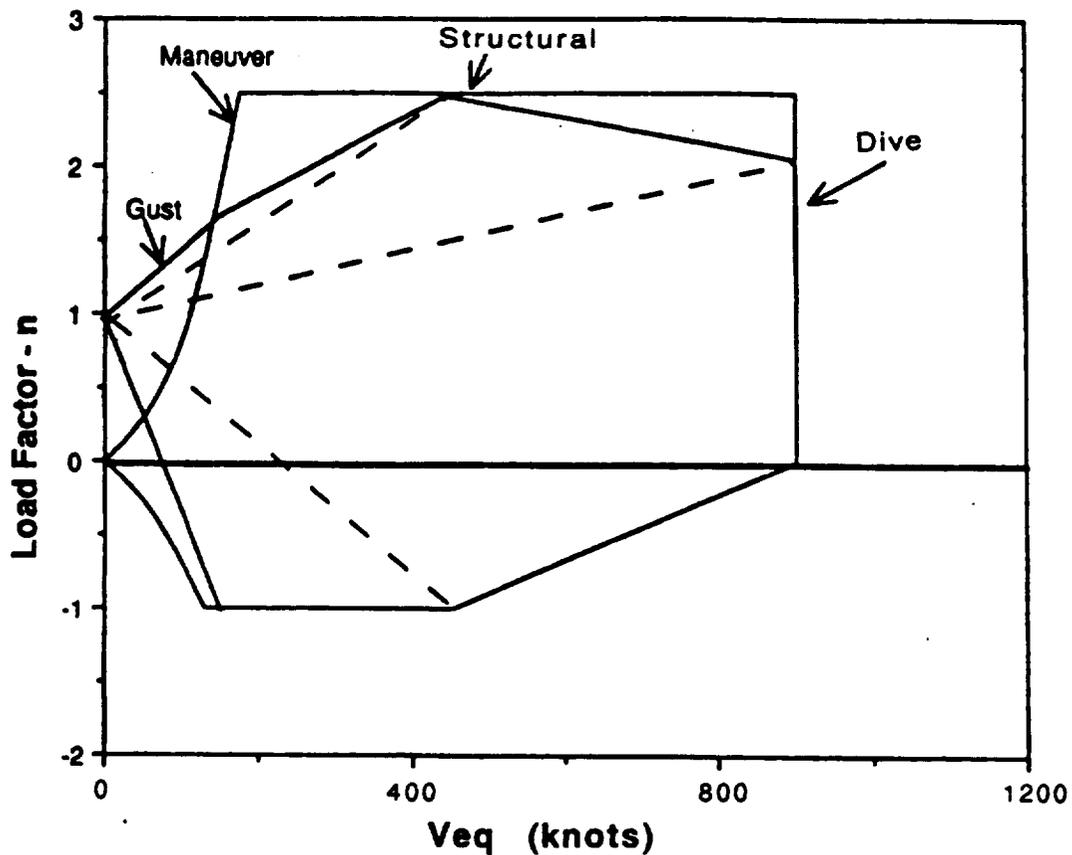
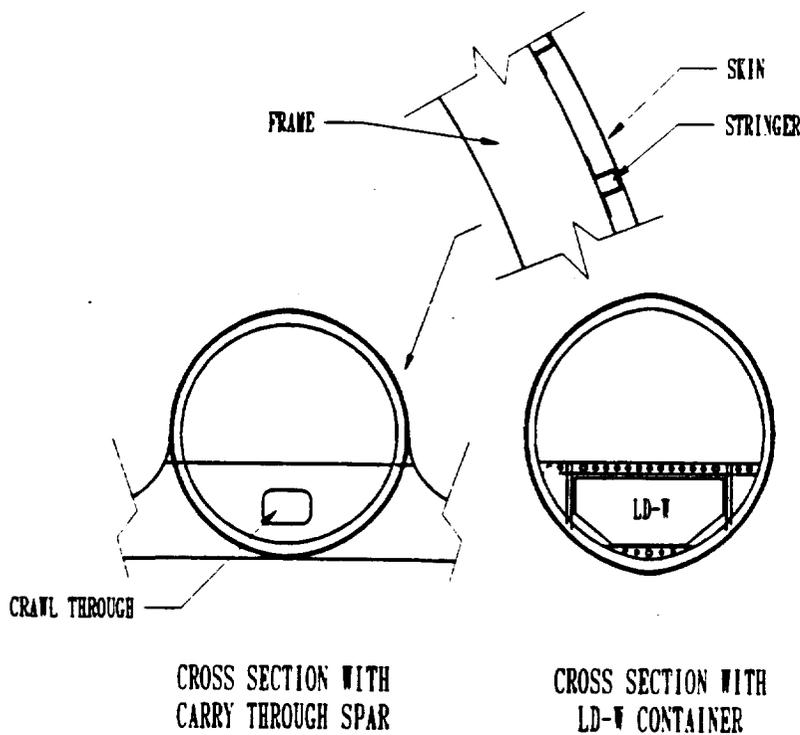


Figure 11.1  
*The Edge* Supersonic V-n Diagram

## 11.2 Structural Layout

### 11.2.1 Fuselage

*The Edge* fuselage is a traditional semi-monocoque structure using a typical frame, stringer, and skin arrangement throughout. The internal structure is composed of frames and stringers spaced at 20 inches and 9 to 12 inches, respectively. Typical cross-section structural layouts, one with LD-W cargo container storage, and one with a carry-through wing spar are shown below in Figure 11.2.



**Figure 11.2**  
**Typical Cross-Section Structural Build-up for *The Edge***

Unlike contemporary transport designs, *The Edge* will not provide passenger windows, except at emergency door locations. The reasons for this decision are manifold. With an altitude differential of over 50,000 ft between the cabin and the outside atmosphere during supersonic cruise, every avenue must be explored to provide maximum passenger and crew safety; as well, this fuselage design greatly reduces structural complexity, thereby enhancing overall integrity, while providing a greatly

needed weight decrease. Additionally, the problems associated with high skin temperatures are somewhat eased in the absence of windows. Moreover, due to the large size of *The Edge* wing, passengers would not greatly benefit from the presence of windows; Section 14.0 of this report details *The Edge's* artificial viewing system which addresses this passenger comfort issue.

Along with the elimination of windows, an extensive system of fuselage skin crack-stoppers will be used to increase structural dependability under the aforementioned pressure loading differential during cruise. Initially, a double-hull fuselage was considered to fulfill the objective of the crack-stoppers; however, this design was rejected in light of the difficulty of inspection between the two hulls, and due to structural weight considerations.

*The Edge* fuselage will be constructed in six sections as shown in Figure 11.3.

- NOTES:
- 1) 20' Frame spacing
  - 2) 9" to 12" stringer spacing
  - 3) Fuselage constructed in 6 sections as shown

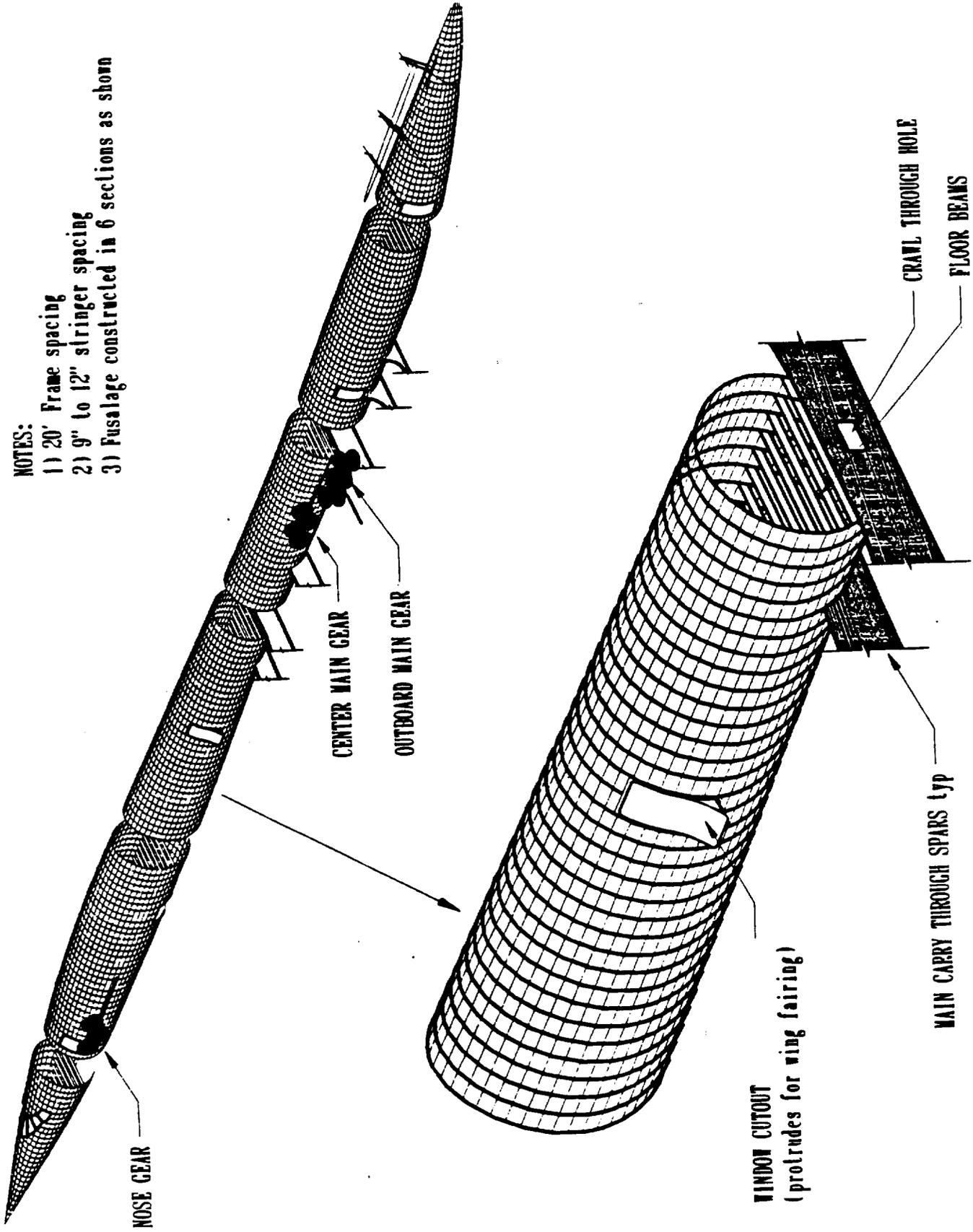


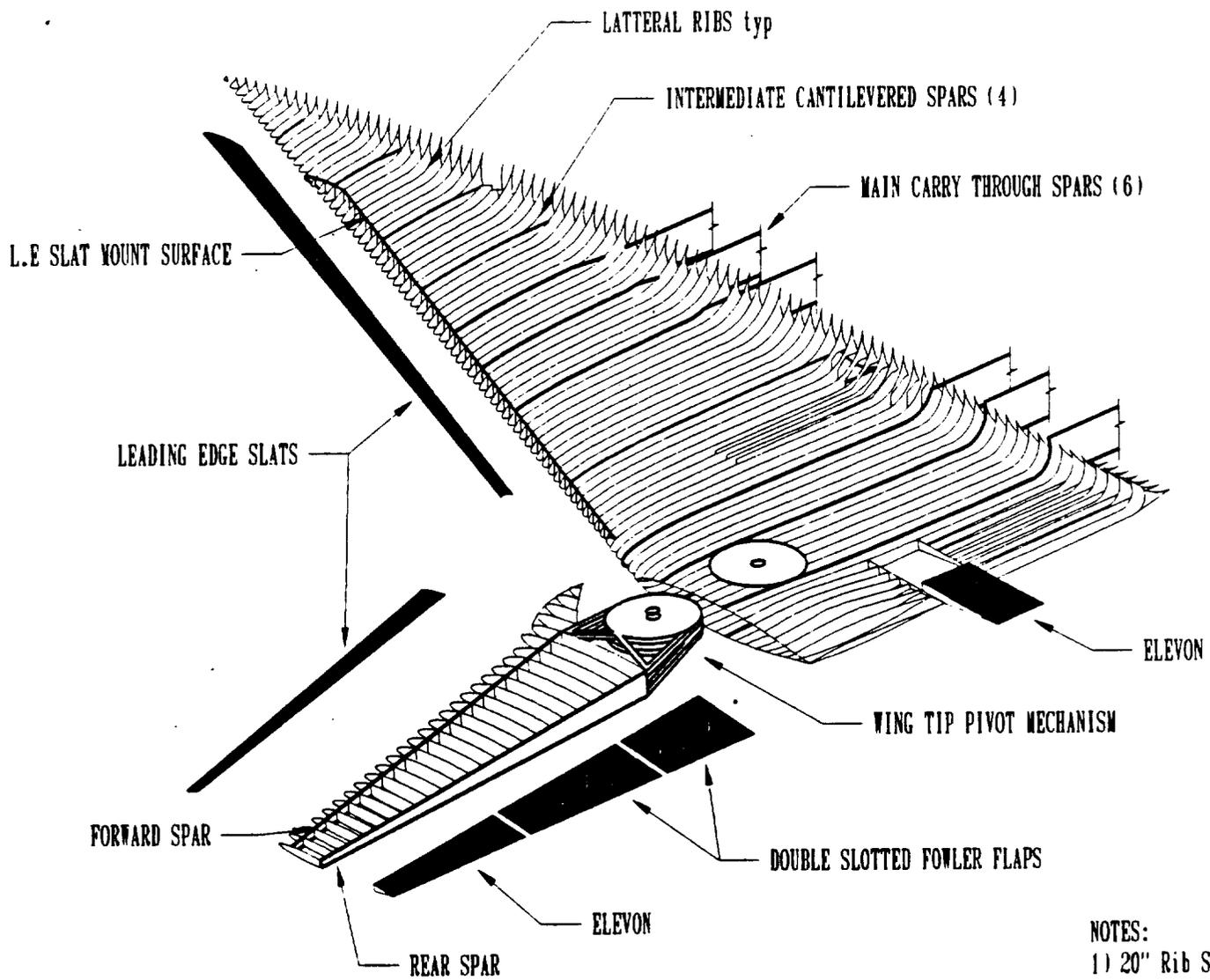
Figure 11.3  
The Edge Fuselage Structure

### 11.2.2 Wing

The heart of the inboard wing structure is an arrangement of carry-through spars which pass through the fuselage cross-section below the cabin floor. As Figure 11.4 illustrates, these members are supplemented by additional spars cantilevered from the fuselage frames<sup>27</sup>. The wing shape is formed by lateral wing ribs spaced at 20 inch increments.

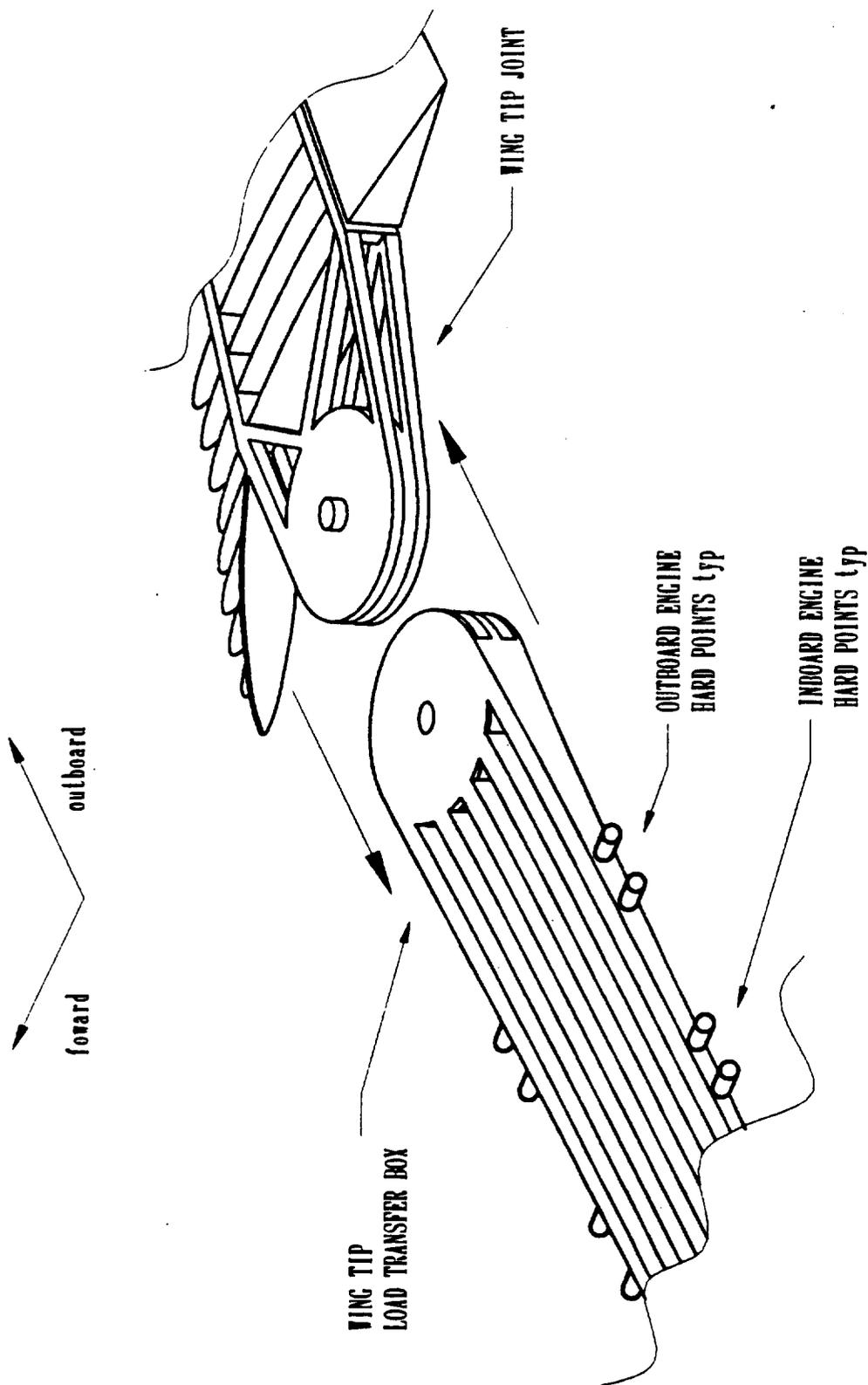
Just as the variable-wing portion of *The Edge* provides significant aerodynamic advantages, it also introduces considerable difficulties with regards to structural feasibility. For instance, these wing tips must supply approximately 40% of the lift required at takeoff. The structural challenge here is to transfer this load effectively to the aircraft itself. Such a system has been accomplished previously by the Rockwell B1-B<sup>24</sup>, which uses a planform size and wing loading similar to those of *The Edge* wing tips; the improvement to be made over this achievement resides in the area of cost-effectivity.

The main component of *The Edge* wing tip load transfer arrangement is a carry-through wing box constructed from diffusion-bonded titanium, which provides an exceptionally high strength-to-weight ratio<sup>24</sup>. The box is approximately 10 feet wide, and extends from one wing tip pivot location to the other, as can be seen in Figure 11.5. A clevis and pin mechanism is used to pivot the wing tips. The pin is essentially a hollow-center titanium bar, 17 inches in diameter; as such, it provides a convenient path for the routing of hydraulic lines to the joint screw-jack actuator. The entire wing tip pivot and load transfer structures has been estimated to weigh between 19% of the wing weight and 4% of the overall aircraft weight. It is expected that technological developments in materials will improve this value considerably; and as it decreases, so will the cost effectivity of *The Edge* increase.



NOTES:  
 1) 20" Rib Spacing  
 2) Intercostals Not Show

**Figure 11.4**  
**The Edge Wing Structural Layout**

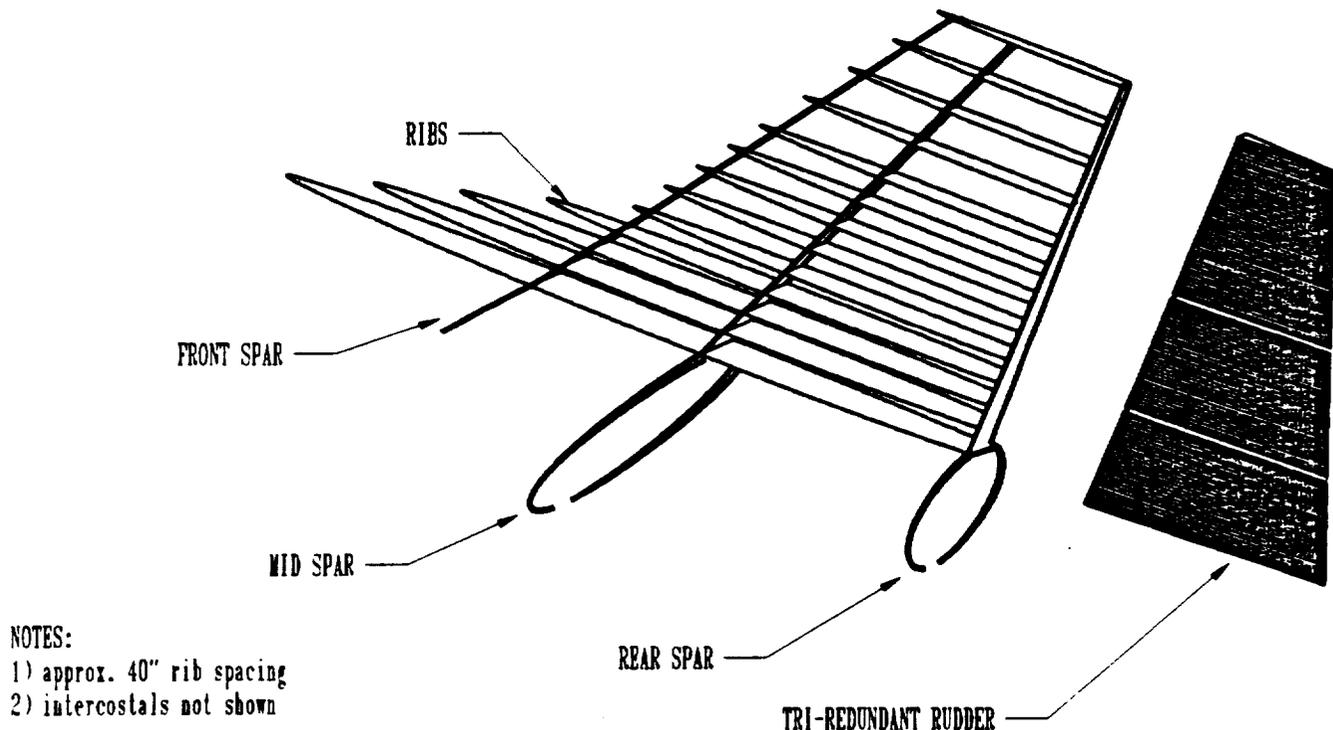


**Figure 11.5**  
*The Edge Variable-Wing Joint Structure*

As is common for wing-sweeping aircraft, a substantial gap in *The Edge's* wing leading edge forms when the wing tips are fully swept aft. This aerodynamic problem is addressed using a lightweight fairing structurally fixed to the wing tip, and fully hidden within the main wing during unswept (subsonic) flight. This fairing results in a resulting "bump" on the wing leading edge. However, this protrusion has no discernible affect on *The Edge's* supersonic performance.

### 11.2.3 Vertical Tail

*The Edge* vertical tail structure is shown below in Figure 11.6. Its layout is relatively simple, with a forward, mid and aft spar arrangement. Upon protruding into the empennage, these spars become canted fuselage frames, thus serving a dual purpose. The rear spar also provides a mounting face for the rudder control surfaces; additionally, the tail structure will allow room for local hydraulic and electronic system placement. It is notable that the vertical tail cross-sectional shape is formed by longitudinal ribs, yielding a NACA 66-series symmetrical airfoil geometry<sup>28</sup>.

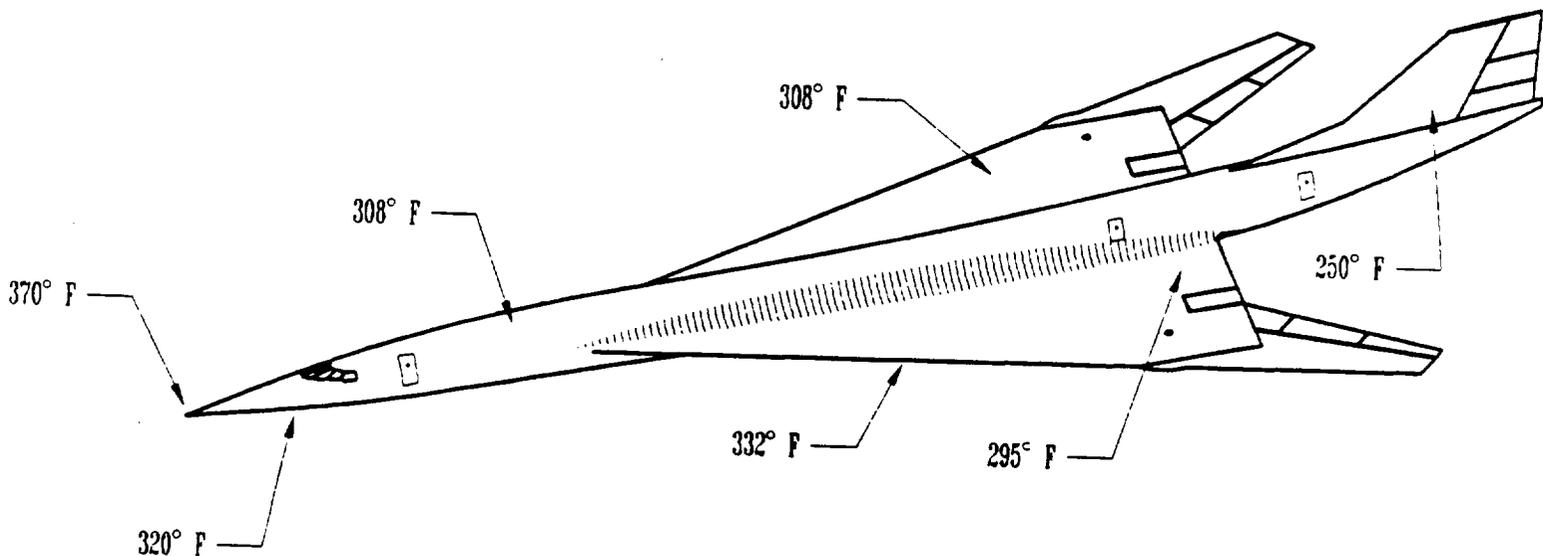


**Figure 11.6**  
***The Edge* Vertical Tail Structural Arrangement**

### 11.3 Materials

The material selection for this aircraft is dependent on many factors, including: strength/weight ratio, stiffness, corrosive properties, manufacturing difficulty, cost, and temperature effects. While all are important considerations, no tradeoffs can be made to solve the problem of excessive skin temperatures (short of installing an elaborate, heavy and expensive skin cooling system). The skin material must be able to withstand the heat with acceptable resilience of material properties.

A dilemma arises between *The Edge* design philosophy and its cruise Mach number. From an economic point of view, the ideal would be to design the aircraft with as few exotic materials as possible. This leads to considering aluminum for the majority of the skin material. Unfortunately, aluminum is not adequate for temperatures above about 250°F. At Mach 2.4 and 60,000 feet, *The Edge's* skin temperatures are generally above 300°F as shown in Figure 11.7<sup>9,10</sup>. The alternative is to use either a titanium skin, a combination of titanium and temperature resistant composite materials, or some as yet undeveloped material with the appropriate characteristics.



**Figure 11.7**  
***The Edge* Aircraft Skin Temperatures**

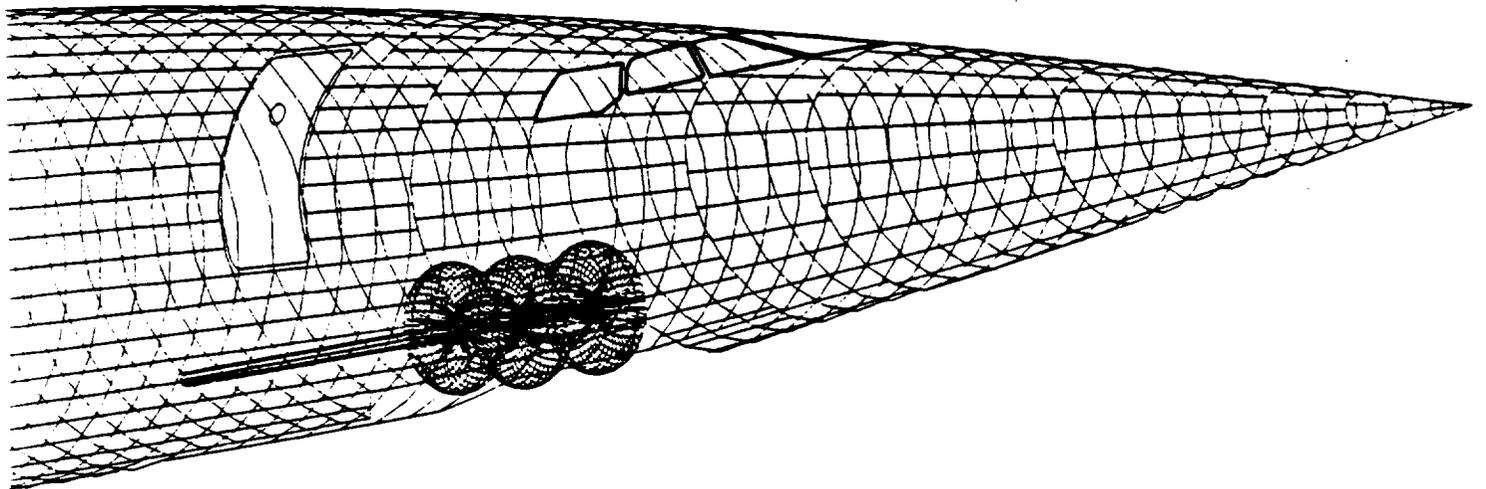
The nose, leading edges and the vertical tail leading edge will be constructed of a titanium skin. Table 11.1 shows a summary of characteristics for titanium and other possible materials, including aluminum for comparison. The decision of which route to take will be based on further trade studies made in the final design stages, when a better view of technological improvements will be available. Clearly, future materials improvements are anticipated to reduce the weight and increase the effectivity of this design<sup>18,19</sup>, and of high Mach number transports in general.

**Table 11.1**  
*The Edge Materials*

Material	Ultimate Tensile Strength (1000 psi)				
	R.T.	200 'F	300 'F	400 'F	Usable Limit
2024-T Al	63	60	58	50	250°
7075-T Al	73	69	60	23	250°
6 Al -4U Ti	130	117	110	105	750°
Graph/Epox	180	N/A	N/A	N/A	350°
Boron/Epox	195	N/A	N/A	N/A	350°
Aramid/Epox	200	N/A	N/A	N/A	350°

The fuselage and wing structure will be primarily constructed from aluminum alloys with the exception of the wing spars and wing pivot box structure. It will be necessary to maximize the strength to weight of these structures by using titanium.

# 12.0 PERFORMANCE



## 12.0 Performance

Table 12.1  
*The Edge* Performance Summary

	Takeoff	Subsonic Cruise	Supersonic Cruise
Altitude (ft)	sea level	35000	60000
Mach	0.24	0.7	2.4
$C_L$	0.84	0.68	0.14
$C_D$	0.109	.0061	0.014
L/D	7.6	11.3	9.6
AOA	11.6	6.0	2.0
Stall AOA	21	13	6.4
$C_{Lmax}$	1.44	1.31	0.22
$X_{cg}(\%cr)$	0.54	0.54	0.56
$X_{ac}(\%cr)$	0.73	0.73	0.51

Before elaborating on *The Edge* performance characteristics, it must be noted that most of the following values were calculated using the methods of reference 29. The matrix used to perform the extensive calculations can be found in the Appendix of this report. Each value specified in this discussion includes a reference to the specific section of this matrix where its calculation is performed. Those numbers obtained using reference 29 include a reference to the specific section used.

For the purposes of performance calculations, *The Edge* wing is classified as a cranked wing when unswept, and as a double delta wing when fully swept. *The Edge* lift curves represent a combination of the actual lift coefficient values obtained using reference 29, and additions made by assumptions which will be noted where applied. Due to nonlinear effects, the actual lift coefficient numbers do not provide a linear lift curve, as can be seen in Figures 12.1, 12.2, and 12.3, and the greatest deviation from experimental values should be expected at a wing angle of attack (AOA) of 4°, which corresponds to an aircraft AOA of 2°<sup>29</sup>.

## 12.1 Flight Regimes

*The Edge* aircraft is a dual configuration aircraft. In subsonic flight it is a double delta wing with a 70° inboard sweep, and a 20° outboard sweep. In supersonic flight, it is an arrow wing. Thus, it provides optimal use of a single wing to attain good performance in two flight regimes. In addition, the large fixed inboard panel of the wing allows for significant wing-body blending, resulting in additional lift. The actual historical numbers for body lift vary from 15% by McDonnell Douglas for its current SST design<sup>5</sup>, to 60% by Rockwell for its B-1B bomber aircraft<sup>24</sup>. Accordingly, a conservative estimate of 15% is estimated for *The Edge* aircraft.

### 12.1.1 Takeoff

As a result of ground effect, it is estimated that *The Edge* will experience a 10% loss of lift curve slope<sup>9</sup>. *The Edge* takeoff lift curve shown in Figure 12.1 illustrates that at the point of rotation (AOA=11.6°), the aircraft is generating a lift coefficient of approximately 0.84. During takeoff, the tips are unswept at 20°, and full deflection of both pairs of double slotted flaps is required. The leading edge slats are deployed prior to, and in conjunction with rotation to keep the flow over the wing attached at high angles of attack. At the point of takeoff, the aircraft is at an angle of attack of 11.6°. Due to the relatively large area of the inboard panel and the high lift generated by the wing tips, a low takeoff speed of 160 kts is achieved. The actual takeoff lift parameters are presented in Table 12.2. Included are their respective matrix locations in the Appendix of this report.

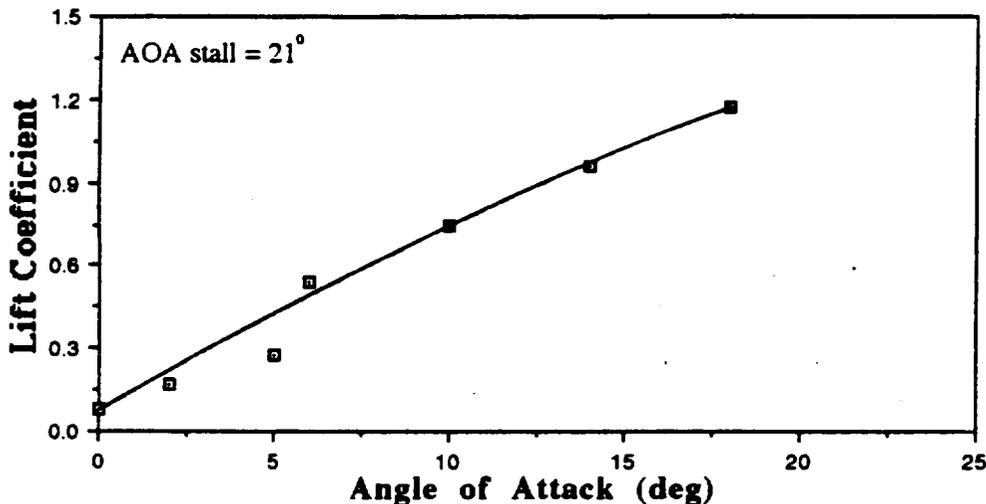


Figure 12.1  
*The Edge* Takeoff Lift Curve

**Table 12.2**  
**The Edge Takeoff Lift Parameters**

	$C_L$	$\Delta C_L$	$C_L$ Total
<b>Clean</b>	0.62	----	0.62
<b>Flaps</b>	----	0.11	0.11
<b>Elevons</b>	----	-0.02	-0.02
<b>Body</b>		0.13	0.13
<b>Total</b>			<b>0.84</b>

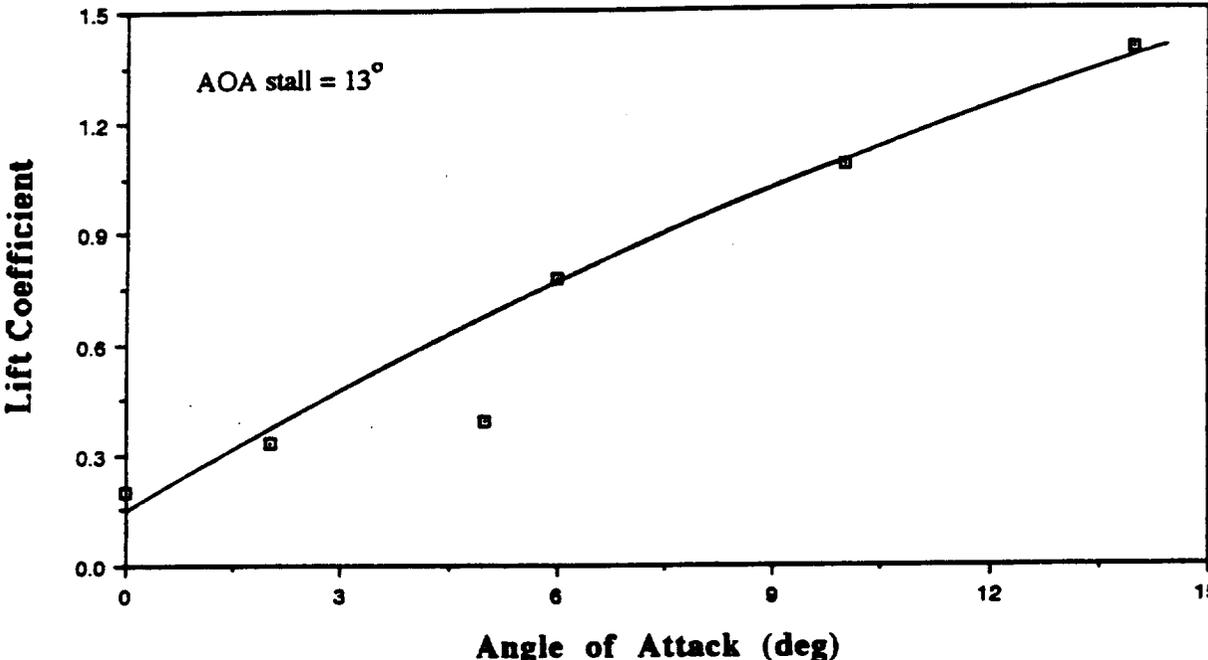
**Table 12.3**  
**Appendix Locations for The Edge Takeoff Data**

	$C_L$	$C_m$	$C_{D0}$	L/D	High Lift
<b>Appendix</b>	p. 3,4 (AA-AF)	p. 9 (BH-BN)	p. 12,13 (DJ-DO)	p. 18 4-16	p. 16,17
<b>Datcom</b>	4.1.1.2-A 4.1.3.2-A 4.1.3.3-A	4.1.4.2-A	4.1.5.1-A	N/A	6.1.1.1-A 6.1.1.1-C 6.1.4.2-1

### 12.1.2 Subsonic Cruise

*The Edge* subsonic lift curve is shown in Figure 12.2. During subsonic cruise, the aircraft is in a clean configuration, with tips fully unswept, and flying at an angle of attack of  $4^\circ$ ; consequently, the only lift generated in addition to that of the wing itself is that produced by the aircraft body<sup>24</sup>. In this mode, the aircraft is performing with

enough efficiency ( $L/D=11$ ) that no high lift devices are required. The reason for a cruise speed of  $M = 0.7$  is two-fold. First, it is the limiting speed of subsonic flight. Any increases would send the aircraft into the transonic region where shifts in the dominance of nonlinear lift are expected and difficult to predict. Second, data regarding highly swept, cranked wings in the transonic flight regime is closely held by private aircraft corporations, and as such it is difficult to obtain.



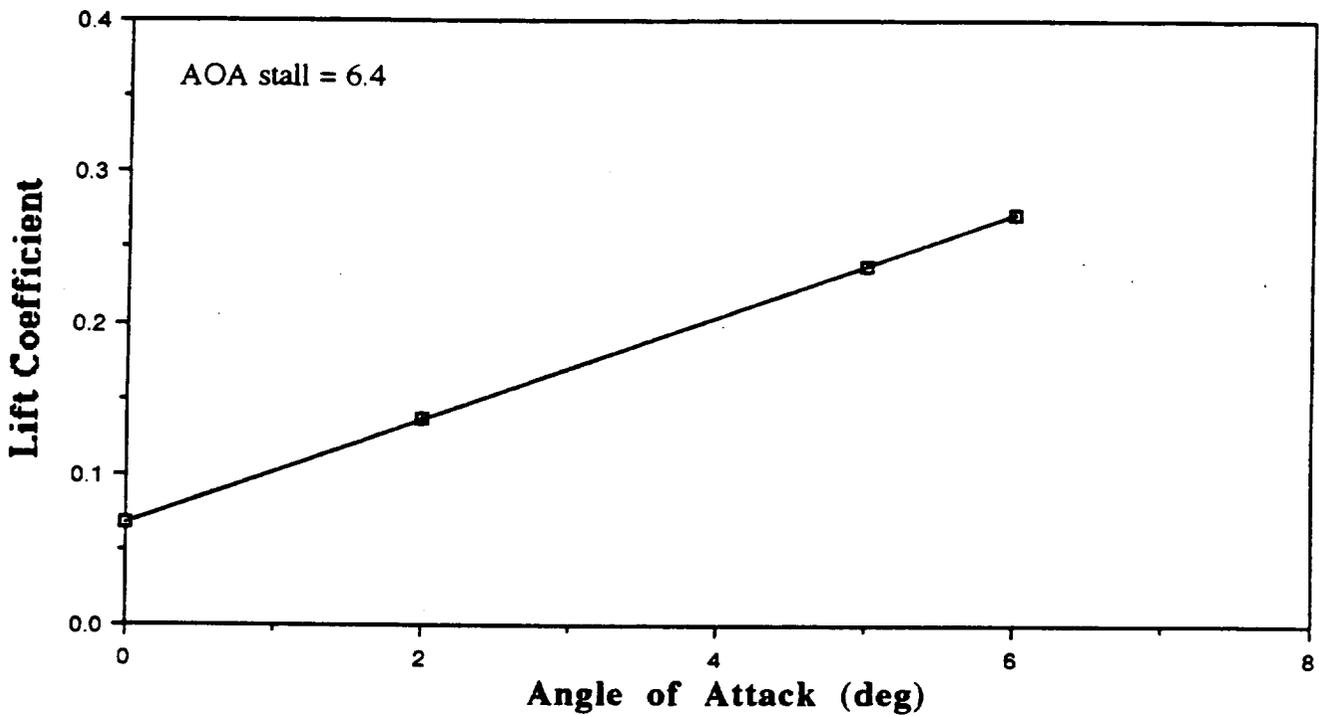
**Figure 12.2**  
*The Edge Subsonic Lift Curve*

**Table 12.4**  
**Appendix Locations for *The Edge* Subsonic Cruise Data**

	$C_L$	$C_m$	$C_{D0}$	$L/D$
Appendix	p. 5, 6 (AN-AS)	p. 10 (BH-BN)	p. 14 (DJ-DO)	p. 18
Datcom	4.1.1.2-A 4.1.3.2-A 4.1.3.3-A	4.1.4.2-A	4.1.5.1-A	N/A

### 12.1.3 Supersonic Cruise

Figure 12.3 shows the aircraft lift curve during supersonic cruise. In this regime, the aircraft was initially designed for an angle of attack of zero (wing incidence of  $2^\circ$ ) and neutral stability. While the latter design point is achievable, not enough lift is generated with the wing incidence angle of  $2^\circ$  to meet the first criterion. As a result, the aircraft is flying at an angle of attack of  $2^\circ$  which allows a comfortable compromise of 4.5% instability, as discussed in Longitudinal Controls and Controllability (Section 13.2). It must be noted that nonlinear effects are not accounted for in the supersonic lift calculations due to the unavailability of data<sup>29</sup>.



**Figure 12.3**  
***The Edge Supersonic Lift Curve***

**Table 12.5**  
**Appendix Locations for *The Edge* Supersonic Cruise Data**

	$C_L$	$C_m$	$C_{D0}$	L/D
Appendix	p. 7,8	p. 11 (BA-BG)	p. 15	p. 19
Datcom	4.1.1.2-A 4.1.3.2-C 4.1.3.3-C	4.1.4.2-C	4.1.5.1-C	N/A

## 12.2 Summary of Performance Characteristics

As shown in Figure 12.4, the immediate advantage of a variable sweep aircraft is evident. The superior subsonic and supersonic cruise L/D values are a direct result of flying a two configuration aircraft. Table 12.6 summarizes these performance values, and drag polars for all flight regimes are presented in Figure 12.5. With these performance characteristics, *The Edge* aircraft allows for efficient subsonic travel; therefore, *The Edge* has an improved ability to provide economical service subsonically overland.

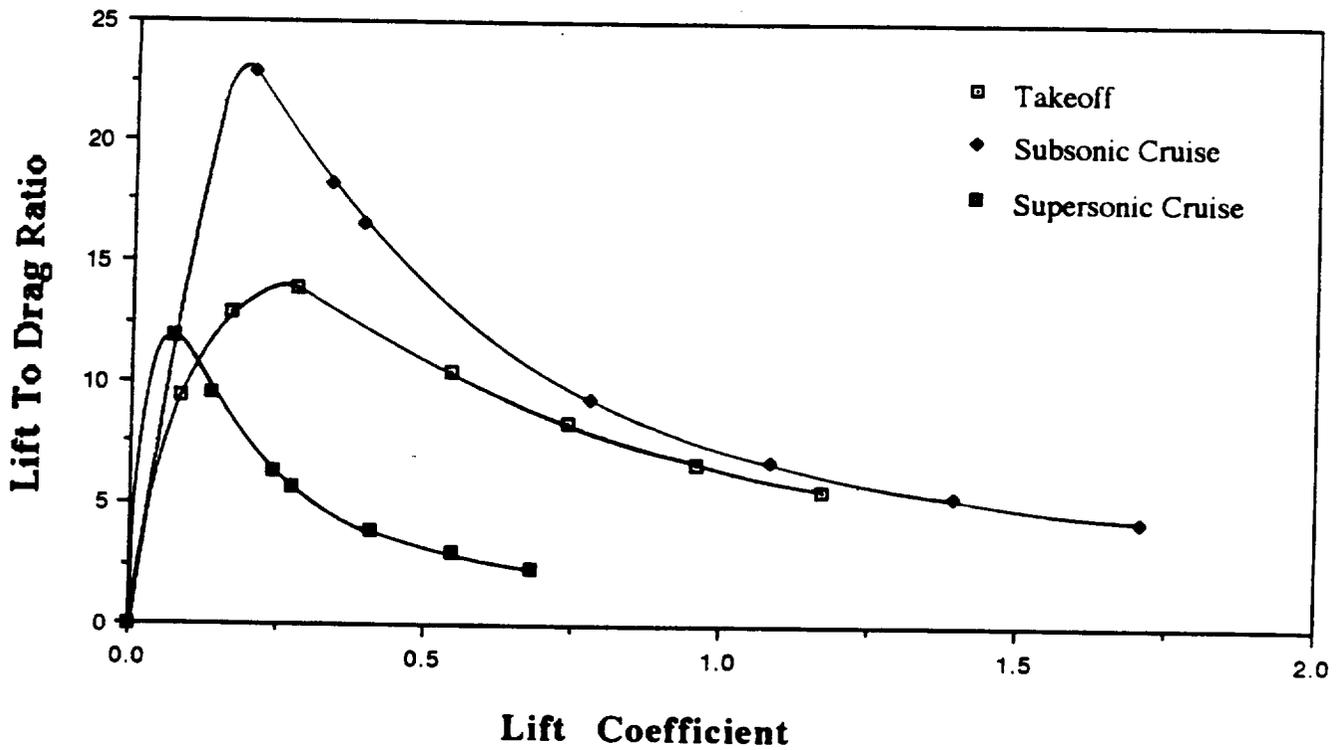
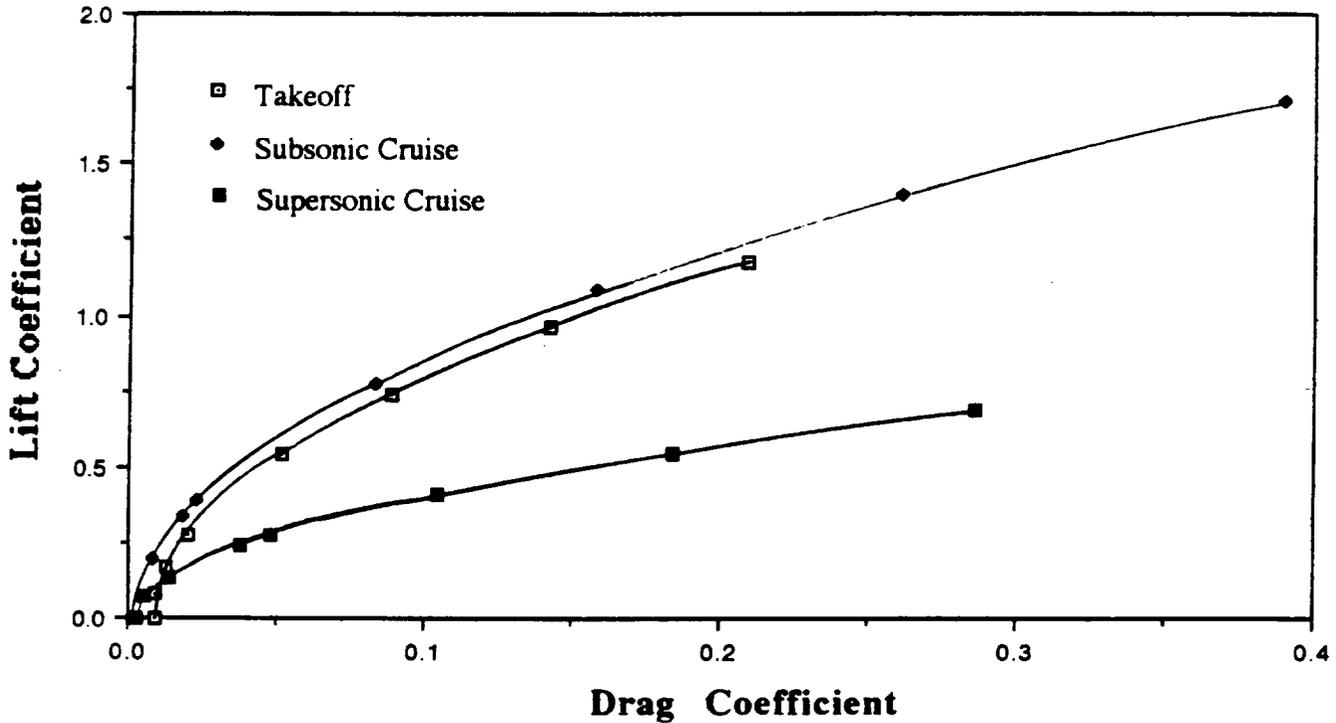


Figure 12.4  
Comparison of Lift-To-Drag vs CL Values for *The Edge*

Table 12.6  
*The Edge* Performance Characteristics Summary

	Mach #	$CL_{required}$	AOA (deg)	$X_{ac}$	L/D	Configuration
Takeoff	0.24	0.84	11.6°	0.73	7.6	TE flaps, LE slats & elevators @ full deflection
Subsonic Cruise	0.7	0.68	5.0°	0.73	11.0	Clean, unswept
Supersonic Cruise	2.4	0.14	2.0°	0.52	9.6	clean swept
Emergency Landing	0.27	0.72	14.6°	0.56	2.4	TE flaps (outboard only) LE slats, swept



**Figure 12.5**  
***The Edge* Drag Polar Comparison**

### 12.3 Emergency Landing Conditions

*The Edge* aircraft is at a most critical stage during takeoff. Namely, it is generating its greatest amount of lift. Once airborne, the aircraft must provide for systems failures and the need for immediate landing. Subsequently, *The Edge* has been designed with enough control power to accommodate such an event, as discussed in Stability and Control (Section 13.0).

Since *The Edge* is a variable sweep aircraft, the possibility of failure of its wing-sweeping mechanism is introduced as an additional safety concern. *The Edge* wing was initially designed to have enough surface area while swept back to provide adequate lift for landing in such a configuration should the need arise. This design point has been met, and the aircraft can indeed land fully swept at 15° AOA and 180 kts<sup>29</sup>. However, other issues need to be addressed in further analysis of this flight condition, such as possible tip stall due to an excessive AOA, which would severely limit or destroy longitudinal control power.

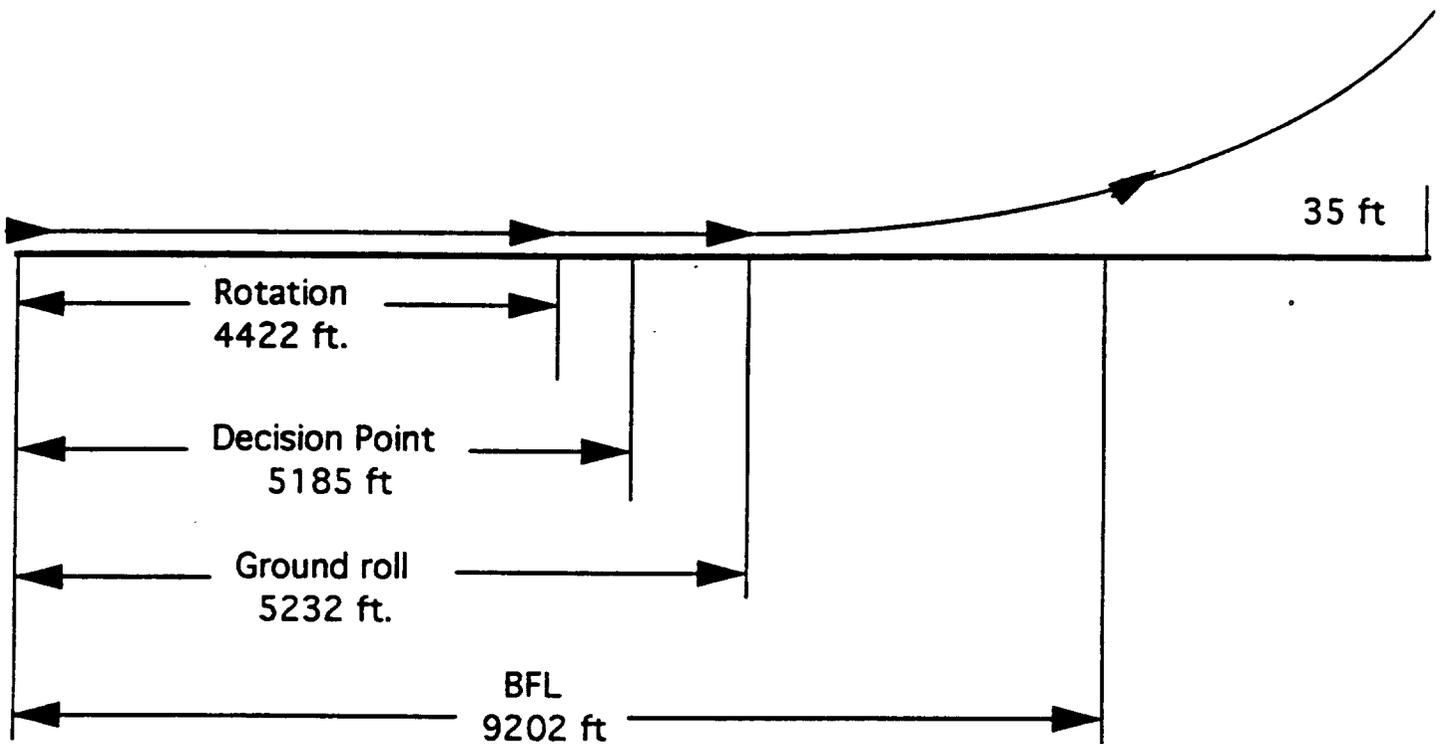
**Table 12.7**

**Appendix Locations for *The Edge* Emergency Landing Condition Data**

	<b><math>C_L</math></b>	<b><math>C_{Do}</math></b>	<b>High Lift</b>
<b>Appendix</b>	p. 3,4 (U-Z)	p. 12 (DD-DI)	p. 16,17
<b>Datcom</b>	4.1.1.2-A 4.1.3.2-A 4.1.3.3-A	4.1.5.1-A	6.1.1.1-A 6.1.1.1-C 6.1.4.2-1

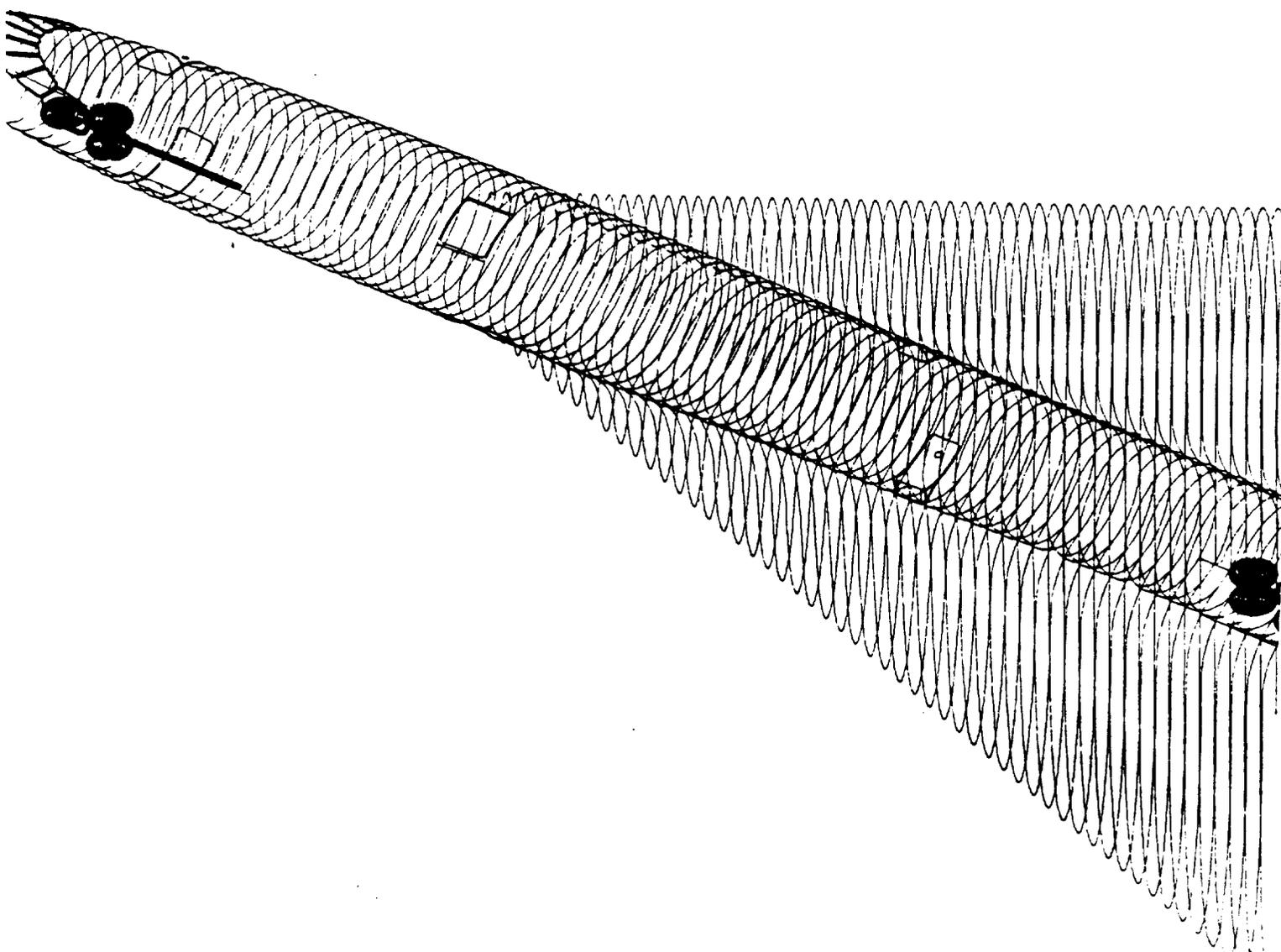
## 12.4 Balanced Field Length

In order for *The Edge* to be compatible with existing airports, the aircraft must have a total takeoff distance of less than 12,000 feet, including the distance required to clear a 35 foot obstacle with one engine inoperative. As can be seen from Figure 12.6, when the aircraft has accelerated to a distance of 4,422 feet, it begins to rotate; the time to rotate to a liftoff attitude is largely dependent upon the pilot, but is typically 3 seconds. After this rotation point, however, the pilot is committed to takeoff. Figure 12.6 also illustrates a ground run of approximately 5,232 feet. From these considerations, the balanced field length is calculated to be 9,202 feet.



**Figure 12.6**  
***The Edge* Balanced Field Length**

# 13.0 STABILITY AND CONTROL



## 13.0 Stability and Control

### 13.1 Longitudinal Stability

As can be seen from the table below, *The Edge* is longitudinally stable except in the supersonic cruise regime, where it has been designed to fly with approximately 4.5% instability.

The jump from a significantly stable configuration in the subsonic regime to a slightly unstable one in supersonic flight is a direct result of *The Edge* swing-tip design. During acceleration throughout low speed and subsonic cruising flight, the aerodynamic center (AC) is being influenced aft by the loading of the wing tips; at the same time, the AC is being drawn forward by the lift generated on the main wing. The result is a virtual negation of any AC shift while accelerating to subsonic cruise at  $M = 0.7$ , resulting in a subsonic cruise AC located approximately 73% aft along the main wing root chord. This AC position may seem odd when compared to a typical delta wing subsonic AC location of approximately 25%; however, it should be clear that the high wing tip loading of *The Edge* is what drives the AC back to this aft position.

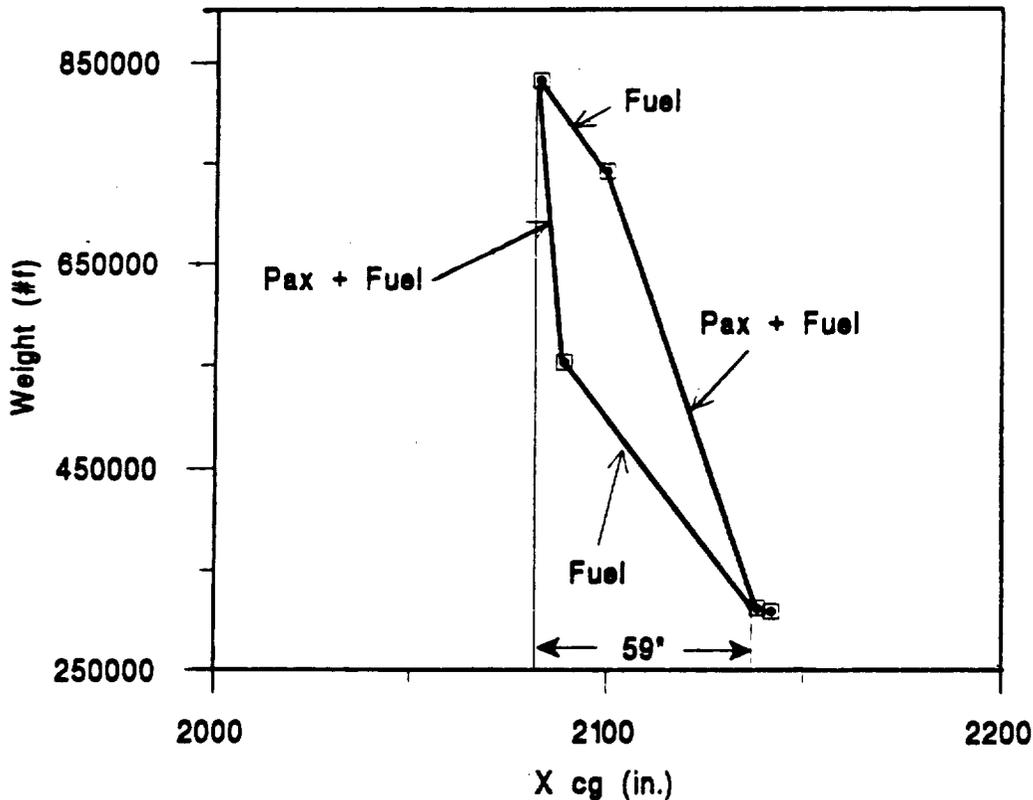
**Table 13.1**  
***The Edge* Longitudinal Stability: Static Margin**

	<b>Takeoff Regime</b>	<b>Subsonic Cruise</b>	<b>Supersonic Cruise</b>
<b>Mach Number</b>	0.24	0.7	2.4
<b>AOA (deg)</b>	11.6	4.6	2.0
<b>X'cg (% Cr)</b>	0.54	0.54	0.56
<b>X'ac (% Cr)</b>	0.73	0.73	0.52
<b>Static Margin (% Cr)</b>	-0.19	-0.19	0.05

While passing through the transonic regime, *The Edge* wing tips sweep incrementally aft. Upon the achievement of full supersonic cruising flight, the tips are fully swept, producing an arrow wing planform and a forward AC shift to about 52% aft along the root chord. It is clear that as the wing tips are swept back, the main wing is left to generate the vast majority of the lift required for cruise; and as expected for a planform such as that of *The Edge*, the supersonic AC position resides at about the 50% root chord position<sup>29</sup>.

*The Edge* has been preliminarily designed with a center of gravity (CG) location as close as possible to the supersonic cruise aerodynamic center. The potential of this philosophy is that marginal positive stability or neutral stability favors extremely small control deflections resulting in lower induced drag. Although this was difficult to achieve for *The Edge*, as is evidenced by its 4.5% instability in supersonic cruise, further design work may indeed push this static margin to a marginally stable value.

Figure 13.1 below illicit the full CG envelope of *The Edge*. This envelope is notably small, allowing the aircraft to operate anywhere in this CG range with only minor affects on stability. As Shown, the range of CG shift is 54% to 56% of the wing root chord.



**Figure 13.1**  
***The Edge* Full Mission CG Excursion Diagram**

## 13.2 Longitudinal Controls and Controllability

A key point in *The Edge* design philosophy is to take the best ideas offered by previous supersonic transport designs, as well as any other maverick ideas of special potential, and evaluate their net worth in achieving the overall design goal of economic feasibility. One decision arising from this evaluation is the elimination of a horizontal tail. The subsequent benefits of reduced aircraft empty weight have been discussed previously in this report; the topic here is the longitudinal control challenge inherent in a tailless design.

In sizing *The Edge* elevon surfaces, the X-plot method<sup>10</sup> was attempted and furnished values of elevon area approaching the size of *The Edge's* main wing (this attempt can be found in the Empennage design section of the Appendix). Preliminary design of these surfaces was therefore accomplished by an analysis of previous tailless transport configurations such as the Concorde and the TU-144. This initial analysis placed the existing elevons to within 10% of their final size, which was determined using longitudinal control analyses<sup>32</sup>. The high aspect ratio wing tips allowed *The Edge* to use elevons which are markedly smaller as a percentage of overall wing area than those of the Concorde design<sup>21</sup>.

Table 13.2 summarizes pertinent information for the flight conditions at which stability and control derivatives were calculated. Table 13.3 is a summary of these derivatives in the three flight regimes of greatest interest: takeoff, subsonic cruise and supersonic cruise. These values were calculated using the methods established in references 29 and 32. However, it is difficult to evaluate their import fully without comparison to other aircraft of similar size and configuration. And since such information is closely held by the private sector, the best information available has been the subsonic data relating to the Boeing 747-SP<sup>23</sup>. Even in the subsonic regime, though, the limitations of using this data are evident since the 747 configuration is substantially different than that of *The Edge*<sup>23</sup>.

With this in mind, initial concerns were focused toward the relatively small values obtained for elevator control power, namely  $C_{m\delta_e} = -0.25$  at takeoff speed as compared to  $-1.4$  for the 747 on final approach<sup>23</sup>. However, Figures 13.2a,b,c verify that sufficient control power is in fact available to handle any normal configuration variations within takeoff, subsonic, and supersonic flight, as well as to maneuver the aircraft between these regimes. On each of these figures, the  $C_m = 0$  line occurs at a reference CG of 0.58; *The Edge* design trim point locations are also shown. Cockpit control forces will be within standard limits<sup>24</sup> by means of an artificial control force feel system<sup>10</sup>.

Table 13.2

*The Edge Flight Condition Summary for Stability and Control Analysis*

Flight Condition	Takeoff	Subsonic	Supersonic
Altitude (ft)	Sea Level	35,000	60,000
Center of Gravity (X'cg)	0.540	0.542	0.562
Mach Number	0.24	0.7	2.4
Nominal Attitude (deg)	11.6	4.6	2
$I_{xx}$ (slug-ft <sup>2</sup> )	$2.64 \times 10^{10}$	$2.64 \times 10^{10}$	$2.40 \times 10^{10}$
$I_{yy}$ (slug-ft <sup>2</sup> )	$7.71 \times 10^9$	$7.71 \times 10^9$	$6.04 \times 10^9$
$I_{zz}$ (slug-ft <sup>2</sup> )	$4.09 \times 10^9$	$4.09 \times 10^9$	$3.87 \times 10^9$
$I_{xz}$ (slug-ft <sup>2</sup> )	$3.03 \times 10^9$	$3.03 \times 10^9$	$2.81 \times 10^9$

Table 13.3

*The Edge Stability and Control Derivative Summary*

Stability Derivatives	Takeoff Regime	Subsonic Cruise	Supersonic Cruise
$C_{m\alpha}$	-0.34	-0.34	0.11
$C_{m\dot{\alpha}}$	-28.1	-28.6	-17.4
$CL_y$	0.02	0.21	-0.21
$CL_\alpha$	2.64	1.66	2.64
$CL_\dot{\alpha}$	1.35	0.83	0.12
$CD_u$	0.01	0.04	0.14
$CL_{\delta E}$	0.51	0.44	4.25
$CD_{\delta E}$	0.04	0.04	0.03
$CM_{\delta E}$	-0.25	-0.41	-1.49
$C_{l\beta}$	-0.447	-0.014	-0.023
$C_{l\dot{\beta}}$	-0.24	-0.241	-0.246
$C_{l\delta A}$	0.02	0.023	0.029
$C_{l\delta R}$	0	0.009	0.003
$C_{n\beta}$	-0.021	0.232	0.408
$C_{n\dot{\beta}}$	0.273	0.081	0.12
$C_{n\delta A}$	0	-0.0018	-0.0024
$C_{n\delta R}$	-0.139	-0.156	-0.367
$C_{y\beta}$	-0.02	-0.07	-0.11
$C_{y\dot{\beta}}$	0	-0.006	-0.018
$C_{y_r}$	0	0.06	0.17
$C_{y\delta A}$	0	0	0
$C_{y\delta R}$	0.047	0.053	0.077

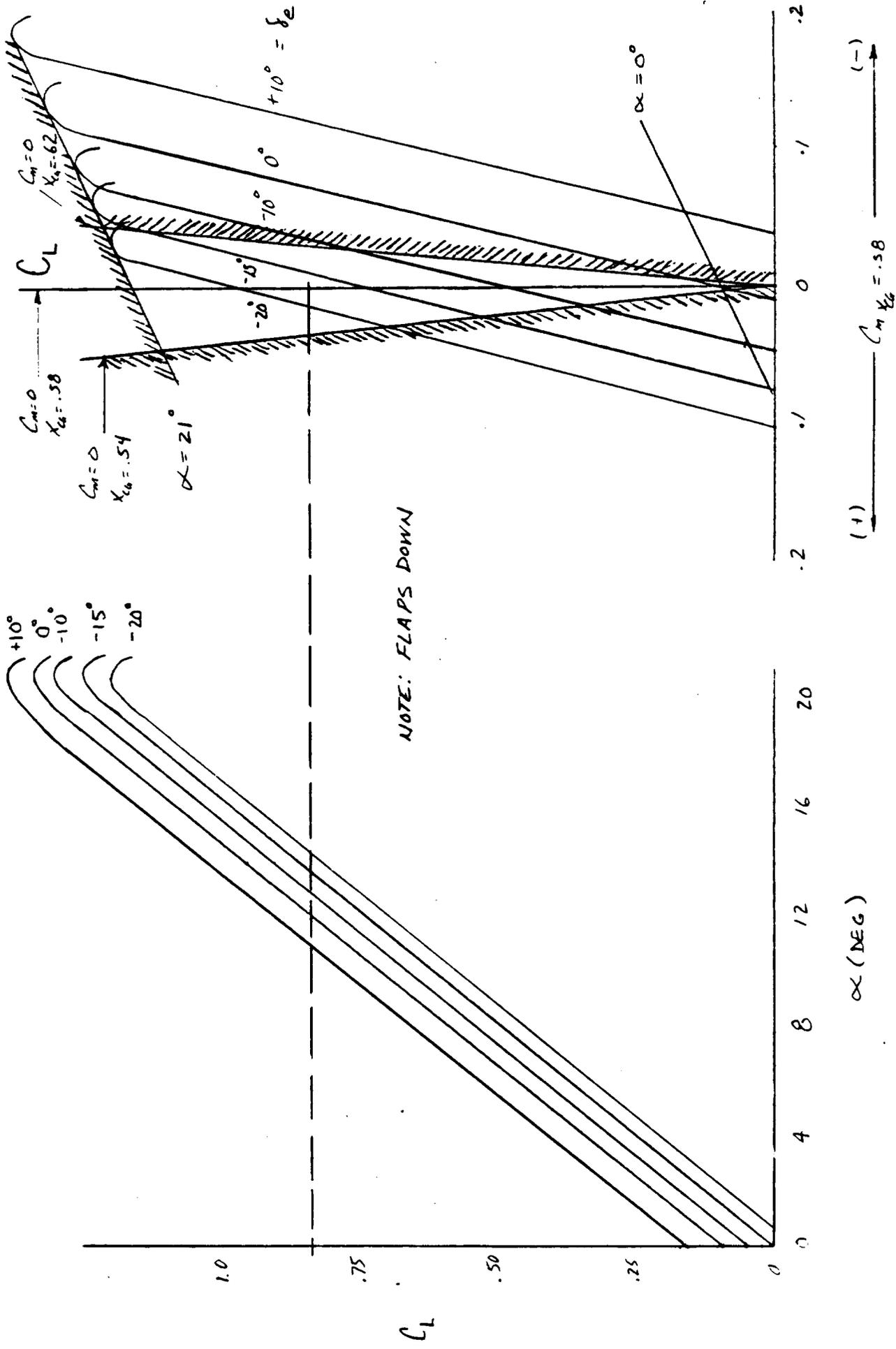


Figure 13.2 (a)  
The Edge Trim Diagram for Takeoff ( $M = 0.24$ )

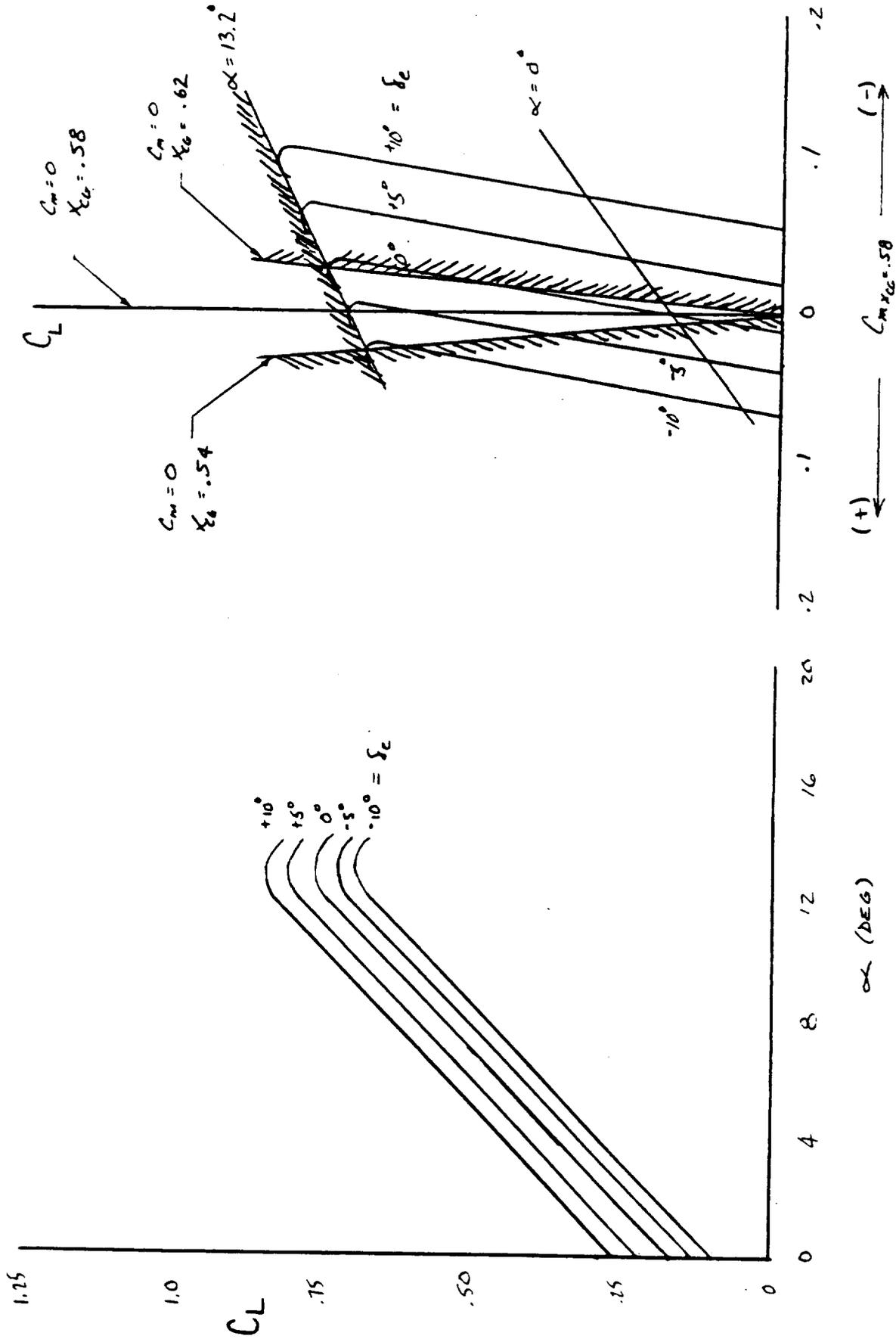


Figure 13.2 (b)  
The Edge Trim Diagram for Subsonic Cruise ( $M = 0.7$ )

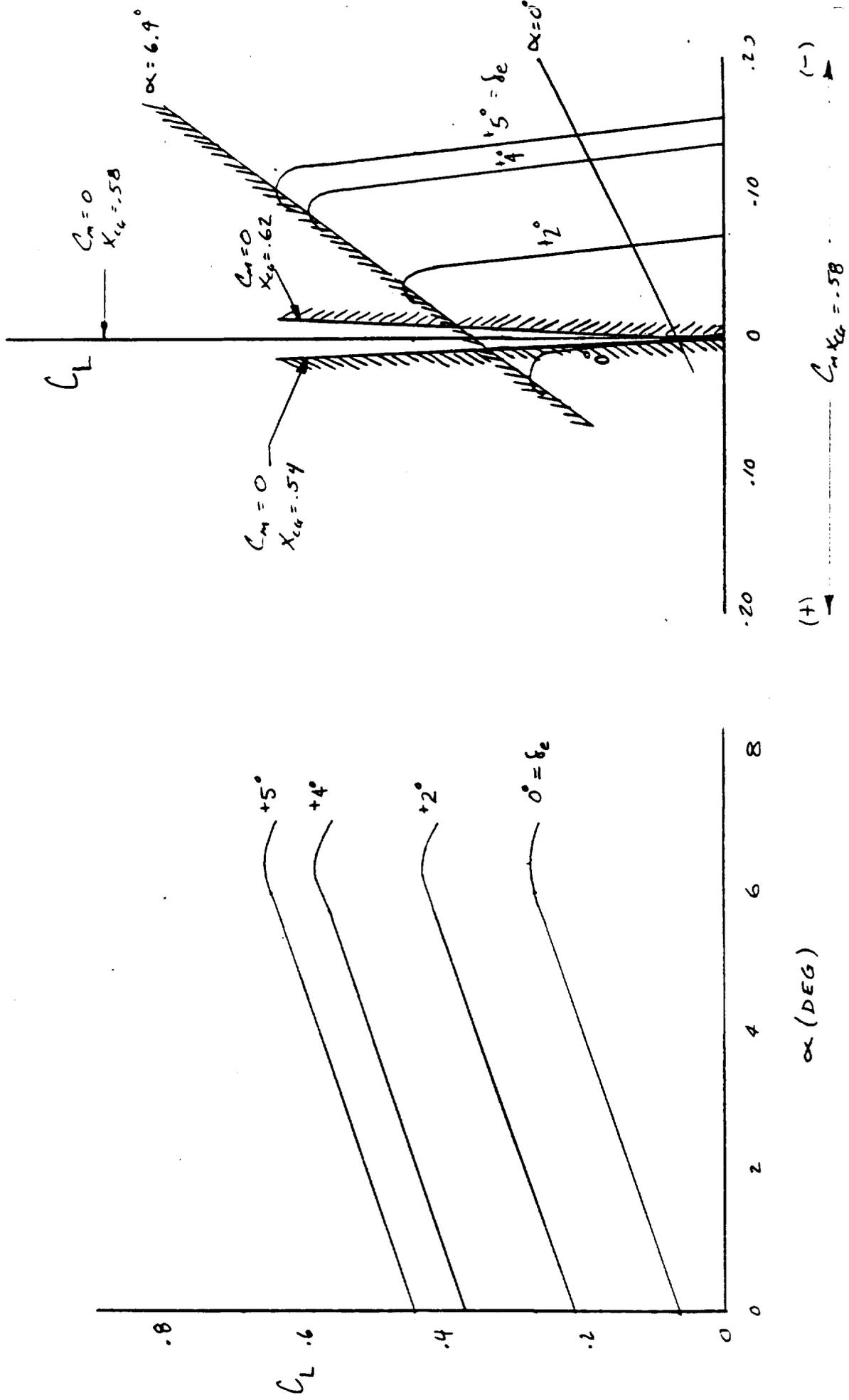


Figure 13.2 (c)  
The Edge Trim Diagram for Supersonic Cruise ( $M = 2.4$ )

*The Edge* will utilize a futuristic fly-by-light flight avionics package. As mentioned in Section 14.0 of this report, the several benefits offered by such a system include those of weight savings, maintainability, and insusceptibility to electromagnetic interference. Fiber optics will be employed to transfer pilot inputs to the appropriate hydraulic or electronic flight control actuators<sup>23</sup>.

For the supersonic cruise condition wherein a longitudinal stability augmentation system (SAS) will be employed, the angle of attack feedback gain for the elevon control loop is determined to be  $K_{\alpha} = 0.003$  deg/deg. This gain is achievable with current technology<sup>10</sup>.

### 13.3 Lateral Stability

During low speed flight, and during takeoff in particular, unstable weathercock characteristics are present, as can be seen through  $C_{n\beta}$  in Table 13.2. Lateral instability, however, while a concern, is not as inherently problematic for *The Edge* as is longitudinal stability; with the exception of structural weight, there are no pressing limits on lateral control surface sizes as there are in the longitudinal case. The vertical tail and rudder control of *The Edge* are designed such that substantial lateral control authority is provided in all flight regimes.

### 13.4 Lateral Controls and Controllability

Lateral instability at takeoff is therefore addressed by using this control authority managed by a lateral SAS with a sideslip to rudder feedback gain of  $K_{\beta} = 0.016$ . It is probable here that the rate of sideslip will also be fed back to the rudder<sup>10</sup>. As discussed in Longitudinal Controls and Controllability, a futuristic fly-by-light flight control system will be employed aboard *The Edge*.

FAR 25.147 states that an aircraft must be able to effect reasonable sudden changes in heading with the wings approximately level. In order to meet this requirement, sideslip angle ( $\beta$ ), aileron deflection ( $\delta_a$ ), and rudder deflection ( $\delta_r$ ) for the control surfaces must be within acceptable limits for the worst case scenario; this situation is that wherein the right outboard engine is inoperative during takeoff. Rolling moment, yawing moment and sideforce due to thrust exhibit their greatest values in this case. Table 13.4 illustrates that  $\beta$ ,  $\delta_a$ ,  $\delta_r$  and are will within the typically acceptable limits; therefore, the requirements of FAR 25.147 are satisfied.

**Table 13.4**  
***The Edge* Lateral Controllability Summary**

	<b>FAR 25.147 Requirements</b>	<b>Takeoff</b>	<b>Subsonic</b>	<b>Supersonic</b>
$\beta$	< 12°	-9.37°	-11.36°	-0.46°
$\delta_a$	< 25°	0°	17.49°	-0.324°
$\delta_r$	< 25°	0.905°	10.9°	-0.528°

### 13.5 Handling Qualities

Without a flight control system, an aircraft such as *The Edge* should exhibit vastly different handling qualities in one regime than in another. This is true for *The Edge*. As can be seen in Table 13.5, the approximations for longitudinal and lateral control do not generate numbers in unstable regimes. *The Edge* aircraft is longitudinally unstable in supersonic cruise and laterally unstable during takeoff. This can be corrected with the implementation of a flight control system with the appropriate control laws. In the remaining flight regimes, *The Edge* aircraft falls into either level 1 or 2 flying qualities for both longitudinal and lateral approximations<sup>31</sup>.

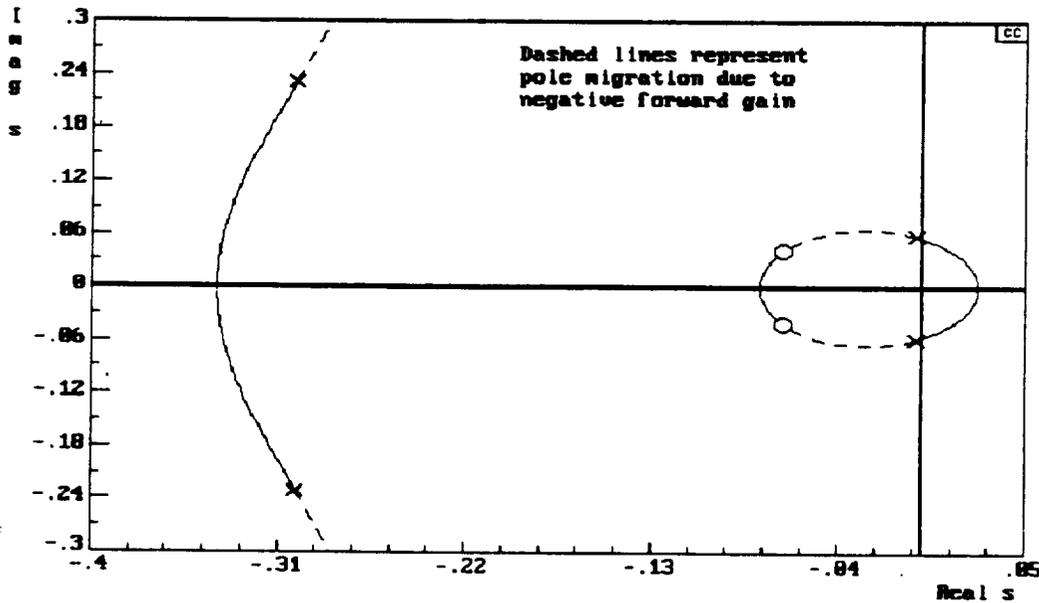
**Table 13.5**  
***The Edge* Handling Qualities**

	<b>Takeoff / (Level)</b>	<b>Subsonic / (Level)</b>	<b>Supersonic / (Level)</b>
<b>Short Period</b>			
$\omega_{SP}$ (rad/s)	0.5	0.2	N/A
$\xi_{SP}$ (rad/s)	0.96 / (1)	0.61 / (1)	N/A
<b>Phugoid</b>			
$\omega_p$ (rad/s)	0.05	0.05	0.04
$\xi_p$ (rad/s)	0.018 / (2)	0.02 / (2)	0.19 / (2)
<b>Dutch Roll</b>			
$\omega_p$ (rad/s)	N/A	0.78 / (1)	0.77 / (1)
$\xi_p$ (rad/s)	N/A	0.08 / (1)	0.05 / (2)

It should be noted that these numbers represent approximations, and the actual aircraft transfer functions could exhibit other problems and/or benefits in the three flight regimes. These approximations do, however, indicate the immediate benefits of the variable sweep design: the achievement of superior subsonic cruise performance, a fact more easily seen when considering the L/D ratio of 11 for this regime.

### 13.6 Proposed Flight Control System

Using *The Edge* geometric data, flight conditions, and the stability derivatives shown in Table 13.3, a preliminary step was performed in the design of a longitudinal flight control system for *The Edge* aircraft in subsonic and supersonic cruise. Using small perturbation theory, aircraft transfer functions were calculated for relating the forward velocity, angle of attack, pitch angle, and pitch angle rate to elevon deflection. The corresponding root locus for pitch angle to elevon deflection was obtained, and a time response to an open loop unit step input for both cruise conditions was produced. These charts are presented in Figures 13.3-13.6 for the two cruise conditions.



**Figure 13.3**  
***The Edge* Subsonic Cruise Root Locus for**  
**Pitch Angle Transfer Function**

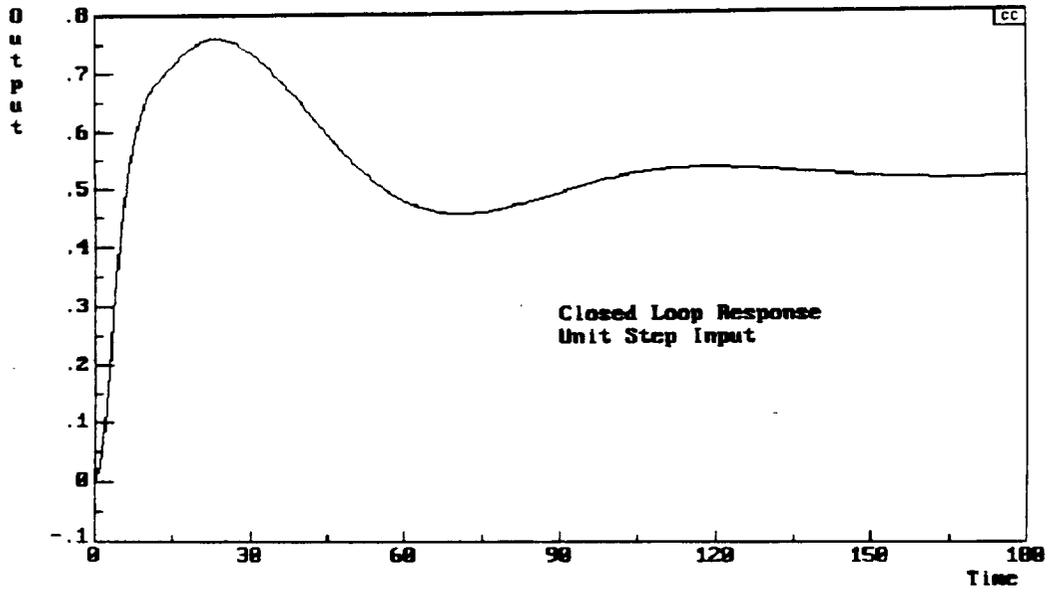


Figure 13.4  
*The Edge* Subsonic Cruise Time Response for Pitch Angle to Elevon Deflection

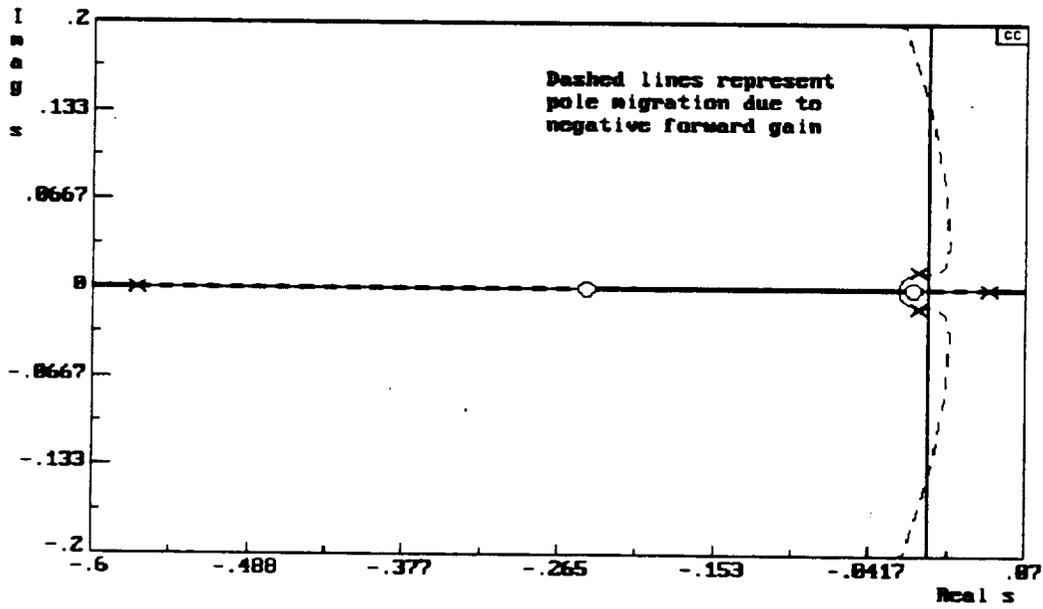
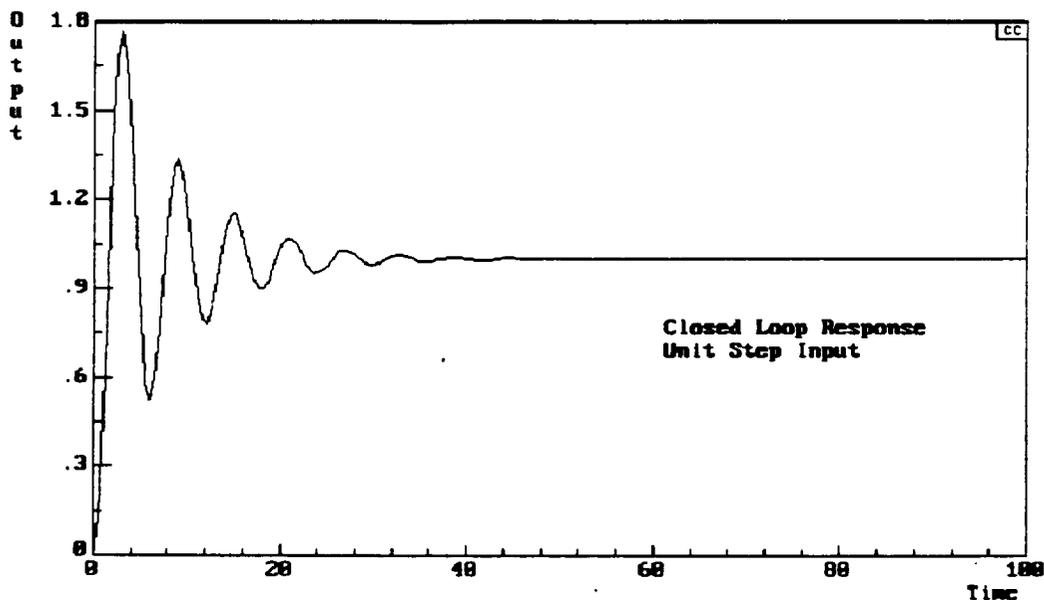


Figure 13.5  
*The Edge* Supersonic Cruise Root Locus for  
 Pitch Angle Transfer Function



**Figure 13.6**

***The Edge* Supersonic Cruise Time Response for Pitch Angle to Elevon Deflection**

From the subsonic cruise root locus shown in Figure 13.3, it is evident that the aircraft is stable providing there is no loop closure. With the addition of lag and/or lead compensators, the migration of the closed loop poles can be altered so as to provide a stable closed loop response. It is clear that the short period damping needs to be increased to reduce transient oscillations.

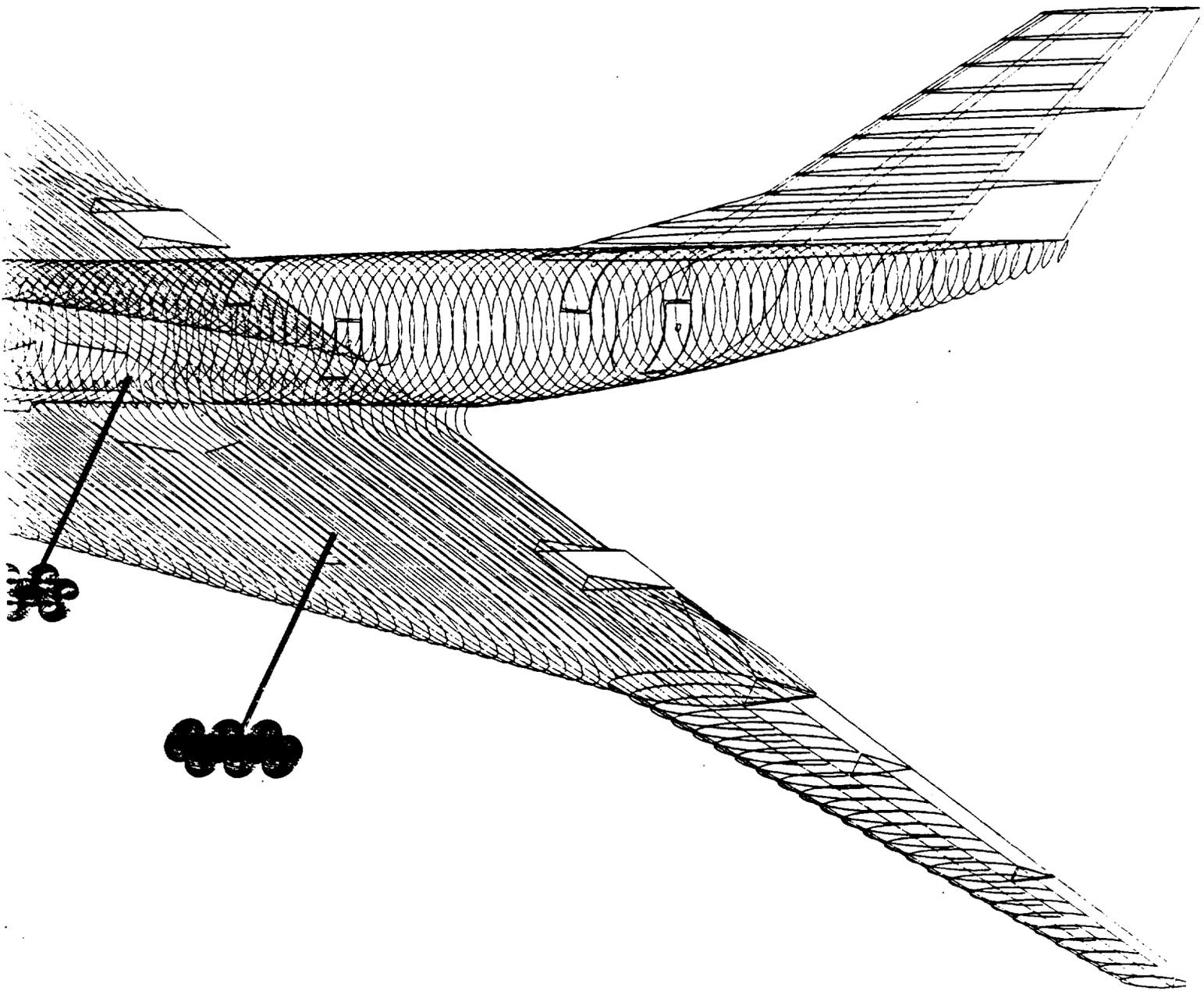
During supersonic cruise, *The Edge* is an unstable aircraft. This is evident from the root locus of Figure 13.5, as there is an unstable pole, thus resulting in inherent instability. First, a negative forward gain would provide stable closed loop pole migration. Second, the addition of a lag and/or lead compensator, would provide

adequate phugoid damping. By adjusting the forward and feedback gains, the proper time response can be achieved.

By utilizing feedback to obtain the resulting g-forces, the constraints on the gains will be evident. Further design would include a Bode plot analysis, and observing the compensator effects on gain and phase margins, crossover frequencies and crossover magnitude curve slopes.

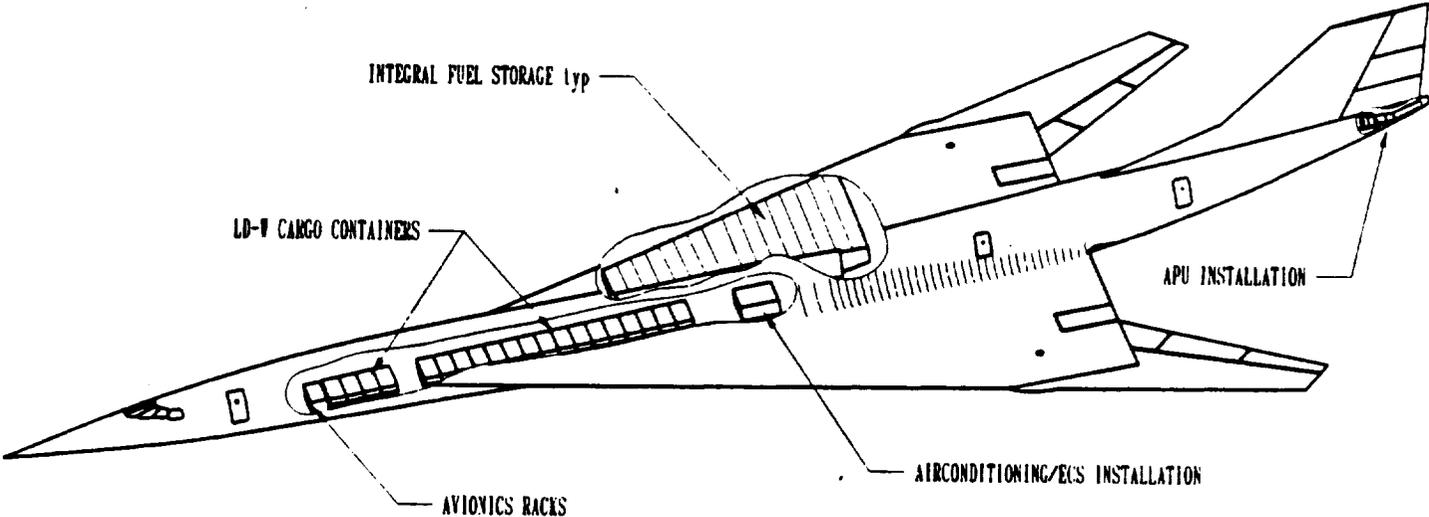
It must be clear that this is the first cut design of a flight control system for *The Edge* aircraft. Upon its completion, a sophisticated flight control system assembly will be required to monitor the a.c. location and its shifts from stable to unstable modes of flight. Further analysis is required for power approach conditions for both unswept and swept configurations. Additions to the flight control system to compensate for these modes of flight will be necessary, with special consideration being given to the emergency landing (fully swept) condition, wherein a loss of control power at high angles of attack could produce a critical situation.

# 14.0 SYSTEM LAYOUT



# 14.0 System Layout

The overall aircraft systems placement is shown below in Figure 14.1.

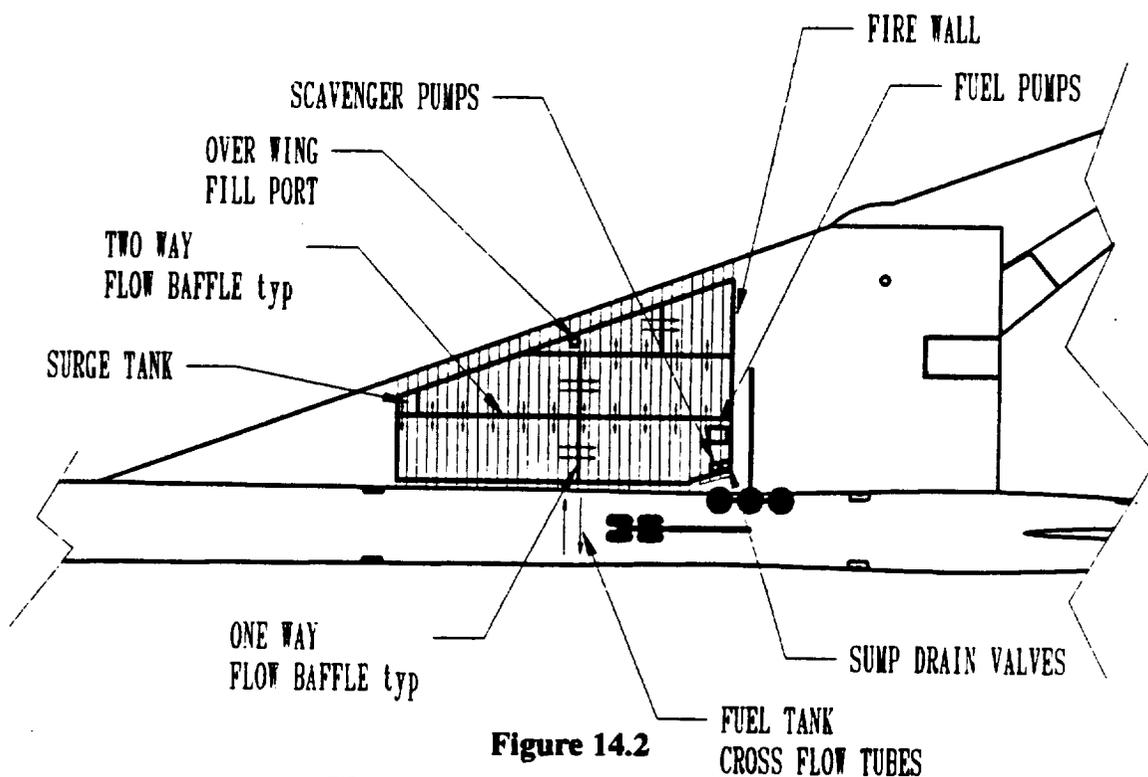


**Figure 14.1**  
***The Edge Systems Layout***

## 14.1 Fuel System

The preliminary design of *The Edge* fuel system is such that the highest degree of versatility, dependability and maintainability will be achieved.

As shown below in Figure 14.2, *The Edge* utilizes two main integral fuel tanks for the storage of JP-4 fuel, one located in the midsection of both wings. These two main tanks make use of the lateral wing rib design of the wing by allowing them to act as longitudinal, unidirectional fuel baffles; two additional bi-directional baffles are located laterally. This design inhibits sudden fuel transfers, while using wing incidence and gravity to feed fuel to the two fuel pump locations aft and inboard in each wing. For in-flight engine starting, fuel may also be pumped using auxiliary DC pumps driven by the auxiliary power unit (APU), which can be operated in flight as well as on the ground<sup>21</sup>.



**Figure 14.2**  
***The Edge* Fuel Tank Configuration**

Both main tanks have identical capacities and, by means of the fuel tank cross flow tubes running bidirectionally along the carry through spar shown in Figure 14.2, both tanks can be used to feed any engine; likewise, each engine has an emergency fuel shut-off valve and backup valve. An electronic fuel imbalance monitoring system will regulate left/right tank pumping to maintain aircraft lateral balance.

The fuel tank cross flow tubes also provide a single point fueling capability (simultaneous fueling of all tanks), with an overwing fuel port located at the leading edge of both wings.

As Figure 14.2 suggests, the rear fuel tank firewalls are placed substantially forward of the landing gear hard points, keeping the tanks out of danger should a tire or gear failure occur with the gear extended or retracted<sup>21</sup>.

## 14.2 Hydraulic and Electrical Systems

*The Edge* hydraulic controls package will be designed around four separate 4000 psi systems, one driven from each engine, and each with the capability to assume vital flight control functions; all flight controls will therefore be thrice redundant. In addition, a Ram Air Turbine (RAT) will be provided with automatic and manual deployment systems in case of full engine failure in flight. The RAT will be capable of providing power to both the flight control computer and the hydraulic controls actuation system during flight at subsonic speeds.

Each independent hydraulic system will be operable on the ground by means of its own electric pump, and will be placed in the aircraft with serviceability as a primary consideration.

*The Edge* electrical system will feature fully isolated primary and standby systems, offering a thrice redundant electrical system arrangement. The flight control computer will be designed to operate if necessary from an additional electric backup motor driven by the RAT.

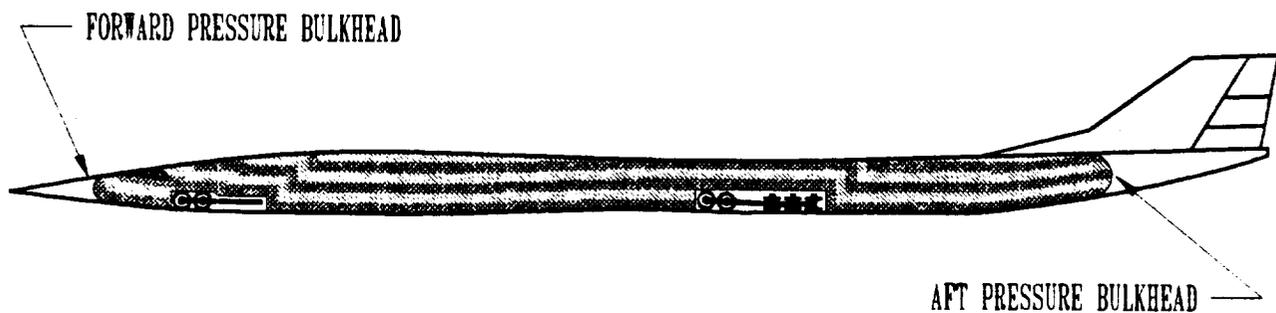
It must be noted that these systems are subject to increases in technology. For instance, by the time of *The Edge* construction, fly-by-light systems may well be at the forefront of technology; this would allow the use of small, DC hydrostatic pumps local to the actuators they are powering. These compact systems would be directed by a fiber-optics network interpreting pilot control inputs. Such a system would be advantageous not only due to its dramatic weight decrease and superior maintainability, but also because of its immunity to electromagnetic interference<sup>23</sup>.

### 14.3 Environmental Control Systems

Since *The Edge* cruises supersonically at altitudes well into the stratosphere, a safe and efficient pressurization system is a crucial priority.

To this end, *The Edge* fuselage will incorporate an extensive system of crack propagation stoppers as discussed in Structures, Section 11.0. *The Edge*'s elimination of windows (with the exception of emergency doors) also aids in a more economical, and therefore, a safer design since this in effect reduces the number of structurally critical areas dramatically. *The Edge* fuselage will be pressurized to an equivalent altitude of 8,000 ft, providing a level of comfort competitive with today's 747-400<sup>20</sup>. An illustration of the pressurized fuselage is shown in Figure 14.3.

The theme for *The Edge* equipment cooling and air conditioning systems will be one of efficiency and passenger comfort. These systems are included in the representation of Figure 14.1. Multi-zone automatic temperature control will be employed in the cabin and cockpit areas, utilizing what is likely to be a liquid-coolant based cooling system pending state-of-the-art improvements by the year 2015. Heating of the cargo compartment and/or the cabin areas may be effected using heat from the outer aircraft surfaces. Efficiency in the pneumatic system design will be achieved by using engine bleed air for only half of the conditioned air volume; the remaining half will be generated through recirculated air filtering<sup>20</sup>.



**Figure 14.3**  
***The Edge* Pressurized Fuselage Representation**

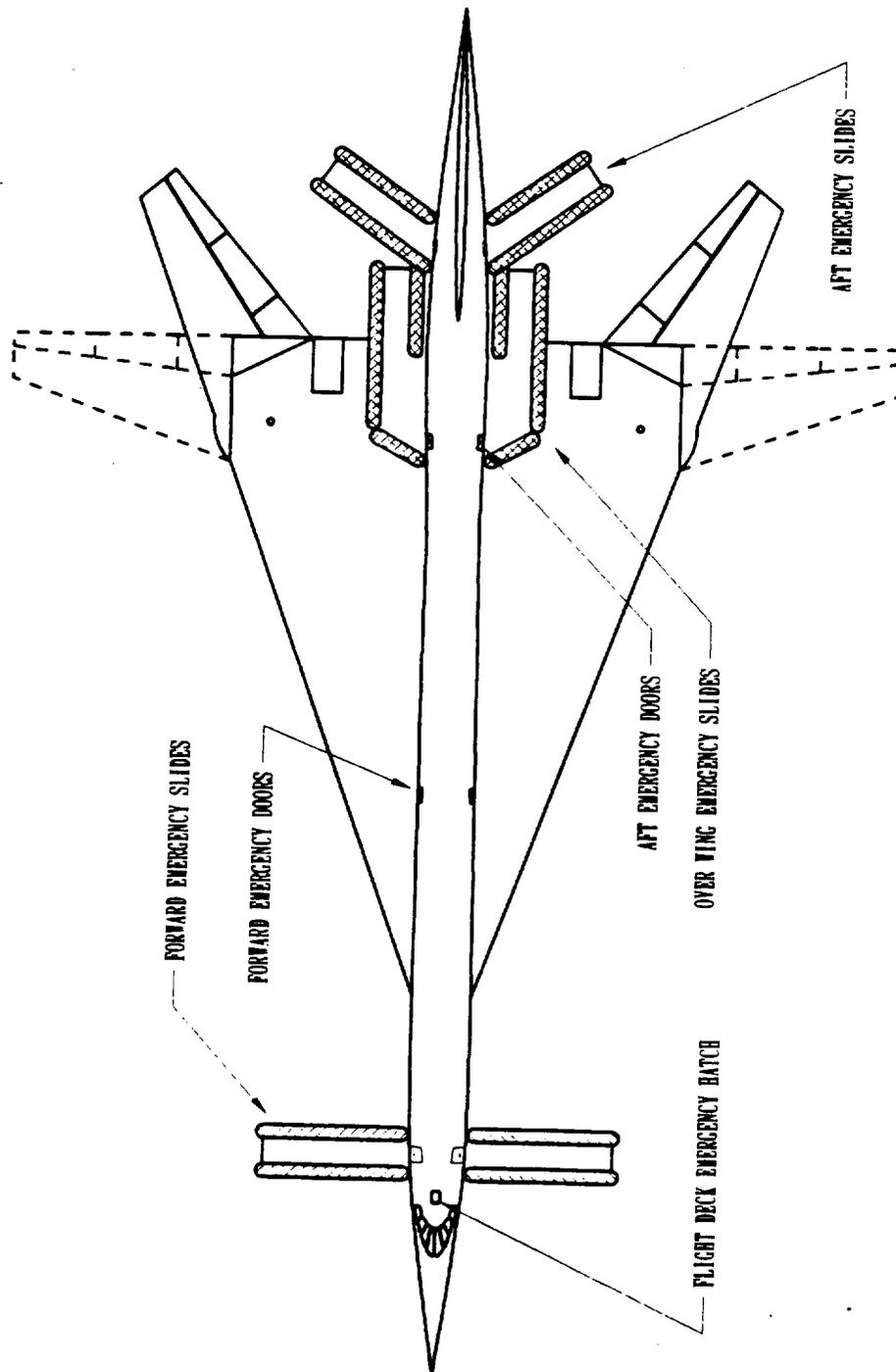
## 14.4 Flight Control System

Please refer to Section 13.6., Stability and Control

## 14.5 Emergency Systems

*The Edge* aircraft is equipped with current state of the art emergency systems in the event of an emergency. In the event of a cabin pressurization failure, oxygen is provided for all occupants. The flight crew is provided with a gaseous oxygen cylinder and two oxygen masks. The passengers, flight attendants and observers are provided with chemical oxygen. If depressurization occurs the chemical oxygen masks will be automatically deployed; an alternate manual deployment is also provided. Additionally, two portable oxygen bottles are to be located at each flight attendant's station<sup>21</sup>.

If evacuation from the aircraft is required, there are nine exits including: two forward loading doors, two aft loading doors, four over-wing emergency doors, one overhead flight deck emergency hatch. Inflatable slides are provided at all four loading doors and the two aft emergency doors which will deploy automatically when an emergency door is opened as shown in Figure 14.4. In addition, a manual override is provided to either open the emergency doors without deploying the slides or deploy any number of slides in the event that an emergency door can not be opened. The evacuation will be aided by the nose gear strut retracting to its loading position automatically with the deployment of a slide<sup>21</sup>. This retraction is fail-safe, since it will be effected under the weight of the nose itself; a manual override will be provided to ensure nose gear retraction.



**Figure 14.4**  
*The Edge* Emergency Departure Systems

## 14.6 Synthetic Vision System

Adequate flight crew vision is challenging to provide in supersonic transport designs, in that aerodynamic concerns requiring long and slender noses conflict with vision needs necessitating extensive viewports nearly perpendicular to the oncoming flow. *The Edge* meets this challenge with a comprehensive synthetic vision system.

There are few methods by which to circumvent the aforementioned problem, one of which is the droop-nose design used by the *Aerospatiale Concorde*<sup>27</sup>. Unfortunately, this compromise includes significant weight penalties, and its benefits are only utilized upon landing. As another alternative, the flight deck window can be designed at appropriate angles for acceptable vision, regardless of aerodynamic penalties; however, these penalties are substantial.

It would be naive to insist that a synthetic vision system is an ideal alternative. Its compromises include a substantial reliance on electronics and artificial optical networks, and the likelihood of substantial expenditures for FAA certification. On the other hand, such a system has the potential to significantly increase the pilots' viewing capabilities, while also serving as an appealing passenger amenity by way of individual, interchangeable LCD screens placed at all seats in the main cabin. Moreover, there are no substantial weight or drag penalties associated with a synthetic vision system. On balance, the benefits of such a system appear to clearly outweigh the detriments.

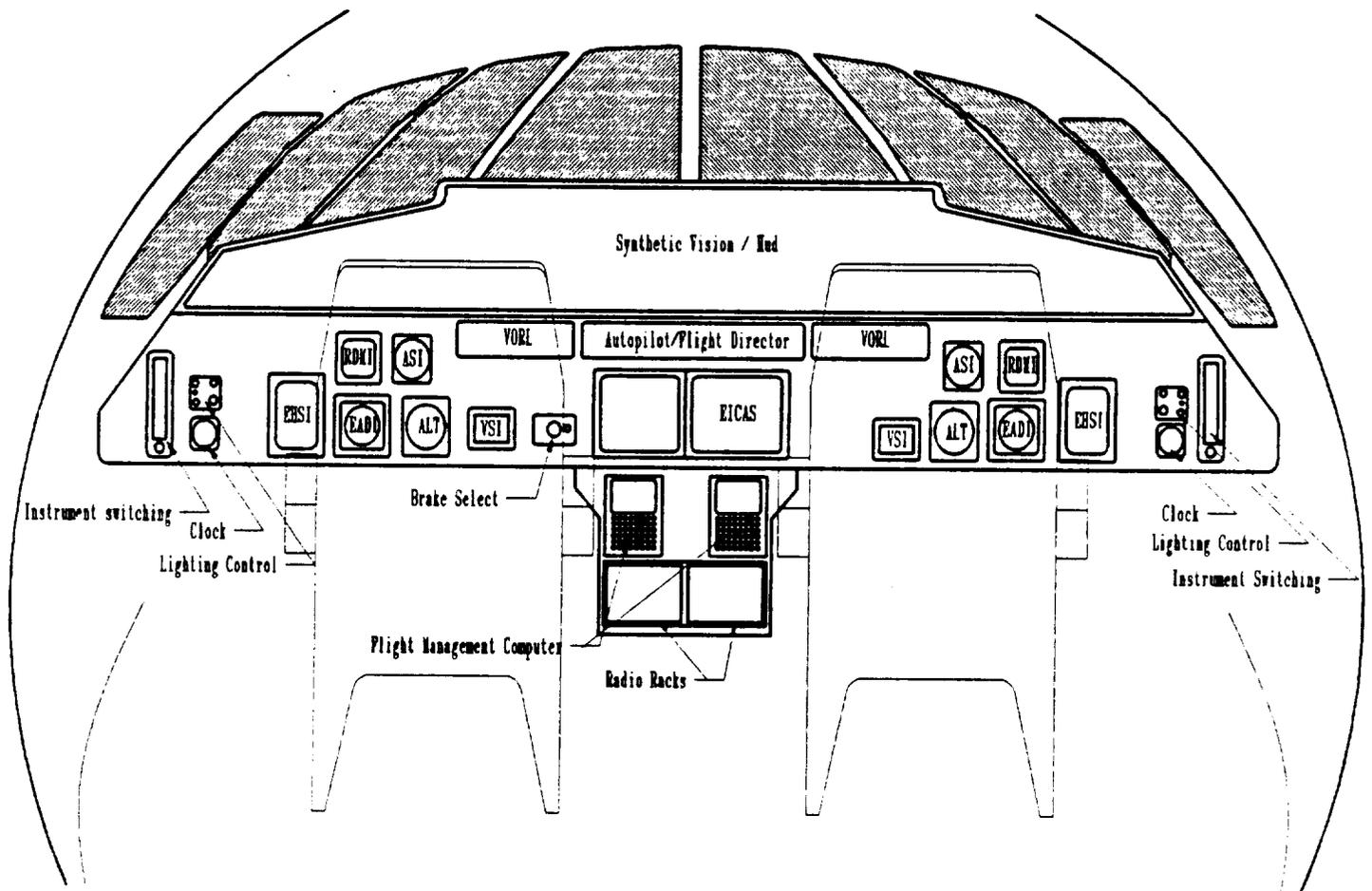
*The Edge* will utilize this type of vision arrangement, while attempting to address the issues of systems reliability and overall safety. First, the see-by-wire or see-by-light system will incorporate substantial redundancy. Second, a mechanical backup system will be designed in addition to flight deck windows; in particular, this backup will be in the form of a gravity-dropped periscope which will lock into place beneath the cockpit fuselage area in emergency situations, and allow limited though crucial forward flight vision.

The synthetic vision system itself will be used in the form of a head's-up display (HUD), whereby the views naturally blocked from the pilots' eyes by the aircraft nose will be seen by means of artificial images projected onto a screen below, and extending up to the bottom of, the flight deck window. This screen can be seen clearly in Figure 14.5.

## 14.7 Flight Deck

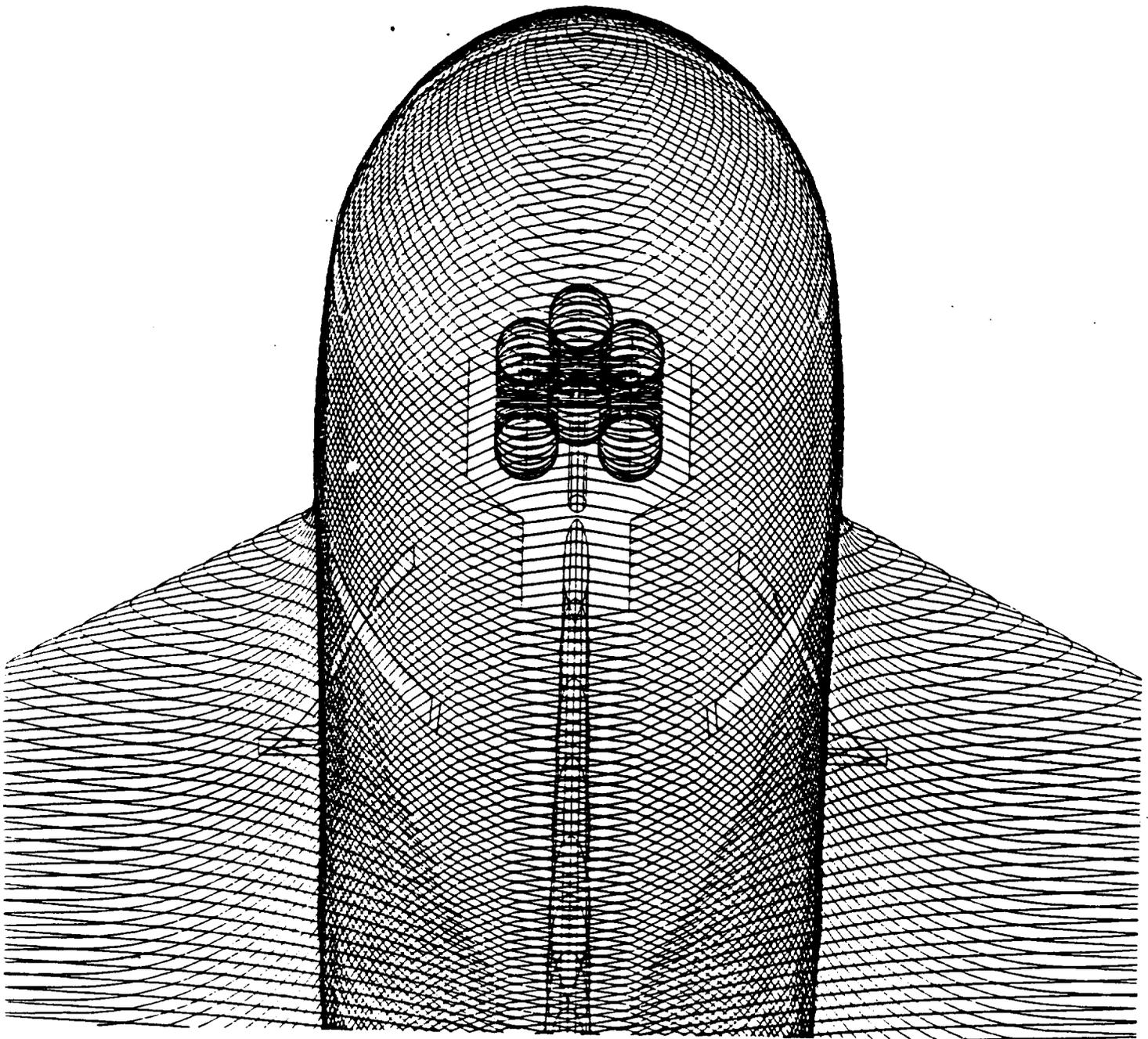
*The Edge* SST is a state-of-the-art commercial aircraft which will begin service in the year 2015. The two-pilot flight deck of this aircraft will therefore be a product of the future, incorporating fly-by-wire or even fly-by-light avionics, and a comprehensive synthetic vision system as described above in Section 14.6.

Additionally, the flight deck as shown in Figure 14.5 will include the use of head's-up displays (HUDs) situated on the flight deck window, providing all critical flight information at an infinite focal point on the pilots' horizon; and while this HUD and the HUD described in Section 14.6 will provide the largely intangible benefit of increased flight safety, they may also translate into a tangible easing of vision requirements by the FAA, since HUD systems will allow superior vision in poor weather environments<sup>23</sup>. Of course, multiple LCD displays will be provided in the cockpit to supplement the functions of the HUD.



**Figure 14.5**  
***The Edge* Flight Deck**

# 15.0 AIRPORT MAINTENANCE AND OPERATION

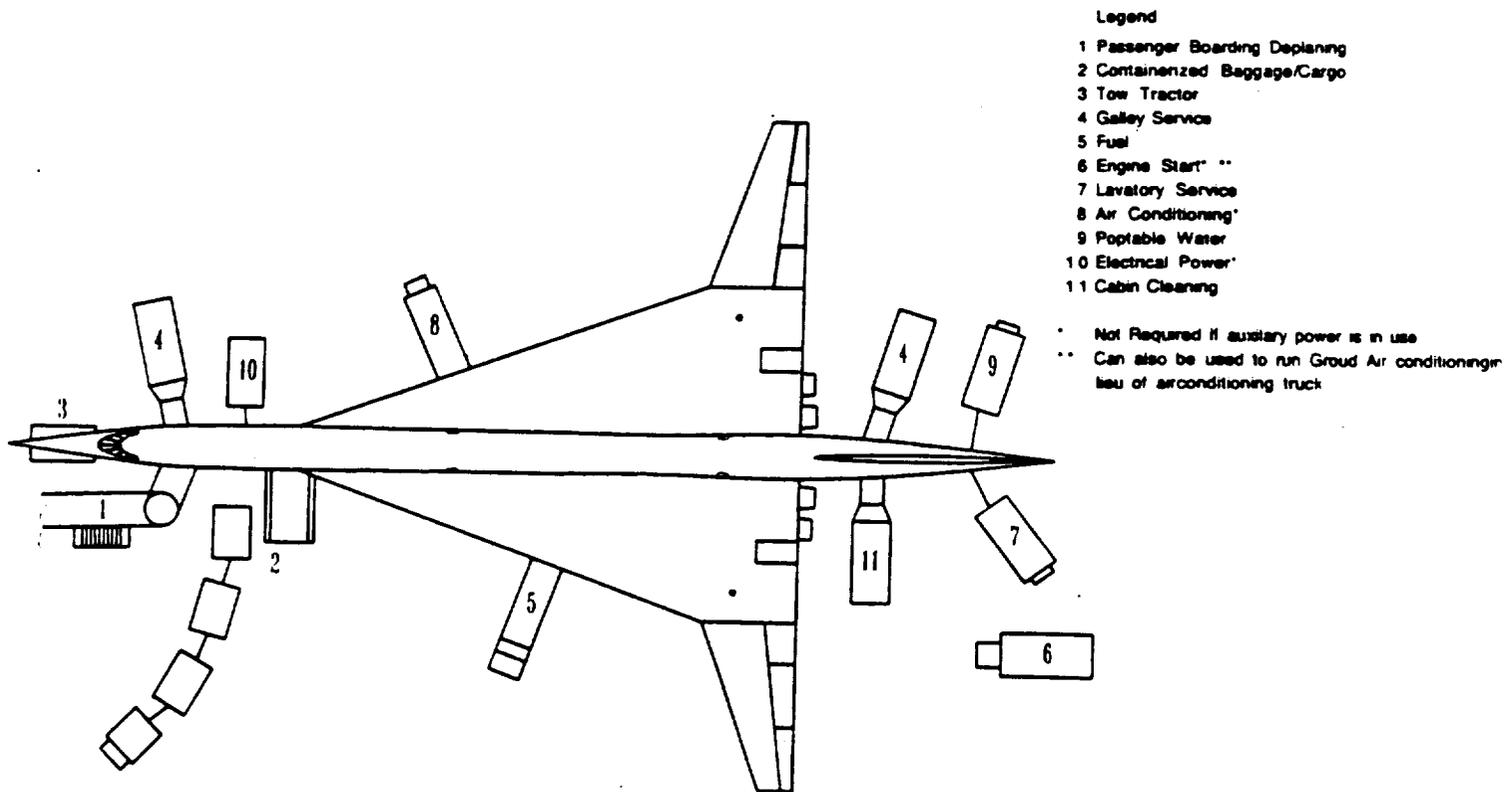


## 15.0 Airport Maintenance and Operation

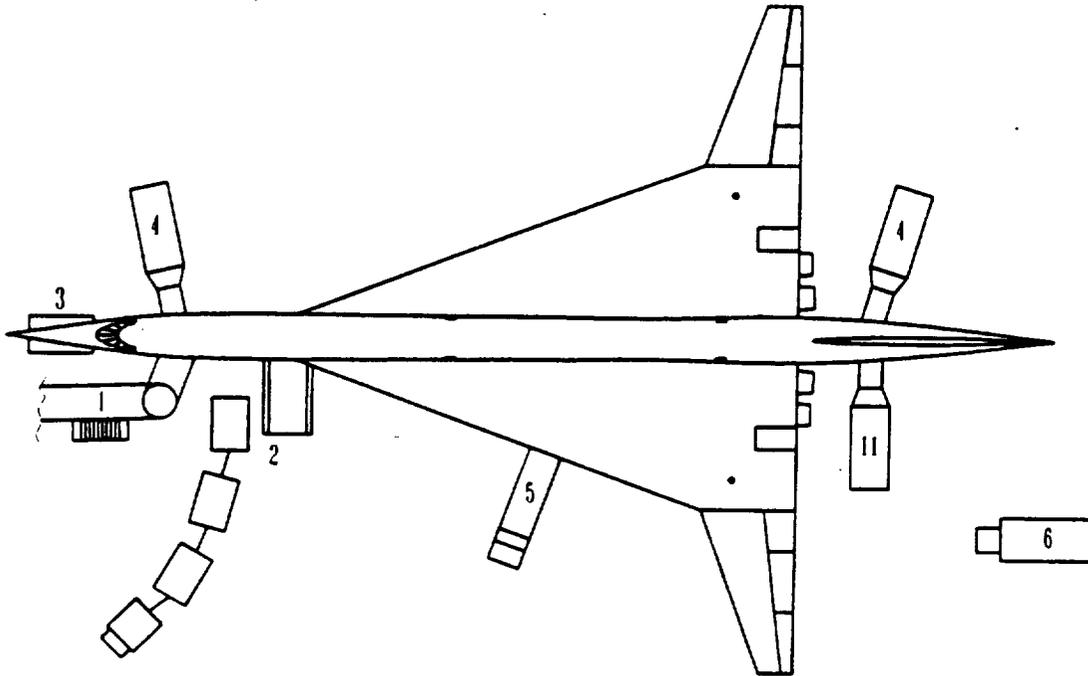
### 15.1 Airport Maintenance

*The Edge* is designed to be compatible for use in all existing major airports. This means that it will require no special fueling, cargo handling, servicing, or maintenance provisions. In particular, *The Edge* provides roughly equivalent airport compatibility to that of the currently popular 747-400.

Figure 15.1(a) shows the servicing arrangement utilized by *The Edge* during stop-overs, and Figure 15.1(b) shows a modified configuration for turnaround servicing.



**Figure 15.1 (a)**  
***The Edge* Stop-Over Servicing Arrangement**

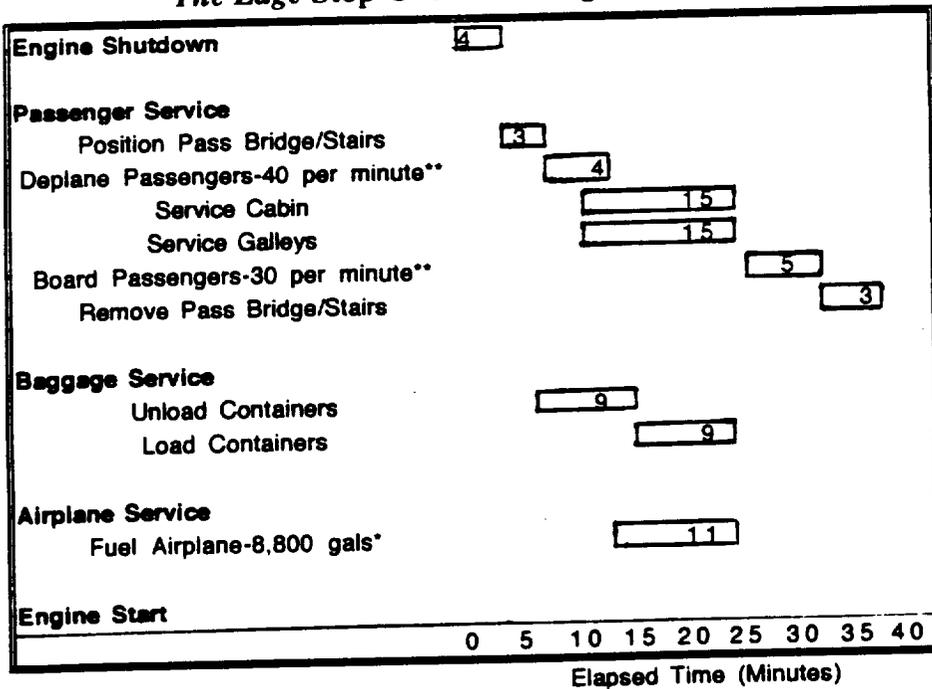


**Figure 15.2 (b)**  
***The Edge* Turnaround Servicing Arrangement**

### **15.2 Airport Operation**

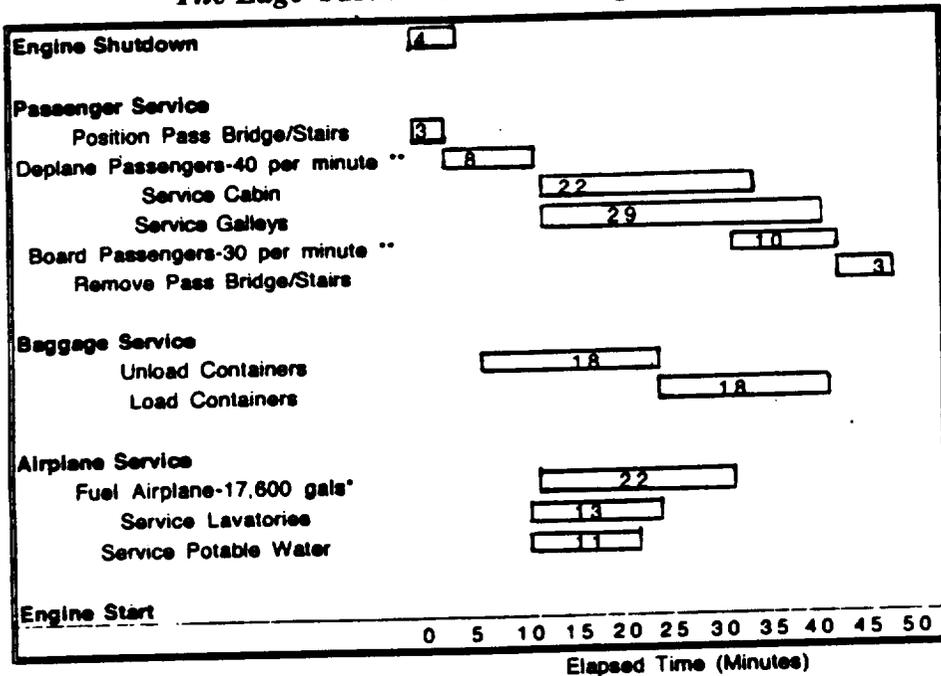
In order to deliver the maximum benefits of *The Edge's* time-saving flights to its customers and operators, it has been designed for minimum stop-over and turnaround times. Table 15.1 illustrates a temporal representation of *The Edge's* stop-through service procedure. It is notable that *The Edge* will be able to stop for fuel and take off again within 45 minutes<sup>20</sup>. As well, Table 15.2 presents a similar diagram for turnaround times. Once again, efficiency is the prevailing concern.

**Table 15.1**  
**The Edge Stop-Over Servicing Breakdown<sup>20</sup>**



\* 800 gals per minute  
 \*\* 100% load factor  
 50% exchange of passengers

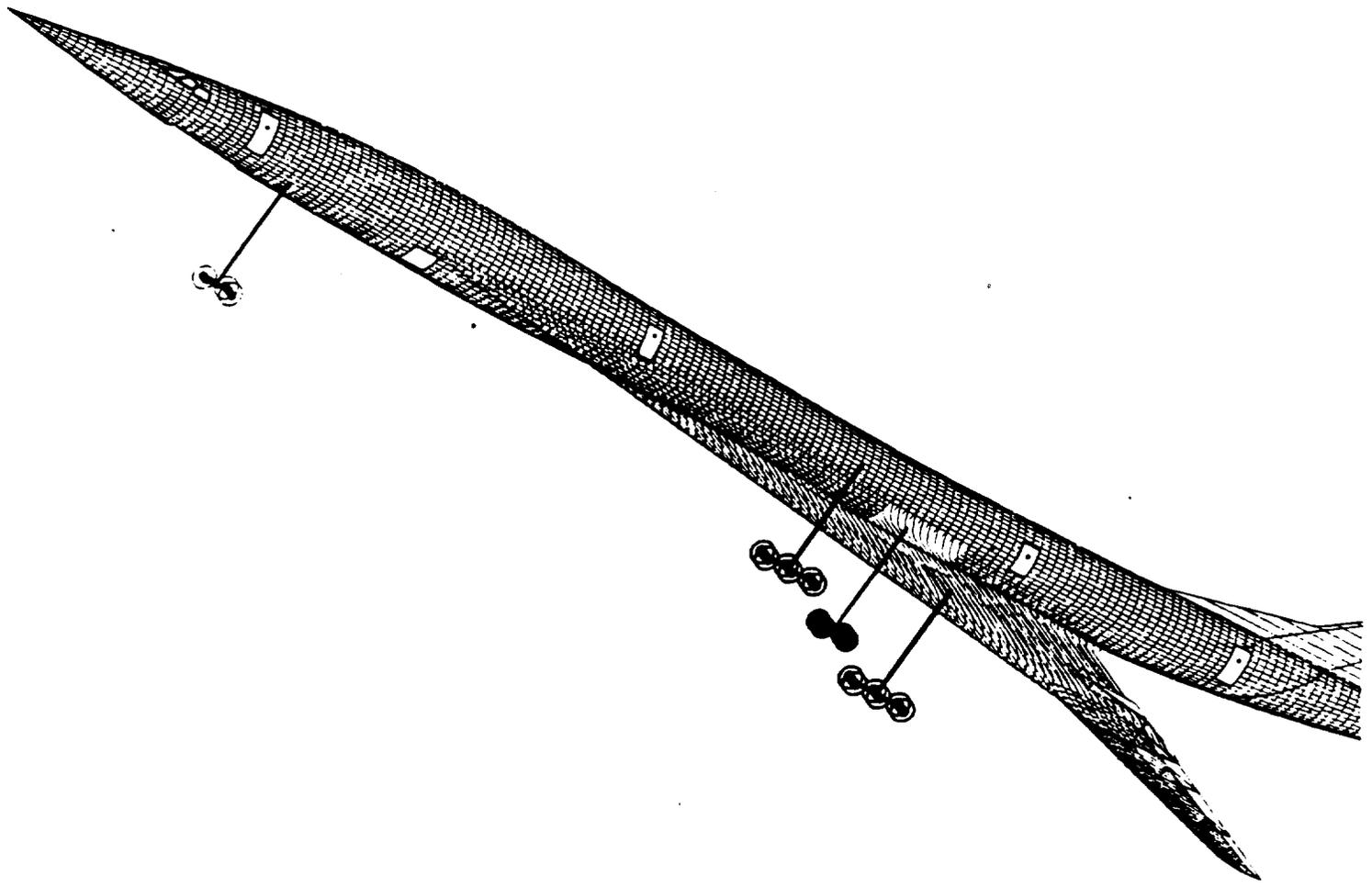
**Table 15.2**  
**The Edge Turnaround Servicing Breakdown<sup>20</sup>**



\*800 gals per minute  
 \*\*100% load Factor

It should be clear from these tables that fueling is a major influence on ground servicing times. One aid in reducing these times, however, is the exclusive use of LD-W baggage containers; these allow the quick and efficient transfer of passenger belongings.

# 16.0 MANUFACTURING



## 16.0 Manufacturing

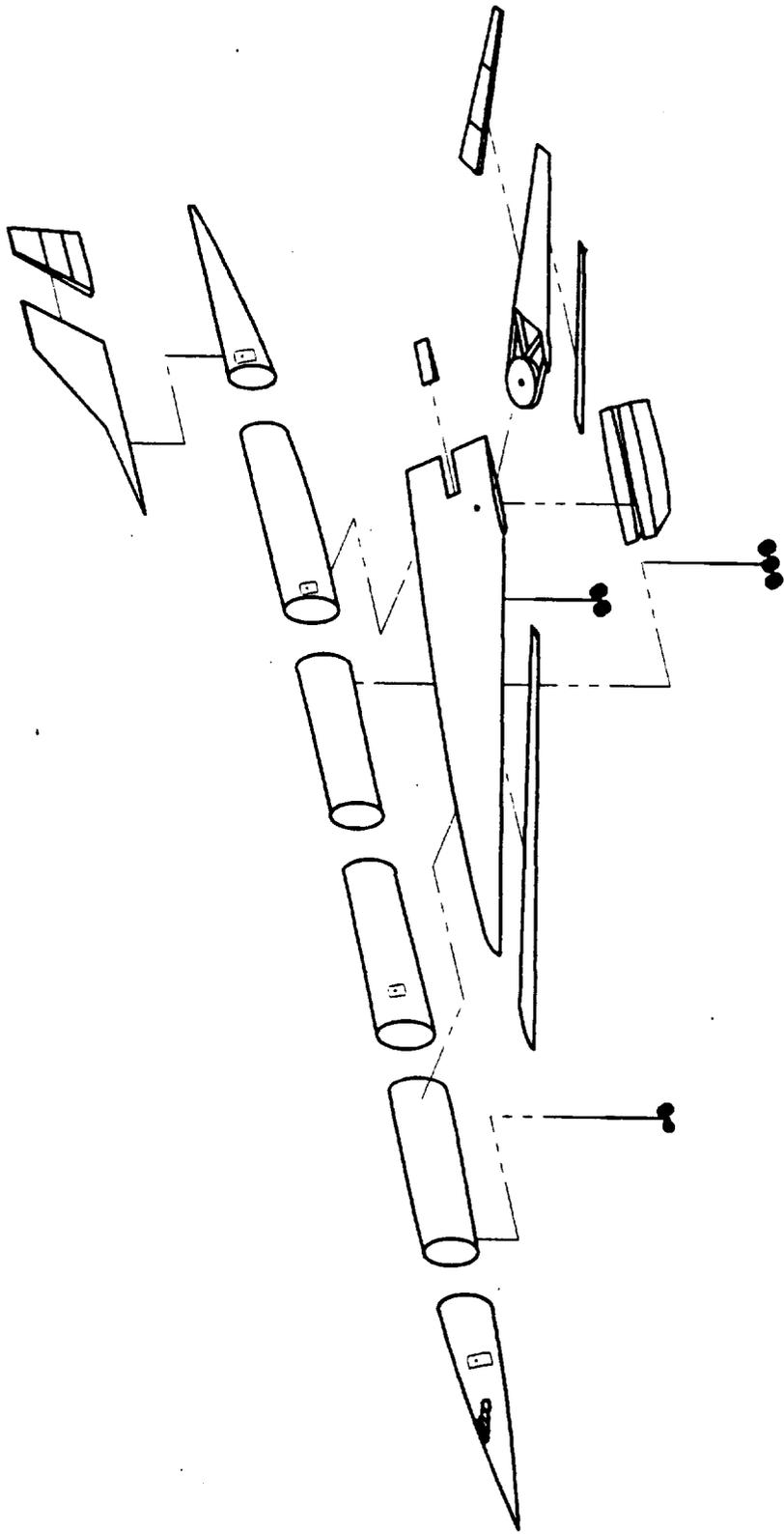
Planning the manufacturing process entails organizing the material flow, so that everything is in the proper place at the proper time. As well, major aircraft sections must be constructed from several smaller parts in order to yield a maximum production rate. Close tolerances and careful planning must always be used when constructing an aircraft, in order that it will not only meet all the requirements, but also be safe.

Since *The Edge* will be largely constructed of titanium or other exotic materials, forming and machining will be relatively difficult and expensive. To help reduce manufacturing costs, parts will be made right/left interchangeable whenever possible. Of course, many of the several million aircraft pieces and components will be subcontracted, entering *The Edge* factory in finished form.

The assembly of *The Edge* will occur in several phases, similar to the assembly of modern transport aircraft. Figure 16.1 allows a glimpse of these steps, which include the assembly of the six fuselage sections, and the subsequent attachment of the vertical tail and wing surfaces to the full fuselage.

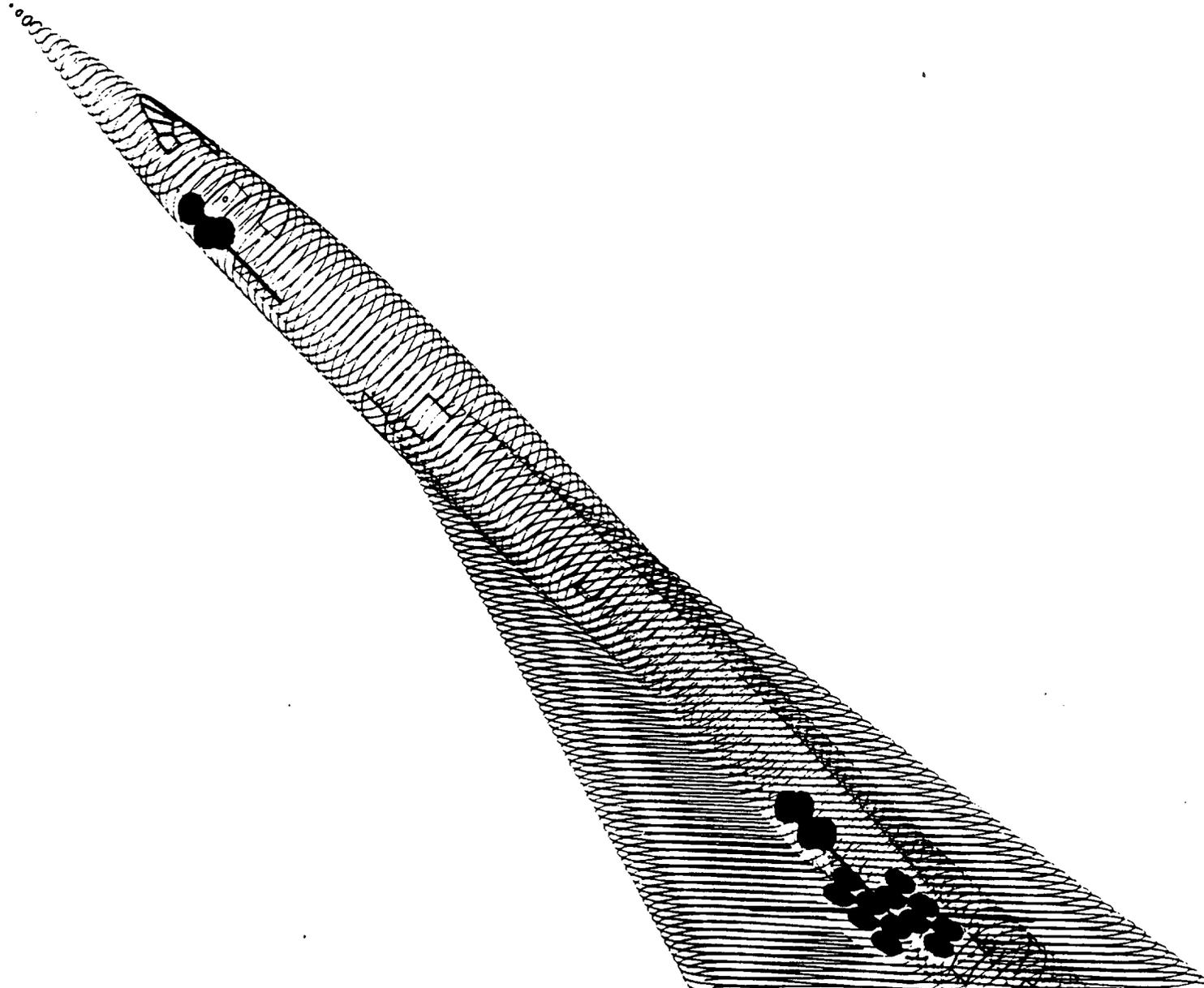
The most dramatic excursion from current manufacturing processes occurs in the attachment of *The Edge* wing tips to the main wing. First, the wing tips are fitted with heating blankets to expand the fitting material. While this is being done, the pins are frozen in liquid nitrogen. These processes take approximately fifteen minutes, after which the tips are slipped into position, and the joint is allowed to swell for an interference fit<sup>33</sup>.

Although this process may appear exotic, it is actually no more than an extension of methods being used today. That is, liquid nitrogen freezing, as well as the preheating of parts is common, though not typically on such a large scale. Aside from this, however, *The Edge* will be constructible using contemporary methods, thus aiding in the ultimate goal of low overall cost.



**Figure 16.1**  
***The Edge Manufacturing Layout***

# 17.0 COST ANALYSIS



## 17.0 Cost Analysis

The economic viability of a Supersonic Transport (SST) is of the upmost concern for *The Edge* design team. Due to the plane's extensive use of high technology materials, the manufacturing techniques will be the very latest available to the airframe builder. A cost analysis is performed here based on contemporary commercial transports for manufacturing and operating costs<sup>30</sup> using 1989 dollars. *The Edge* economic study is scaled to 1992 dollars using a Cost Escalation Factor (CEF), and a price of \$167 million per aircraft is determined for a production run of 400 supersonic transports.

### 17.1 Costs for Research, Development, Test, and Evaluation

The cost for research, development, test, and evaluation (RDT&E) is based on an Aeronautical Engineering Manufacturer's Planning Report (AEMPR) value of 205,000 lbs. This is the weight of the aircraft that the airframe manufacturer will be building. This cost is broken down into seven categories as shown in Figure 17.1.

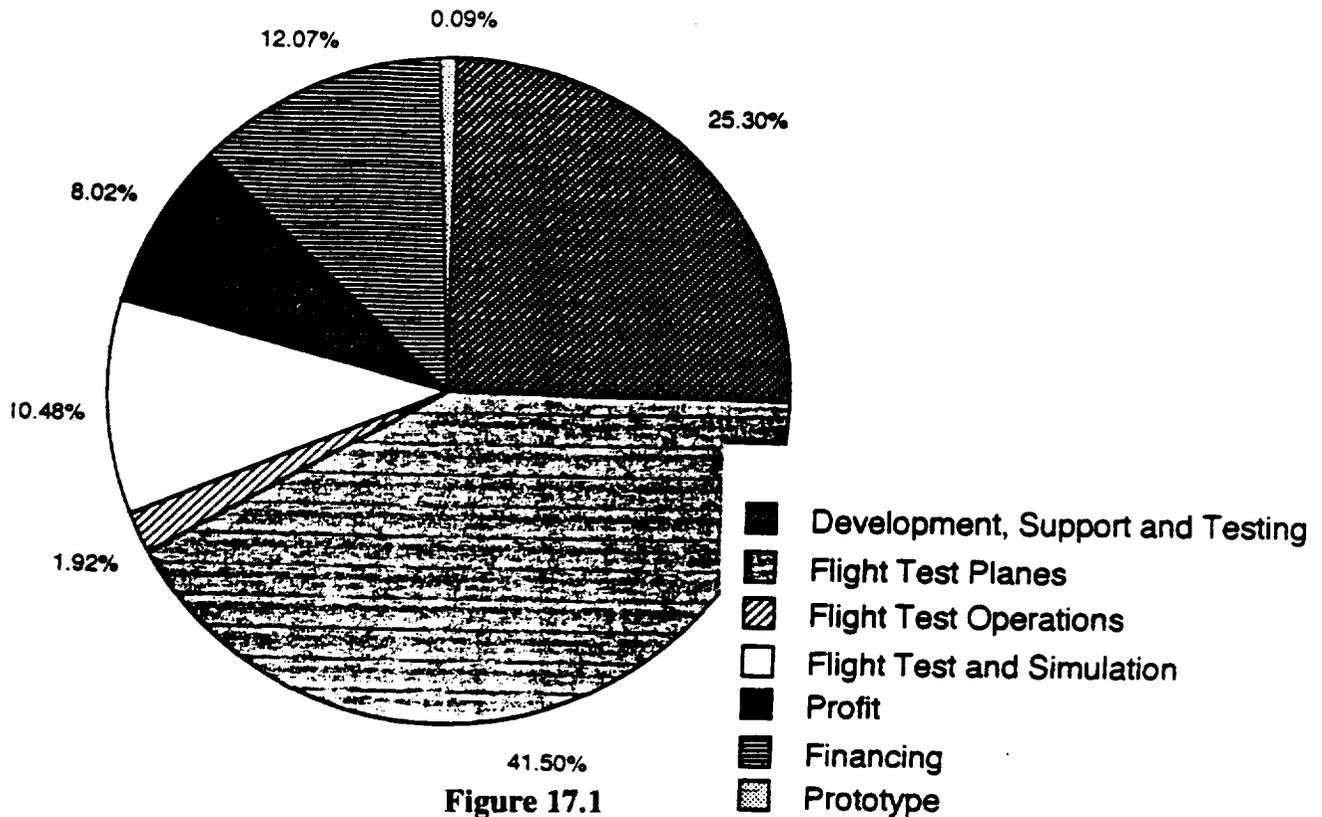


Figure 17.1

Summary of

Research, Development, Testing and Evaluation Costs for *The Edge*

### **17.1.1 Engineering and Design Cost**

Based on the AEMPR, an estimation for the number of hours required for airframe engineering and design is 89 million hours. This translates into 8,000 engineers working for 5 and one half years. Producing a total of three aircraft for testing should be sufficient; one will be exclusively for flight test, and two for ground static tests. Accounting for the design difficulties caused by the materials currently being considered, and offsetting these with future computer-aided design capabilities, a total cost for engineering and design is estimated at 570 billion dollars.

### **17.1.2 Development Support and Testing**

The cost for development and support for three aircraft is estimated at \$350 million<sup>30</sup>.

### **17.1.3 Flight Test**

The cost of building three flight test aircraft must include engine costs, avionics, materials, tooling, and quality control. An estimated 76 million hours will be required to build the tooling for manufacturing at 1992 tooling labor rates of \$45 per hour. In addition, manufacturing labor rates of \$35 dollars per hour and 47 million hours are estimated to build these test aircraft. Thus, a total projected flight test program cost of 574 million dollars will include the cost of the engines, avionics, tooling, manufacturing, materials, and quality control<sup>30</sup>.

### **17.1.4 Flight Test Operations**

Aircraft flight testing operations for airworthiness and FAA certification is estimated at \$26 million<sup>30</sup>.

### **17.1.5 Test and Simulation Facilities**

Test and simulation facilities will provide a place for static ground testing and simulator testing for the pilots and avionics. This was estimated at 10% of the total cost for RDT&E <sup>30</sup>.

### **17.1.6 Profit and Financing**

Adding a 10% for profit and an interest rate of 15% to the total cost for RDT&E will account for financing while allowing an acceptable profit margin. This estimate for profit is an approximate estimate and could range between 8% and 12%. Due to the high cost of an SST program, a consortium of companies and countries will doubtlessly be involved in the project, and the cost of financing will subsequently be affected by this influence<sup>30</sup>.

### **17.1.7 Prototype**

The first article prototype is estimated to cost \$83.8 million. This amount reflects only the cost to manufacture one airframe, excluding engines and avionics. After all costs are taken into account for RDT&E, an estimation of the total program cost is approximately \$580 billion<sup>30</sup>.

## **17.2 Manufacturing Cost and Acquisition**

Manufacturing cost and acquisition is delineated into four categories and will yield a projected cost for manufacturing as described below.

### **17.2.1 Airframe Engineering and Design**

Airframe engineering and design, including a production run of 200 aircraft results in an estimated airframe engineering and design cost of \$12.3 billion<sup>30</sup>.

### **17.2.2 Manufacturing Cost**

The manufacturing cost for a 300 seat SST consists of interior, tooling, materials, and quality control. Estimating an average value of \$2000 per seat<sup>30</sup> results in \$125 million for the interior. It must be noted that this is only an average and may fluctuate depending on the airline. A total manufacturing cost of \$32.5 billion is estimated for the manufacture of 200 aircraft at a production rate of 5 aircraft per month, allocating 10% of the total cost for quality control.

### 17.2.3 Flight Testing

Flight testing must be performed for every aircraft manufactured. An operating cost of \$4,190 per hour and 10 hours of testing for each aircraft will cost approximately \$35.5 million for 200 aircraft.

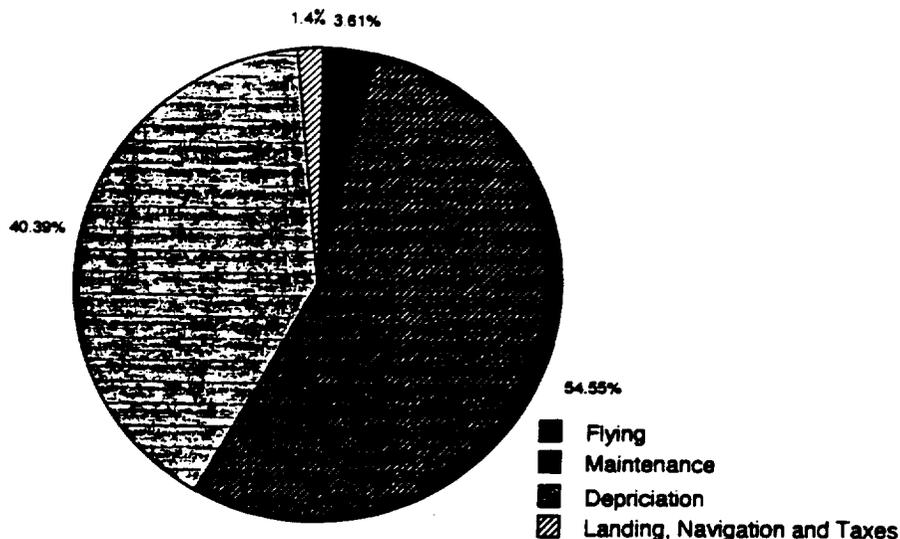
### 17.2.4 Financing Costs

The cost of financing is challenging to estimate due to the fact that a consortium of countries will most likely be involved throughout the SST project. Therefore, although it may vary for different countries depending on their relative project involvements, an approximate finance cost is 15% of the total manufacturing debt. Profit also fits into this category. No one country will be building an entire SST as a sole venture, so profits will be taken out of each manufacturing phase as it is completed. For the purpose of this design report, a 10% profit margin will be assessed to the total cost of manufacturing.

The total cost of manufacturing 200 SST aircraft is estimated to be \$52 billion.

### 17.3 Direct and Indirect Operating Cost

Direct and indirect operating cost is divided into several categories as illustrated below.



**Figure 17.2**  
**Summary of Operating Costs for *The Edge***

### **17.3.1 Flying**

Flying the aircraft incurs several costs, including flight crew, fuel and oil, and insurance. As previously explained, a crew of two will fly *The Edge*. Use of this minimal crew will cut operating costs. The cost incurred by the crew includes their salaries, travel expenses, vacation, sick leave, insurance and miscellaneous expenses. Average salaries for the captain and first officer are estimated at \$150,000 and \$70,000, respectively (1992 dollars)<sup>30</sup>. Considering the costs mentioned and flying 750 hours annually yields a flight crew cost of \$0.46 per nautical mile. Fuel and oil costs are substantial to an airline; at a fuel cost of \$0.60 per gallon and oil at \$15 per gallon, the total costs for fuel and oil are estimated at \$0.31 per nautical mile. Additionally, insurance is estimated at \$0.03 per nautical mile. This projects a total flying cost of \$0.80 per nautical mile.

### **17.3.2 Maintenance**

Maintenance of the airframe and engines is essential to the safety of the passengers and crew. The man-hours required to maintain an aircraft of this size total approximately 21.7 per hour of flight time. Materials for engine maintenance is the largest expense at \$356 per hour of flight time. Combining the cost for labor and materials for the airframe will bring the total cost for maintenance to \$46,344 per hour of flight time<sup>30</sup>.

### **17.3.3 Depreciation**

Depreciation allows the airline to know how much its investment is worth after the aircraft has served its life cycle. This cost includes the depreciation of the airframe, engines, avionics and spare parts. The depreciation period is difficult to project due to the high speed and exotic aircraft materials being used. This period has been projected to 10 years for the airframe, 7 years for the engines and 5 years for the avionics. The total depreciation of *The Edge* is estimated at \$8.92 per nautical mile<sup>30</sup>.

### 17.3.4 Fees

Fees for landing, navigation, and various taxes will vary since the plane is designed for intercontinental travel. Expenses incurred as the aircraft travels internationally and uses each country's navigational equipment are difficult to estimate due to the fact that fees differ in different countries and are levied in different ways. An average cost for this has been estimated at \$0.32 per nautical mile<sup>30</sup>.

### 17.3.5 Financing

The means by which each airline is financed is dependent upon the country of its operation and the condition of the overall market. An average finance cost has been estimated at 7%. The total direct operating cost of *The Edge* SST is estimated to be \$23.62 per nautical mile<sup>30</sup>.

The aircraft cost model outlined in Reference 30 yields a statistical price of \$240 million per aircraft based on the gross takeoff weight<sup>30</sup>. *The Edge* cost analysis yields a cost of \$167 million per aircraft (in 1992 dollars) for a production run of 400 supersonic transports, as can be seen in Figure 17.3.

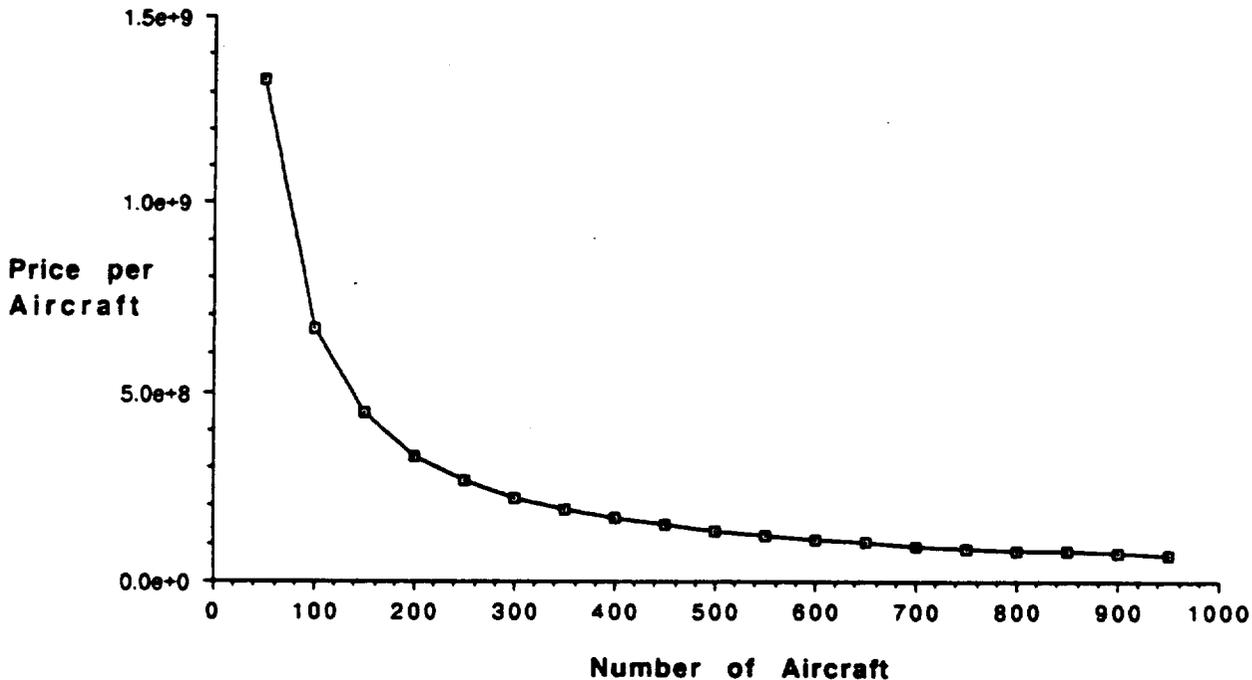
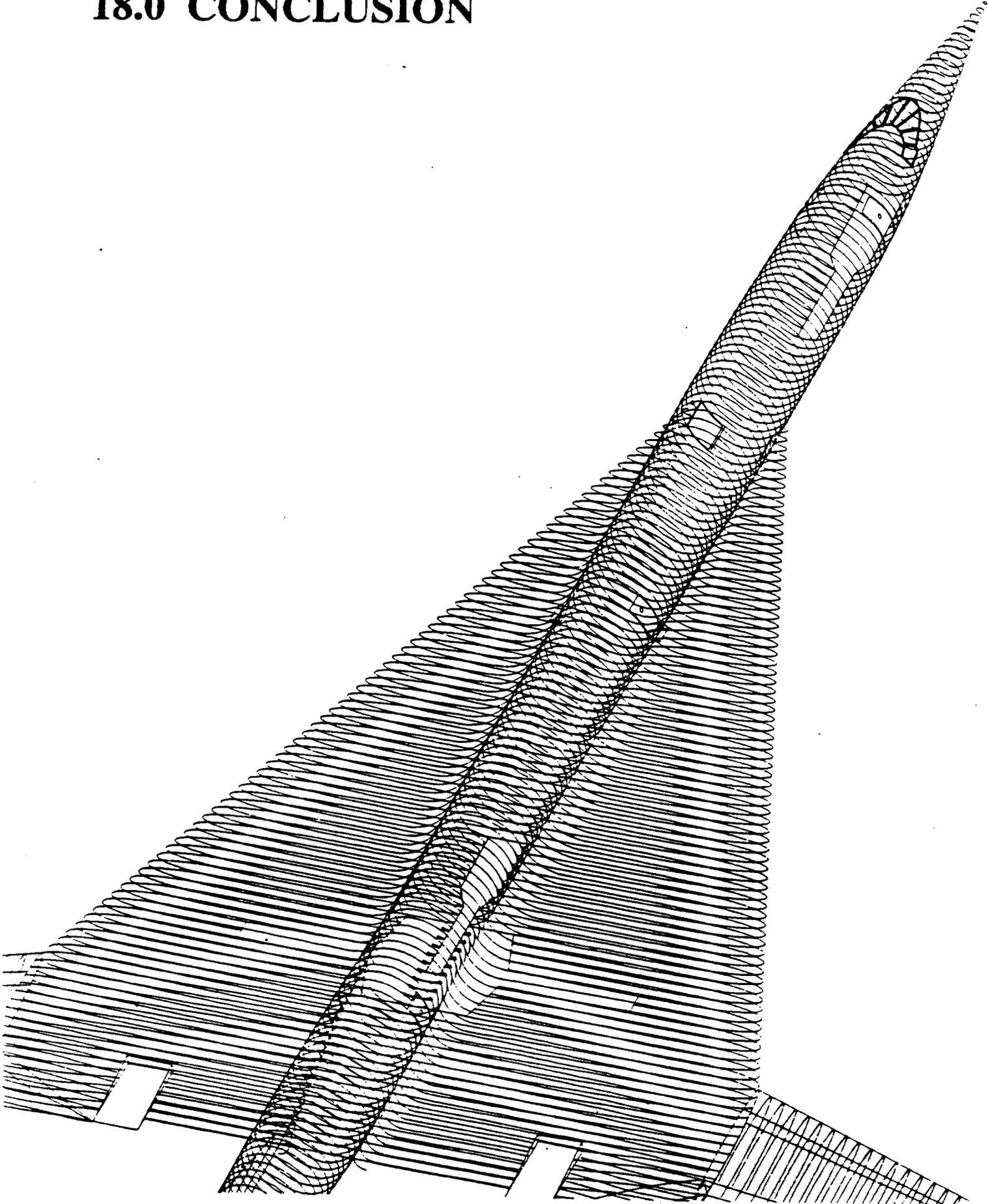


Figure 17.3  
*The Edge* Price per Aircraft vs Production Number

# 18.0 CONCLUSION



## 18.0 Conclusion

*The Edge* supersonic transport aircraft is designed specifically to capture a substantial share of the international travel market, particularly in the trans-pacific and trans-Atlantic areas. As a result of this, it is comparable to its main competitor, the 747-400, with regards to ergonomic, service, maintenance, and airport compatibility considerations. Moreover, at a cruise speed of  $M = 2.4$ , *The Edge* provides the remarkable benefit of cutting travel times for its 294 passengers in half for distances reaching up to 5750 nm.

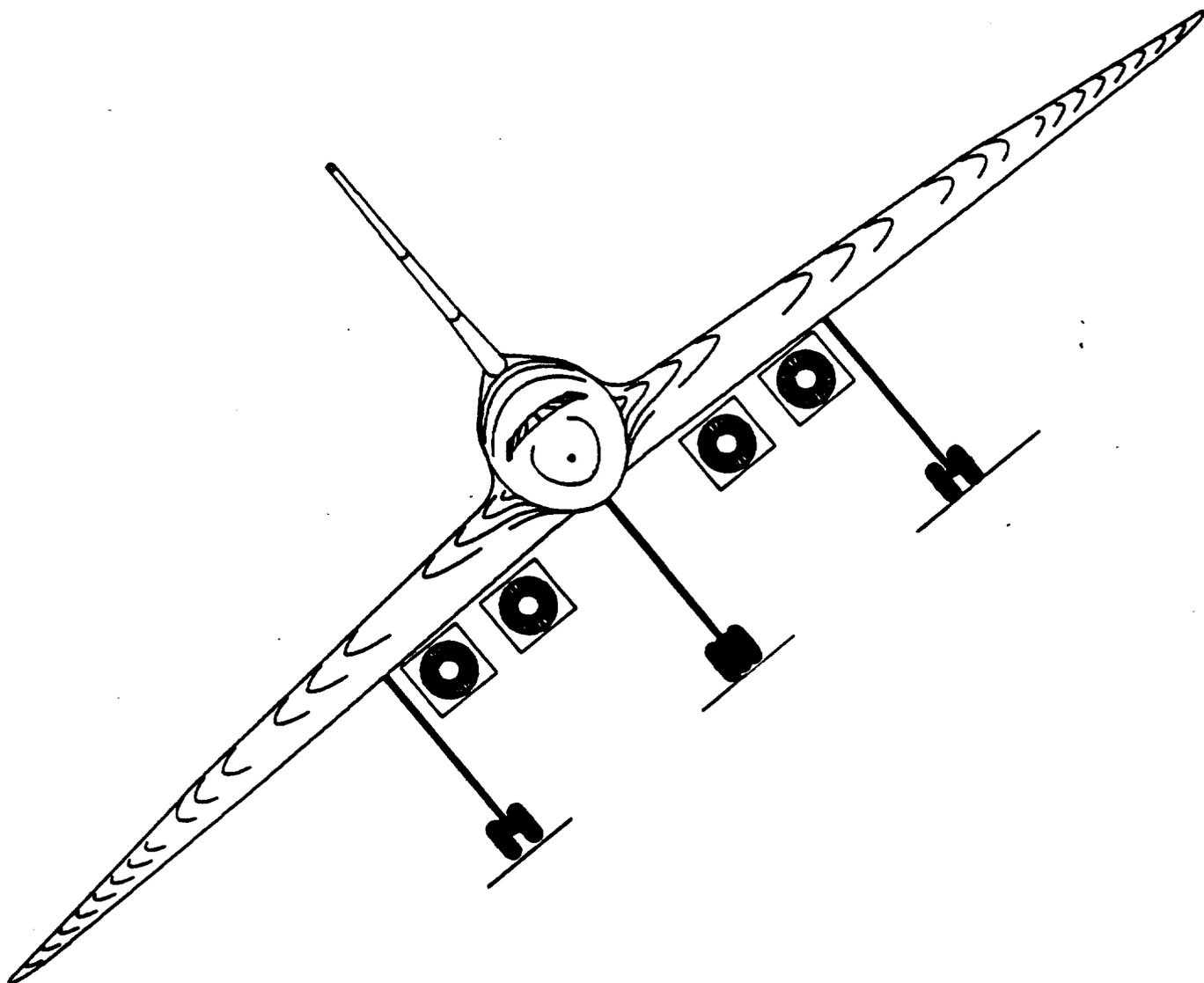
*The Edge* is a futuristic design, in that it will not begin service until the year 2015. It is expected by this time that engine SFC values of 1.0 will be achievable, and that pollutants destructive to the stratosphere will be reduced dramatically, making *The Edge* fully environmentally compatible. In consideration of established aircraft noise limits, *The Edge* will also be able to meet all FAR Part 36, Stage III noise requirements. However, excessive over-pressure levels generated in supersonic cruise will likely inhibit *The Edge's* ability to fly supersonically over land; while on the other hand, with a subsonic cruise  $L/D = 11$ , *The Edge* will be able to perform efficient subsonic flights overland.

*The Edge* clearly rides the outer limits of technology. Utilizing a fly-by-light flight control system, an advanced synthetic flight vision system, and new-age materials, *The Edge* is indeed a revolutionary transport. But it is not without technical hot-spots, the most significant of which is the weight of *The Edge's* wing tip load transfer structures. It is therefore in the materials and structural areas that technological improvements will be most helpful in confirming *The Edge* as a second generation supersonic transport possibility. For as these areas improve, so will the overall economic feasibility of the aircraft itself.

*The Edge* shows an education from past errors. Specifically, it represents a design methodology focused on economic viability. And from this preliminary view, it does seem feasible

. With a production run of 400 aircraft, *The Edge* will be sold for \$167 million per transport.

## 19.0 REFERENCES



## 19.0 References

1. Boeing Commercial Airplanes, NASA Contractor Report 4234: High Speed Civil Transport Study. Seattle: BCA New Airplane Development, 1989.
2. Gilkey, S. C. and Hines, R. W. Propulsion Perspective of the Second Generation Supersonic Transport. Cincinnati: GE Aircraft Engines Advanced Technology Operation, and East Hartford: Pratt & Whitney Commercial Engine Business, 1991.
3. Hansen, A. and Pueschel, R. and Snetsinger, K. AIAA-91-3161: Soot in the Stratosphere: The Impact of Current and HSCT Aircraft Emissions. Berkeley: University, Moffett Field: NASA Ames Research Center 1991.
4. Inoue, T. and Hirokawa, J. (Tokyo: Ishikawajima-Harima Heavy Ind. Co., Ltd., 1991), Hanai, T. and Takami, H. (Nagoya: Mitsubishi Heavy Industries, Ltd., 1991), AIAA-91-3133: Conceptual Study of Supersonic Propulsion Systems. Baltimore: AIAA Aircraft Design Systems and Operations Meeting, 1991.
5. Mizuno, H. and Hagiwara, S. (Tokyo: Japan Aircraft Development Corporation, 1991), Hanai, T. and Takami, H. (Nagoya: Mitsubishi Heavy Industries, Ltd., 1991), AIAA-91-3104: Feasibility Study on the Second Generation SST. Baltimore: AIAA Aircraft Design Systems and Operations Meeting, 1991.
6. Seidel, J. and Haller, W. and Berton, J. AIAA 91-3132: Comparison of Turbine Bypass and Mixed Flow Turbofan Engines for a High-Speed Civil Transport. Cleveland: NASA Lewis Research Center, 1991]. Baltimore: AIAA Aircraft Design Systems and Operations Meeting, 1991.
7. Toon, O. B. and Turco, R. P. and Pollack, J. B., and Whitten, R. C. and Poopoff, J. G. and Hamill, P. NASA Reference Publication 1058: Stratosphere Aerosol Modification by Supersonic Transport Operations With Climate Implications. Moffett Field: Ames Research Center, 1980.

8. Roskam, J., Airplane Design: Part I. Preliminary Sizing of Airplanes. Kansas: Roskam Aviation & Engineering Corp, 1989.
9. Raymer, Aircraft Design: A Conceptual Approach, Washington DC.: American Institute of Aeronautics and Astronautics, Inc., 1989.
10. Roskam, J, Airplane Design: Part II. Preliminary Configuration Design and Integration of the Propulsion System, Kansas: Roskam Aviation and Engineering Corp, 1989.
11. Discussion with Mike Dudley at NASA Ames, 12/91.
12. Discussion with John Seidel, Aeropropulsion Analysis Office, NASA Lewis Research Center, Cleveland, 4/92.
13. Discussion with Dr. Ken Bushall, Rolls Royce Engine Company, 4/92.
14. AIAA Report # 91-3132.
15. AIAA Report # 91-3328-CP.
16. SAE Technical Paper Series # 901892.
17. Discussion with Professor Robert van't Riet, Cal Poly San Luis Obispo, 12/91.
18. Corning, Gerald, Supersonic and Subsonic CTOL and VTOL Airplane Design, Maryland: Corning Publishers, 1960.
19. Bruhn, E. S., Analysis and Design of Flight Vehicle Structures, Jacob Publishing, Indianapolis.
20. Boeing Commercial Airplanes, Inc., Boeing 767 General Description, Washington: Boeing Commercial Airplanes, Inc., 1988.
21. Roskam, Airplane Design Part IV: Layout Design of Landing Gear and Systems, Kansas: Roskam Aviation and Engineering Corp., 1989.
22. Studies of the Impact of Advanced Technologies Applied to STNC, Vol III, Virginia: NASA Langley Research Center, Sept. 1973.
23. Lecture by John King, McDonnell Douglas McDonnell Corporation.
24. Discussion with Al Lee, Rockwell International.
25. Discussion with General Dynamics Engineering Department.

26. Discussions with Bill Sutherland, F-111 Structural Engineer, 3/92, 4/92.
27. Green, Swanborough, Mowinski, Modern Commercial Aircraft, Portland House, New York: 1987.
28. Abbott, H. Ira and Von Doenhoff, E. Albert, Theory of Wing Sections, Dover Publications, Inc.: New York, 1959.
29. USAF Stability and Control DATCOM, Flight Control Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base: Ohio, 1975.
30. Roskam, J., Airplane Design: Part VIII, Airplane Cost Estimation: Design Development, Manufacturing and Operating, Kansas: Roskam Aviation and Engineering Corporation, 1988.
31. Roskam, J., Airplane Flight Dynamics and Automatic Flight Controls. Kansas: Roskam Aviation and Engineering Corporation, 1979.
32. Roskam, J., Airplane Design: Part VI, Determination of Stability, Control and Performance Characteristics, Kansas: Roskam Aviation and Engineering Corporation, 1989.
33. Sweetman, Bill, Great Books of Modern Warplanes, New York: Salamander books Ltd., 1987.
34. Lecture by Tom Edwards, NASA, *Configuring for Sonic Boom Minimization*, 1/29/92.