Shuttle

THE DELTA BODY - A POTENTIAL SPACE SHUTTLE ORBITER

(Figure 1)

The Delta Body Orbiter Configuration provides a basis for the solution to many of the key Space Shuttle technology problems. The Delta Body was evolved to meet the shuttle technology requirements, is a logical result of 15 years of evolution, permits efficient space shuttle orbiter designs, is an efficient lightweight low-risk design approach, and is a potential candidate for the Space Shuttle Orbiter configuration.

THE DELTA BODY

A POTENTIAL SPACE SHUTTLE ORBITER

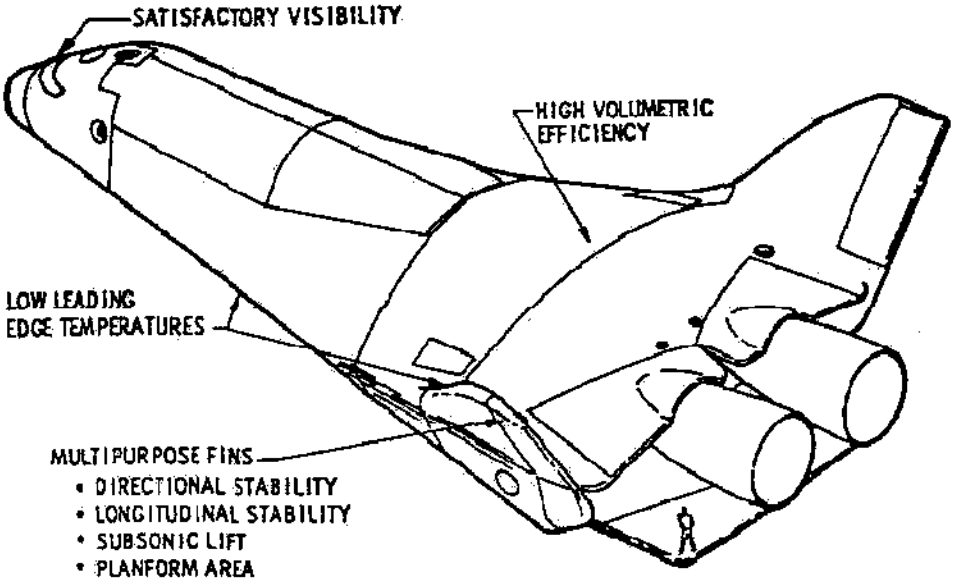

Figure 1

SPACE SHUTTLE TECHNOLOGY REQUIREMENTS - CONFIGURATION RELATED

(Figure 2)

Aerodynamic Performance - The technology requirements of today's Space Shuttle Orbiter have not changed significantly from those which led to the evolution of the Delta Body Concept. Those related directly to the orbiter configuration are indicated here. Hypersonic L/D is important to cross range capability. Delta Bodies (or lifting bodies) can develop hypersonic L/D values as high as 3.0 in practical configurations. Subsonic L/D establishes ferry efficiency and minimum approach glide path for landing approach. Present Delta Body designs exhibit subsonic L/D values of 5.8, entirely adequate for subsonic performance. Landing speed is determined to a large extent by the subsonic trimmed lift capability of the orbiter. Present Delta Body designs show high trimmed lift values resulting in landing speeds not significantly different from competing designs.

Satisfactory Flight Characteristics - Aerodynamic stability and control characteristics are determined primarily by the inherent shape of the configuration. Modern Delta Body designs exhibit aerodynamic stability and control in all three axes (stability) throughout their atmospheric flight. The resulting handling qualities are, in general, quite acceptable as demonstrated in the lifting body flight tests at Edwards Air Force Base, California. Visibility is a result of a specific design approach. Present Delta Body designs for the Space Shuttle orbiter have been tailored to provide acceptable visibility for all flight phases.

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(Figure 2, Cont.)

Low Inert Weight - A driving factor that led to the evolution of Delta Body orbiter configurations is the requirement for a compact design of low wetted area. The result which has directly followed is a design of low structural weight and low thermal protection system weight. This latter factor is enhanced by the absence of shock impingement and flow interference with their associated high heating rates.

High Propulsive Efficiency - With their compact shape and high volumetric efficiency, the Delta Bodies are natural propellant carriers. This leads to high λ' values and, with proper arrangement, simple tank geometries.

The Delta Body design is particularly well suited for the Space Shuttle orbiter technology requirements.

SPACE SHUTTLE TECHNOLOGY REQUIREMENTS

CONFIGURATION RELATED

- AERODYNAMIC PERFORMANCE
  - HYPERSONIC L/D
  - SUBSONIC L/D
  - SUBSONIC C_L
- SATISFACTORY FLIGHT CHARACTERISTICS
  - STABILITY AND CONTROL
  - HANDLING QUALITIES
  - PILOT VISIBILITY
- LOW INERT WEIGHT
  - LOW STRUCTURAL WEIGHT
  - LOW TPS WEIGHT
- HIGH PROPULSIVE EFFICIENCY
  - HIGH λ'
  - EFFICIENT VOLUME

Figure 2

DELTA BODY SPACECRAFT DEVELOPMENT

(Figure 3)

Two factors most of all led to the evolution of the Delta Body design approach. These were:

1. The desire to increase leading edge sweep angle and radius to reduce aerodynamic heating levels and to reduce shock impingement,

2. The desire to have a simple compact configuration of minimum inert weight.

These desires started (in the late '50's) the search for a configuration which would combine these features into a configuration with satisfactory flight characteristics.

Since that time the search has proven extremely successful with a variety of configuration evolutions. Three of these are presently undergoing flight tests at Edwards Air Force Base with a frequency of flight operations not significantly less, at times, than that projected for the Space Shuttle itself. A vast amount of flight experience and familiarity exists, as a result of these programs. Hypersonic flight of a lifting body vehicle has also been demonstrated through flight of the SV-5. Flight with a Delta Body orbiter would not be a new experience.

DELTA BODY SPACECRAFT DEVELOPMENT

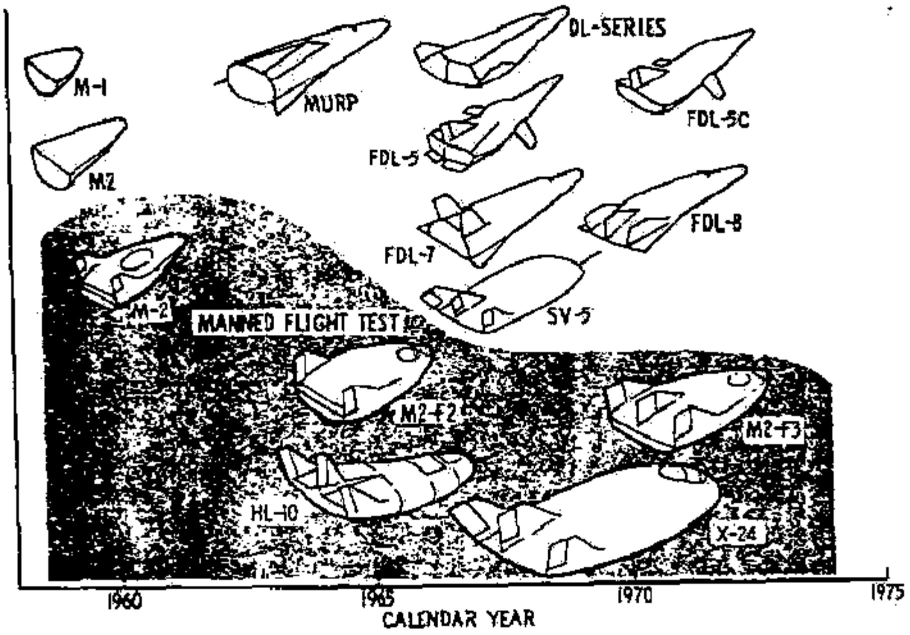

Figure 3

(Figure 3, Cont.)

The Delta Body concept and its advantageous features have been incorporated into designs for a wide range of hypersonic L/D values (1.1 for the HL-10 to 3.0 for the DL and FDL series). The inherent advantages of the concept are not restricted to a given L/D range.

The Delta Body concept is versatile and proven.

DELTA BODY ORBITER CONFIGURATION EVOLUTION

(Figure 4)

From the rich background of design information existing for Delta Bodies, attention was focused by Lockheed in 1968 on the evolution of an improved orbiter design to meet the rigorous requirements of a powered orbiter stage in a reusable launch system. The result has been a design of improved aerodynamic performance with a realistic answer for each design requirement. In particular, improvements have been achieved in configuration shaping which allow the design to exploit its advantages of volumetric efficiency, low heating rates, and compact size.

The modern Delta Body orbiter exploits its inherent advantages of volumetric efficiency and compact size while providing improved aerodynamic characteristics.

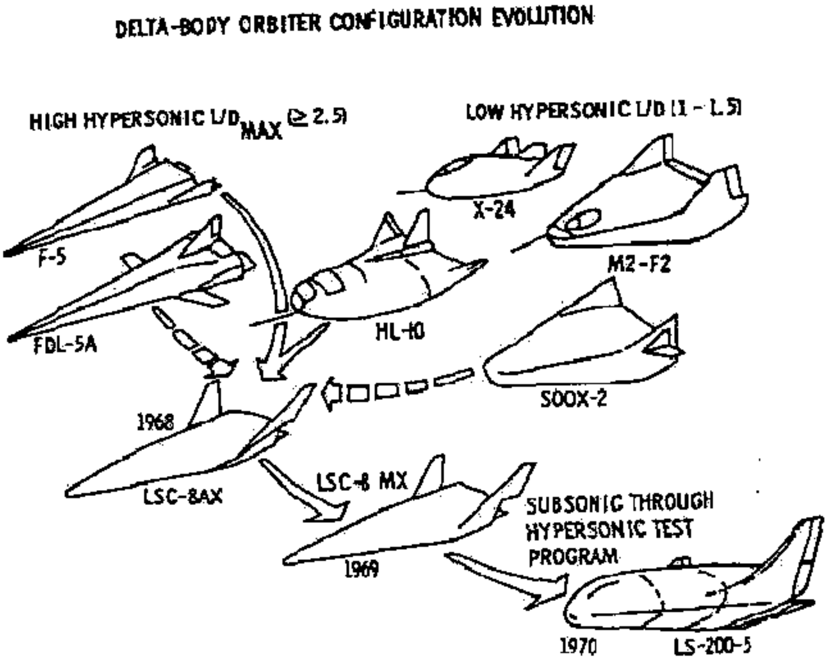

Figure 4

PARAMETRIC TESTING

(Figure 5)

The development of the Delta Body orbiter has been supported and substantiated by extensive wind tunnel testing. Lockheed has performed over 3,000 hours of aerodynamic and aerothermodynamic testing on Delta Body configurations. Many tests have been performed on parametric variations of promising configurations. Tests such as the one indicated have explored the variations of every key geometric element including body cross-section shape, body camber, leading edge sweep, leading edge radius, fin shape, fin size, fin orientation, control surface size, control surface shape, and control surface orientation. These parametric test data have been supplemented with comparable thermodynamic, materials, structural, and design data to achieve a complete data bank of design information for the Delta Body Orbiter.

An extensive parametric data bank exists for the confident development and assessment of the Delta Body orbiter.

PARAMETRIC WIND TUNNEL MODEL – DELTA-BODY

- LTV 7 FT BY 10 FT SUBSONIC WIND TUNNEL
- TEST CONDITIONS
  - MACH NUMBER = 0.24
  - ANGLES-OF-ATTACK = $-10^0 \longrightarrow +30^0$
  - SIDESLIP ANGLES = $-10^0 \longrightarrow +10^0$
- TEST DURATION
  - 307 RUNS, 176 HR OCCUPANCY
- CONFIGURATION PARAMETERS
  - FIN
    - ROLLOUT
    - TOE-IN
    - AREA
    - LEADING EDGE GEOMETRY
    - WASHOUT
    - CENTER FIN
    - RUDDER DEFLECTIONS
  - BODY
    - CAMBER
    - L.E. RADIUS
    - BOAT-TAILING
    - ENGINE NOZZLES
    - TRIM FLAP DEFLECTIONS

Figure 5

BODY PARAMETRICS

(Figure 6)

The wealth of parametric data for the Delta Body has been systematically examined to identify design trends and effect design improvements. Important design trades are known and the configuration can be readily modified to achieve a desired change in aerodynamic or design characteristics. In this manner every line, contour, and angle on the configuration is selected to provide the best combination of system characteristics. In addition to the aerodynamic parameters shown, similar thermodynamic and design parametric data exist.

The shaded squares indicate the more significant trades.

AERODYNAMIC CONFIGURATION PARAMETERS FOR THE BODY

	L/D_{MAX}		PITCH STABILITY		YAW STABILITY		MAX α_{TRIM}		EFFECTIVE DIHEDRAL		C_{L_α}	
	SUB	HYP	SUB	HYP	SUB	HYP	SUB	HYP	SUB	HYP	SUB	HYP
↑ SWEEP	■	■	–	–	–	–	–	–	↑	–	■	■
↑ CAMBER	–	↑	–	↑	–	–	■	■	–	–	–	–
↑ L.E. RADIUS	■	■	■	■	↑	↓	↓	–	–	–	–	–
↑ BASE AREA	■	■	–	–	–	–	–	–	–	–	–	–
↑ ROLLOUT	■	■	–	–	■	■	–	–	–	–	–	–

↑ DENOTES INCREASE ↓ DENOTES DECREASE ■ CONFIGURATION DRIVER

Figure 6

FIN PARAMETRICS

(Figure 7)

The parametric data on the aerodynamic characteristics of the Delta Body orbiter have shown the fins to be effective in providing a wide range of aerodynamic characteristics. The fins serve the multiple purposes of providing lateral-directional stability, longitudinal stability, directional control, and lift augmentation through their "end plate" effect on the aft upper body. Performing the dual purposes of fins and wings, the surfaces could appropriately be called "fings".

AERODYNAMIC CONFIGURATION PARAMETERS FOR THE FIN

	L/D_{MAX}		PITCH STABILITY		YAW STABILITY		MAX_{α} TRIM		EFFECTIVE DIHEDRAL		C_{L_α}	
	SUB	HYP	SUB	HYP	SUB	HYP	SUB	HYP	SUB	HYP	SUB	HYP
↑SWEEP	–	↑	↓	–	■	■	↑	–	–	–	–	–
↑ASPECT RATIO	↑	↓	↓	–	■	■	↓	–	■	■	↑	–
↑AREA	■	■	↑	–	■	■	↓	–	■	■	■	–
↑TOE-IN	↓	↓	–	–	■	■	↓	–	■	■	–	–
↑ROLLOUT	↑	↓	↑	↑	■	■	↓	↓	■	■	↑	↑
↑L.E. RADIUS		■		–		–		–	–	–		–

↑ DENOTES INCREASE ↓ DENOTES DECREASE ■ CONFIGURATION DRIVER

Figure 7

DELTA BODY ORBITER THREE VIEW

(Figure 8)

An example of the family of Delta Body designs suitable for Space Shuttle orbiter configuration is shown in the three view figure. The compact design exploits the volumetric efficiency of the Delta Body concept by providing ample volume for design flexibility in the internal arrangement, with overall dimensions smaller than competing designs. The configuration shown can be packaged to serve as a two-stage or stage-and-one-half orbiter. This configuration is under study in the Lockheed Study of Alternate Space Shuttle Concepts under Contract NAS 8-26362 for George C. Marshall Space Flight Center.

Present designs employ a lower surface trim flap with trailing elevons. These surfaces provide pitch trim and control and roll control for high speed flight and for low angles of attack (up to maximum L/D) during low speed flight (landing). A set of upper surface flaps provide for pitch trim and control and added roll control for transonic and subsonic (landing flare) flight. Rudders and yaw dampers provide directional stability and control throughout the flight range. In addition, differential rudder settings can be selectively employed to improve stability and performance characteristics.

A design tail-scrape angle of 22° is provided to permit a wide range of landing attitudes. The nose section is shaped to provide acceptable pilot visibility for all landing altitudes.

Practical efficient Delta Body orbiter designs have been defined and are being evaluated.

DELTA BODY ORBITER THREE VIEW

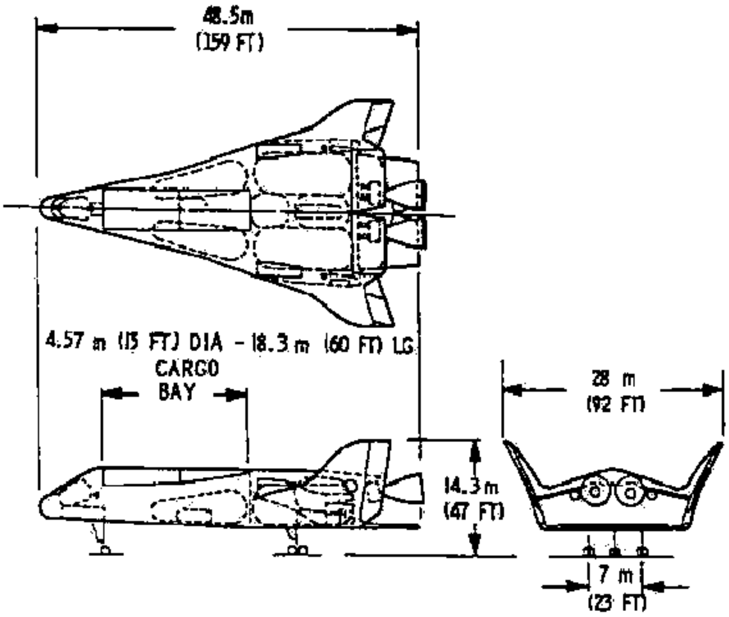

Figure 8

STATIC STABILITY

(Figure 9)

The aerodynamic flexibility of the Delta Body orbiter has permitted the observance of a simple groundrule in its aerodynamic development. That ground rule is "Neutral or positive aerodynamic stability in all three axes (stability) throughout the required aerodynamic flight spectrum with aerodynamic trim and control". This ground rule is essential to the selection of early design concepts to assure that during the final development of the configuration, adequate performance and handling qualities can be provided without undue sophistication in the flight control and stability augmentation system. With this ground rule, major configuration changes to correct deficiencies discovered late in the development program (with the associated increases in development cost) can be avoided. The Delta Body design approach permits adherence to this ground rule without large weight penalties. This is due to the facts that (1) a large portion of the inherent aerodynamic stability is provided by effective body shaping and (2) the fins (or "fings") serve several purposes (directional stability, longitudinal stability, directional control, longitudinal trim, and lift augmentation through their effectiveness as end plates) - consequently, the stability is established by adding a relatively small set of aerodynamic surfaces.

The curves show that neutral or better pitch and yaw stability has been designed into the Delta Body orbiter for all anticipated flight conditions and for far aft center-of-gravity locations characteristic of Space Shuttle orbiter (in this case a Stage-and-One-Half orbiter).

The Delta Body concept permits design with three axis aerodynamic stability and control, reducing development risk, and schedule slippage due to late configuration fixes during the development program.

It is not necessary (with the Delta Body concept) to sacrifice aerodynamic stability to achieve a compact orbiter design.

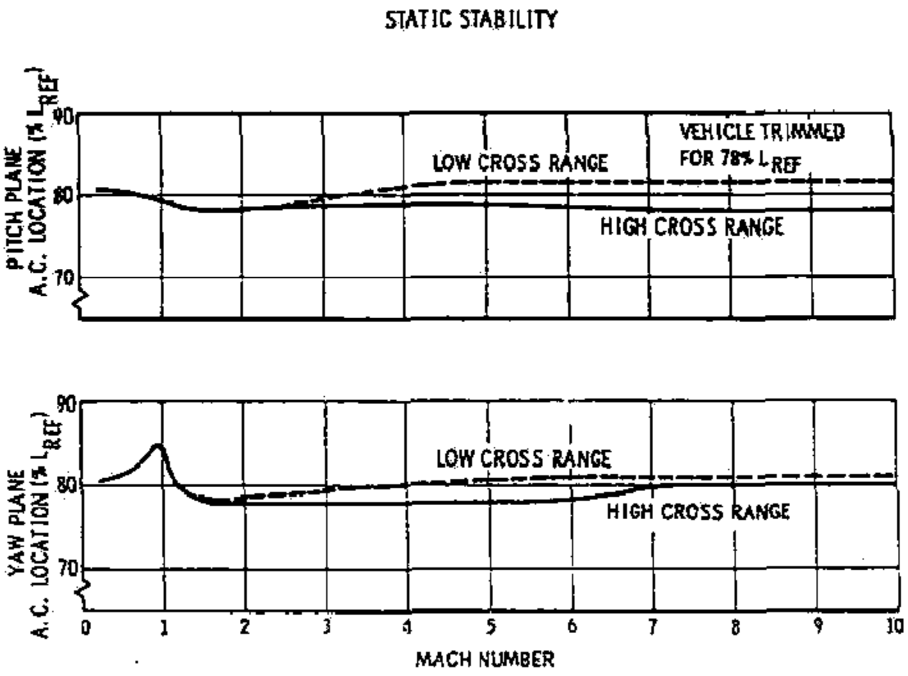

Figure 9

UNAUGMENTED SUBSONIC HANDLING QUALITIES

(Figure 10)

Parameter plane analyses of the Delta Body orbiter concept has indicated that the configuration will have excellent handling qualities when compared with most of the relative handling qualities criteria, the only major exception being that of the damping in Dutch roll. This deficiency may be common to the Space Shuttle orbiter concepts where their directional-to-roll stability ratio is low as is the roll inertia-to-yaw inertia ratio. The aerodynamic flexibility of the Delta Body design offers several solutions to this deficiency, such as damping by aileron deflection (and/or yaw dampers).

The Delta Body orbiter is presently being simulated by Lockheed under contract to NASA Manned Spacecraft Center (NAS-9-11459) to further verify the concept handling characteristics during low speed flight.

Level 1 handling quality characteristics are predicted for the Delta Body orbiter for most large transport category criteria. Aerodynamic design flexibility offers cures for any deficiencies which may exist.

UNAUGMENTED SUBSONIC HANDLING QUALITIES

MODE	CRITERIA	RATING*
LONGITUDINAL		
• SHORT PERIOD	DAMPING RATIO NATURAL FREQUENCY	LEVEL 1 LEVEL 2
• PHUGOID	DAMPING RATIO	LEVEL 1
LATERAL/DIRECTIONAL		
• ROLL	ROLL MODE TIME CONSTANT NATURAL FREQUENCY	LEVEL 1 LEVEL 1
• DUTCH ROLL	DAMPING RATIO	UNACCEPTABLE (REQUIRES AUGMENTATION)
CONTROL		
• LANDING APPROACH	VERTICAL VS ANGULAR ACCELERATION FOR MAX PITCH CONTROL	LEVEL 1
• SIDESLIP TRIM FOR 30 KNOTS SIDEWIND	β_{TRIM} VS AILERON DEFLECTION	LEVEL 1
• 30 DEG ROLL IN 2 SEC	δ_A VS ROLL RATE	LEVEL 1

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*HEAVY TRANSPORT, CLASS III, MIL-F-8785B (ref. 2)

Figure 10

AERODYNAMIC PERFORMANCE

(Figure 11)

The configuration shown in Figure 8 has been configured to provide cross-range capability of up to 1500 nautical miles. The required maximum lift-to-drag ratio of 1.7 has been provided for hypersonic flight conditions.

For subsonic flight the maximum subsonic lift-to-drag ratio had, until recently, been conservatively predicted at 4.5, a value proven adequate for the power-off landings during the NASA Flight Research Center lifting body flights. Recent wind tunnel test data indicate considerably higher lift-to-drag ratios. The data indicated show a maximum trimmed lift-to-drag value of 5.65 at 14° angle of attack. This extrapolates to a free flight value of 5.8. (All lift-to-drag ratio values indicated are for the aerodynamically trimmed case.)

The high subsonic lift-to-drag ratios result partially from the approach used to trim the vehicle. The lower surface trim flap and control surfaces are deflected upward to achieve trim, and effectively streamline the flow over the large base area. The apparent aerodynamic base area is therefore greatly reduced from that of the actual base area. Consequently, trim is achieved with reduced axial force and improved L/D values in contrast with the trim losses associated with winged bodies.

The normal operating ranges of angle of attack are indicated for the subsonic and hypersonic regimes. The subsonic range provides adequate approach control and landing flare capability. The hypersonic range permits modulation of the configuration's cross-range capability to achieve high or low cross-range values ($0.6 \leq L/D \leq 1.7$).

The Delta Body has a high performance capability and operational flexibility.

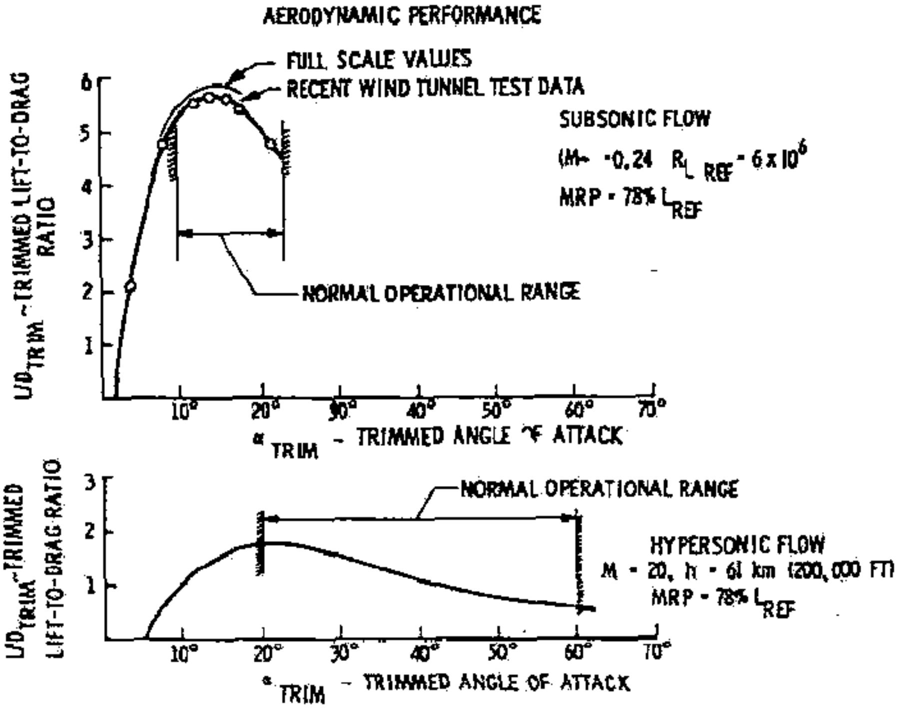


Figure 11

DELTA BODY/DELTA WING-BODY GEOMETRIC COMPARISON
(Figure 12)

A comparison of configurations reveals that the Delta Body configuration is smaller in length, span, and height than a comparable base-line Delta Wing-Body orbiter presently under study in the Phase B program. The larger cross-section area of the Delta Body is apparent in the end view. Potentially more favorable visibility characteristics are attributable to the Delta Body design with its steep nose angle, although a similar angle is possible as a revision to the Delta Wing-Body design.

The Delta Body configuration provides a compact Space Shuttle orbiter design.

DELTA BODY/DELTA WING-BODY GEOMETRIC COMPARISON

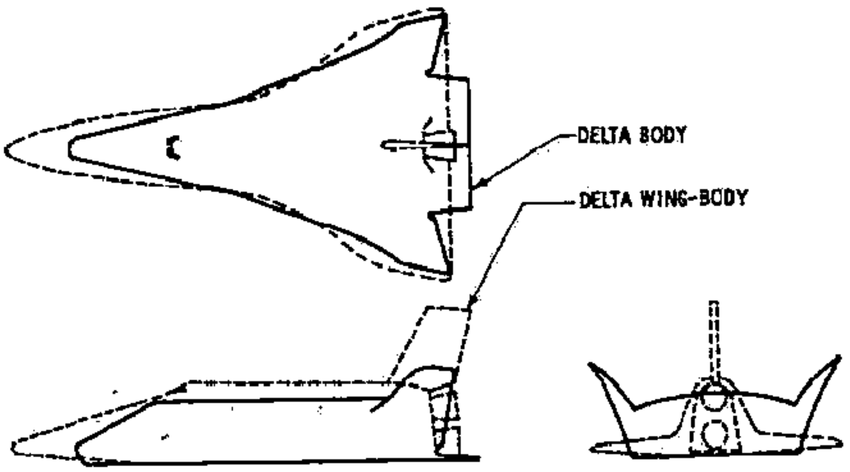


Figure 12

LANDING SPEED AND ATTITUDE COMPARISON

(Figure 13)

Preliminary considerations of landing speeds and attitude show little difference between Delta Body and Delta Wing-Body values. Recent wind tunnel data were used to compute the respective landing speeds. The values shown reflect weights for the two-stage Space Shuttle orbiter landing with the payload in.

Experience with the lifting bodies at the NASA Flight Research Center indicates the pilots' preference to land at speeds high enough to provide good control rather than minimum speeds. Consequently, it is reasonable to expect that the Space Shuttle orbiters will land at speeds of approximately 180 knots and at attitudes near 15° angle of attack. The Delta Body design has provided ample pilot visibility for the required landing conditions.

Flight tests at the Flight Research Center would support the acceptance of these characteristics for Space Shuttle operations.

The Delta Body landing conditions are acceptable for the Space Shuttle operations and essentially equivalent to those of the Delta Wing-Body.

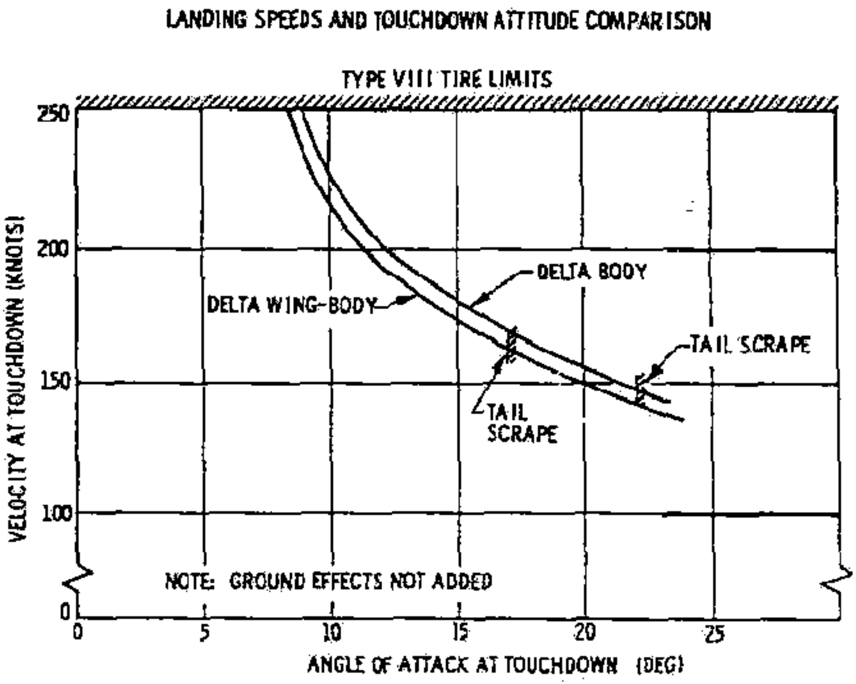


Figure 13

COMPARISON OF VOLUME VARIATION WITH LENGTH

(Figure 14)

The relative compactness of the Delta Body design results from the inherent volumetric efficiency of the configuration and the design steps taken to employ that volume. Comparing with the baseline Delta Wing-Body configuration shown in figure 12, a Delta Body fuselage packaged for the two-stage Space Shuttle orbiter is 39.4 m (129.5 feet) long as compared with the 48.3 m (158.5 feet) long fuselage of the Delta Wing-Body baseline.

Of considerable importance is the fact that the small Delta Body size has been achieved while employing non-integral internal tanks of no greater complexity than simple conical tanks of circular cross section.

The total volumes of the configuration compare closely. The Delta Body is seen to have little unusable volume. In recent designs, 80 percent of the available volume is occupied, leaving ample access for inspection, maintenance and repair.

COMPARISON OF FUSELAGE VOLUME VARIATION WITH LENGTH

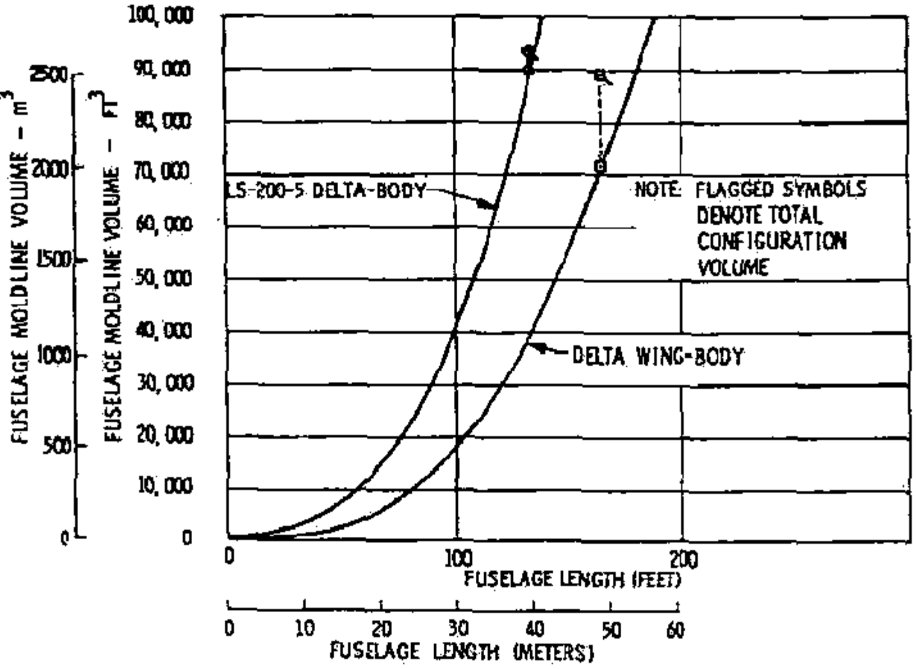


Figure 14

VOLUMETRIC EFFICIENCY COMPARISON

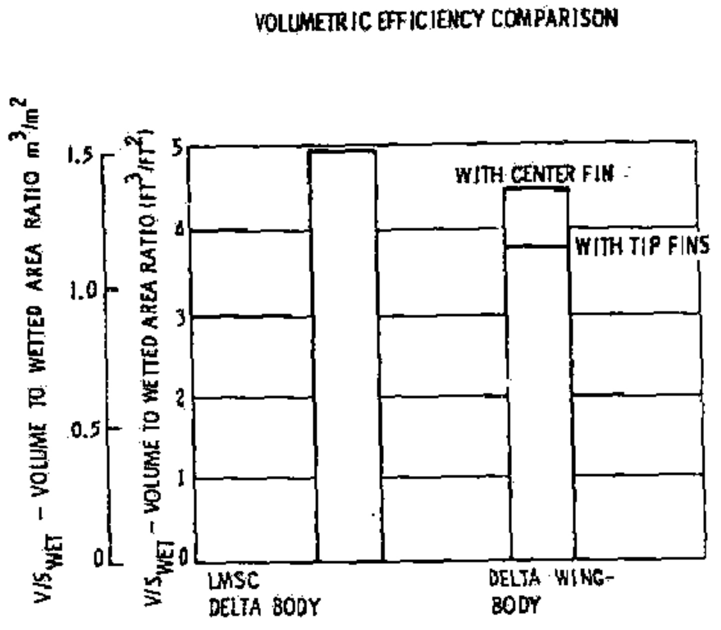
(Figure 15)

A significant advantage of the Delta Body design is its reduced wetted area necessary to contain the required volume for the Space Shuttle orbiter. An index of merit is the ratio of volume contained per unit of wetted area since wetted area is directly related to structural (and thermal protection system) weight. Recent total volume numbers for the Two-Stage Delta Body orbiter, the Delta Wing-Body with tip fins, and the Delta Wing-Body with a center fin only are 2,648 m^3 (93,492 ft^3), 2,384 m^3 (84,241 ft^3) and 2,532 m^3 (89,485 ft^3), respectively. Corresponding wetted areas are 1.750 m^2 (18,837 ft^2), 2,087 m^2 (22,462 ft^2), and 1,860 m^2 (20,019 ft^2). The ratios are indicated in the figure. The efficiency of the Delta Body configuration is seen to be 10% to 25% greater than the Delta Wing configuration with corresponding center fin and tip fin configurations.

The increased efficiency of the center finned Delta Wing-Body configuration over the Delta Wing-Body with tip fins is achieved at the expense of reduced directional yaw stability at hypersonic and supersonic speeds.

Body structure and wing and fin surface unit weights are typically 17.1 kg/m^2 (3.5 pounds per square foot). The potential differences in the Delta Body and Delta Wing-Body inert weights due to reduced surface area are therefore 1,878 kg (4,140 lb) (center fin) and 5,761 kg (12,700 lb) (tip fins) in favor of the Delta Body. An equivalent savings in thermal protection system weight is obtained with the Delta Body.

The reduced surface area of the Delta Body configuration can result in reduced structural and thermal protection system weights.



VOLUMETRIC EFFICIENCY COMPARISON

Figure 15

PEAK TEMPERATURE ISOTHERMS - DELTA BODY

(Figure 16)

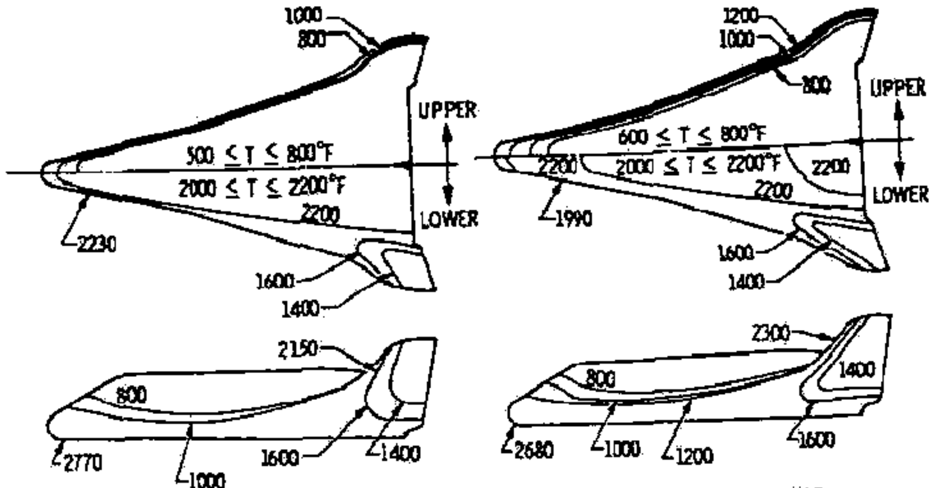
The smooth contours of the Delta Body result in low aerodynamic heating rates and correspondingly low surface temperatures. This is a direct result of the inherent Delta Body philosophy of swept leading edges and large leading edge radii.

The contours show a distinct absence of shock impingement and its associated high heating rates. In addition, there is a lack of high temperature gradients. Consequently, the design of the thermal protection system for the Delta Body would be simplified as compared to the TPS system for the Delta Wing-Body with its potential shock impingements and high leading edge temperatures.

One feature of the Delta Body is the relative insensitivity of heating distribution and level with angle of attack [when the trajectory is constrained to not exceed a given temperature $T = 1533^\circ$ K (2300° F)]. The resulting temperature distributions for the 200 nautical mile cross range ($\alpha \approx 52^\circ$) and the 1500 nautical mile cross range ($\alpha \approx 25^\circ$) trajectories are shown to be quite similar, again simplifying the TPS design and providing a versatile design. Insulation requirements increase with time of flight (cross-range).

The Delta Body design results in no shock impingement, low temperature levels and simplified thermal protection system requirements.

PEAK TEMPERATURE ISOTHERMS – DELTA BODY



NOTE:
TO CONVERT TO °K, $°K = (5/9)(°F + 459.67)$

Figure 16

SURFACE TEMPERATURE COMPARISON
(Figure 17)

With only the nose cap (0.5% of wetted area) experiencing high temperature levels (T > 1644° K, 2500° F), the Delta Body design offers maximum TPS reusability potential using external insulation or metallic materials presently under development.

Competing systems involve significant areas (up to 5% for the Delta Wing-Body) with temperatures greater than 1644° K (2500° F). Although ablatives and certain high temperature materials allow consideration of initial flights at these temperatures, the desired degree of reusability (100 flights) is jeopardized. Lack of reusability can seriously increase operational costs.

The Delta Body offers maximum reusability potential for the Space Shuttle orbiter thermal protection system.

SURFACE TEMPERATURE COMPARISON

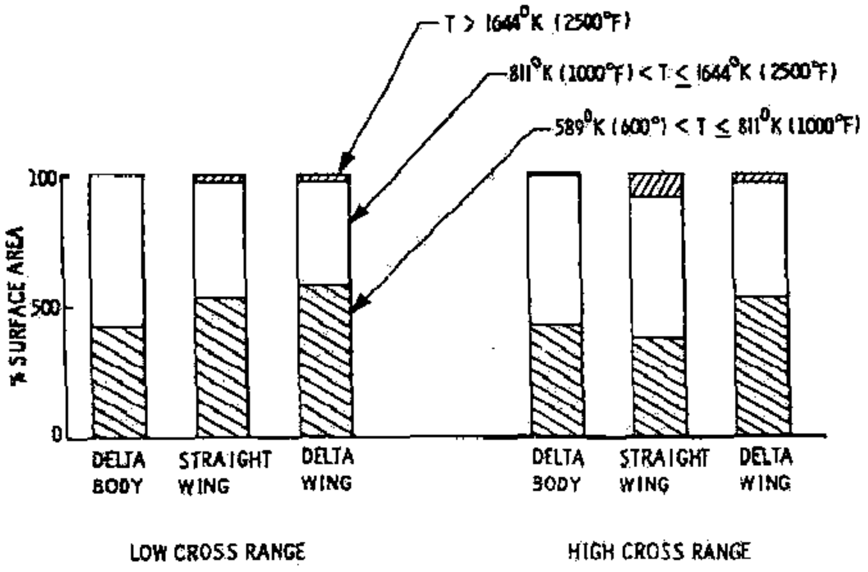


Figure 17

ONE-AND-ONE-HALF-STAGE ORBITER PRIMARY STRUCTURE - DELTA BODY

(Figure 16)

The compact size and large body cross-sections of the Delta Body orbiter design affords many structural advantages.

- Low body line loads (use aluminum for primary structure)
- Short load paths (mass concentrated aft)
- Inertial and aerodynamic loadings tend to maximize where the available fuselage cross section maximizes (low line loads)
- Reduced aerodynamic surfaces with high line loads
- Nonintegral tanks

~~These advantages are inherent in the configuration and afford advantages to either the two-stage~~ or stage-and-one-half orbiter designs.

The Delta Body has many features which contribute to low structural weight and reduced design complexity.

ONE-AND-ONE-HALF-STAGE ORBITER PRIMARY STRUCTURE – DELTA BODY

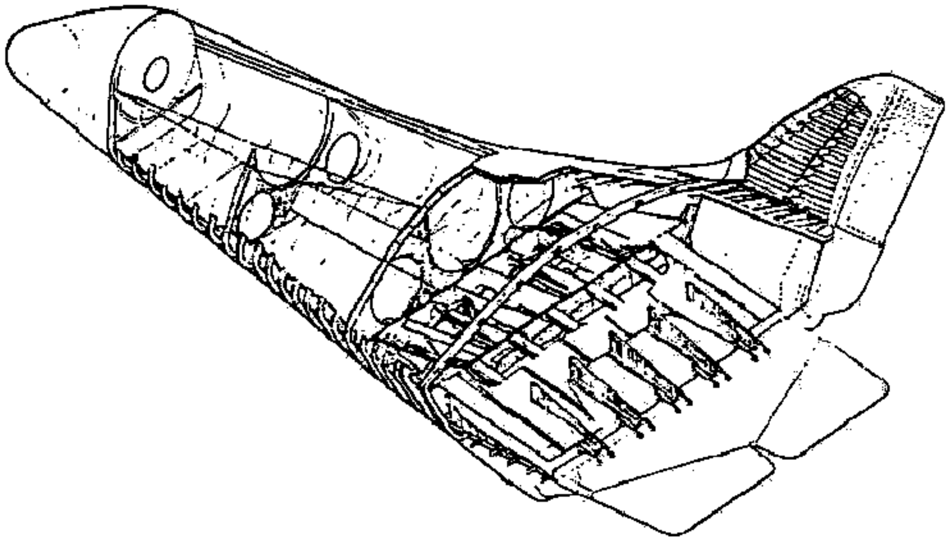


Figure 16

PRODUCTION BREAKDOWN - DELTA BODY

(Figure 19)

The simplified structural design features of the Delta Body orbiter will permit development and manufacturing to proceed on a modular basis with no undue complexity required to coordinate the system elements. This is true for either the two-stage or stage-and-one-half orbiter designs. Avoiding integral tanks, the structural system and propulsion system developments can proceed relatively independent of each other. This should greatly simplify development and scheduling. In addition, the incorporation of technology advances into one of the systems (tanks for instance) can proceed with no impact on the other (body structure).

The Delta Body design can reduce development risk.

DELTA-BOBY MAJOR STRUCTURAL BREAKDOWN

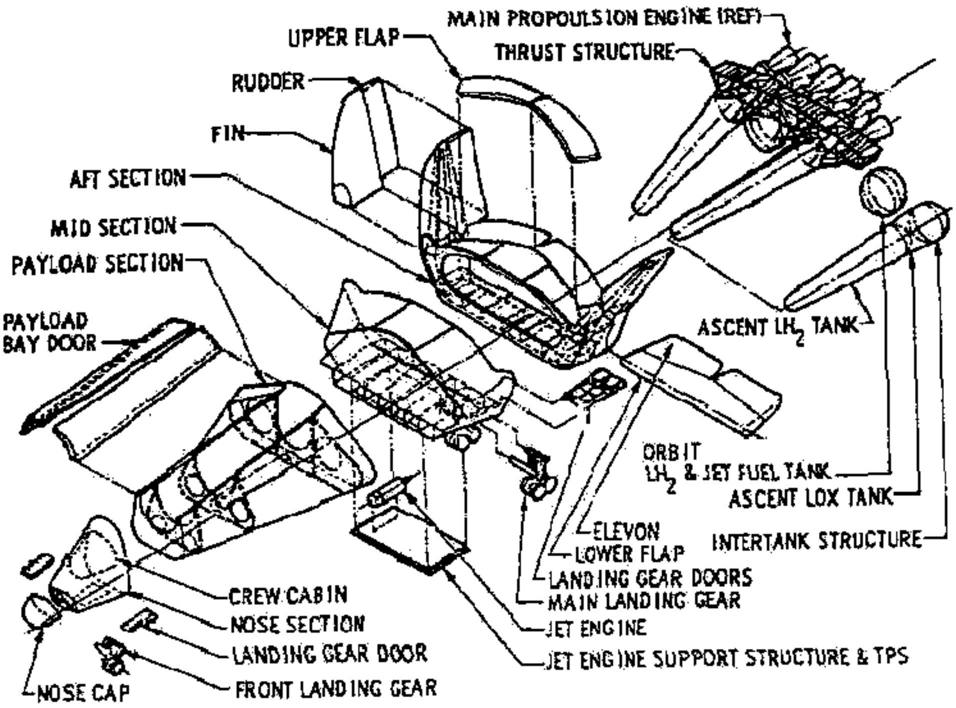


Figure 19

DELTA BODY/DELTA WING-BODY COMPARISON - TWO STAGE ORBITER
(Figure 20)

The Delta Body design approach is seen to have many potential advantages over the contemporary Delta Wing-Body design approach. This comparison reflects the two design approaches being worked to the same ground rules (Phase B) and to reasonably comparable depth. While the characteristics of each design are expected to change with further definition, the relative features are not expected to change significantly.

Properly exploited, the Delta Body design can yield an efficient Space Shuttle Orbiter.

DELTA BODY/DELTA WING-BODY COMPARISON TWO-STAGE ORBITER

		DELTA BODY	DELTA WING-BODY (CENTER FIN)
SIZE: (OVERALL DIMENSIONS)	LENGTH	48.5 m (159 ft)	52.1 m (171.0 ft)
	SPAN	28.0 m (91.83 ft)	29.72 m (97.5 ft)
	HEIGHT	11.1 m (36.4 ft)	17.2 m (56.3 ft)
	DRY WT.	94,305 kg (207908 lb)	102693 kg (226400 lb)
	VOLUME	2648 m^3 (93492 ft^3)	2514 m^3 (89485 ft^3)
	WETTED AREA	1750 m^2 (18835 ft^2)	1860 m^2 (20019 ft^2)
λ'		0.711	0.698
THERMODYNAMICS/TPS FLOW FIELD		Predictable, No Shock Impingement	Flow Interference and Shock Impingement on Leading Edge
TEMPERATURES		Total Surface (Except Nose Cap 0.46%). Less Than 1644° K (2500° F)	1% of Surface Area Above 1644° K (2500° F)
LEADING EDGE		T ≤ 1533° K (2300° F)	T ≥ 1977° K (3100° F)
LANDING:	TOUCHDOWN VELOCITY (POWER OFF)	180 Knots	180 Knots
MINIMUM GLIDE SLOPE		9.94° (L/D = 5.8)	9° (L/D = 6.5)
STABILITY		All axis aerodynamic trim, control, and static stability at α, ϕ require required throughout aerodynamic flight regime.	Directionally unstable (static) hypersonic/supersonic ($C_{n_{\beta}}$ dynamic is stable)

Figure 20

CONCLUDING REMARKS

The Delta Body orbiter is a potential candidate for the Space Shuttle orbiter. The advantages of using the Delta Body design approach are

1. Bow shock impingement and flow interference is avoided
2. Only the nose cap sees surface temperatures above 1644° K (2500° F), therefore the TPS can be fully reusable with the proposed materials.
3. Static aerodynamic stability and control is provided for all three axes during atmospheric flight - the configuration has sufficient aerodynamic performance.
4. Low structural weight is achieved without resorting to integral tanks.
5. The concept provides a simple development/manufacturing approach.
6. Fifteen years of background evolution supports the concept.
7. The Delta/Body Space Shuttle orbiter will perform the Space Shuttle mission.

REFERENCES

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