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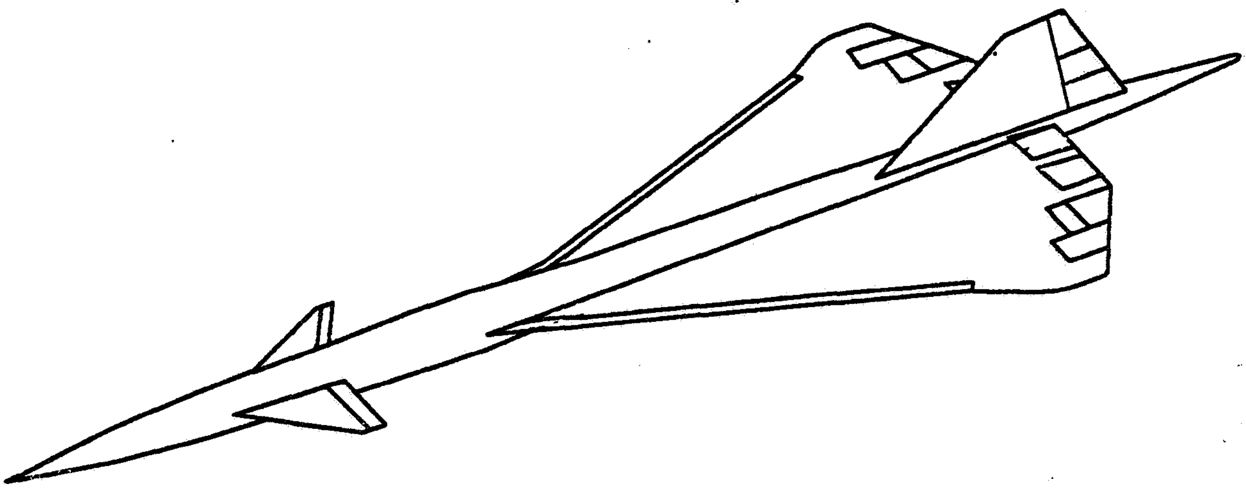
MM-122
High Speed Civil Transport



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ABSTRACT

The rapidly expanding Pacific Rim market along with other growing markets indicates that the future market potential for a high speed civil transport is great indeed. The MM-122 is the answer to the international market desire for a state of the art, long range, high speed civil transport. It will carry 250 passengers a distance of 5200 nm at over twice the speed of sound. The MM-122 is designed to incorporate the latest technologies in the areas of control systems, propulsions, aerodynamics and materials.

The MM-122 will accomplish these goals using the following design parameters. First, a double delta wing planform with highly swept canards and an appropriately area ruled fuselage will be incorporated to accomplish desired aerodynamic characteristics. Propulsion will be provided by four low bypass variable cycle turbofan engines. A quad-redundant fly-by-wire flight control system will be incorporated to provide appropriate static stability and Level I handling qualities. Finally, the latest in conventional metallic and modern composite materials will be used to provide desired weight and performance characteristics.

The MM-122 incorporates the latest in technology and cost minimization techniques to provide a viable solution to this future market potential.

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LIST OF SYMBOLS and ABBREVIATIONS

Symbol	Definition
A_c	Capture Area
AR_w	Wing Aspect Ratio
BR	Bypass ratio
C_d	Coefficient of Drag
C_j	Thrust specific fuel consumption
C_l	Coefficient of Lift
$C_{l\alpha}$	Slope of the Lifting Curve
C_{lmax}	Coefficient of Lift for maximum L/D
DOC	Direct operating cost
IOC	Indirect operating cost
LCC	Life cycle cost
L/D	Lift to Drag Ratio
M	Mach number
n	Load Factor
OPR	Overall Pressure Ratio
RDTE	Research, Development, Test, and Evaluation Cost
ROC	Rate of Climb
ROI	Return on investment
T	Thrust
T/W	Thrust Loading
V_e	Equivalent air speed
V_t	True air speed
W(AMPR)	Airframe Manufactures Planning Report Weight
Wc	Crew Weight
We	Aircraft Weight Empty
Wf	Trapped Fuel and Oil Weight
Wp	Payload Weight
Wto	Gross Take-off Weight
W/S	Wing Loading

Greek Symbols

α	Angle of Attack
$\Lambda_{c/2W}$	Wing half cord sweep angle
$\Lambda_{c/4W}$	Wing quarter cord sweep angle

Stability Derivatives

$C_{D_{ic}}$	Drag due to Canard Incidence
C_{D_u}	Variation of Drag Coefficient with Speed
C_{D_α}	Variation of Drag Coefficient with angle of attack
$C_{D_{\delta c}}$	Drag due to Canardvator deflection
C_{D_1}	Coefficient of Drag - Steady State
C_{l_r}	Rolling moment due to yaw rate derivative
C_{l_p}	Rolling moment due to roll rate derivative
C_{l_β}	Rolling moment due to sideslip derivative
$C_{l_{\delta a}}$	Rolling moment due to aileron deflection
$C_{l_{\delta r}}$	Rolling moment due to rudder deflection
$C_{L_{ic}}$	Lift due to Canard Incidence
C_{L_u}	Variation of Lift Coefficient with Speed
C_{L_α}	Variation of Lift Coefficient with Rate of Change of angle of attack
$C_{L_{\delta c}}$	Lift due to Canardvator deflection
C_{L_1}	Coefficient of Lift - Steady State
$C_{m_{ic}}$	Pitching moment due to canard incidence
$C_{m_{T_1}}$	Thrust Pitching Moment - Steady State
C_{m_u}	Pitching moment due to speed derivitive
C_{m_α}	Pitching moment due to angle of attack derivitive
$C_{m_{\delta c}}$	Drag due to canardvator derivative
C_{n_r}	Yawing moment due to yaw rate derivative
C_{n_p}	Yawing moment due to roll rate derivative
C_{n_β}	Yawing moment due to sideslip derivitive
$C_{n_{\delta a}}$	Yawing moment due to aileron derivative
$C_{n_{\delta r}}$	Yawing moment due to rudder derivative
C_{n_1}	Yawing moment Coefficient - Steady State
$C_{T_{x1}}$	X- Thrust Coefficient - Steady State
C_{y_r}	Sideforce due to yaw rate derivative
C_{y_p}	Sideforce due to roll rate derivative
C_{y_β}	Sideforce due to rate of sideslip
$C_{y_{\delta r}}$	Sideforce due to rudder derivative

1.0 INTRODUCTION

Since the beginning of aviation, man has had the inherent desire to travel faster and further then ever before. In todays modern times, this desire for speed has been driven by the nature of the business world. Time is money. For this reason, the means to travel from one location to another in as short a period of time as possible has become a profitable proposition. Profitability dictates that the time for development of a modern High Speed Civil Transport (HSCT) is now upon us.

The world long range international civil transport market in the near future is predicted to be large enough to support a long range high speed civil transport fleet with a profitable market share (Reference 1). This prediction is true only if the HSCT can overcome the financial and technological obstacles encountered by the Concorde, the only HSCT that has operated in the free world to date. Some of the obstacles that have hindered the Concorde include environmental concerns, propulsions, aerodynamics and economics.

Perhaps the single most detrimental design flaw encountered by the Concord is that of environmental concerns. These environmental concerns include takeoff noise levels, sonic boom over-pressures and Nitrous Oxide (NOx) emission levels. Takeoff noise levels produced by the Concord have greatly reduced the aircraft's permissible area of operation. Sonic boom over-pressures have also severely limited the aircraft's potential market capture as the aircraft has been limited to no overland supersonic flight. Ozone depleting emission levels produced by the Concord have prompted some to call for an actual service retirement. The future of an HSCT relies directly on the ability to overcome these environmental obstacles.

The fundamental propulsion concern encountered by the Concorde is specific fuel consumption. HSCTs by nature are very sensitive to engine fuel consumption in that typically half the weight of the aircraft at takeoff is that of fuel. For a future HSCT to be viable, the propulsion systems must be efficient, quiet, have low NOx emissions and provide adequate amounts of thrust.

Since the introduction of the Concord, many advancements in the area of supersonic aerodynamics have been made. These advancements include wave drag reduction through appropriate area ruling, trim drag reduction through fly-by-wire control systems and improved lift to drag ratios through boundary layer control. A modern HSCT must employ all these advancements to be technologically viable.

Finally, the Concorde has proven that the success of an HSCT, as with any civil aircraft, is dictated by economics. For an HSCT to be successful it is necessary that it provide a positive profit margin. In order to do this, the modern HSCT must be designed to minimize plane purchase cost, minimize maintenance costs, maximize airplane life time and minimize operational costs.

From the lessons of the Concorde, it is evident that a modern HSCT must be designed employing the latest in aerodynamics and propulsions while minimizing environmental impact, all at an affordable rate. The MM-122 is the aircraft designed to overcome these difficult design obstacles while providing affordable high speed civil transport service for the future.

The MM-122 is designed incorporating the latest in aerodynamics, propulsions, controls and materials while paying special attention to minimizing environmental impact. This aircraft takes advantage of modern area ruling techniques to cruise efficiently at supersonic speeds. The MM-122 also utilizes the most advanced propulsion systems to further enhance efficiency, while minimizing takeoff noise and harmful NOx emissions. The modern fly-by-wire control system increases the MM-122 efficiency levels at cruise while enhancing passenger safety throughout the flight regime. The aircraft will also be limited to a cruise altitude of 55,000 ft and no overland supersonic flight in order to minimize it's environmental impact.

The MM-122 will provide affordable high speed civil transportation by integrating the most modern technologies into present day proven facilities. The MM-122 is the solution to the need for a modern high speed civil transport.

FOLDOUT FRAME

FOLDOUT FRAME

	Wing	Canard	Vertical Tail
Area	9230 sq.ft	400 sq.ft	656 sq.ft
Span	133ft	24ft	24ft
MGC	84ft	8.5ft	13.2ft
AR	2.0	1.5	0.9
Sweep ang.	63-50deg	63deg	57deg
Taper ratio	0.08	0.17	0.16
Thick. ratio	0.04-0.02	0.03	0.03
Airfoil:			
Root	NACA 64-A204	NACA-65A004	NACA-65A004
tip	Diamond Wedge	NACA-65A004	NACA-65A004
Dihedral	Variable	0deg	0deg
Incid ang.	0deg	0deg	0deg
	Fuselage	**Cabin Inter.**	**Overall**
Length	300ft	205ft	300ft
Max. height	52ft	7.5ft	52ft
Max. width	13.5ft	12.5ft	133ft

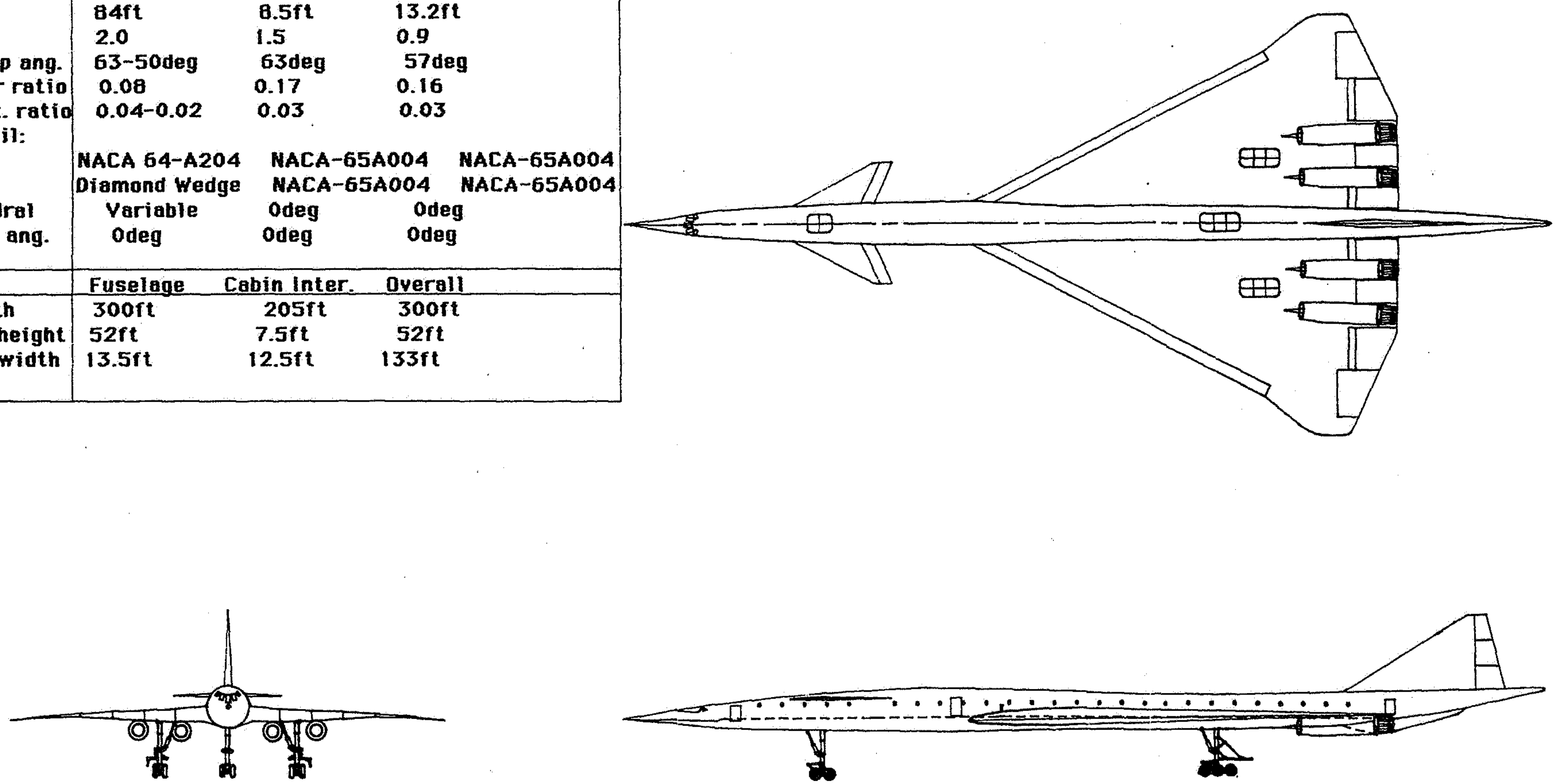


Figure 1.1 MM-122 Three view Summary

2.0 MISSION PROFILE

2.1 MISSION SERVICE

The major purpose of the MM-122 consists of a supersonic flight service to various city pairs which meet a 5200 nautical mile range criteria. Therefore the MM-122 will service various mission profiles to accommodate the different flight routes associated with the city pairs. On typical flight, the mission profile of the aircraft will consist of a supersonic cruise (M = 2.2) of approximately 5200 nautical miles without the option of supersonic flight over land. Major city pairs serviced by the design range of the aircraft include L.A.-Tokyo, L.A.-Honolulu, Honolulu-Sydney, Paris-Wash. D.C. and London-New York. These city pairs have flight paths over water and need not comply with the sonic boom restrictions which are enforced over land by FAR requirements. These routes will also be increasingly traveled during the the next century due to travel predictions. The following mission summary represents a typical flight scheme for the MM-122.

2.1 MISSION SEGMENTS

The mission profile for a typical 5200 nautical mile flight was broken down into mission phases from takeoff of the aircraft to landing in order to emphasize the various flight regions of the MM-122. Many of the limitations for the flight segments were governed by FAR requirements. The specific mission profile requirements for the MM-122 are visually exemplified in Figure 2.1. The mission profile of the aircraft was divided into 9 separate phases of flight for organization and begin with the startup-taxi phase. Phase one of the aircraft's flight consists of the start-up run and taxi procedures of the aircraft in preparation for take-off. This phase precedes the loading of the 250 passengers and their cargo into the aircraft. To meet FAR requirements for subsonic climb, the velocity of the aircraft just after takeoff and below 10,000 ft will not exceed 250 knots (Reference 2) . The initial climb of the aircraft will be limited to 10,000ft, after which the aircraft will accelerate from a Mach of 0.9 to 1.2 into the third stage of the flight. This phase three climb will take the aircraft to the design cruise altitude of 55,000ft where it will accelerate to the cruise Mach number of 2.2. It will remain at a Mach of 2.2 for the rest of the phase four cruise unless the flight route crosses any land masses. The cruise flight altitude of the aircraft was chosen in order to minimize the ozone layer depletion by flying below it's main concentration while minimizing fuel burn and aircraft drag. The fifth phase of the flight consists of the deceleration of the aircraft and descending to the altitude of 10,000ft. After reaching the 10,000ft level the aircraft has the option of diverting to an alternate location, holding in a pattern over the approach site, or following through to an approach and land. The approach and landing phase of the flight will consist of a low speed approach 180 kts (1.3 times the stall speed) and landing on a minimum 10,000ft runway. The landing phase of the aircraft will be followed by a taxi maneuver to the terminal for unloading.

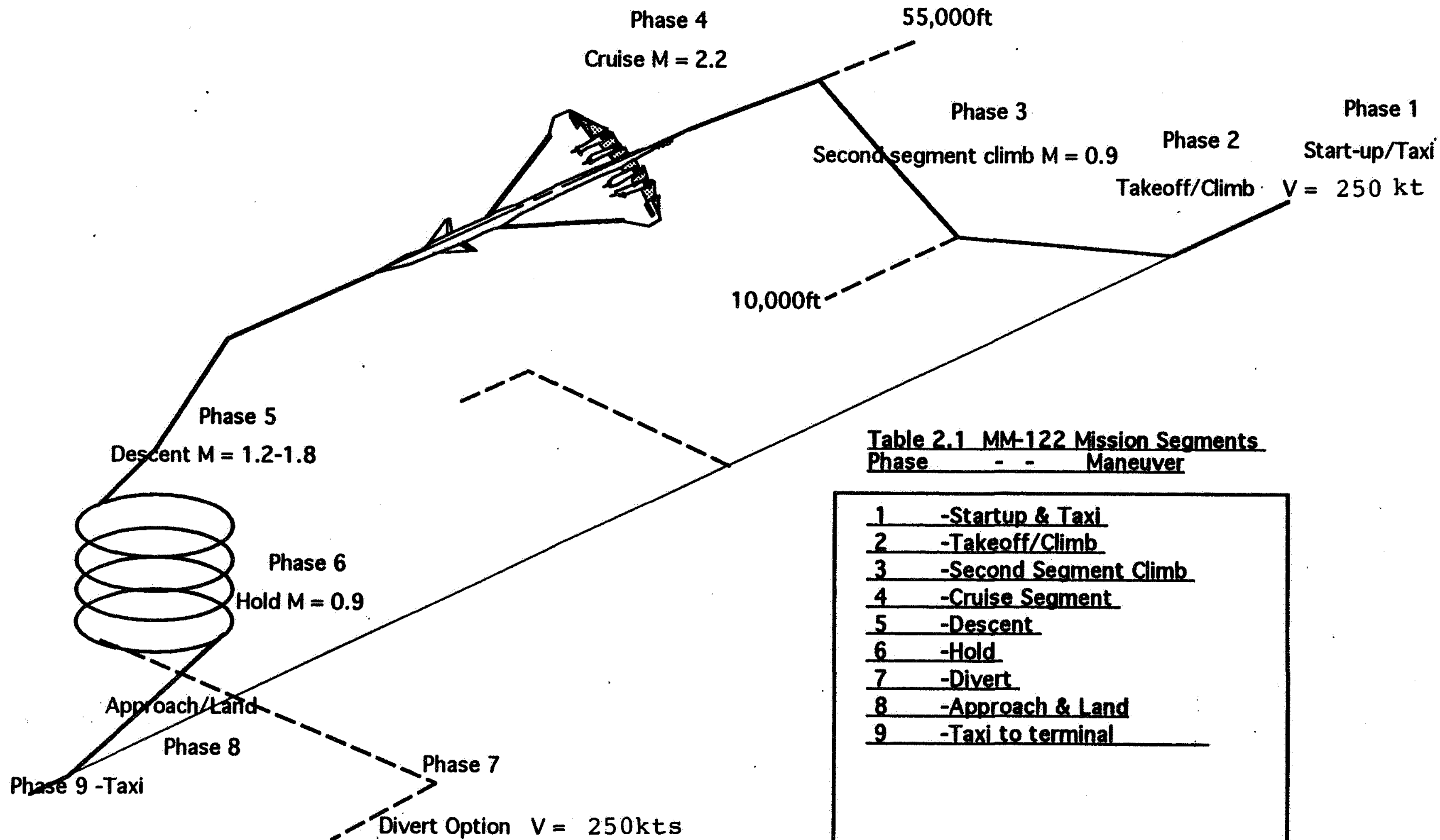


Table 2.1 MM-122 Mission Segments

Phase	Maneuver
1	-Startup & Taxi
2	-Takeoff/Climb
3	-Second Segment Climb
4	-Cruise Segment
5	-Descent
6	-Hold
7	-Divert
8	-Approach & Land
9	-Taxi to terminal

MM-122 Mission Profile
Figure 2.1

3.0 PRELIMINARY DESIGN

3.1 PRELIMINARY SIZING

In order to complete the preliminary design of the MM-122, the specific mission specification was combined with a class one sizing method (Reference 4). To calculate the aircraft parameters such as gross weight, fuel weight and empty weight, the fuel fraction method was used in conjunction with the given parameters of the mission specification given in the MM-122 RFP. In the process of calculating the design parameters of the aircraft, certain performance parameters of the aircraft were calculated from empirical data found on similar aircraft. The results for the preliminary sizing process are given in Table 3.1. These numbers show that the MM-122 has approximately twice the gross takeoff weight and is one third longer than the Concorde. The thrust to weight ratio and average wing loading for the two aircraft are very similar.

TABLE 3.1 MM-122 Summary of Class one Design Parameters with a Concorde comparison

Gross $Wt._{to}$	795,000lb	T/W	0.36
Fuel Wt.	417,000lb	W/S	86 lb/sq.ft
Payload Wt.	50,000lb	Swing	9230 sq.ft
Empty Wt.	357,000lb	T_{to}	280,000lbf
Crew Wt.	1700lb	C_{Lmaxto}	1.4
		C_{Lmaxl}	1.8

Concorde Data

Gross Wt.to	408,000lb	T/W	0.37
Payload Wt.	28,000lb	W/Smax	100psf
Empty Wt.	203,000lb		

3.2 AIRCRAFT WEIGHT SIZING

The sizing process used to calculate the gross takeoff weight, empty weight, and fuel weight of the aircraft was the iterative fuel fraction method described in Reference 4. This method breaks the mission profile of the aircraft into flight segments from which the weight of the aircraft is evaluated for each segment. For each flight segment, values of L/D and cj were chosen from existing supersonic aircraft and employed into the range and endurance equations for the sake of initial approximation. Empty weight calculations were done by adding cargo, crew and trapped fuel and oil weights. For the sake of initial weight sizing of the aircraft many iterative methods were used in conjunction with empirical data of previous supersonic transports to estimate the final design weights.

3.3 AIRCRAFT TAKEOFF SIZING

In order to size to MM-122 for takeoff requirements, performance parameters such as takeoff weight, speed, thrust loading and wing loading were used in conjunction with the takeoff field length restrictions to determine the design constraints of the aircraft. For this supersonic transport aircraft, the rotation angle at take-off is limited due the length of the aircraft, the positioning of the main landing gear and tail drag strike restrictions. In addition to limited rotation angle at take-off, the lift slope curve of delta wings is relatively shallow, therefore requiring high angles of attack for substantial lift. In order to produce the required C_{Lmaxto}, without over-rotating the aircraft the area of the double delta wing of the MM-122 was designed using a large reference area. More lifting area from the wing decreased the Clmax required for takeoff and brought the 15 degree rotation angle of the delta wing into a designable range. A plot of the takeoff thrust loading verses the wing loading for the aircraft with various takeoff lift coefficients is provided in Figure 3.1. This figure shows a broad range of thrust to weight and wing loading factors for a CLmaxto of 1.4. The maximum aircraft lift coefficient was calculated to be in the range of 1.4 to 1.6 and hence this corresponds to a thrust to weight range of 0.2 - 0.4 and a wing loading range of 80 to 140 psf.

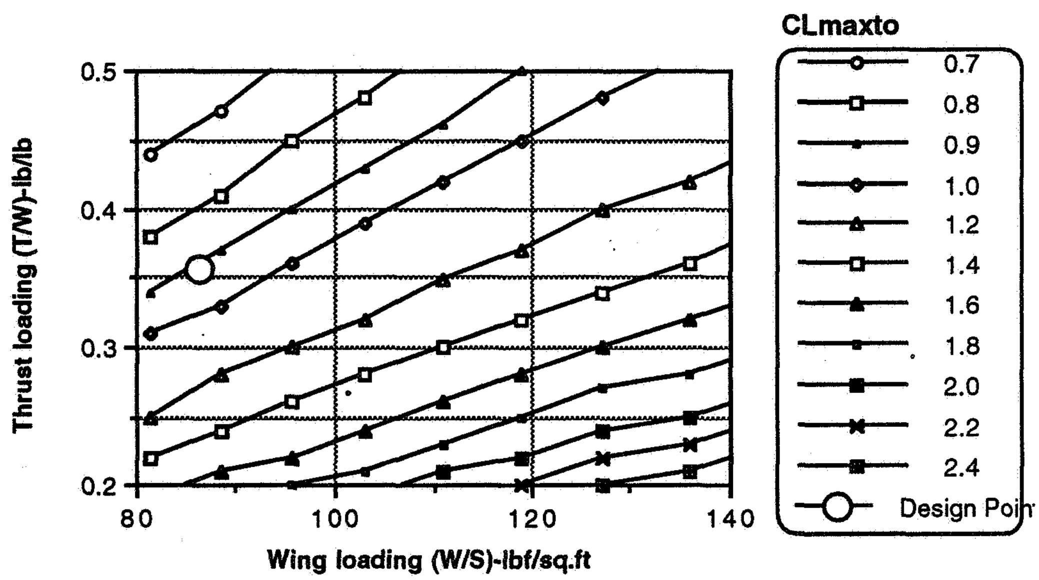


FIGURE 3.1 MM-122 Takeoff Contraint

3.4 AIRCRAFT LANDING RESTRICTIONS

In the preliminary sizing process of the aircraft, the landing requirement was estimated using the relationship between wing loading and maximum landing lift coefficient. The landing constraint of the aircraft is also dependent on the following factors: landing weight, approach speed and field length. Figure 3.2 shows the landing constraint as a function of landing lift coefficient and thrust loading on the aircraft. This figure shows that in a landing situation with flaps down and an CLmaxL of 1.4 the wing loading range of the aircraft is between 107 -125 psf. This plot shows that the landing CLmax of the aircraft need not be greater than 1.6 for the wing loading range of a supersonic aircraft.

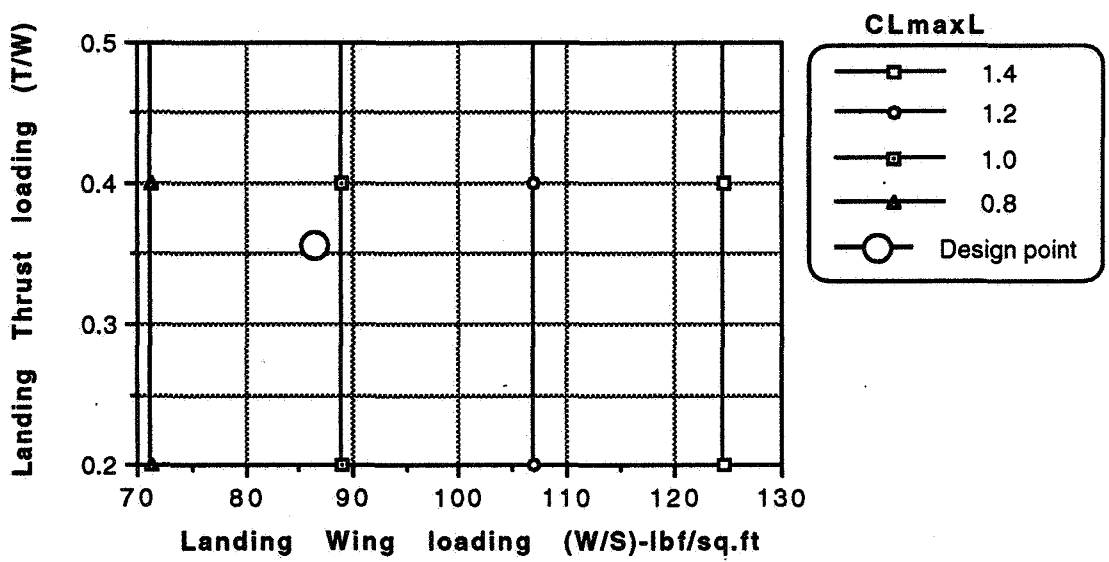


FIGURE 3.2 MM-122 Landing Constraint

3.5 MANEUVER AND CRUISE REQUIREMENT

In order to size the MM-122 for the flight conditions of cruise and for maneuvering a relationship between thrust loading, dynamic pressure, and drag coefficient was developed (Reference 4). The aircraft was sized to the cruise requirement at the design Mach number of 2.2 and the flight altitude of 55,000 ft. The results of the sizing to cruise requirements are given in Figure 3.3. In terms of the limiting thrust-to-weight ratio, the requirements for cruise were not critical as compared to the maneuver requirement. The landing maneuver requirement established the sizing constraint due to the high drag in this approach configuration. This is depicted in Figure 3.3.

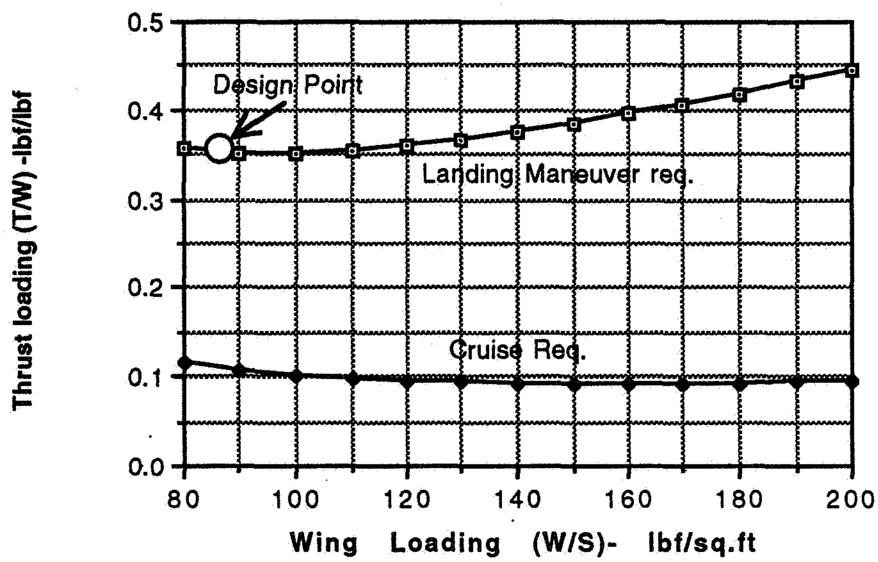


FIGURE 3.3 MM-122 Manuver and Cruise Constraint

3.6 MATCHING OF SIZING RESULTS

After completion of all the design constraints for the MM-122 the final wing loading, thrust loading and other performance parameters could be compiled to find a resulting design region. Figure 3.4 shows the a summary of the design constraints and the most efficient area in which to design. After all the constraints were known and placed in Table 3.2 the design parameters were chosen . As shown in the Figure 3.4 the thrust-to-weight for the aircraft was found to be 0.356 lbf/lbf and the wing loading was found to be 86.33 psf. These numbers were decided upon by the limiting design constraints. For the thrust to weight constraint, the predominant constraints were the FAR one engine out (OEI) requirement and the landing maneuver constraint. For the wing loading, the major constraint was the landing maneuver requirement but the landing CLmax also constrained the limiting wing loading allowable for the aircraft.

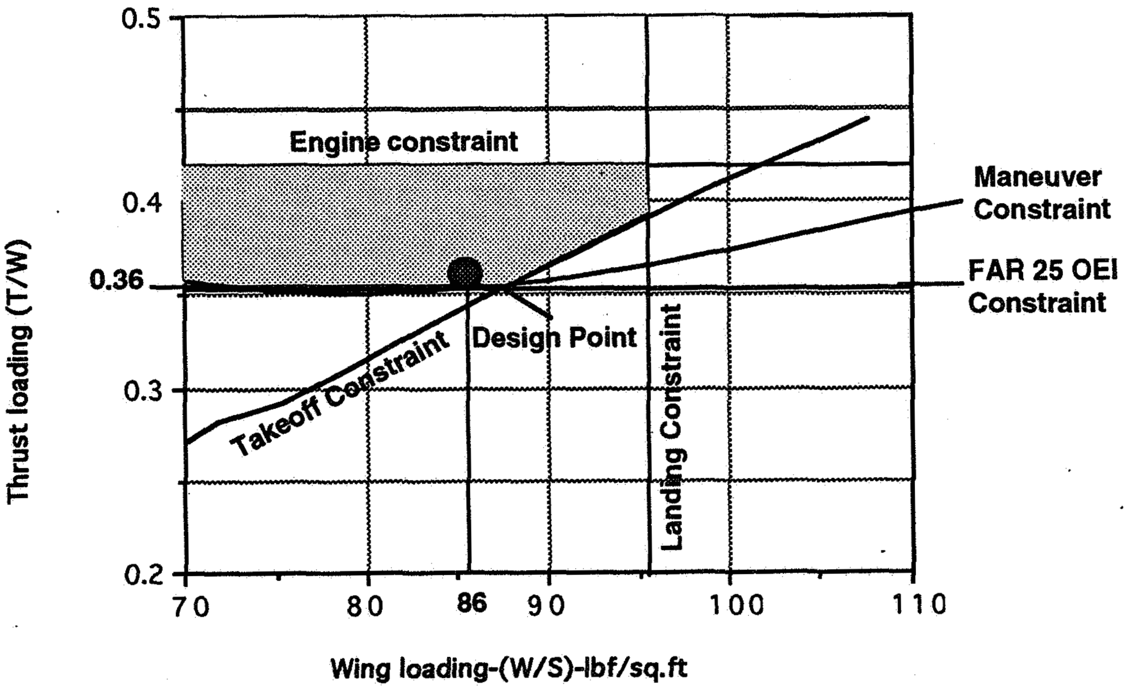


Figure 3.4 MM-122 Design Location

Table 3.2-MM-122 Summary Constraint Chart

Constraint	T/W range	W/S range
Takeoff	0.2 - 0.4	80 to 140 psf.
Landing	No constraint	80 -145 psf
FAR - OEI	0.355 - 0.43	No constraint
Maneuver	See Figure 3.3	No constraint
Cruise	0.1 - 0.43	No constraint
MM-122	**0.356**	**86.33 psf**

4.0 AIRCRAFT CONFIGURATION

4.1 CONFIGURATION TRADE-OFF

There are many acceptable configurations for an HSCT as seen in Table 4.1. These configurations include oblique wing, variable sweep wing and conventional planform designs. An oblique wing configuration provides superior lift at takeoff up to Mach of .8 and good supersonic lift-to-drag ratios . However, the oblique wing configuration is structurally difficult to construct do to the extremely complex pivot action of the wing. Likewise, a variable sweep wing configuration has excellent lift characteristics for takeoff and landing. However, it is similarly limited by the complexity of a variable sweep mechanism. The psychological affects of these complex configurations on the passengers is also detrimental, in that the passengers would likely feel insecure watching the wings of the aircraft being skewed.

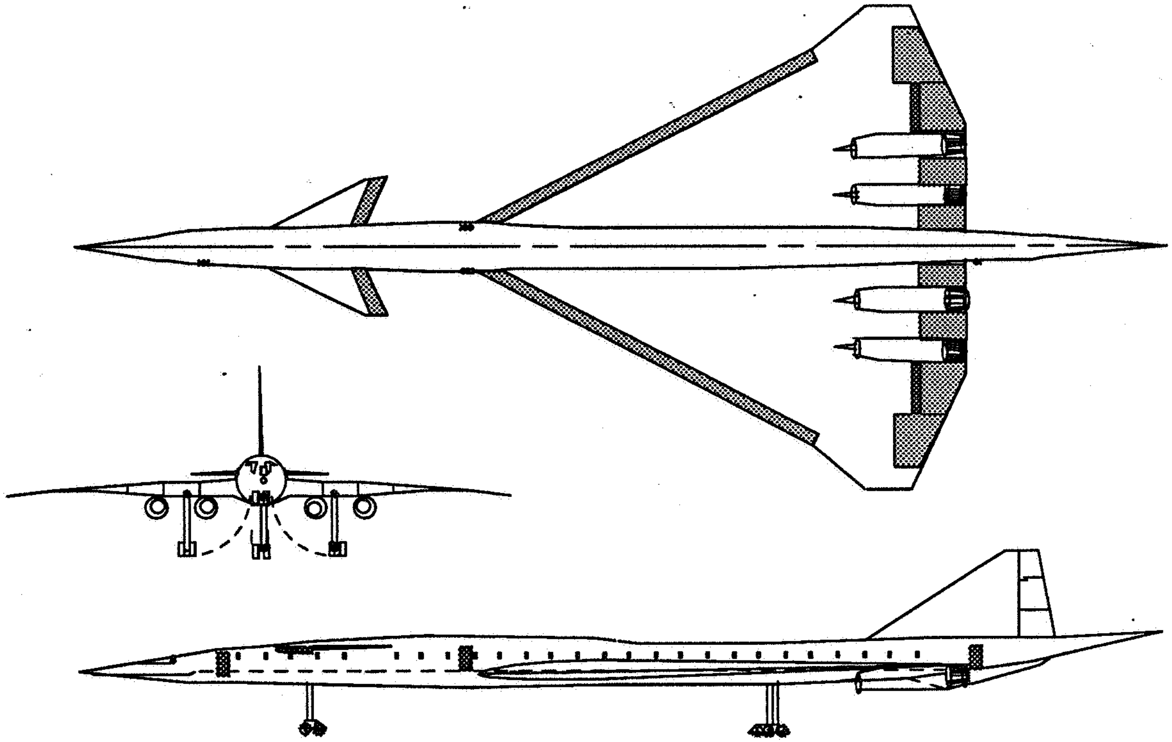
Table 4.1 - Configuration Trade-off

Configuration	Advantages	Disadvantages
Oblique Wing	High Lift At Take-Off	Structurally Complex
	High Supersonic Lift-to-Drag Ratio	Psychologically Detrimental
Variable Sweep Wing	High Lift At Landing	Structurally Complex
	High Supersonic Lift-to-Drag Ratio	Difficult to Certify
Conventional	Structurally Simplistic	Low Lift At Take-Off and Landing
	Psychologically Soothing	Low Lift-to-Drag At Supersonic Cruise

Conventional configurations can be divided into subcategories, including those with horizontal stabilizers and those with canards. A conventional wing planform with horizontal stabilizer provides beneficial lift-to-drag ratios during supersonic cruise for statically unstable aircraft. A horizontal stabilizer is also structurally efficient and psychologically soothing. However, it is poor for takeoff rotation power and decreases overall lift at this critical time. On the other hand, a conventional wing planform with canards provides beneficial lift-to-drag ratios during supersonic cruise for a statically stable aircraft. Also, it provides increased lift at takeoff in that it is up-loaded for rotation power and increases wing lift coefficients by inducing vortices over the wing. Canards are structurally more complex and less proven then horizontal stabilizers and may be psychologically less acceptable to the passengers.

4.2 CONFIGURATION SELECTION

The MM-122 employs a conventional configuration with highly swept canards as seen in Figure 4.1. This configuration was selected to minimize structural complexity, maximize aircraft performance and minimize adverse passenger psychological affects. Canards are employed to provide added lift at cruise for the statically stable configuration, added lift at takeoff due to induced vortices and appropriate rotation power at takeoff.



MM-122 Configuration Summary

1. Land based design
2. Fuselage configuration
    a) conventional supersonic
    b) Area ruled
3. Engine Type and disposition
    a) Low-Bypass turbo-fans with variable cycles
    b) Four engine pusher design
    c) Below wing location
4. Wing configuration
    a) Double delta with slight trailing edge sweep
    b) Low mounting position
    c) Large aft sweep
5. Stabilizing Surface configuration
    a) Canard: High fuselage mounted, fixed
    b) Vertical stabilizer
6. Landing Gear type and dispsition
    a) Retractable
    b) Conventional tricycle design
    c) Mounting on fuselage and wing

Figure 4.1-Configuration Summary

5.0 WING DESIGN

5.1 AIRFOIL SELECTION

The wing planform of the MM-122 utilizes two distinct airfoil sections. The first, a NACA 65A004 is utilized on the subsonic inboard section of the wing. The second is a biconvex supersonic airfoil and is used on the supersonic outboard wing section. The NACA 65A004 as designated by its number is a series 6 airfoil section with a 4% thickness. The aerodynamic center of the airfoil section is located at the half chord point. The airfoil is close to symmetrical and has a design lift coefficient of zero at zero angle of attack as seen in Figure 5.1. This airfoil was selected for its very low pressure drag at low angles of attack and supersonic wave drag characteristics. The outboard section of the wing is swept outward of the Mach wave and therefore has a supersonic leading edge. The airfoil selected for this section is a conventional supersonic biconvex airfoil section with a 4% thickness.

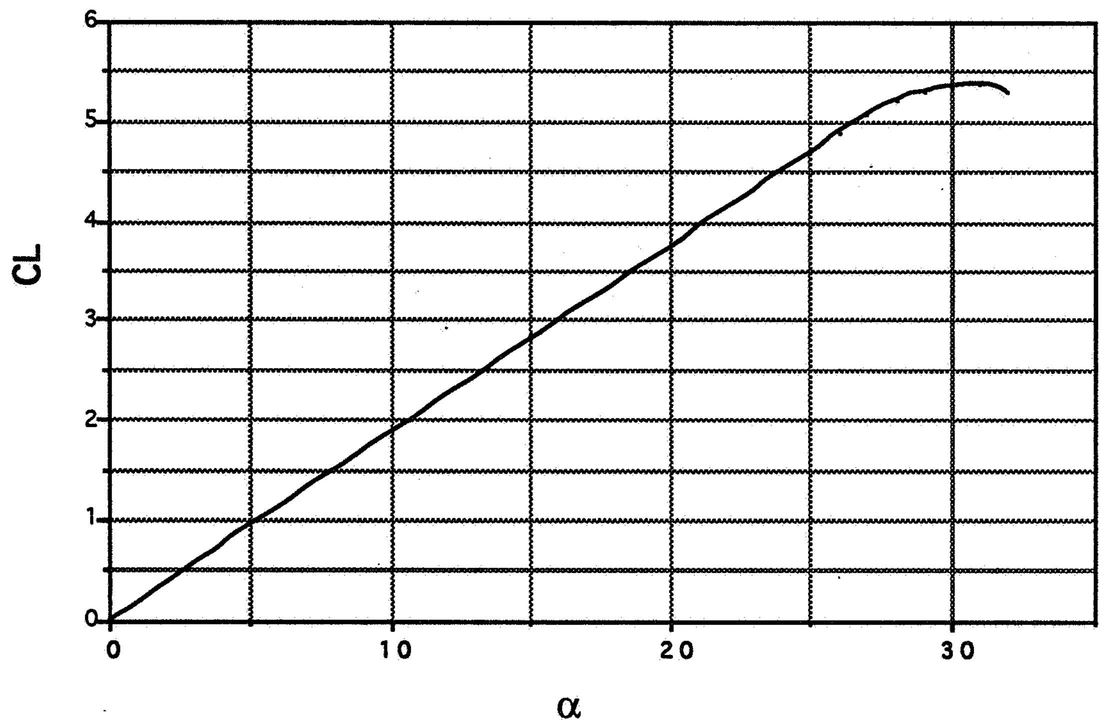


Figure 5.1 Cl vs. Alpha Curve for NACA 65A004

The selection of these two airfoil sections reflect the drive to reduce pressure and wave drag at supersonic cruise and low angles of attack. They also indicate a compromise in subsonic lift characteristics and volume provided by airfoil thickness.

5.2 WING PLANFORM

The wing of the MM-122 consists of a conventional double delta planform with a slight trailing edge aft sweep as seen in Figure 1.1. The wing is designed primarily to provide minimum drag at supersonic cruise, with the least amount of structural complexity as possible. Other considerations influencing the wing planform include airfoil selection, high lift devices, available fuel volume and landing gear volume. The size of the wing was determined primarily by wing loading constraints.

The unique wing planform feature observed on the MM-122 is that of slight trailing edge aft sweep as seen in Figure 1.1. There are several considerations that influenced this design decision. First, trailing edge aft sweep provides optimum area ruling results and thus minimizes aircraft supersonic wave drag. Secondly, this wing planform provides minimum structural complexity and weight in that all spars may be placed perpendicular to the fuselage center line. Trailing edge aft sweep also provides increased fuel volume by extension of the root cord. Finally, the wing planform should extend the trailing edge shock wave past the area of influence of the vertical stabilizer, thus reducing vibratory loading of the vertical stabilizer. The wing is positioned approximately at the cabin's floor level to allow for partial blending while still permitting the existence of windows.

5.3 CANARD PLANFORM

The canards use the same NACA 65A004 airfoil, again indicating the desire to maximize supersonic cruise efficiency. The vertical stabilizer uses a symmetric airfoil with a 4% thickness and subsonic leading edge. The canards were positioned on the top section of the fuselage to allow maximum use of the internal volume.

5.4 HIGH LIFT DEVICES:

The slightly cambered, highly swept wing configuration employed by the MM-122 dictates the need for extensive use of high lift devices. This is due to the fact that the wing generates little lift at moderate angles of attack. The wing therefore contains leading edge slates over 94% of the wing leading edge and single slotted flaperons over 65% of the trailing edge as seen in Figure 1.1. Single sloted flaps were selected for simplicity and ease of maintenance. These high lift devices serve to increase wing lift coefficients at moderate angles of attack by increasing the wing geometric cord, increasing effective wing camber and inducing vortices over the leading edge of the delta wing. An increase in lift coefficient of .38 is generated by the high lift devices deployed at 30 degrees.

6.0 FUSELAGE DESIGN

6.1 AREA RULING

The primary factors influencing the fuselage configuration of the MM-122 is that of area ruling and slenderness ratio. The first fuselage configuration design process used to minimize the wave drag on the aircraft is decreasing the fuselage slenderness ratio to 0.045. This slenderness ratio was calcualted by restricting the length of the fuselage to 300ft as required in the MM-122 request for proposal and minimize the fusealge diameter to 4-6 person abreast passenger seating. To come up with the optimum area ruling possible the Sears-Hack body approximation was employed for our design (Reference 5). This method shows that the aircraft wave drag is a direct result of the way in which the aircraft's volume is distributed. Figure 6.1 is an example of the Sears Hack area approximation for the MM-122.

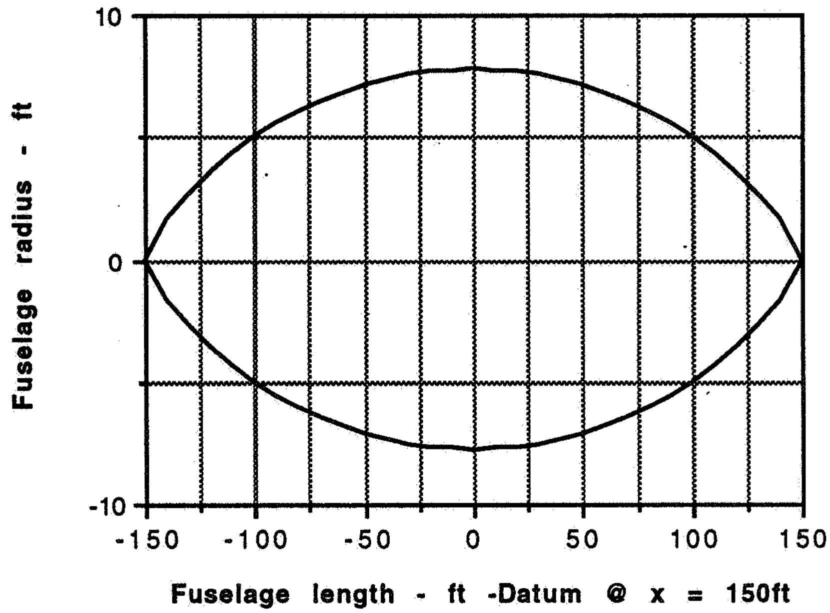


Figure 6.1 Sears Hack Body Approximation

In order to minimize the wave drag on the fuselage at the cruise Mach of 2.2 the fuselage and wing combination are sliced at the Mach cone angle of 27.0 degrees every 25 feet (Reference 5). The fuselage, wing, canard and vertical stabilizer are divided into areas and plotted verses the fuselage length for correlation with the Sears Hack approximation. The final areas of the separate wing and fuselage are computed and minimized with respect to the Sears Hack model to come up with the final fuselage area distribution. Figure 6.2 shows the final area distribution of the fuselage and wing combination after area ruling is completed. The smooth central curve represents the Sears Hack model for the MM-122.

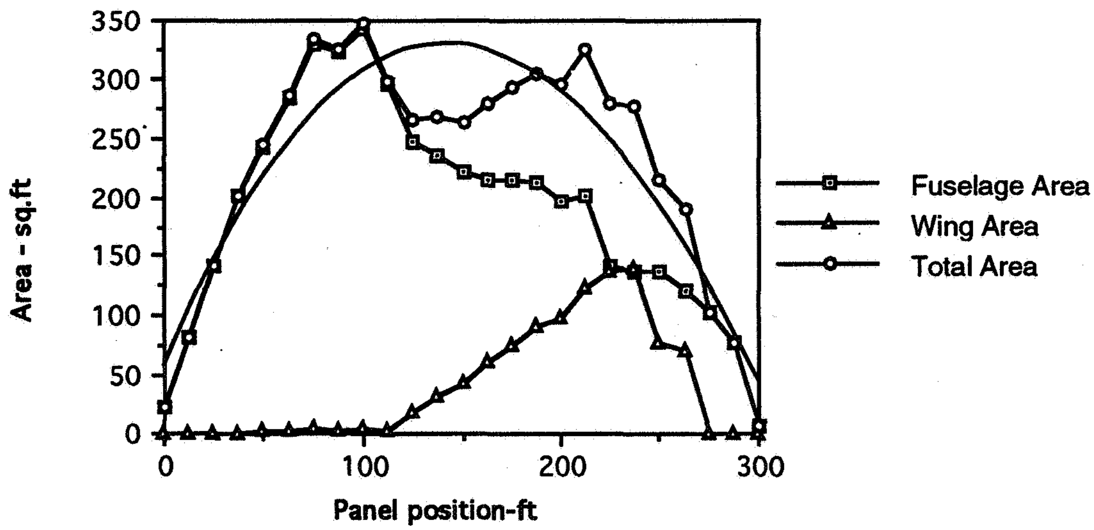


Figure 6.2 MM-122 Cross Sectional Area

6.2 INTERNAL LAYOUT

The main cabin section of the MM-122 is configured for 250 passengers with three different class seating arrangements including first, business and economy classes. In order to satisfy the RFP requirements (Reference 1), the passenger class arrangement of 15% first, 40% business and 45% coach have been accommodated for. The aircraft internal layout including class arrangement, emergency exits, galleys, lavatories and crew seating are depicted in Figure 6.4. The class arrangement was primarily dictated by optimization of first class and business passenger comfort respectively. Comfort considerations include noise levels, ease of loading and unloading and lavatory accessibility. As shown in Figure 6.4, these arrangements were made in a such way that first class section is located furthest away from the engines and closest to the boarding doors. Galley and lavatory locations were similarly established with respect to passenger comfort. Internal cross-sectional layouts including seat size, seat displacement, seat pitch, cargo configuration, displacement and dimensions may be observed in Figure 6.3. Cross-sectional configurations are designed for optimal utilization of space while maintaining maximum passenger comfort.

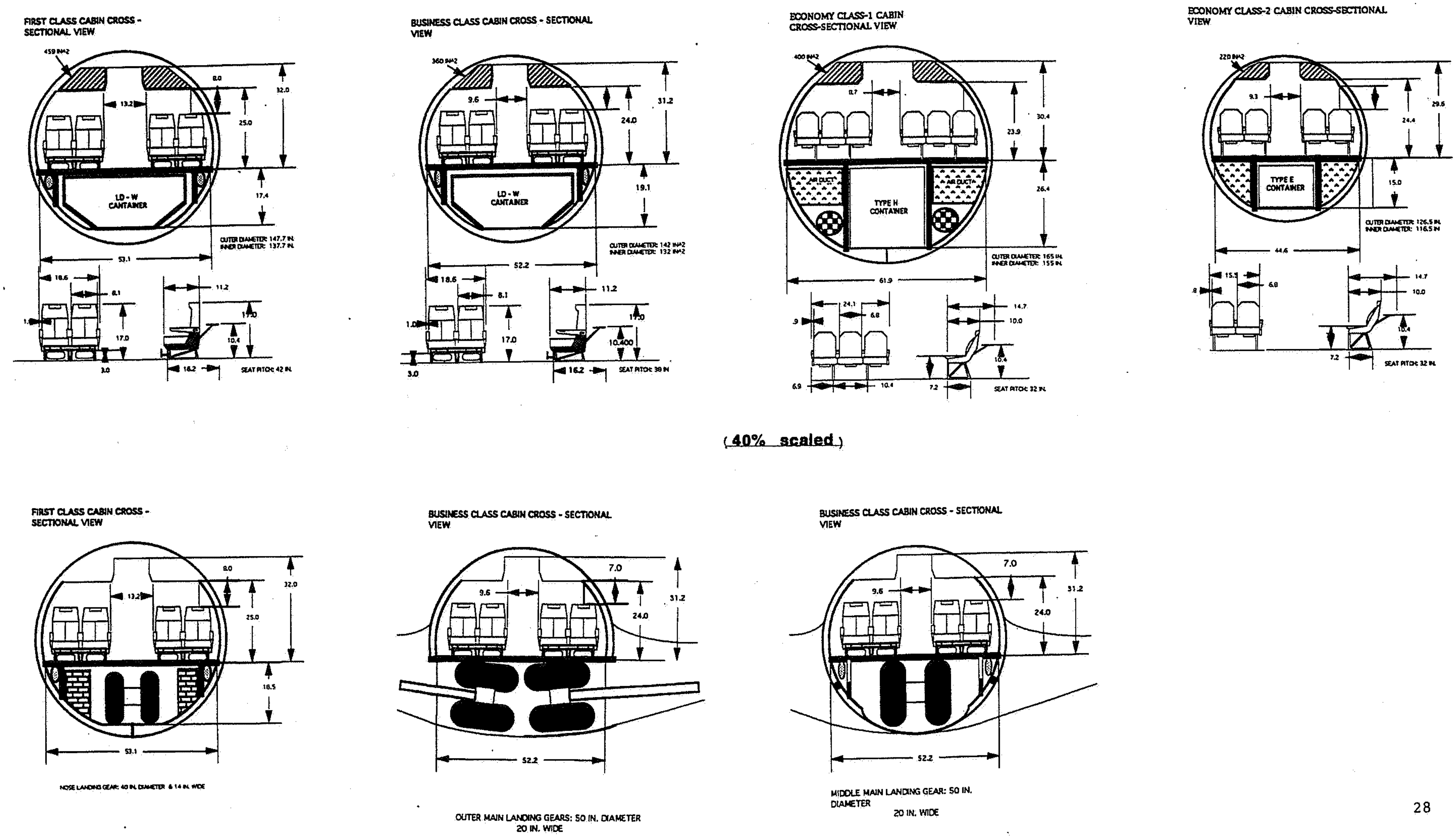
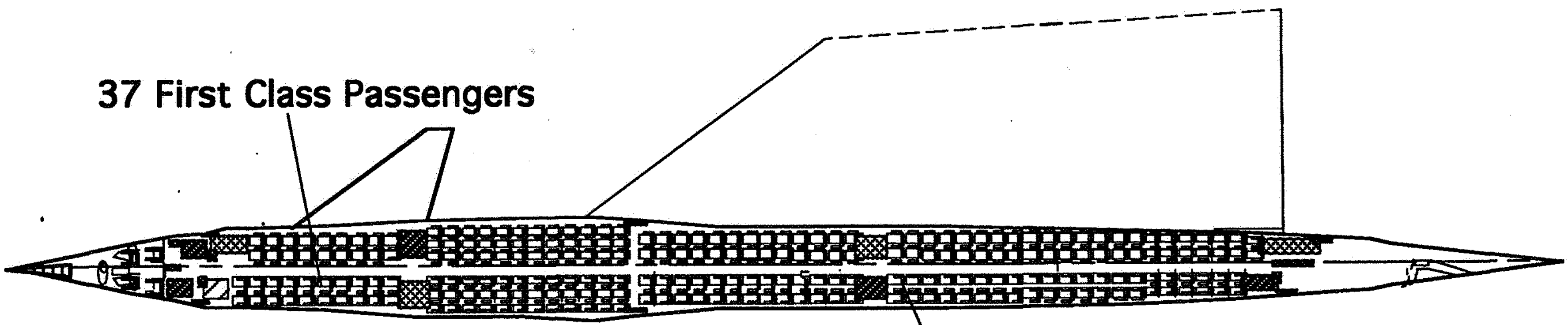


Figure 6.3 Internal Cross-sectional Layout



Class Breakdown

15% First class
40% Busimess class
45% Economy class

(Fuselage expanded for detail)

Figure 6.4 MM-122 CABIN LAYOUT

6.3 CARGO CAPACITY

For the lower deck capability, as summarized in Table 6.1, every section of cabin was designed to hold standardized cargo containers. These standardized cargo containers provide sufficient cargo capacity while maintaining enhanced airport compatibility.

Table 6.1 MM-122 Cargo Capacity

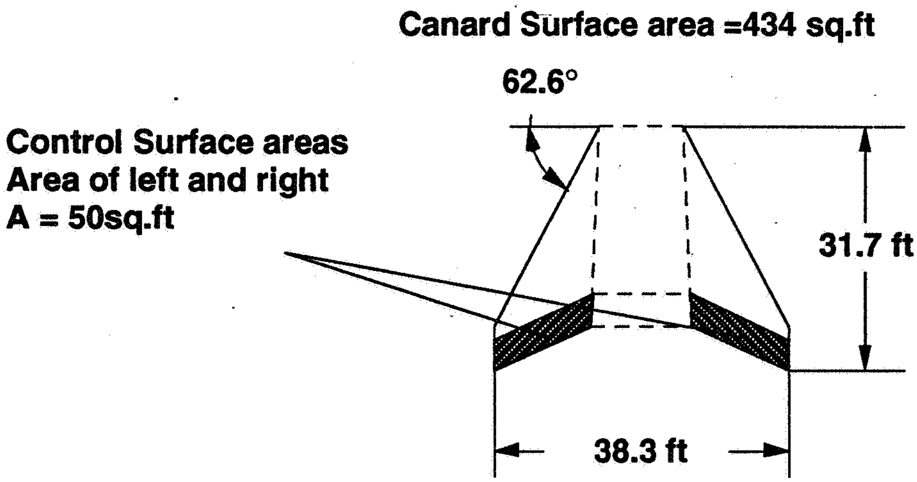
FLOOR AREA (FT^2)	USABLE VOLUME (FT^3)	LANDING GEAR VOLUME (FT^3)
1666.6	5416.6	1130.2

CLASS		TYPE OF CONTAINER	QUANTITY
1 ST		LD - W	2
	VOLUME (FT^3)	70	
BUSINESS		LD - W	9
	VOLUME (FT^3)	70	
ECONOMY 1		TYPE H	5
	VOLUME (FT^3)	157	
ECONOMY 2		TYPE E	15
	VOLUME (FT^3)	16	
		TOTAL CONTAINER VOLUME	1795 (FT^3)
		VOL/PASSENGER	7.18 (FT^3)

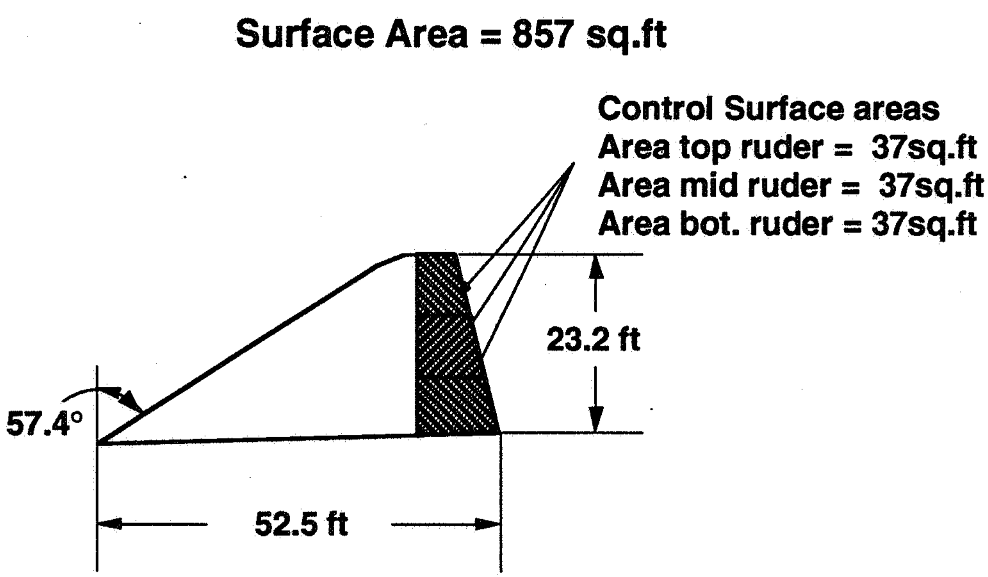
7.0 STABILITY SURFACE DESIGN

7.1 STABILITY SURFACE CONFIGURATION

The stability surfaces employed by the MM-122 include a single vertical stabilizer and highly swept canards. A single vertical stabilizer was selected in order to provide directional stability with the least amount of surface area. The selection of a single vertical stabilizer was made with safety in mind since it is the most proven directional control surface seen on aircraft today. Canard empennage surfaces were selected for several reasons. First, canards provide increased lift at takeoff by inducing vortices across the upper surface of the delta wing. Canards will also provide increased total lift upon takeoff while providing rotation power due to the neurally stable configuration. At supersonic cruise, the configuration becomes statically stable. Canards were selected over a horizontal stabilizer in order to maximize efficiency in this regime by providing increased total lift and decreased induced drag. Canards will provide the MM-122 with optimum efficiency throughout the aircraft's range of operation.



Canard Configuration



Vertical Stablizer Configuration

Figure 7.1 Stability Surfaces Configuration

All empennage surfaces are highly swept as seen if Figure 7.1 in order to reduce wave drag in the transitory Mach region. The highly swept empennage surfaces of the MM-122 will also provide the aircraft with the least amount of wave drag during the critical cruise phase.

7.2 STABILITY SURFACES SIZING

The empennage surfaces of the MM-122 were originally sized using volume coefficient methods. There is insufficient data available for aircraft of this type with canards, and therefore the canards were originally sized using horizontal stabilizer volume coefficient data.

Secondary sizing of the canards was determined from the X-plot data given in Figure 7.2, which shows the aircraft center of gravity and aerodynamic center locations as a function of canard size. From the X-plot data it can be seen that the canards are sized to provide neutral stability at take-off. Neutral stability will allow for greater roll power at takeoff as apposed to a similar configuration that is statically stable. Neutral stability will also allow for less redundancy and greater ease of certification of the control system since the pilot will be able to land the aircraft even with a control system failure. The canard size determined by the X-plot data was found to be sufficient to provide the aircraft with the necessary longitudinal control power throughout the range of operation. Canard surfaces are designed as fail-safe structures in order to maximize aircraft safety margins.

Secondary sizing of the vertical stabilizer was determined by engine out control power constraints. The propulsion system configuration of the MM-122 produced large moments during engine out flight and thus resulted in the vertical stabilizer sizing.

7.3 STABILITY SURFACE CONTROL SURFACES

The MM-122 employes canards with canardvators to provide longitudinal controllability and trim. The canardvators as seen in Figure 7.1 provide the lift required upon take-off for sufficient roll power. The canardvators will also provide appropriate lift during supersonic cruise in order to trim the aircraft.

The vertical stabilizer of the MM-122 employes triple rudder surfaces to provide lateral controllability and trim. Each rudder supplies sufficient lateral controllability, thus providing enhanced safety through redundancy.

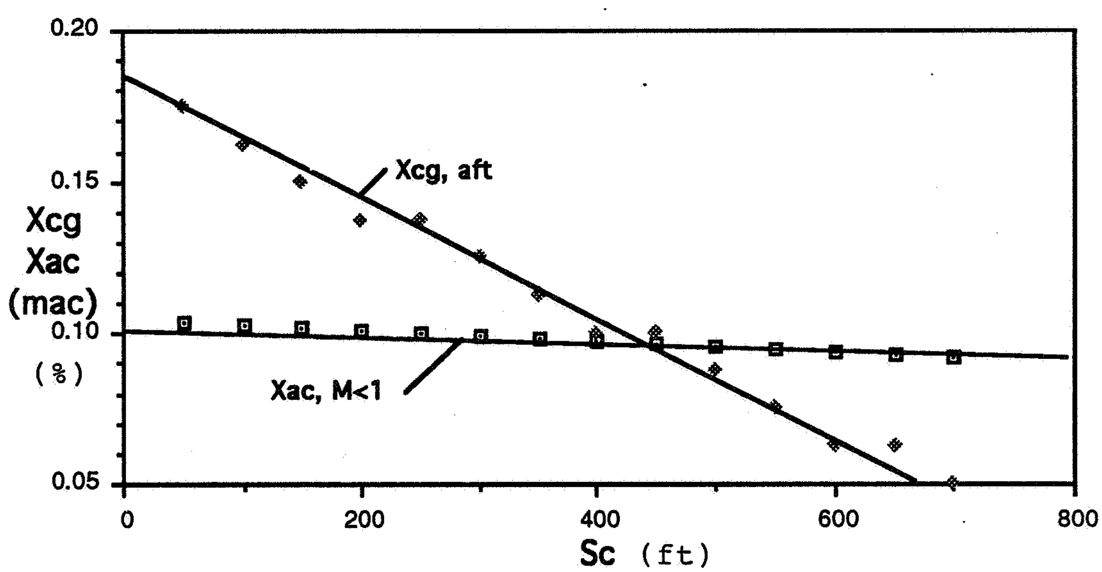


Figure 7.2 Longitudinal X-Plot

8.0 PROPULSION SYSTEM

The propulsion system of the future MM-122 supersonic transport is a sensitive and complex problem which faces it's design. In order to come up with an engine which will meet the future noise requirements and concurrently meet the high thrust levels of the aircraft, extensive design work will need to be done by the engine manufacturer. In order to meet these requirements the cost of the engine will become a significant portion of the aircraft. Cost of an engine that will meet the FAR noise requirements and performance requirements for the MM-122 is extremely important because an increased manufacturer cost due to research and development will increase the cost of the MM-122 as a whole. Low-bypass turbojet engines which are in current use on the Concorde develop noise levels which exceed the FAR Part III requirements and therefore would not be a plausible answer to the problem. To answer to noise level problem, the high thrust level and the fuel consumption problem, the engine of the future will need to have many variable performance parameters. The current engine that most closely meets the previous problems is the low-bypass turbofan engine with variable cycles. The term variable cycle can have many meanings depending on the engine manufacturer, but the general consensus depicts an engine which uses variable bypass ratio to change the performance of engine during flight. Variable geometry consists of variable air bypass systems, variable inlet geometry and nozzle shroud variations. The engine that has a performance level which meets the performance criteria for the MM-

122 is a NASA prototype Turbofan engine with variable geometry inlet, bypass ducts and variable nozzle. The NASA prototype will be called the MM-VC for the remainder of the report. A sketch of the MM-VC is given in Figure 8.1. This figure shows the inlet selection, the variable multi-bypass ducting system and the supersonic nozzle design. To illustrate the variable geometry of the engine Figure 8.2 is given pointing out the difference between cruise and takeoff engine conditions. The engine parameters and requirements for the engine are given in table 8.1.

At the high thrust levels required for the take-off condition, the M-122 is limited to a scarce selection of engines. Turbo-jets present a very good thrust range in the takeoff condition but were not considered because of the high noise levels and low engine flow rate. The Tandem Fan Engine developed by Rolls-Royce was another engine which was investigated for it's highly variable geometry and noise solutions. This engine had a cruise specific fuel consumption at cruise which was 11% higher than the MM-VC and the general engine was far more complex than the MM-VC and therefore not chosen. Other engines which met the takeoff thrust requirements did not compare either in the noise requirement or the fuel consumption range needed for the MM-122's design range.

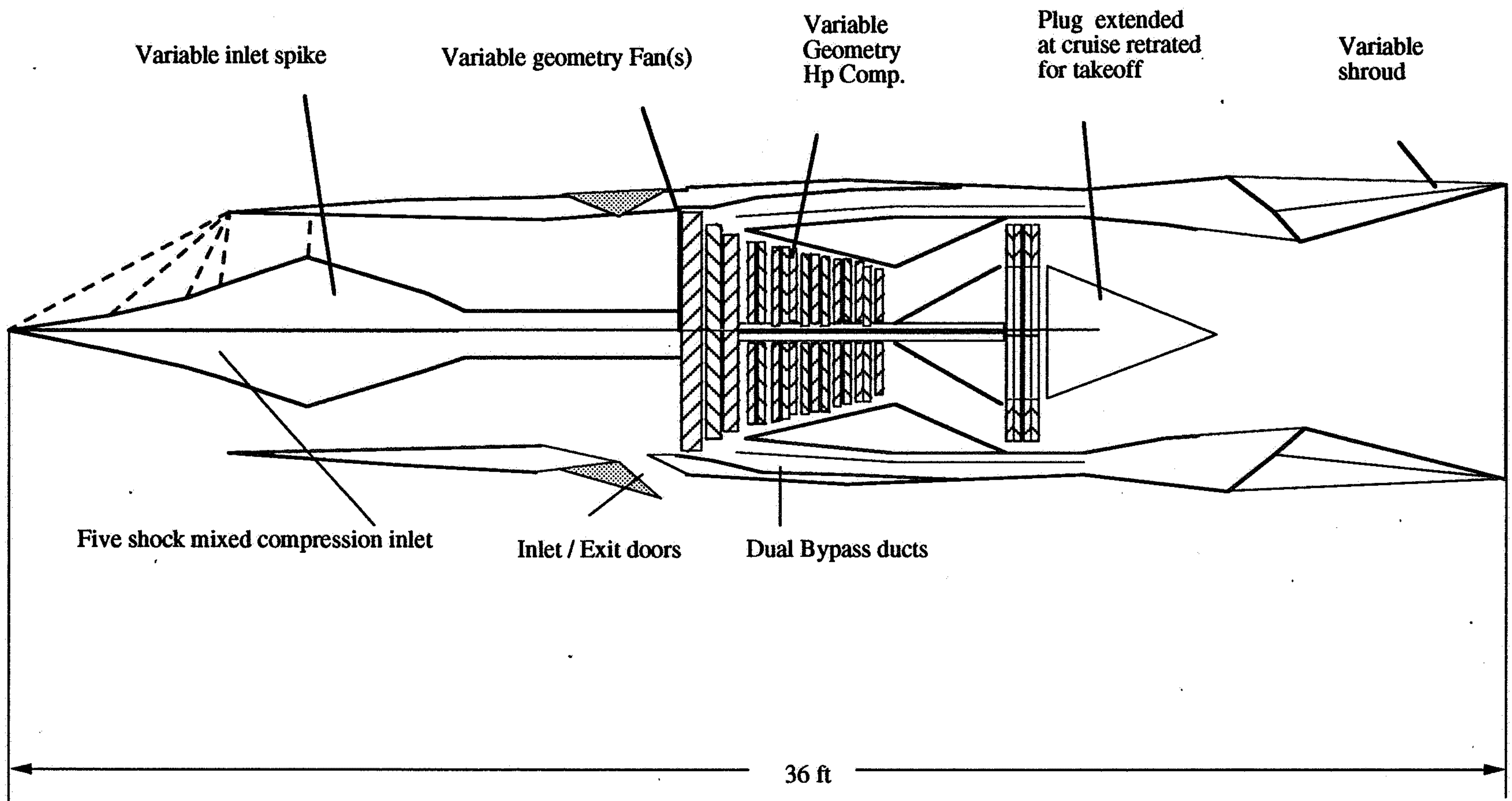
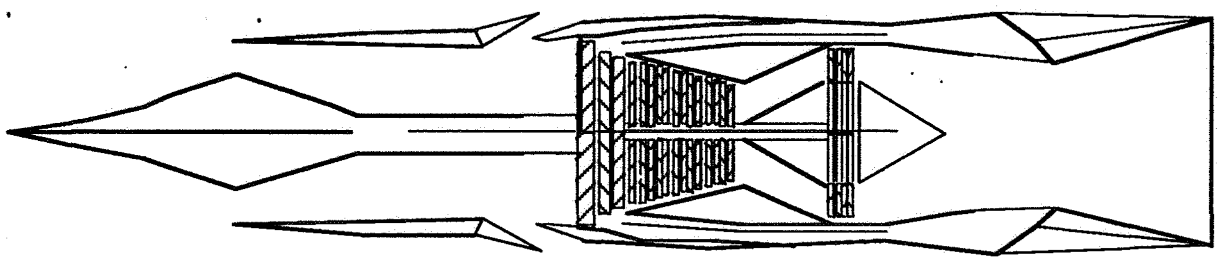


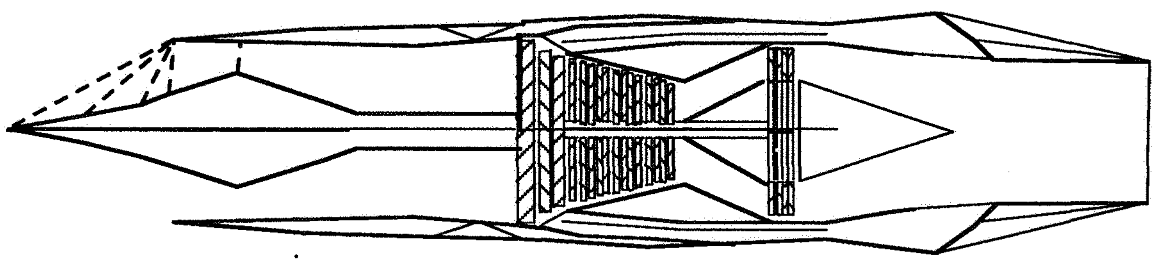
Figure 8.1 MM-122 Variable Cycle Turbo-fan Engine

Takeoff Geometry



-Outer Bypass open
-Turbofan performance
-Augmentor unlit
-Plug retracted
-Shroud retracted
-Fixed nozzle setting
-Inlet spike extended

Cruise Geometry



-Outer bypass passage closed
-Turbo-jet performance
-Augmentor lit
-Plug extended for cruise
-Shroud extended
-Fixed nozzle throat
-Inlet spike retracted

Figure 8.2 MM-122 Variable Geometry

TABLE 8.1 Engine Performance Specifications

Cruise speed	M = 2.2
Takeoff speed	M = 0.4
	Tto = 70,000lb/eng.
Landing Speed	V = 1.3(Vst) = 180kts
Cruise Alt.	H = 55,000ft
	S.f.c = 1.18 lb/lb-hr
Service ceiling	H = 60,000ft
Meet FAR part III noise requirements	
Fuel - Jet A	
Pusher type engine placement	
Materials - 30% titanium - 70% Aluminum	

TABLE 8.2 Engine Dimensions and Weights

	Inlet	Engine	Nozzle	Total
Weights	3500lb	8,523lb	3938lb	16,406lb
Lengths	12.6ft	11.4ft	11.6ft	36ft
Diameter	5.2ft	7.2ft	7.2-7.9ft	5.2-7.9ft

8.1 INLET SELECTION

In supersonic flight the inlet of the propulsion system produces up to 80% of the total thrust of the system, therefore the inlets selected for the MM-122 were considered for a maximum pressure recovery, minimum weight, structural integrity and minimum wave drag characteristics. In order to maximize the pressure recovery of the inlet and hence minimize the amount of energy taken from the flow, the axisymmetrical spike inlet was chosen. The axisymmetrical spike inlet has a pressure recovery which exceeds that of the 2-D inlet by approximately 10% with a cruise Mach flight velocity of 2.2. Figure 8.3 shows the efficiency trends of the inlet through the various flight Mach numbers. An axisymmetrical inlet with variable spike inlet has the advantages of light weight, stronger construction and shorter subsonic diffuser length. Variable geometry of the inlet includes bleed slots located on the spike and bleed doors which act to increase or decrease air flow into the engine. The capture area of the inlet was calculated at the takeoff and cruise conditions and are given in Table 8.3. In order to prohibit turbulent boundary layer air from entering the inlets of the MM-VC the engines were place 1.5 ft off the wing.

Table 8.3 Capture Area

Takeoff condition	Ac = 21.4sq.ft
Cruise condition	Ac = 23.0sq.ft

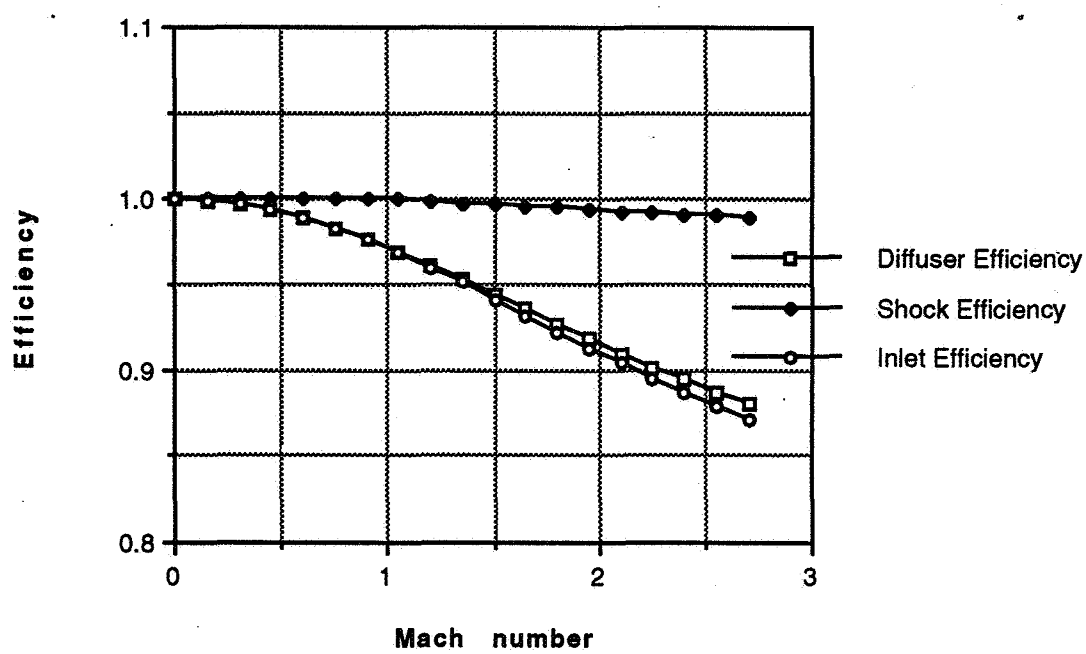


Figure 8.3 MM-122 Axisymmetrical Inlet Efficiency

8.2 ENGINE CYCLE SELECTION

In order to meet the FAR stage III noise requirements for the MM-122 in the take-off flight condition and the high thrust levels for cruise, a variable cycle engine was selected. In terms of the inlet, the spike and the bypass ducts change with different mission phases. When the aircraft is in a high thrust, low speed flight condition the spike inlet is moved to the forward position and the extra inlet doors are opened to increase the flow rate into the inlet and hence the engine core. Hence the engine runs as a turbo-fan engine with multiple bypass ducts open around the core of the engine. The high flow rate through the engine decreases the noise level of the aircraft to an acceptable level. At cruise flight condition the inlet spike is retracted and the outer bypass doors or closed to minimize the flow through the engine and establish a five shock ramp system on the inlet. The nozzle shroud and the engine nozzle plug are retracted during cruise to maximize thrust at altitude. The different geometry conditions associated with cruise and takeoff are illustrated in Figure 8.2. In terms of the bare engine, the variable cycles will consist of a variable geometry high pressure compressor with variable stators and duct sizing. In order to run the variable geometry of the engine there will be a flight computer to instantaneous monitor and maximize the cycles to the specific flight condition.

8.3 ENGINE PERFORMANCE

The engine designed for the MM-122 is the MM-VC low bypass turbo-fan engine with variable cycles. The performance of this engine in the flight regimes of takeoff-landing, cruise, and intermediate altitude flight were provided by the manufacturer. The MM-VC turbo-fan prototype which will be used on the MM-122 is a rubberized version of the original engine with a scaling factor of 1.187. This engine can produce 70,000 lbs of installed thrust at sea level standard at a Mach number of 0.4. In order to meet the thrust to weight ratio of 0.356 given from the sizing analysis the aircraft will need to have a net thrust of 280,000 lbs of thrust at takeoff and 20,000 lbs at the cruise condition. These thrust levels assume level unaccelerated flight. The installed thrust performance of the engine as a function of Mach number is illustrated in Figure 8.4.

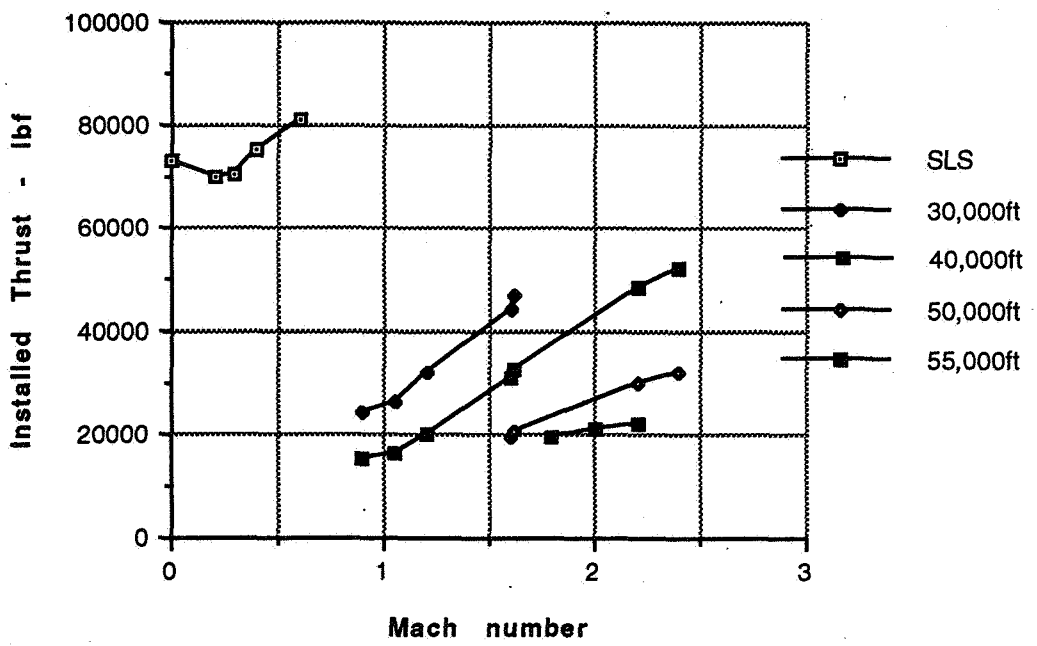


Figure 8.4 Full Power Installed Thrust Performance

The installed fuel consumption of the engines are plotted as a function of Mach number and altitude in Figure 8.5. The installed cruise specific fuel consumption for the aircraft in the cruise condition is 1.18 lb/lb-hr.

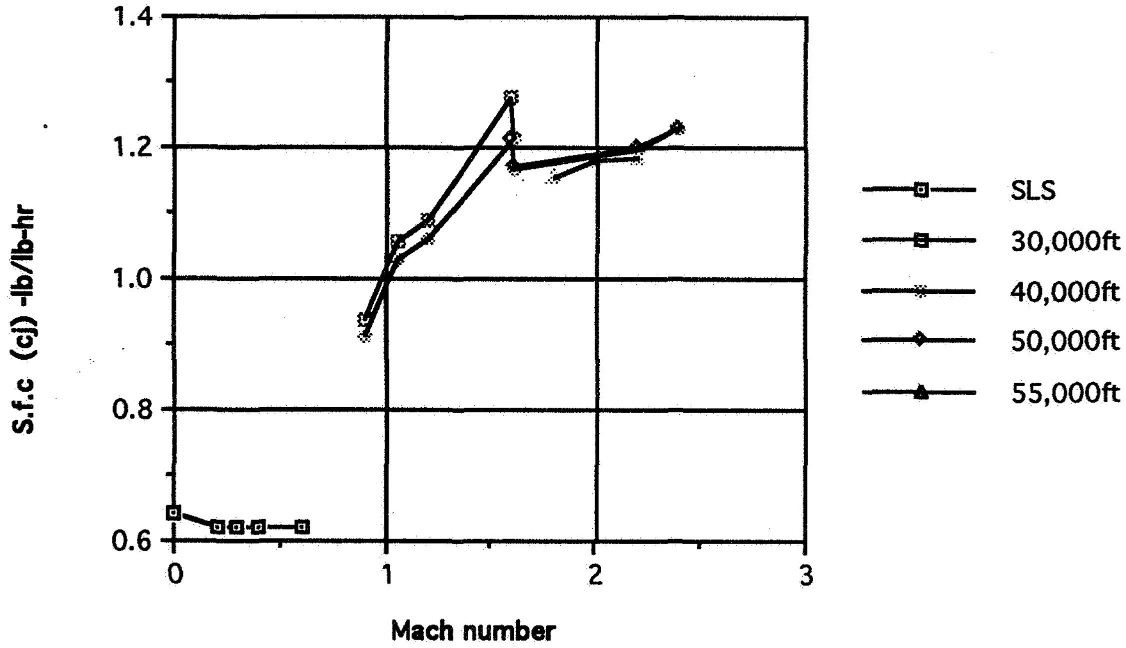


Figure 8.5 Full Power Fuel Consumption

8.4 ENGINE AIRFRAME INTEGRATION

In order to integrate the propulsion system into an efficient formation with the airframe a few design considerations were considered. Engine placement was dependent on the following: foreign object damage, shock interference with airframe and wing, local flow angle, location with respect to center of gravity and the clearance of the engine nozzle during takeoff rotation. To compensate for the change in local flow angle of the airflow under the wing and fuselage prior to the engine inlet the engines were slightly canted inward. The inner engine is canted inward at an angle of 1 deg. while the outer engine 2 deg. To compensate for the boundary layer build up over the aircraft prior to the inlet of the engine the axisymmetric inlets are equipped with bleed ramps in the inlet to absorb the turbulent layer. These boundary layer absorption ramps will increase the diffuser efficiency of the engine (See figure 8.6 for details). To combat the problem of FOD, the landing gear were equipped with deflectors and placed in position between the inlets and as far aft as the center of gravity limits would allow. The location of the engines with respect to wing, fuselage and landing gear is illustrated in Figure 8.6

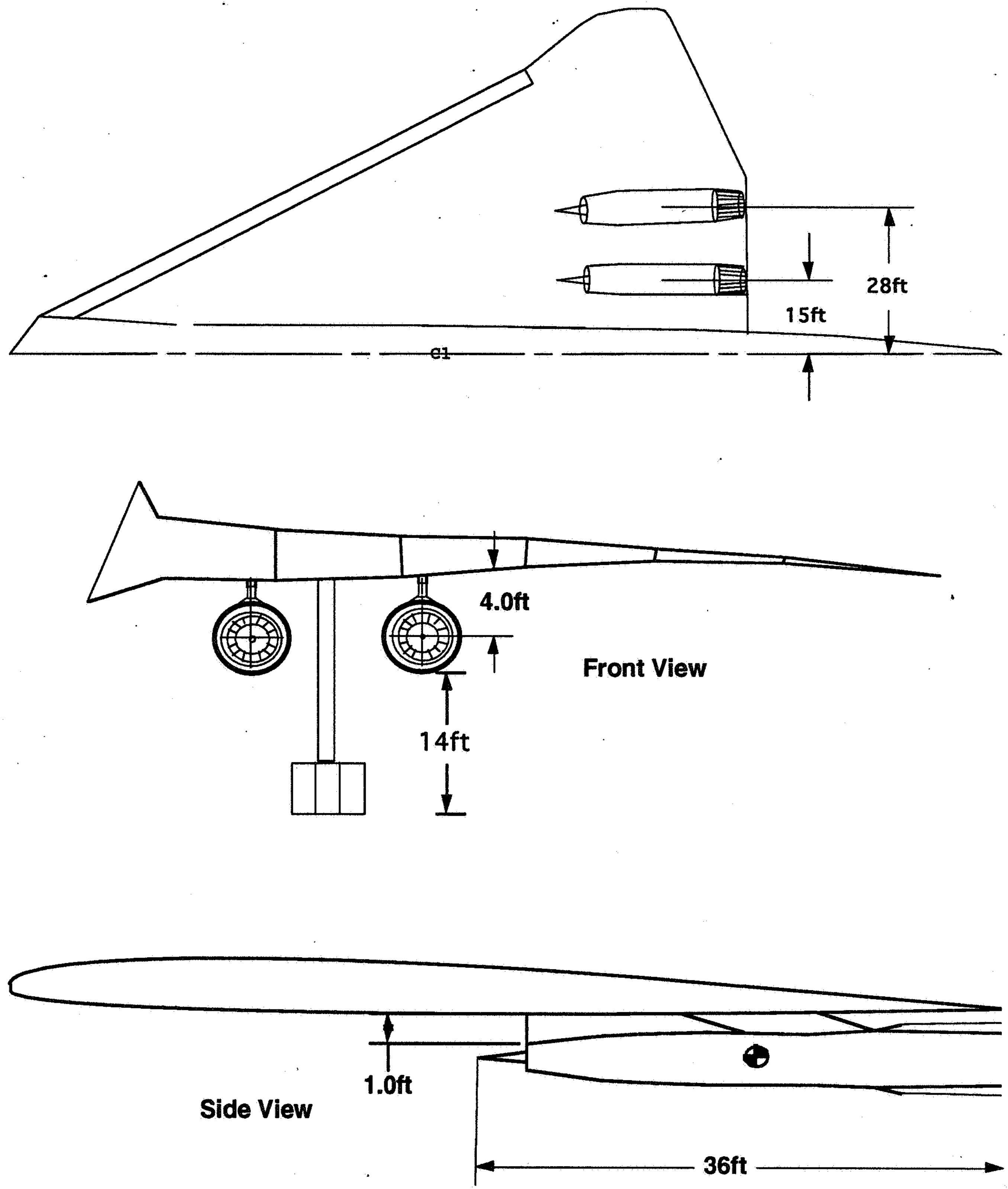
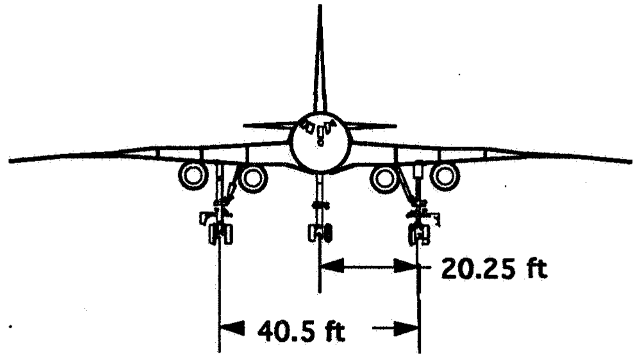


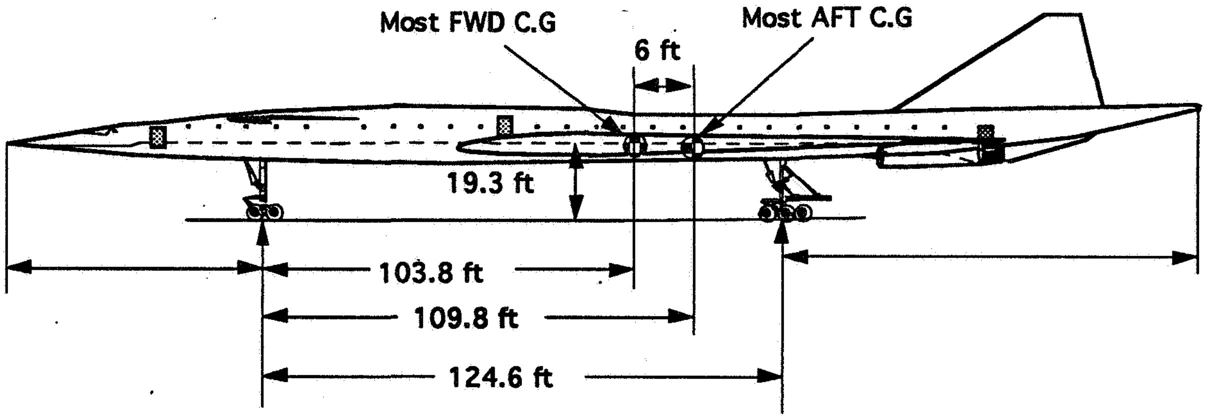
Figure 8.6 MM-122 Engine Placement Diagram

9.0 LANDING GEAR DESIGN

MM-122 is equipped with a conventional tricycle type landing gear; three main wheels aft of the c.g. and auxiliary wheel forward of the c.g. This arrangement would improves forward visibility of the pilot on the ground, permits a flat cabin floor for passengers and cargo loading, and provides good ground maneuverability during taxi operation. The gear arrangement includes multiple wheels to share the aircraft's load. The location of each landing gear unit and its distributed load are shown in Figure 9.0. The disposition of the landing gear was dictated by ground clearance and tip-over criteria. MM-122 has one 4-wheel boogey on the nose unit and three 6-wheel boogey on the main units. All the landing gear units on MM-122 are hydraulically actuating systems which enable all unit to be fully retracted into the fuselage after airborne.



(a) Front View



Pn,max. = 132,713 lbs

Pm,max. = 233,523 lbs/ per Strut

Pn,min. = 94,430 lbs

Pm,min. = 220,762 lbs/ per Strut

Dynamic Nose Gear Load = 165,649 lbs

(b) Side View

Figure 9.0 Landing Gear Loading Diagram

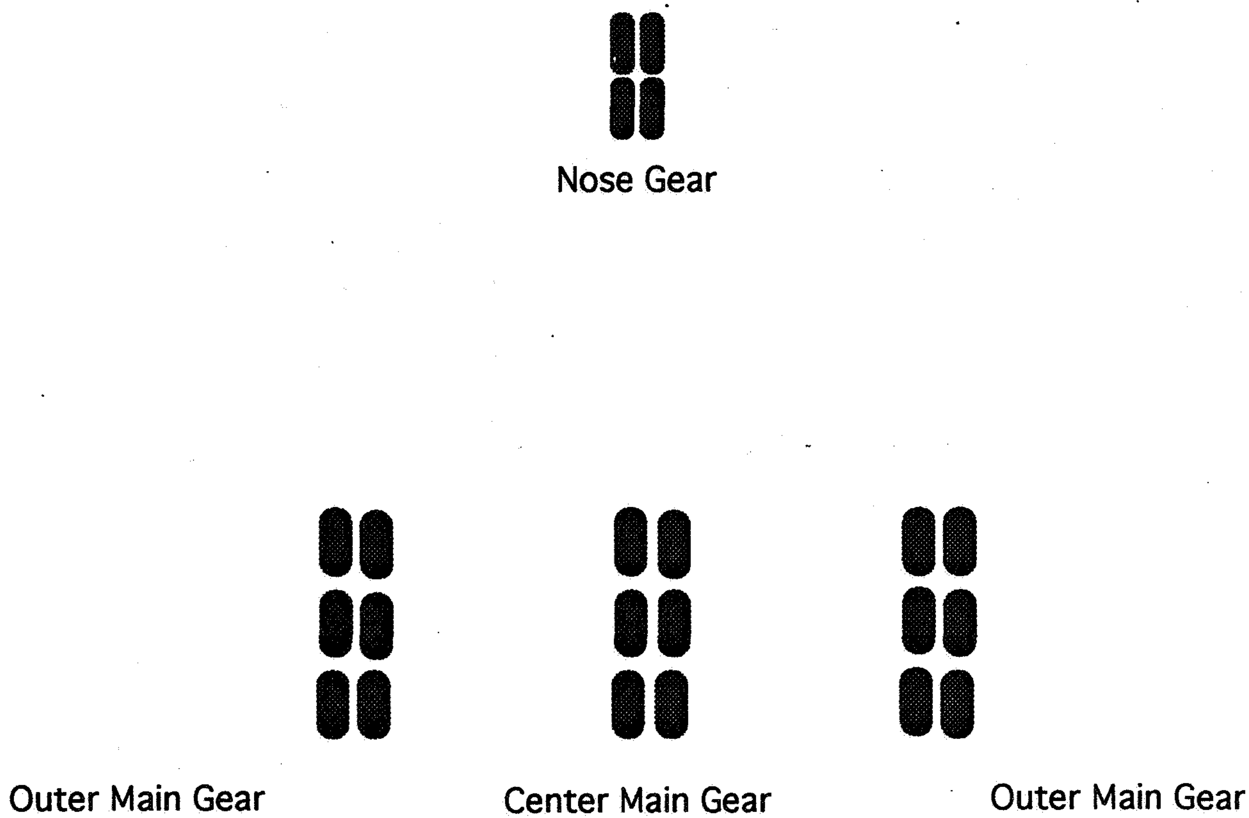
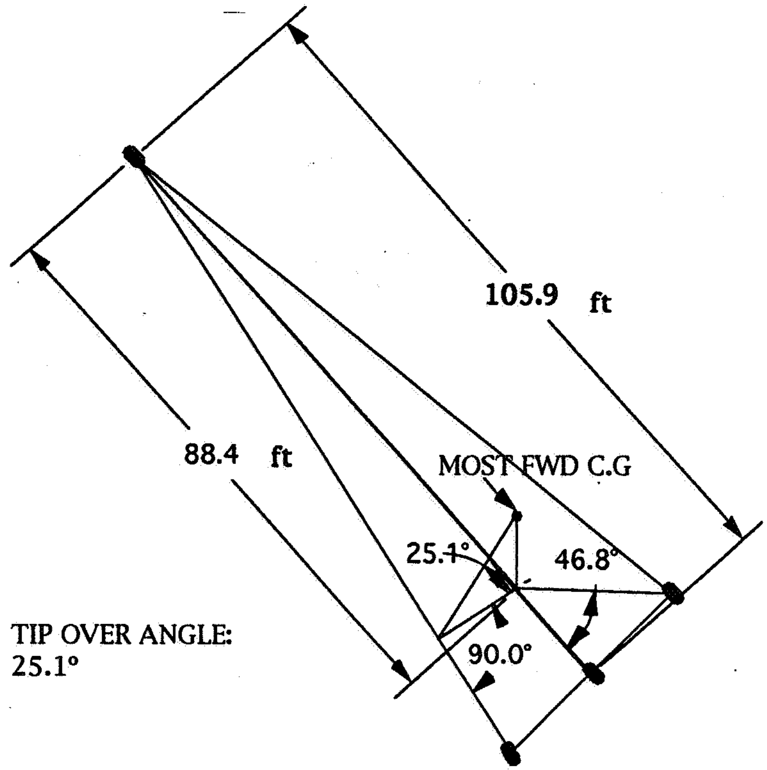


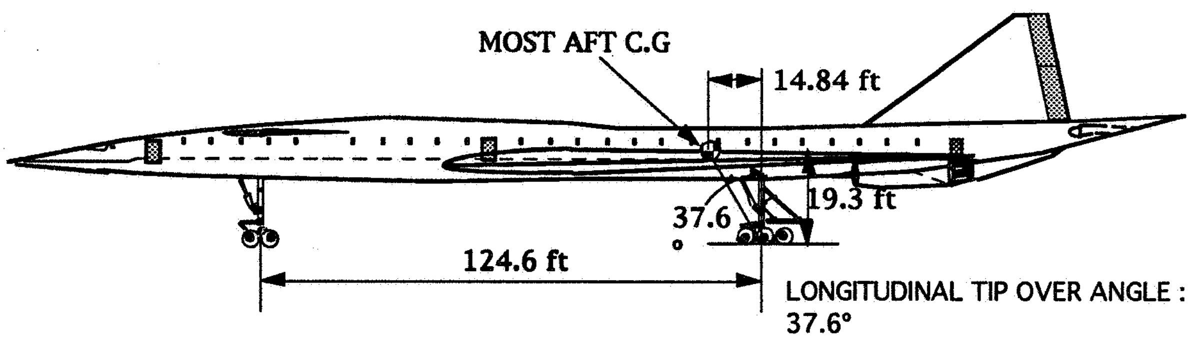
Figure 9.1 MM-122 Landing Gear Footprint

9.1 LANDING GEAR CRITERIA

The landing gear disposition is designed such that all pertinent criteria will be met. These criteria include lateral and longitudinal tip over criteria and lateral and longitudinal ground clearance criteria. As seen in Figure 9.2, the landing gear will meet lateral tip over criterion with a tip over angle of 25.1º and longitudinal tip over angle of 37.6º . Similarly, it can be seen from Figure 9.3 that the landing gear will also meet ground clearance criteria . It is these criterion that dictated the disposition of the landing gear.



(a) Lateral Tip Over Criterion



(b) Longitudinal Tip Over Criterion

Figure 9.2 Tip Over Criteria

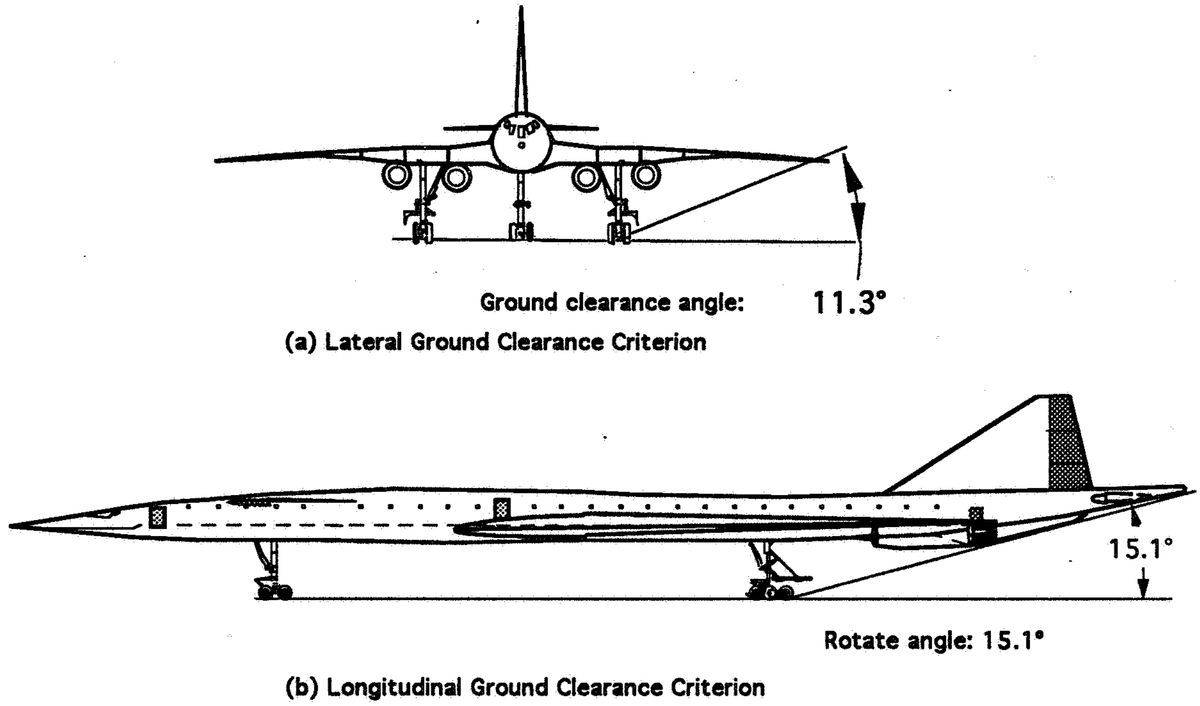


Figure 9.3 Ground Clearance Criteria

It may be seen in Figure 9.3 that the landing gear has a deflection fin just above the main gear tires. This deflection fin is intended to minimize foreign object damage (FOD) that may be produced due to the main gear disposition with respect to the engine inlets. FOD angles for the aircraft are just outside of standard criterion, however any damage that may have happened should be contained by the deflection fin. It is suggested that a trade-study be made on relocation of landing gear and engine inlets due to FOD potential prior to final aircraft production.

9.2 TIRE SPECIFICATIONS

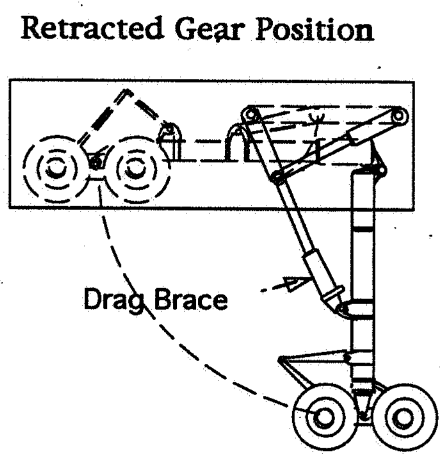
Tire specifications for the MM-122 are summarized in Table 9.2. These specifications were selected primarily with concern for safety and industry compatibility.

Table 9.2 Tire Specifications

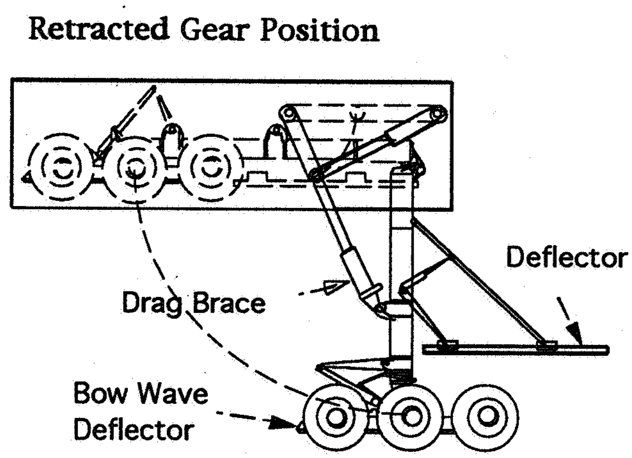
	Nose Gear	Main Gear
Number of tires	4	18
Type of tire	VII	VII
Size of tires	40 in Dia, 14in Width	50 in Dia, 20in Width
Weight	127 lbs	220 lbs
Max. Loading for each tire	33,500 lbs	38,200 lbs
Actual Loading for each tire	31,637 lbs	12,379 lbs
Loaded Radius Static tire Flat tire	 16.5 in 11.6 in	 20.6 in 13.6 in
Max. Shoulder Dia.	35.1 in	44.6 in
Max. Ws	12 in	17.6 in
Max. Speed	200 MPH	200 MPH
Ply Rating Unloaded inflation Pressure	28 200 PSI	24 135 PSI

9.3 MECHANISM OF LANDING GEAR

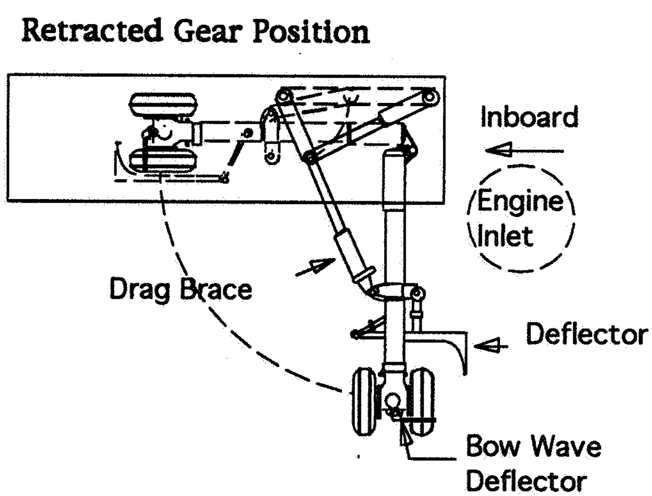
The nose gear unit of the MM-122 retracts forward by hydraulically driven ballscrews. This retraction will allow for self deployment in the event of deployment system failure. This self deployment can be done by an integral pressurized pneumatic storage cylinder and gravity assist. Single nose shock absorber and three main gear shock absorbers are employed to absorb landing loads. Two of the main gear units under the wing retract inward toward the fuselage by hydraulically driven ballscrews. The middle main gear unit under the fuselage will have the same mechanism as in the nose gear unit and like all the gear, will deploy under it's own weight in the event of a failure. The gear disposition and retraction sequence are illustrated in Figure 9.0 and Figure 9.4.



(a) Nose Landing Gear



(b) Outer Main Landing Gear



(c) Outer Main Landing Gear

Figure 9.4 Landing Gear Schematic

10.0 STRUCTURES

10.1 FUSELAGE

The MM-122 has a fuselage structural arrangement typical of current jumbo jets consisting of stringers, frames and longerons. The fuselage member spacing and frame depths may be seen in Figure 10.1.a. One noticeable feature on the MM-122 differing from other civil transports is the larger distance between windows. Each passenger row does not have a window. The windows of the MM-122 will be subjected to higher temperatures and larger pressure variations then found on current jumbo jets such as the Boing-747. For these reasons window utilization was kept to a quantitative minimum. It was decided that windows must be used to provide reasonable passenger comfort, thus resulting in about one window every two rows. The structures used to attach the windows to the fuselage differ from current jumbo jets in that a pair of longerons does not brace the top and bottom of the windows as seen in current jubo jets like the the Boeing-747. The MM-122 uses individual bracings over the top and bottom of each window with the only exceptions being where a longeron runs near the normal bracing. In these cases, as can be seen in Figure 10.1, the longeron is used instead of individual bracing . This serves to save weight and ease construction . The MM-122 uses hemispherical pressure bulkheads in order to support cabin pressurization while minimizing structural weight.

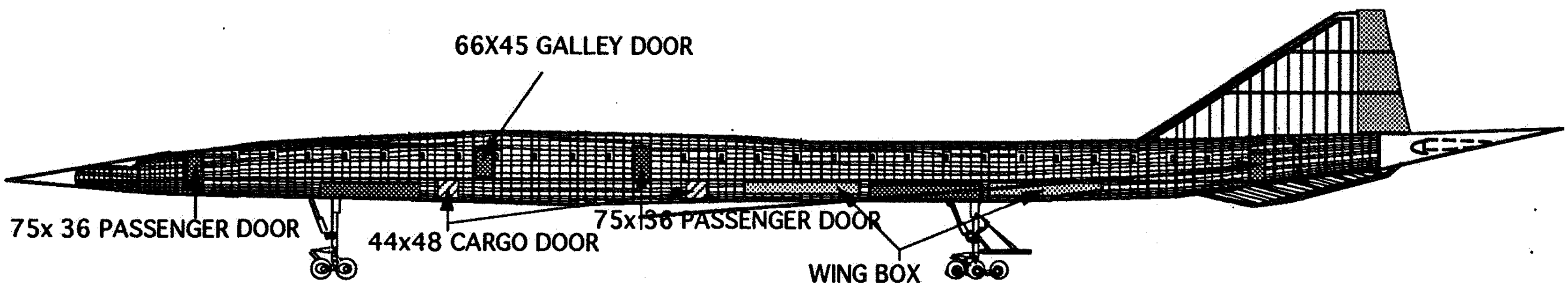


Figure 10.1.a MM-122 Structural Layout

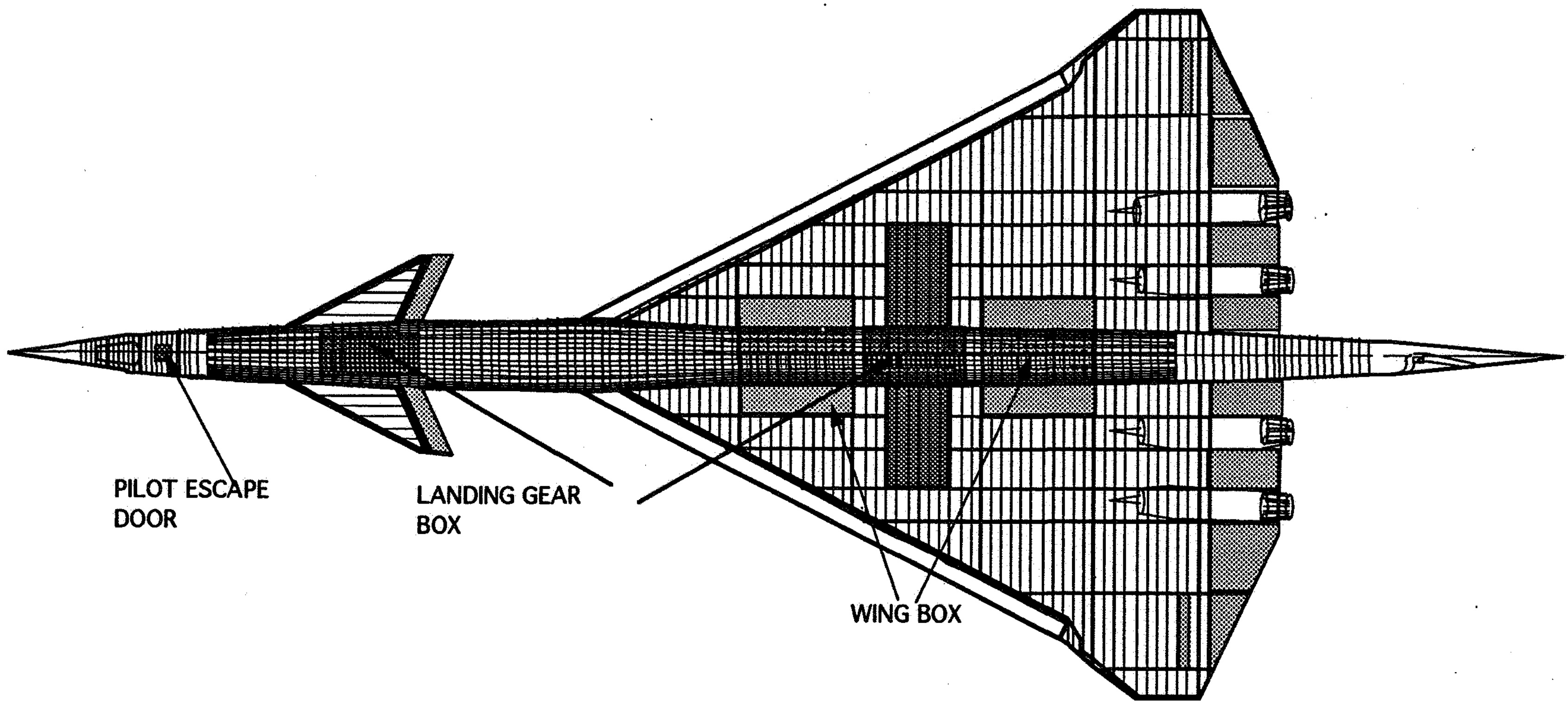


Figure 10.1.b MM-122 Structural Layout

10.2 WING AND WING BOX STRUCTURE

Due to the large root and short relative wing span employed by the MM-122 as compared with a typical jumbo jet, the conventional two spar with flow wise rib combination will not work well for this configuration. The combination of excessive space between spars and too long of ribs would not provide enough support to the middle of the wing if a conventional structural configuration were used. A combination of leading edge, transverse and flow wise spars gives the middle of the wing greater strength and still provides a wing box with fuel capacity in the fuselage. The transverse spars are positioned to provide support to the landing gear bay, engine mounts and forward portion of the wing respectively. The flow wise spars are positioned to provide additional support to the landing gear bay, trailing edge control surfaces and the engine mounts as seen in Figure 10.1.b. It may also be noted that the slight trailing edge aft sweep utilized by the wing plan form allows for a longer root cord. A longer root cord provides the MM-122 with more room for fuel at the thickest part of the wing while providing more room for trailing edge control surfaces.

10.3 EMPENNAGE STRUCTURE

The vertical tail is structurally constructed similarly to the wing employing leading edge, flow wise, and transverse spars with vertical ribs as shown in Figure 10.1.a. The leading edge spar is positioned to provide support to the leading edge of the vertical stabilizer. The flow wise spars are positioned to provide structural support for the loads produce by the rudder. The vertical spars are positioned to support the loads encountered by the rear of the tail as well as the the rudder members and to support the flow wise spars. The MM-122 utilizes lateral ribs in the tail in that, like the wing a shorter rib configuration provides greater structural integrity. The vertical stabilizer is mounted on the fuselage by connecting the leading edge and vertical spars with heavy frames located in the fuselage.

The canard employes a duel spar with crosswise rib design as shown in Figure 10.1.b. The canard is structurally connected to the fuselage by connecting the spars with a pair of heavy fuselage frame members. The canard is fixed with articulating canardvators in order to reach trim conditions.

One special feature of the MM-122 is that of a rear fin used to induce vortices over the lower, rear fuselage surface of the aircraft. These vortices have been shown to delay flow separation over the lower portion of the fuselage thus significantly reducing aircraft pressure drag (Reference 9). These strakes are constructed using two spars with crosswise ribs. These are connected to the fuselage by the spars and a pair of heavy frames in the fuselage.

10.4 MATERIAL SELECTION

A number of properties are important to the selection of materials for the M.M 122. The selection of the best material depends upon the application. Factors to be considered include yield and ultimate strength, stiffness, density, fracture toughness, fatigue crack resistance, creep, corrosion resistance, temperature limits, productibility, repairability, weight saving, cost, and availability.

Material selection for the aircraft will make use of traditional metals such as aluminum and titanium. In the areas of the aircraft where the flow stagnates such as the nose and the wing leading edge the materials will need to handle very high temperatures. Other extreme temperature regions such as engine components will need to be equipped with high temperature retarding titanium . For the fuselage and wing skin sections typical Aluminum such as Al 6061 and Al 2618 will be employed. The supersonic skin temperature (M=2.2) is shown in Figure 10.2

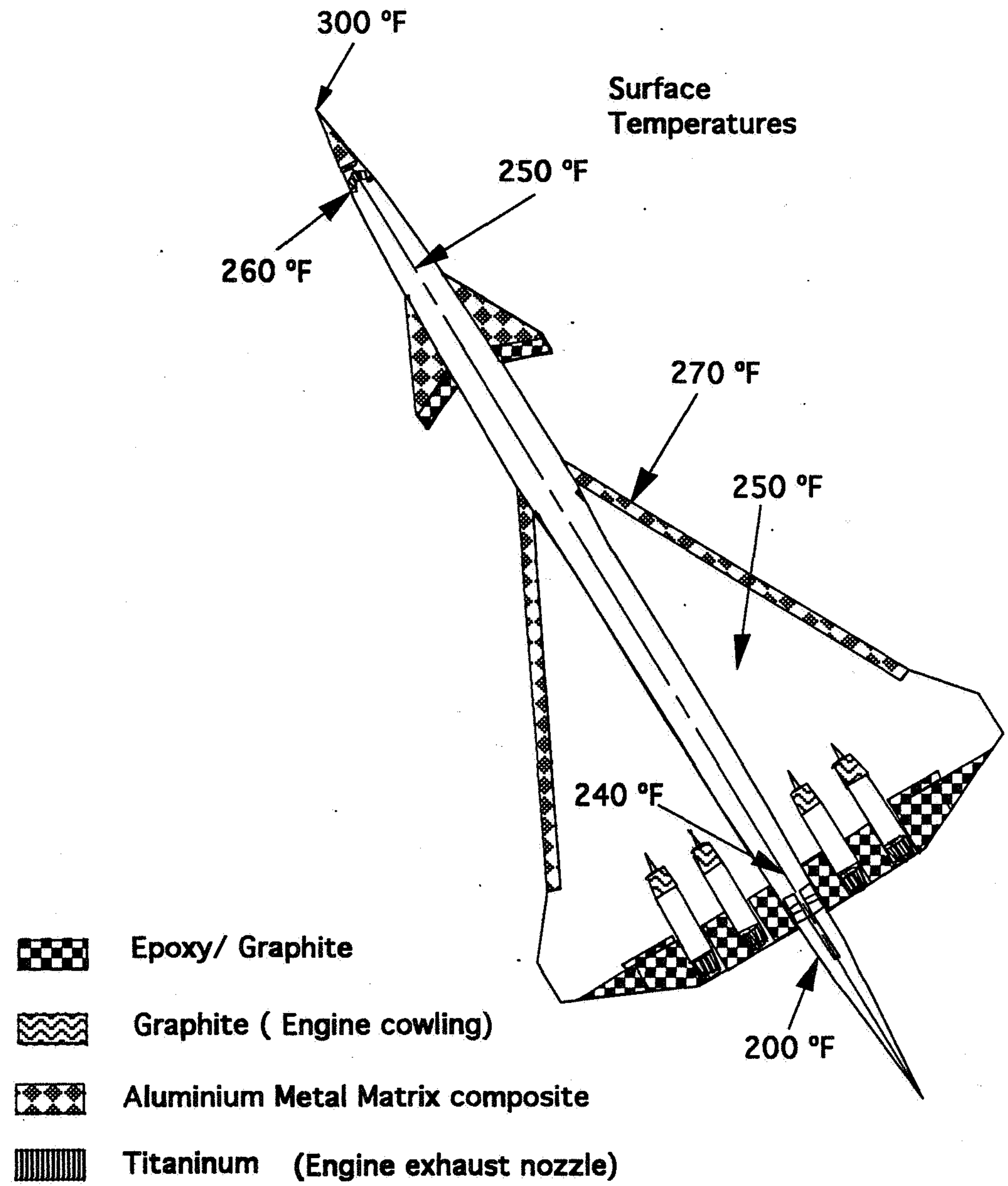


Figure 10.2 Advanced Composite Material Applications

Al 6061 has a very high specific modulus (230) and specific compressive yield of 1,160 at room temperature. Al 2618 has a steady specific modulus (at 150) up to a temperature of 400º F where it becomes slightly nonlinear. At the elevated temperature surfaces such as fuselage nose, leading edge, canard and empennage an advanced composite material will be applied to withstand the high temperature shown in Figure 10.2. Al Metal Matrix Composites (Al MMC) are quite capable of sustaining high specific yield strength (1,200) and high specific modulus value (210). For control surfaces such as the canard, elevon, spoiler and vertical stabilizer graphite-epoxy composites will be applied. The fraction of graphite composites will be minimized using modern construction techniques. Also wing structure including fairings and fuel tanks will be predominantly made of composite material such as graphite and polyimide.

10.5 V-n DIAGRAM

In order to calculate the limiting loading flight conditions for the MM-122 the V-n diagram was constructed. This plot gives the limiting structural load factors which can be accommodated during various flight conditions. The positive and negative limit load factors are +2.5 and -1.0 respectively. These positive and negative limit loads are typical for standard civil transport. Figure 10.3 and 10.4 illustrate the limiting load factor in a gust and maneuver situation respectively.

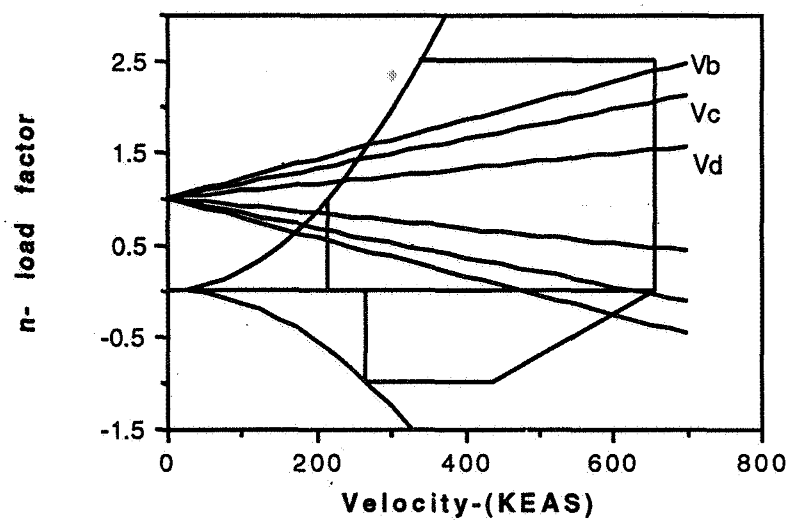


Figure 10.3 Gust V-N Diagram

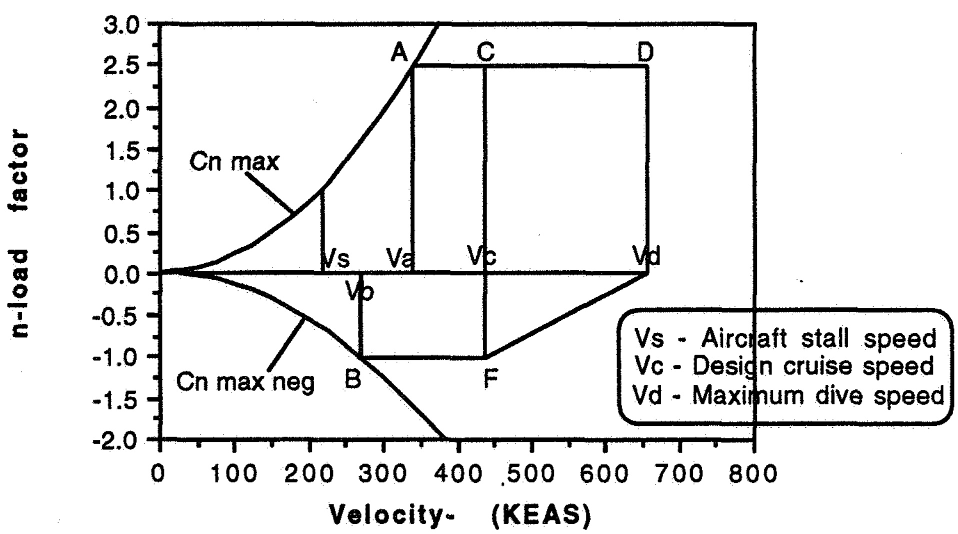


Figure 10.4 Maneuver V-n Diagram

In the takeoff condition for the MM-122 the flight velocity will be approximately 1.1 to 1.15 times the stall speed of the aircraft and hence will be limited to load factor of 1.0. For the range of velocities between aircraft approach, cruise and maximum dive speed Va, Vc and Vd the positive load factor of the aircraft will be 2.5. The negative load factor limit for the aircraft will be -1.0 between the approach velocity and the cruise velocity and linearly decreased to zero at the maximum dive velocity. These critical points are illustrated as points A, C and D in Figure 10.3.

11.0 PERFORMANCE

11.1 Drag Polar Calculation Method

The drag polars were calculated using the method of chapter 12 in the aircraft design text written by Roskam (Reference 12). The subsonic skin friction drag was calculated at a speed of 250 knots using form factors, skin friction coefficient, and wetted area's. The miscellaneous parasite drag was calculated using the techniques listed in Reference 12. Included in the miscellaneous drag calculation is the drag due to fuselage upsweep, flap deflection, leaks and disturbances, and the landing gear. The clean drag polar includes fuselage upsweep and leaks and disturbances drag. The landing miscellaneous drag includes the above plus the flap drag at a 60 degree deflection and the landing gear drag. The takeoff drag polar includes a flap deflection of 20 degrees and landing gears down. The subsonic drag due to lift was calculated using the leading edge suction method with 80 percent suction and a Cl alpha of 2.5.

The transonic parasite drag rise was estimated using the method given in Reference 12. The assumption is made that the wave drag at Mach 1.05 is equal to the wave drag at Mach 1.20. Also, the method assumes a wave drag at a Mach number of 1 to be one half of the wave drag at Mach 1.20.

The supersonic skin friction drag was calculated using the component build up method which is a function of the coefficient of friction and the wetted area. All supersonic calculations were evaluated for a cruise speed of Mach 2.2 and an altitude of 55,000 feet. The parasite wave drag was found using a Sears-Hack area ruling and calculation as presented in Reference 12. This value was then corrected to an actual wave drag value. Supersonic parasite drag includes upsweep and leaks and perturbations drag. The supersonic drag due to lift was calculated using the method of Reference 12. Table 11.1 contains the values used in the buildup of the parasite drag. A list of all values used in the calculations is included in the appendix.

In order to determine effeciencies of the MM-122 the lift to drag ratios were calculated for varius configurations. The results of these calculations are pressented in Figure 11.2 through Figure 11.5.

Table 11.1 MM-122 Drag Component Buildup

Drag Source	Delta C_{do}
Skin Friction (Subsonic)	.007
Skin Friction (Supersonic)	.005
Fuselage Upsweep	.0003
Take off Flaps	.031
Landing Flaps	.094
Landing Gear	.020

The following drag polars were determined for various configurations:

Table 11.2 MM-122 Drag Polars

Clean	$.007457 + .205782\ Cl^2$
Takeoff(Gear down)	$.059915 + .205782\ Cl^2$
Takeoff (Gear up)	$.039915 + .205782\ Cl^2$
Approach	$.092000 + .205782\ Cl^2$
Landing	$.124032 + .205782\ Cl^2$
Cruise	$.008324 + .254500\ Cl^2$

The coefficient of lift for maximum lift to drag ratio and the corresponding lift to drag ratios are as follows:

Table 11.3 MM-122 Lift to Drag Ratios

	Cl(max)	L/D(Max)
Clean	.19	12.76
Takeoff (Gear down)	.54	4.50
Landing	.78	3.13
Cruise	.18	10.86

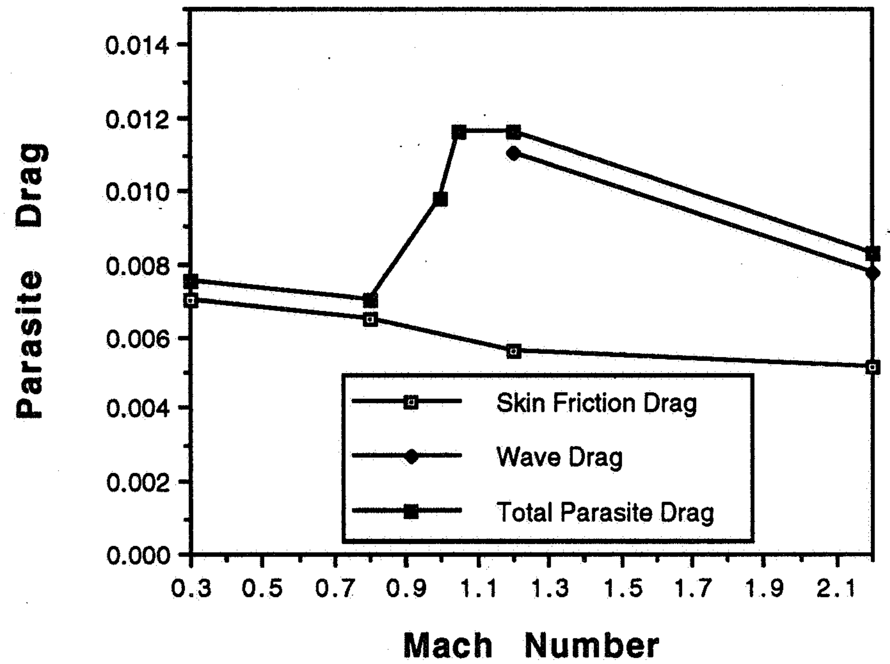


Figure 11.1 MM-122 Parasite Drag vs Mach Number

11.2 Rate of Climb

Rate of climb calculations show a 1,440 ft/min maximum climb rate at takeoff with gear down. In clean configuration a climb rate of 7994 ft/min can be obtained. The cruise rate of climb is 186.4 ft/min. Landing configuration shows a rate of climb of -6602 ft/min. Rate of climb calculations were done using the excess power divided by the weight of the aircraft.

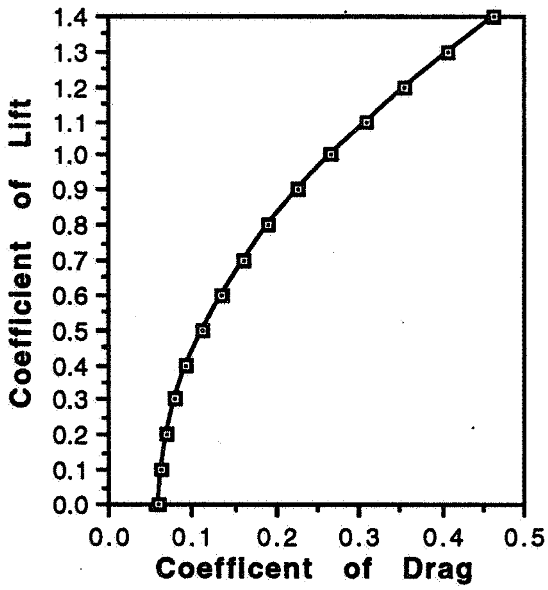


Figure 11.2: Cl vs Cd for Takeoff

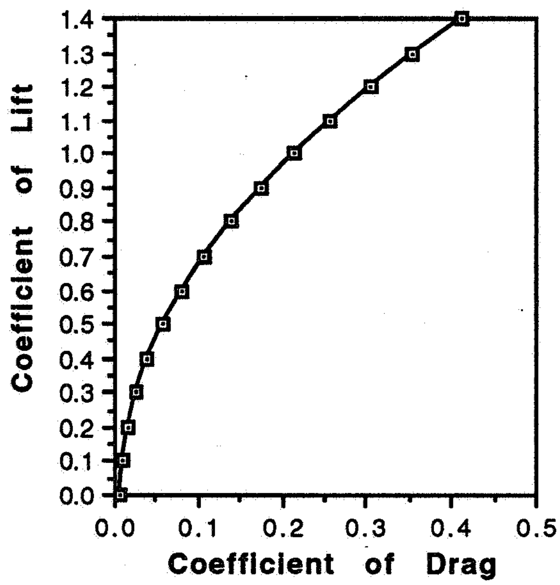


Figure 11.3: Cl vs Cd for Clean Configuration

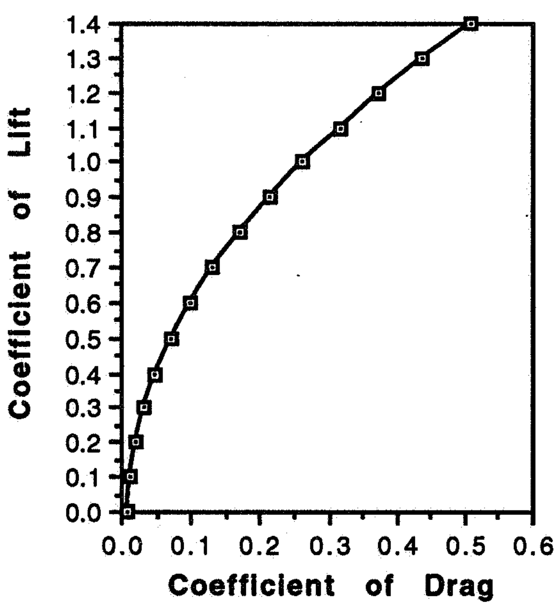


Figure 11.4: Cl vs Cd for Cruise

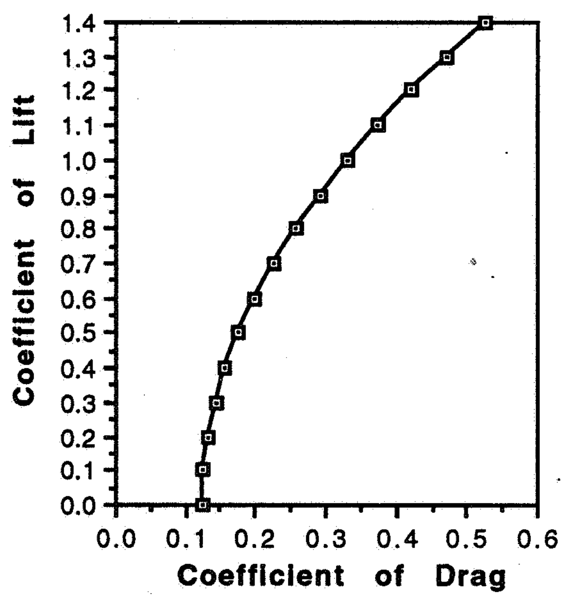


Figure 11.5: Cl vs Cd for Landing

12.0 STABILITY AND CONTROL

12.1 STATIC STABILITY

The MM-122 was designed to be neutrally stable at take-off and to be statically stable throughout the flight phase. This is to provide added safety in the unlikely event of a controls system failure and to provide ease of certification. With the statically stable configuration, the canards will be uploaded in trim as seen in the trim diagram of Figure 12.1. As the aircraft burns fuel, the cg location travels forward as seen in Figure 12.2, increasing the level of static stability. Fuel distribution techniques will be utilized to maintain as small a load as possible on the canards, thus increasing aircraft efficiency.

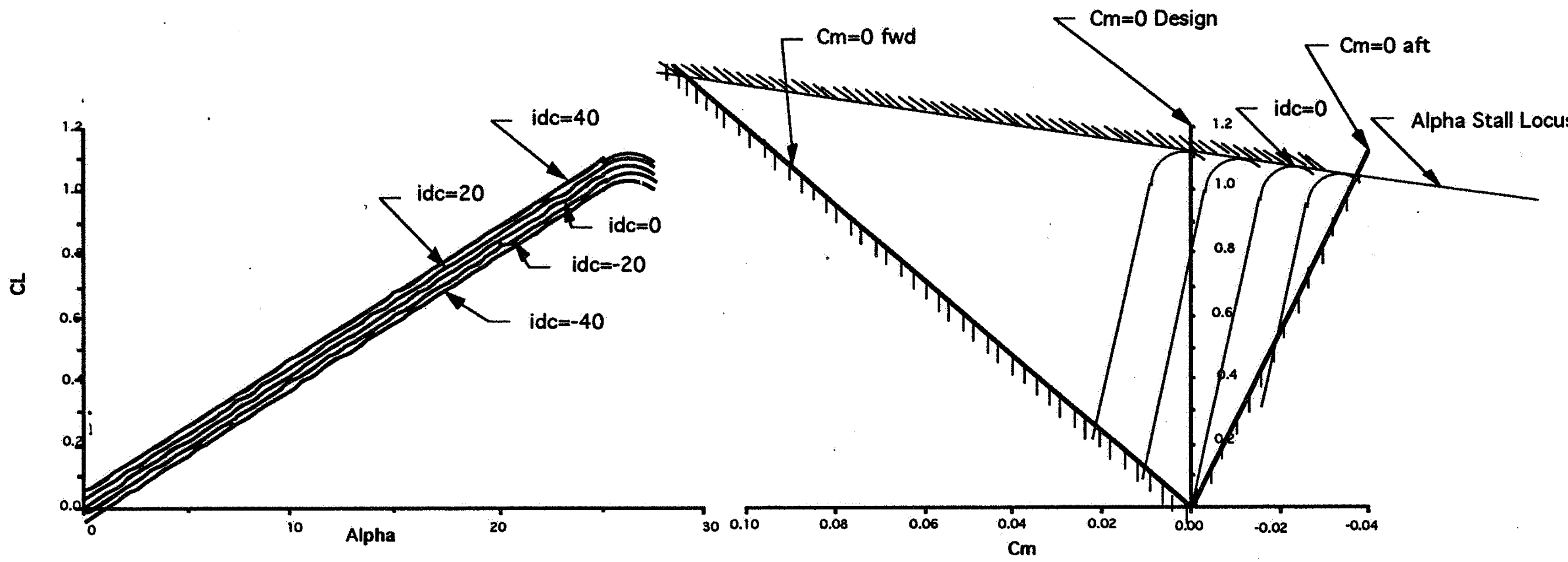


Figure 12.1 MM-122 Trim Diagram with respect to Canardvator Deflection

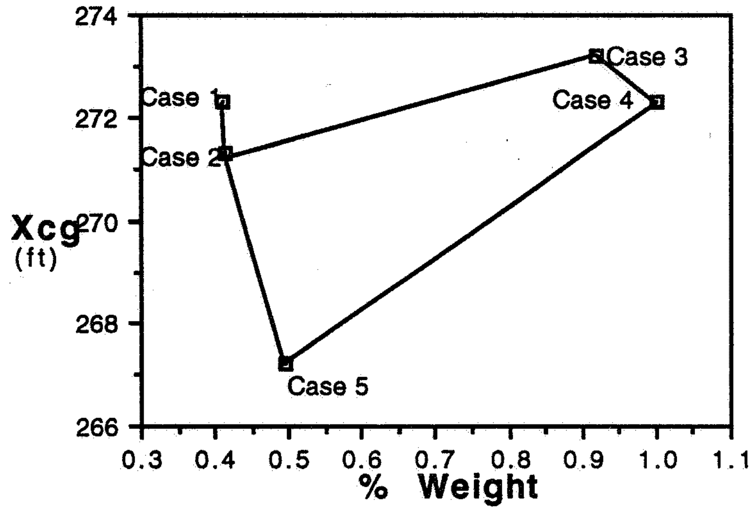


Figure 12.2 MM-122 CG Excursion

Table 12.1 CG Excursion Case

Case #	Definition	Weight (lbs)	Xcg (ft)
1	We	325775	272.3
2	We+Wc	327973	271.3
3	We+Wc+Wf	729108	273.3
4	We+Wc+Wf+Wp	795000	272.3
5	We+Wc+Wp	395200	267.2

12.2 DYNAMIC STABILITY AND HANDLING QUALITIES

The extensive aircraft parameters of the MM-122 were utilized in the calculation of the stability derivatives for the three flight phases given in Table 12.2 (Reference 10). From these stability derivatives dynamic stability for the bare airframe may be calculated. However, the MM-122 incorporates the latest in multiple loop, quad-redundant fly-by-wire flight control systems to provide appropriate static and dynamic stability.

It is apparent from the stability derivatives in Table 12.3 that the most that may be accomplished from the bare airframe of the MM-122 is Level II handling qualities. Again, the control system is such that the pilot will never experience the flying qualities of the bare airframe. Instead the aircraft will appear to the pilot to have Level I handling qualities provided by the flight control system. It is through the fly-by-wire flight control systems the the MM-122 will achieve dynamic stability and Level I handling qualities.

Table 12.2 Flight Conditions

Flight Condition	1 Power Approach	2 Subsonic Cruise	3 Supersonic Cruise
Mach #	0.3	0.8	2.2
Altitude (ft)	5000	30000	55000
Air Density (slug/ft^3)	0.002378	0.000891	0.000364
Speed (ft/s)	335.0	796.0	2129.0
Xcg (ft)	172.0	172.0	165.0
q∞ (lbs/ft^2)	133.0	282.0	824.0
Wing Area (ft^2)	9200.0	9200.0	9200.0
Span (ft)	133.0	133.0	133.0
Wing Mean Geometric Chord	83.7 ft	at 27.3 ft out	
Weight (lbs)	795000	795000	400000
Ixx (slug ft^2)	6470880	6470880	3874945
Iyy (slug ft^2)	56381368	56381368	45487871
Izz (slug ft^2)	53117972	53117972	43564364

Table 12.3 Steady State Derivatives

C_{L_1}	0.518	0.308	0.105
C_{D_1}	0.063	0.027	0.014
$C_{T_{x1}}$	-0.063	-0.027	-0.014
C_{n_1}	0.000	0.000	0.000
$C_{m_{T1}}$	0.000	0.000	0.000

Table 12.4 MM-122 Stability Derivatives

Stability Derivatives	Flight Condition 1	Flight Condition 2	Flight Condition 3
C_{L_u}	0.019	0.105	-0.220
C_{m_u}	0.000	-0.132	0.013
C_{D_u}	0.000	0.088	0.007
C_{L_α}	2.399	2.547	2.143
C_{m_α}	0.000	0.000	-0.225
C_{D_α}	4.920	3.920	2.190
$C_{L_{ic}}$	0.107	0.115	0.089
$C_{m_{ic}}$	-0.159	-0.130	-0.100
$C_{D_{ic}}$	0.150	0.172	0.103
C_{l_β}	-0.179	-0.189	-0.137
C_{n_β}	0.390	0.407	0.233
C_{y_β}	-0.795	-0.830	-0.476
C_{l_r}	0.100	0.107	0.072
C_{n_r}	-0.381	-0.397	-0.228
C_{y_r}	0.780	0.815	0.467
C_{l_p}	-0.898	-1.032	-0.694
C_{n_p}	0.051	0.052	0.046
C_{y_p}	-0.151	-0.157	-0.090

Table 12.5 MM-122

Stability Derivatives

Stability Derivatives	Flight Condition 1	Flight Condition 2	Flight Condition 3
$C_{L\delta c}$	0.090	0.787	1.020
$C_{m\delta c}$	-0.134	-0.102	-0.102
$C_{D\delta c}$	0.843	0.787	1.020
$C_{y\delta r}$	0.059	0.062	0.035
$C_{n\delta r}$	-0.127	-0.132	-0.076
$C_{l\delta r}$	0.024	0.026	0.015
$C_{n\delta a}$	-0.011	-0.018	-0.001
$C_{l\delta a}$	0.153	0.244	0.014

13.0 SYSTEM LAYOUT

The prime concerns in the preliminary design of the hydraulic, electrical, and fuel systems were safety, maintenability and accessibility. Both the electrical and hydraulic circuit are redundant (2 circuits) and employ tested technology. All systems are serviceable from beneath the airplane to reduce delay time and provide good working conditions.

13.1 HYDRAULIC SYSTEM

The MM-122 is equipped with two hydraulic systems, each designed to provide enough pressure and liquid flow rate to operate autonomously. As shown in Figure 13.1, both circuit are pressurized by two hydraulic pump connected to the engines gear box. The circuits are redundant everywhere except for the front landing gear where a gravity actuated fallout will be employed in case of a loss of pressure. The hydraulic system is also connected to a pump powered by the Auxiliary Power Unit. This provides two advantages. In the unlikely event of a engine out maneuver, The pilot would still be able to control the airplane. Also, the hydraulic system could be pressurized for maintenance purpose without a need for an outside power source, reducing costs.

Minimum electrohydrostatic actuators will be used on the airplane due to the shortage of long term testing and high cost of these products.

1.

FOLDOUT FRAME

2.

FOLDOUT FRA...

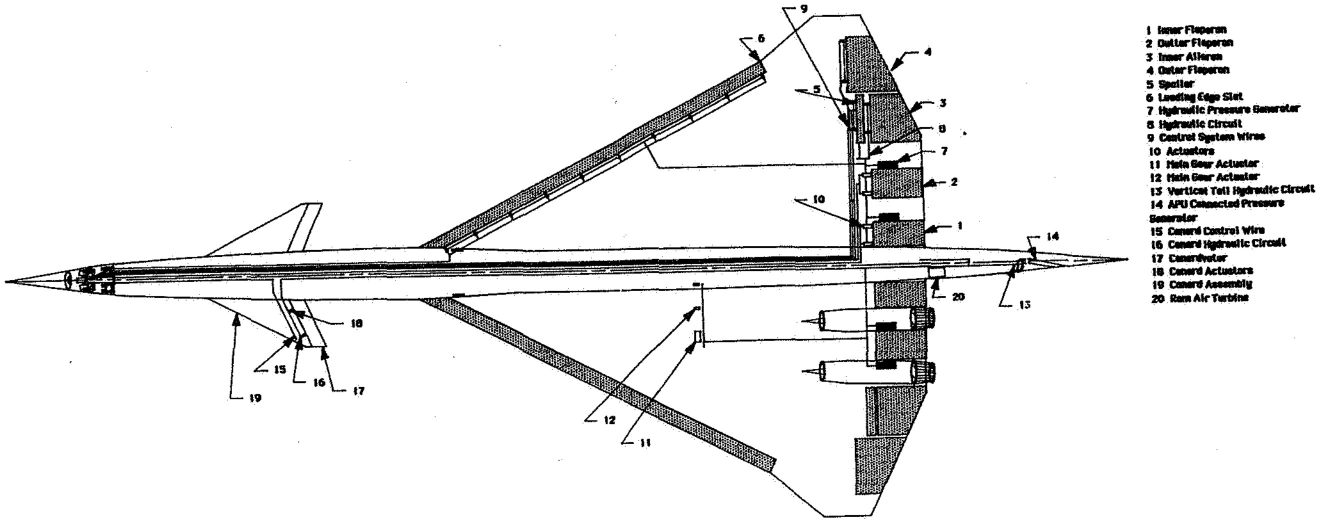
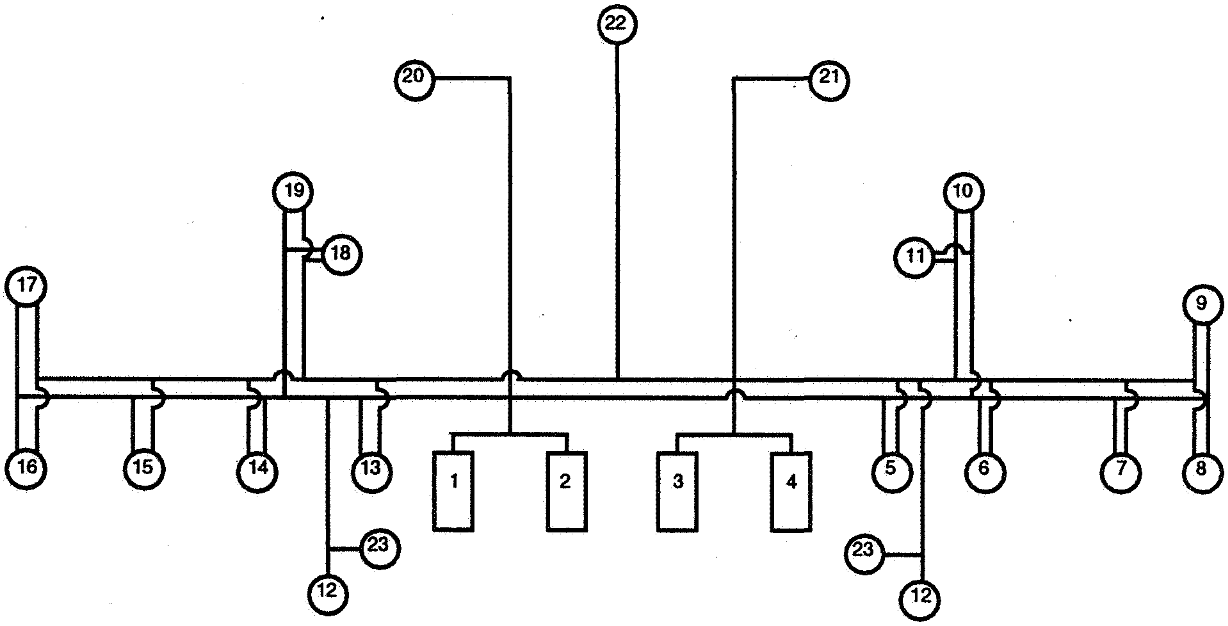


Figure 13.1 Hydraulic Systems



1. Pressure Generator 1
2. Pressure Generator 2
3. Pressure Generator 3
4. Pressure Generator 4
5. Right Flaperon 1
6. Right Flaperon 2
7. Right Aileron 1
8. Right Aileron 2
9. Right Spoiler
10. Right Leading Edge Slat
11. Right Landing Gear Actuator
12. Rudder 1&2
13. Left Flaperon 1
14. Left Flaperon 2
15. Left Aileron 1
16. Left Aileron 2
17. Left Spoiler
18. Left Landing Gear Actuator
19. Left Leading Edge Slat
20. Left Canardvator
21. Right Canardvator
22. Front Landing Gear Actuator
23. Ram Air Turbine

Figure 13.2 Hydraulic System Layout

The hydraulic system is also connected to a Ram Air Turbine that could be used in case of extreme emergency and provide enough power to control the airplane.

13.2 ELECTRICAL SYSTEM

The basic layout of the electric circuit is pictured in Figure 13.3. In the same safety philosophy as for the hydraulic circuit, the electrical circuit is redundant and uses only proven technology for generators or actuator valves.

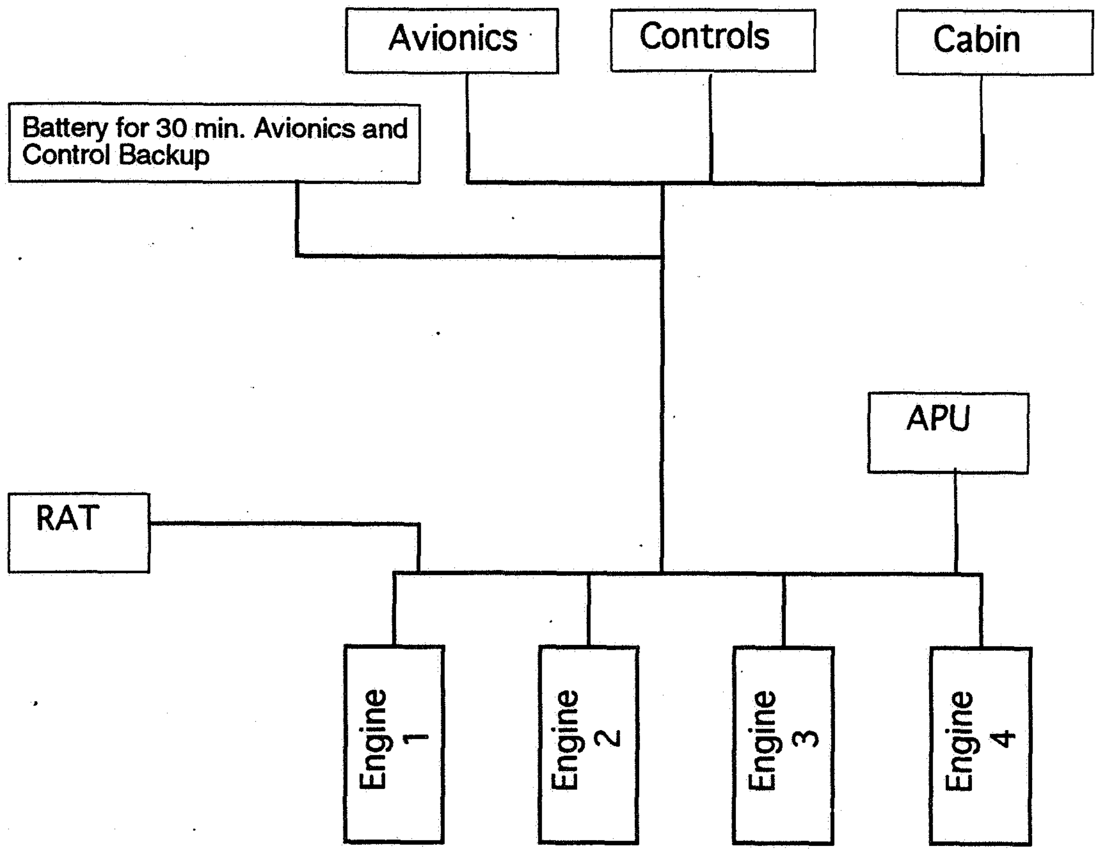


Figure 13.3 Electrical System Layout

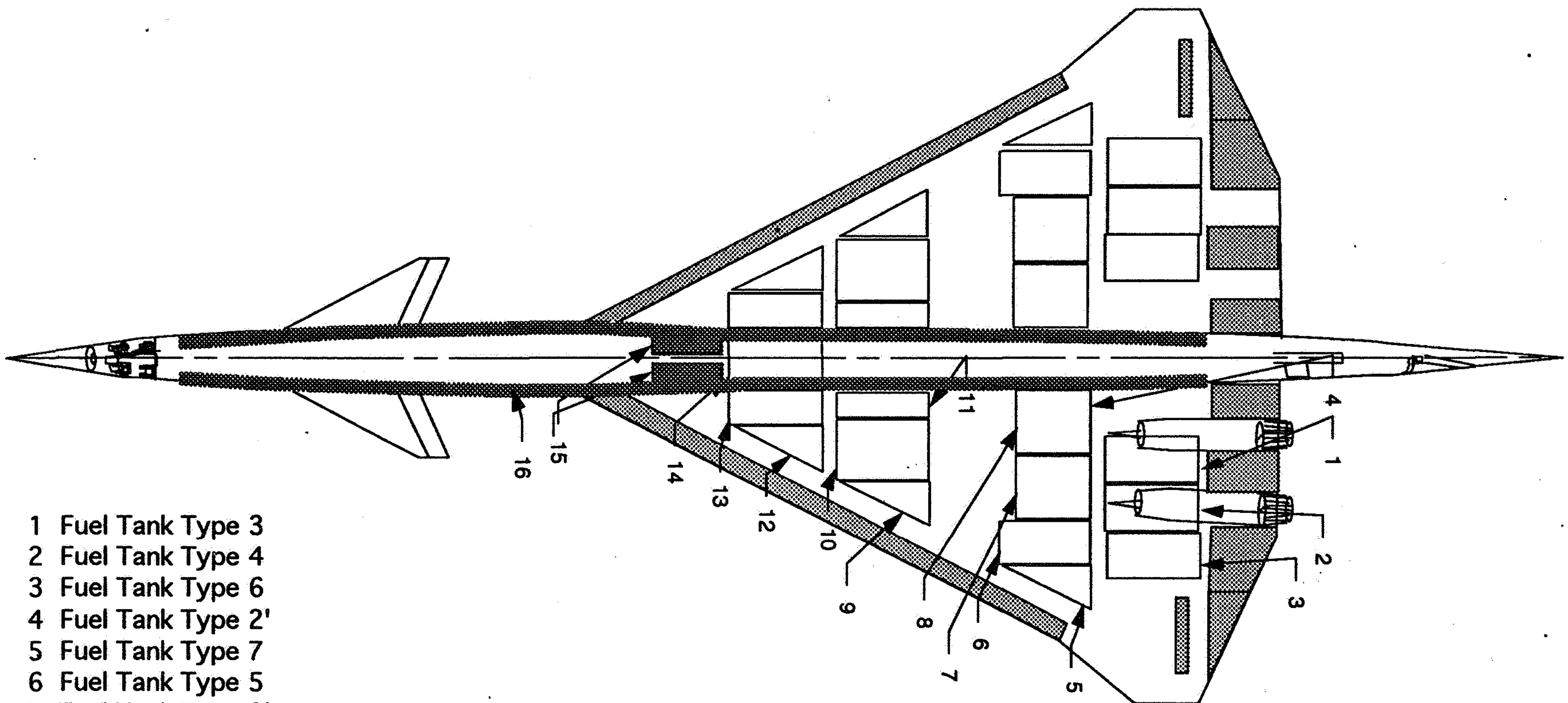
The electrical circuit is powered by four generators driven by the four engines. It is also connected to the APU and the RAT. The airplane employs an emergency battery to power the avionics and the flight control system in case of a failure in the circuit or in the four engines.

13.3 FUEL SYSTEM LAYOUT

As with most of the systems on the MM-122, the fuel system is redundant. Four separate lines run from the system of fuel tanks to the four engines with two lines per side of the aircraft. The fuel tanks are integrated for CG management conferring the system a complete redundancy. The aircraft is equipped with 25 tanks of different sizes. As shown in Figure 13.4, most of the tanks are located in the wing for two major reasons. By locating the fuel tanks in the wing, we are able to improve the safety of the passengers in case of any accident. Second, the weight of the fuel will counteract the lift force during some parts of the flight and reduce fatigue in the structures. Table 13.1 shows the sizes and locations of the fuel tanks.

TABLE 13.1- Fuel Tank Sizes and Locations

Tank Type	Volume (ft^3)	Xcg (ft)
1	571	57.3
1'	571	74.7
2*2'	1176	74.7
2*3	736	82.4
2*3'	623	75.4
2*4	679	82.4
2*5	1211	75.4
2*7	100	75 9
2*8	860	64.2
2*9	926	64.2
2*10	244	65.5
2*11	490	58
2*12	618	57.3



1 Fuel Tank Type 3
2 Fuel Tank Type 4
3 Fuel Tank Type 6
4 Fuel Tank Type 2'
5 Fuel Tank Type 7
6 Fuel Tank Type 5
7 Fuel Tank Type 3'
8 Fuel Tank Type 2'
9 Fuel Tank Type 10
10 Fuel Tank Type 9
11 Fuel Tank Type 8
12 Fuel Tank Type 11
13 Fuel Tank Type 12
14 Fuel Tank Type 1
15 Air Conditioning Unit 1,2
16 Cool Air Ducts

Figure 13.4 MM-122 Air Conditioning and Fuel Tank layout

14.0 AIRPORT OPERATION AND MAINTENANCE

14.1 AIRPORT OPERATION

The constraint associated with the airport are similar in nature to every large aircraft. They consist of the runway maximum loading, field length, the minimum turn radius, the area needed for loading and servicing, as well as the compatibility with airport equipment.

The MM-122 utilizes 18 wheels on the main gear, allowing the weight to be distributed. As a result, the MM-122 is comparable to any large size aircraft currently in service today such as a Boeing 747. The minimum turn radius criterion is determined with respect to the location of the nose of the airplane to the pivot wheel. Because of its low aspect ratio, the aircraft's wing span is not the determining factor as with a large subsonic transport. The aircraft's minimum turn radius is 125 ft.

The MM-122 can be parked in the diagonal of the rectangle that would be used by a Boeing 747. The major issue of aircraft compatibility with the different airports is the compatibility with the different equipment of the airport. The passenger loading doors are located 20 feet off the ground. Any walk-in ramp must be compatible with this height. The same problem is faced with servicing of the systems. Although all major systems have a servicing panel under the wing, servicing the aircraft will require being elevated about 10 feet. This will require some special equipment whence the aircraft becomes fully operational

14.2 MAINTENANCE

The MM-122 was designed with ease of maintenance as a major philosophy. All systems are serviceable from one designated location, reducing servicing time and improving quality. The engines were also mounted under the wing with a single attaching spar in order to minimize any time associated with the maintenance and remove of the engines.

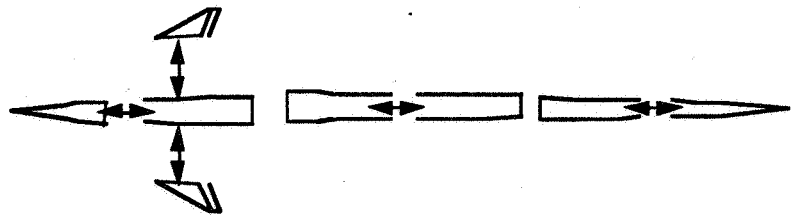
15.0 MANUFACTURING BREAKDOWN

15.1 MANUFACTURING COMPATIBILITY

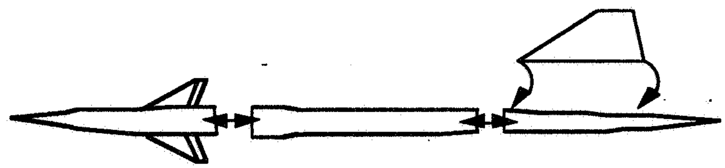
The MM-122 was designed to be as simple to manufacture and inexpensive as possible. The manufacturer will use no new production techniques or technology and due to its almost entirely aluminum structure, tooling, manufacturing, and material costs are kept to a minimum. Only a few relatively small sections of the airframe are non-aluminum, allowing them to be constructed at separate facilities more suited to their mass production. These components, which include the canards, tail, nosecone, control surfaces, engine cowlings, and engine exhaust nozzles are easily mass produced and can be easily integrated into the airframe at the appropriate stage on the assembly line.

15.2 MANUFACTURING PROCESSES

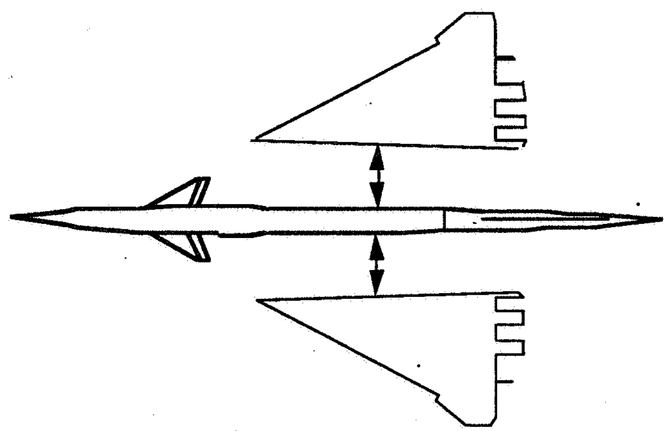
For manufacturing purposes the MM-122 airframe is divided into five main parts: the nose, fuselage sections, wing and wing box, canards and tail. During the construction phase of airframe production, the five main sections are produced in parallel. The first production phase consists of the addition of the vertical tail, canards, nose cone and fuselage sections to their respective structural supports. In the second production phase the aft, mid and forward sections of the fuselage are mated followed by the third phase where the wings are joined to the body thus completing the airframe. An illustration of this process can be seen in Figure 15.1.



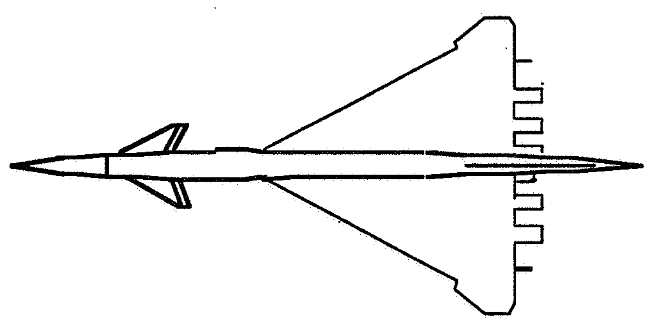
PHASE 1:Connecting nose and canards to fuselage section . 1. .
connect fuselage 2 to 3 and fuselage 4 to 5.



PHASE 2: Connect forward and aft fuselage section to mid fuselage and vertical stabilizer to aft fuselage.



PHASE 3: Connecting wings to main body.



Complete airframe

FIGURE 15.1 MM-122 Assembly Processes

Figure 15.1 Manufacturing Processes

16.0 COST ANALYSIS

16.1 Market Price and Ticket Price

The aircraft market price for the MM-122 will be $249 million. In order for an airline to break even with this aircraft an average ticket price of $2,290 per passenger must be charged, this is assuming a 70% load factor. An average ticket price of $2,500 shows a $290.8 million return on investment over the 20 year life cycle. An average ticket price of $3,000 would increase the life cycle return on investment to $986.6 million. All ticket prices and return on investment calculations are based on the 5200 nautical miles flight from Los Angeles to Tokyo.

16.2 Life Cycle Costs

The total life cycle cost of this aircraft program has been estimated to be $950 Billion. This cost includes $18 billion for research, development, testing, and evaluation (RDTE), acquisition costs of $57 billion, and operating costs of $876 billion. Should a disposal cost be anticipated this cost could be estimated to be 1% of the life cycle costs. This life cycle estimation assumes 298 production standard aircraft and 2 testing aircraft over a 20 year life cycle. A breakdown of the RDTE costs is shown in Table 16.1. The breakdown of the manufacturing and acquisition cost are shown in Table 16.2. Figure 16.1 is a pictorial presentation of the life cycle costs and shows the dominance of the operating costs over the life cycle.

16.3 Operating Costs

The operating costs for the MM-122 will be $35.00 per nautical mile. These operating costs are estimated for the 5200 nautical mile flight from Los Angeles to Tokyo. The direct operating costs including, flight, maintenance, depreciation, fees, and financing, will be $23.34. The indirect operating costs were then calculated as one half of the direct operating costs, $11.67. A passenger load of 250 then shows a cents per seat mile of $0.14. Table 16.3 presents a breakdown of the operating costs per nautical mile. Figure 16.2 presents the operating costs in pictorial form to show the relative size of the each cost area.

Table 16.1 MM-122 RDTE Costs

RDTE Cost	1992 Dollars (Millions)
Airframe Engineering and Design	4,917
Support and Testing	1,996
Flight Test Airplanes	5,329
Flight Test Operations	191
Test and Simulation Facilities	2,486
RDTE Profit	1,492
Total RDTE Cost	18,052

Table 16.2 MM-122 Manufacturing Costs

Manufacturing Cost	1992 Dollars (Millions)
Airframe Engineering and Design	11,057
Airplane Program Production	34,887
Production Flight Test Operations	438
Financing Costs	4,638
Total Manufacturing	51,020
Manufactures Profit	5,102
Acquisition Cost	56,121
Unit Price	249

Table 16.3 MM-122 Operating Costs

Operating Cost	1992 Dollars(per Nautical Mile)
Flight	13.54
Maintenance	3.25
Depreciation	4.52
Landing, Navigation, and Registry Fees	.5
Total DOC	23.34
IOC	11.67

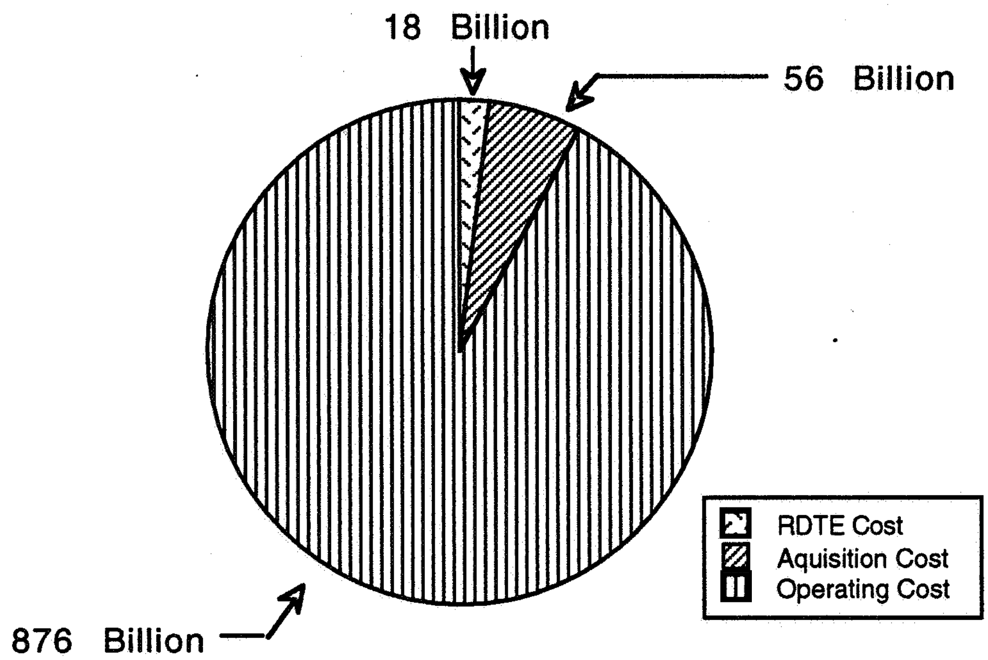


Figure 16.1: MM-122 Life Cycle Costs

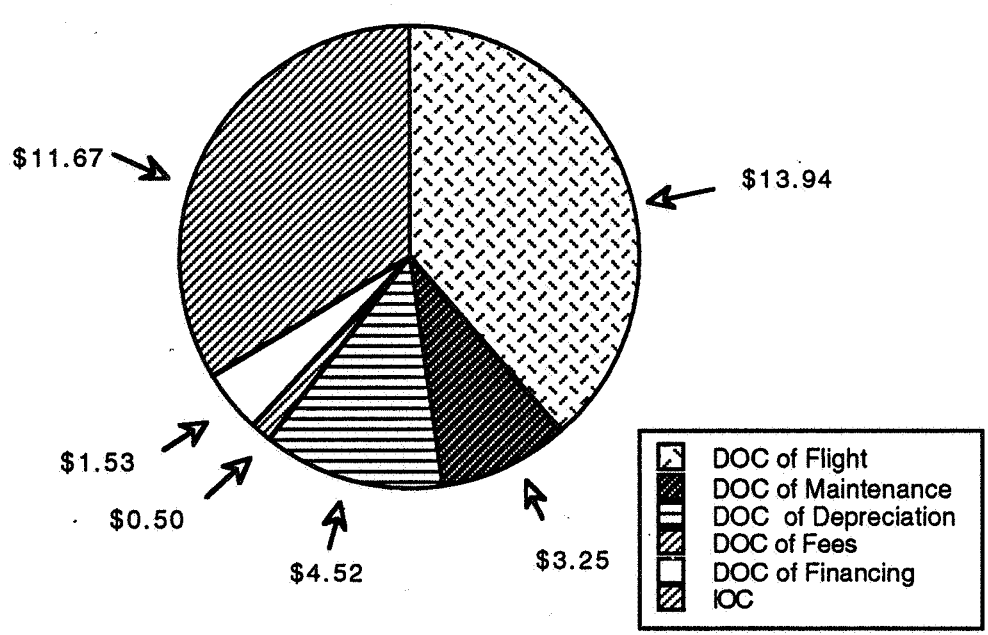


Figure 16.2: MM-122 Operating Costs
Cost per nautical mile

17.0 CONCLUSIONS AND RECOMMENDATIONS

17.1 CONCLUSIONS

The future of high speed civil transport is bright indeed. The MM-122 combines the latest in aerodynamics, propulsions, controls and cost minimization techniques to establish itself in the forefront of this future. This aircraft's uniquely tailored configuration is designed to travel twice the speed of sound as efficiently as possible. The MM-122 integrates the most modern of propulsion systems to provide required thrust while minimizing fuel consumption, harmful NOx emissions and take-off noise levels. The control system utilized by the MM-122 will provide appropriate static and dynamic stability and excellent handling qualities. These technologies will all be employed with a sense of total quality management in an effort to minimize cost and maximize quality. Using these techniques and technologies, all the specifications presented in the RFP have been accomplished. It is for these reasons that the MM-122 is the solution to the need for a modern high speed civil transport.

17.2 RECOMMENDATIONS

Although much research in the area of high speed civil transports has been done in the recent past, there is still much room for improvement. Some areas that must be finalized prior to production of the MM-122 include:

- Engine and gear disposition study
- Engine noise suppression

- Engine NOx emission reduction
- Composite material stress analysis
- Control system design and analysis
- Laminar flow control for L/D maximization
- Visibility augmentation analysis
- Over water sonic boom environmental impact study

With further research in these and other areas associated with high speed civil transport, the development of a feasible HSCT such as the MM-122 is within our grasp.

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