Lifting Entry Rescue Vehicle Configuration

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An alternative means of providing crew return capability for the Space Station Freedom is being considered in the event that the Space Shuttle is not available. This assured crew return vehicle would be docked to the station and would be available for a variety of return or rescue missions. A lifting entry configuration concept is presented herein to meet anticipated mission requirements. The design is driven by the need to safely return injured, ill, or deconditioned crew members. This need is a significant consideration for limiting re-entry *g*, minimizing impact loads with ground or water, and minimizing transport time from the station to definitive medical care. Therefore, the capability for land landing with ready access to medical help is highly desirable. The present design is shown to meet these objectives. It features a moderate L/D design ($L/D \approx 1.0$) that provides a minimum-risk, inexpensive solution featuring simple geometry and structure. It provides significant cross-range capability combined with low re-entry *g* load (1.8 *g*), utilizing state-of-the-art thermal protection and a parachute landing system.

Nomenclature

AFRSI	= Advanced Fibrous Reuseable Surface Insulation
D	= drag coefficient, $C_D = D/(\rho U^2 S)/2$
d	= reference length, cylinder diameter, ft
GMT	= Greenwich Mean Time
g	= resultant load factor
HTP	= High Temperature Performance
L	= lift; coefficient $= L/(\rho U^2 S/2)$
Q	= heat rate, Btu/ft^{2}s
$Sref$	= reference area; $S = \pi d^2/4$, ft^2
U	= freestream velocity, ft/s
x_{CG}	= center-of-gravity location from nose, ft
α	= angle of attack, deg
δ	= flap deflection or flare cut angle, deg
ρ	= freestream density, lb s^2/ft^4

Introduction

THE Space Station Freedom represents our nation's permanent manned presence in space. It is planned to be operated continuously in Earth orbit over an expected lifetime of 30 years. Normal operations at the station, including crew rotation and resupply, will be supported with periodic visits by the National Space Transportation System (NSTS) Space Shuttle Orbiter. However, it is impractical to keep a shuttle always in readiness as a rescue vehicle in the unlikely event that an emergency onboard the station would require immediate evacuation of all or part of the crew. The obvious solution is an assured crew return vehicle (ACRV) that is docked to the space station and available and ready (i.e., always supplied with the necessary life-support expendables and propellants) for immediate undocking, deorbit, and return to Earth.

The main missions identified for the ACRV are to 1) provide emergency return of a seriously ill or injured crew member; 2) provide immediate crew return when an emergency requires evacuation of the station; and 3) provide crew return from the station, if the NSTS is not available in the time frame needed. Thus, the vehicle is fundamentally a re-entry vehicle capable of returning the crew to Earth and landing safely. This paper presents what is believed to be an innovative lifting re-entry technology solution to the crew return vehicle design problem.

Requirements

Although requirements have not yet been finalized, it is evident that the need to recover ill or injured crew members may drive the re-entry vehicle design. For example, it is preferable to return ill or injured crew members to land bases where medical help is readily available, such as government facilities where safety equipment/procedures and controlled access also exist. Thus, the vehicle must have the crossrange capability to maneuver to certain preferred landing sites. Additionally, the re-entry deceleration loads must be small, probably no more than 2 *g*, to avoid further injury to an already incapacitated crew member. The desire is to achieve low *g*, short time to medical care, low life-cycle cost, and land landing. The low *g* implies a moderate hypersonic L/D. Short time and land landing imply significant crossrange and terminal precision to reach desired landing sites. The low life-cycle cost implies a simple, lightweight structure with common materials for low development and production cost, and low refurbishment cost and reusability achieved with few landing sites for low operation costs.

Two major performance attributes have, therefore, been identified for successful accomplishment of these missions. They are the re-entry load factor and re-entry crossrange capability, which are functions of L/D and are determined by the aerodynamic configuration (Fig. 1). Therefore, to satisfy the low *g* mentioned earlier, configurations with a hypersonic L/D near 1.0 are of particular interest.

The Space Station orbit track will be ± 28.5 deg latitude. This restricts continental U.S. ground landing sites to south Florida or south Texas for a purely ballistic vehicle. Therefore, moderate crossrange capability would increase landing-site options and timely accessibility to medical facilities. Landing access opportunities increase dramatically with the benefit of crossrange capability. Both the frequency of access to a selection of candidate sites and the frequency of access with favorable lighting conditions are greatly enhanced with a crossrange approximating 700 n.mi. (Fig. 2). Because of both the *g*-load and crossrange benefits described, a configuration having a maximum hypersonic L/D of $0.8 \le L/D \le 1.1$ was desired (Fig. 1).

In addition to meeting the foregoing performance attributes, it is desirable that the ACRV be capable of accom-

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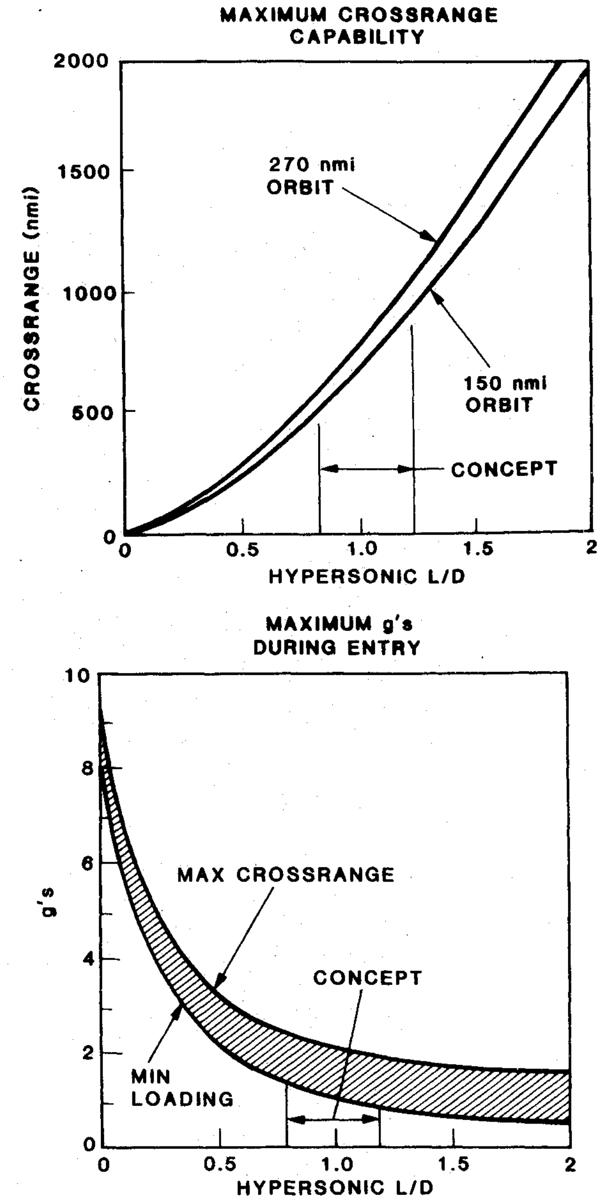


Fig. 1 Performance attributes.

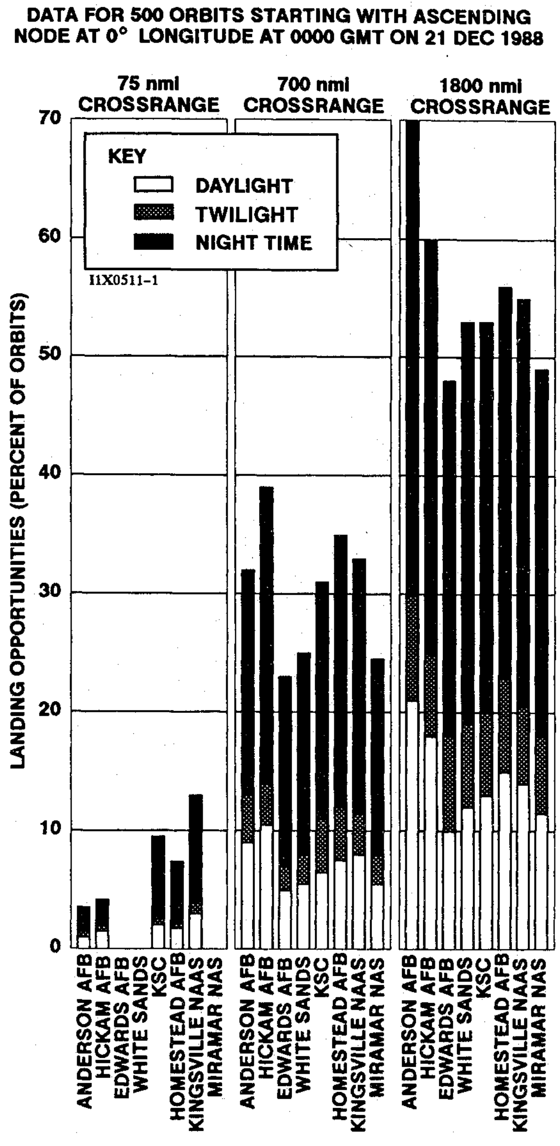


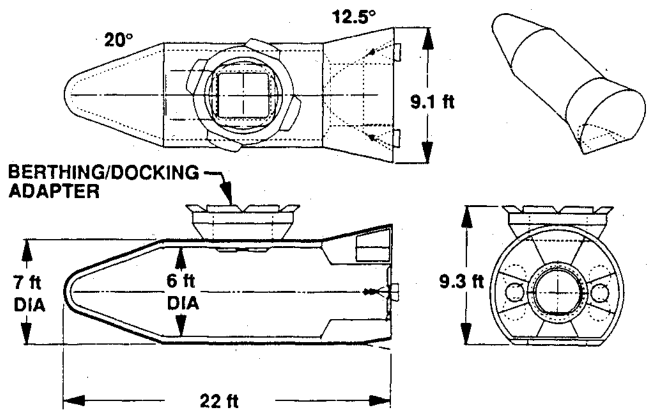
Fig. 2 Landing access opportunity.

modating from one to six crew members and be small enough so that two vehicles can be transported to the Space Station within the Shuttle cargo bay. It is also desirable that the vehicle be low-cost, of simple design, easy to manufacture, and, above all, involve low technical risk.

Aerodynamic Design

A lifting entry configuration concept has been defined to meet anticipated mission requirements. This configuration (Fig. 3) is a 22-ft-long cone-cylinder-flare aeroshell enclosing a 6-ft-diam cylindrical crew compartment that can accommodate six persons and an integral deorbit propulsion subsystem. The anticipated vehicle weight is approximately 15,000 lb. A berthing and docking adapter provides attachment to the Space Station Freedom and crew ingress/egress. The adapter hatch is located on the leeside of the vehicle and is thus shielded from the re-entry heating environment. An alternate hatch is available at the rear between the deorbit engines. A trim flap on the flat lower surface of the flare provides the necessary pitch trim capability.

Because a parachute is used for landing (Fig. 4), the aerodynamic design is not driven by landing L/D requirements, thus avoiding the need for complex, hard-to-package lifting surfaces. This also allows the vehicle to be optimized for the re-



LENGTH	22.0 ft
MIDBODY DIA	7.0 ft
FORECONE HALF-ANGLE	20.0 deg
NOSETIP RADIUS	1.52 ft
FLARE HALF-ANGLE	12.5 deg
L_{REF}	7.0 ft
S_{REF}	38.48 ft^2
WEIGHT (ESTIMATED)	15,000 lb
ACCOMMODATIONS	6 PERSONS

Fig. 3 ACRV flared-cylinder reference configuration.

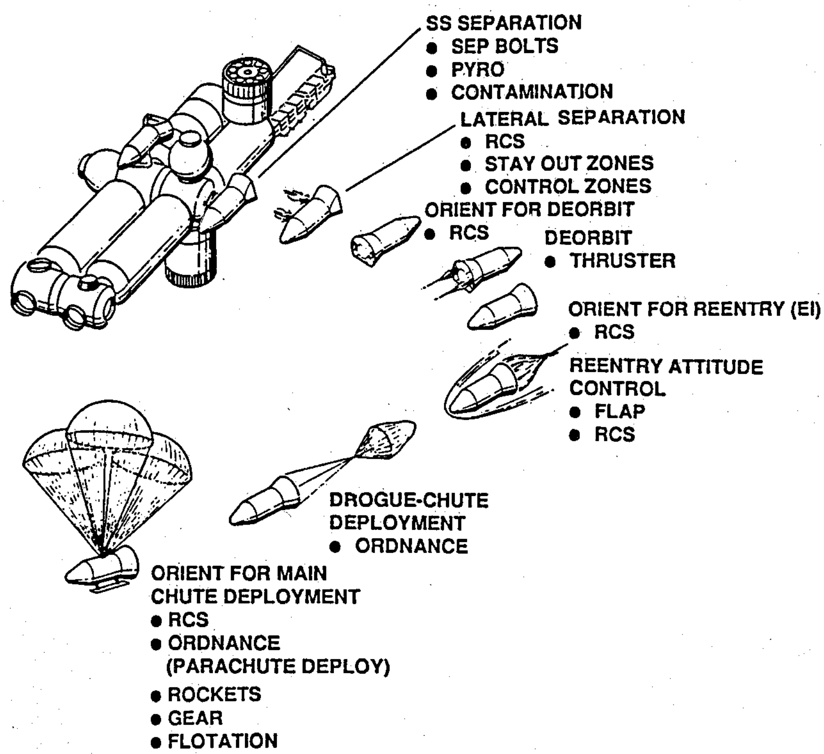


Fig. 4 Re-entry and landing concept.

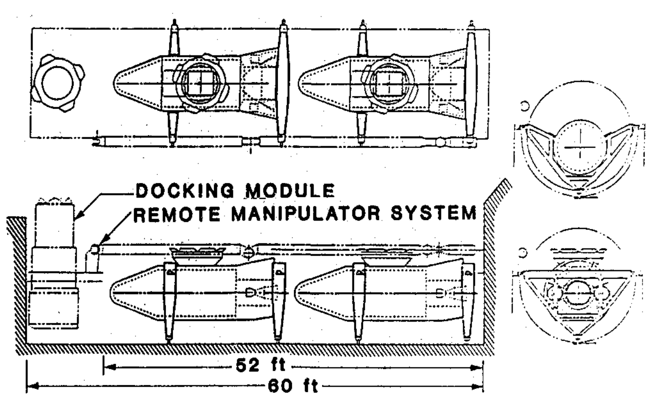


Fig. 5 Two vehicles in Orbiter cargo bay.

entry flight regime only. The result is a technically conservative airframe, structure, and heat shield as will be described later. Furthermore, the cylindrical fuselage is an excellent, easily manufacturable, pressure vessel. Two of these compact ACRV vehicles are easily packaged in the Shuttle cargo bay (Fig. 5).

Aerodynamic Trade Studies

The initial flared-cylinder aerodynamic configuration was selected to meet two basic objectives. First, to maintain a reentry g level of less than 2 g, a maximum inviscid hypersonic L/D of greater than 0.8 was required; second, in order to permit two vehicles to be transported in the orbiter cargo bay, the maximum vehicle length was constrained to be no greater than 25 ft.

Beginning with an extensive wind-tunnel data base[1-3] calculations were made using a simplified version of the Supersonic, Hypersonic Arbitrary Body Program (S/HABP)[4] called SIMP. Pitching-moment increments for various flare cuts were applied to a $M = 8.0$ wind-tunnel data base to determine if it was possible to achieve an $L/D = 1.0$ with a blunt-cylinder-flare configuration (Fig. 6). Not only could $L/D =$ 1.0 be achieved but it was found possible to achieve a nearly 20-deg trim angle range in the vicinity of maximum L/D with moderate control flap deflections and only a 10% loss in L/D_{max}.

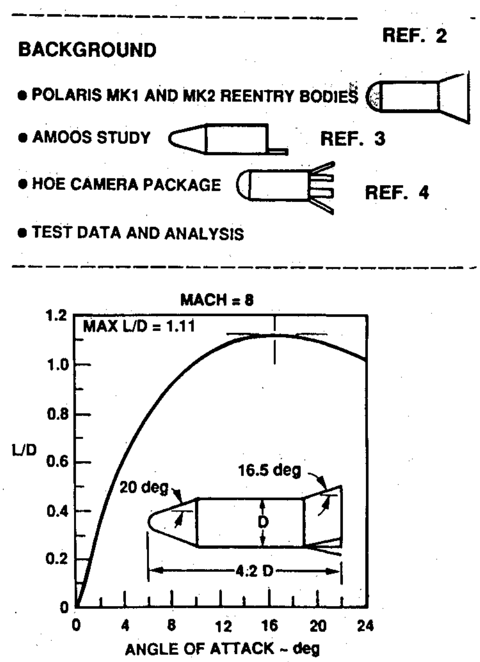


Fig. 6 Initial flared-cylinder configuration.

This initial configuration, with a maximum hypersonic L/D of 1.1 at approximately 17-deg angle of attack, had a cylinder diameter of 7 ft (to allow a 6-ft-diam internal crew compartment) and was almost 30 ft long, exceeding the maximum length objective. Therefore, a configuration sensitivity analysis was performed to define an acceptable length configuration. The effects of the various geometric parameters—nose bluntness, nose angle, cylinder length, and flare angle on performance (L/D)— were assessed using the SIMP code (Fig. 7).

These trades were used to optimize the vehicle performance within the length constraints required to package two ACRVs within the Shuttle cargo bay. The result is the reference configuration shown in Fig. 3. The initial configuration shown in Fig. 6 (which was too long to meet Shuttle constraints) is denoted by the circled points in Fig. 7, and the final reference configuration (Fig. 3) is denoted by arrows. It should be noted that the sensitivities are for excursions from the initial configuration of each element individually; thus, the reference elements are not shown in combination.

Aerodynamic Characteristics

A wind-tunnel test was conducted in the NASA Ames Research Center 3.5-ft hypersonic wind tunnel on a 3% scale model (Fig. 8) at Mach numbers of 5 and 10 to validate the aerodynamic performance of the reference configuration and to obtain parametric data to verify configuration trade and control effectiveness studies. Other ACRV candidate configurations were also tested.

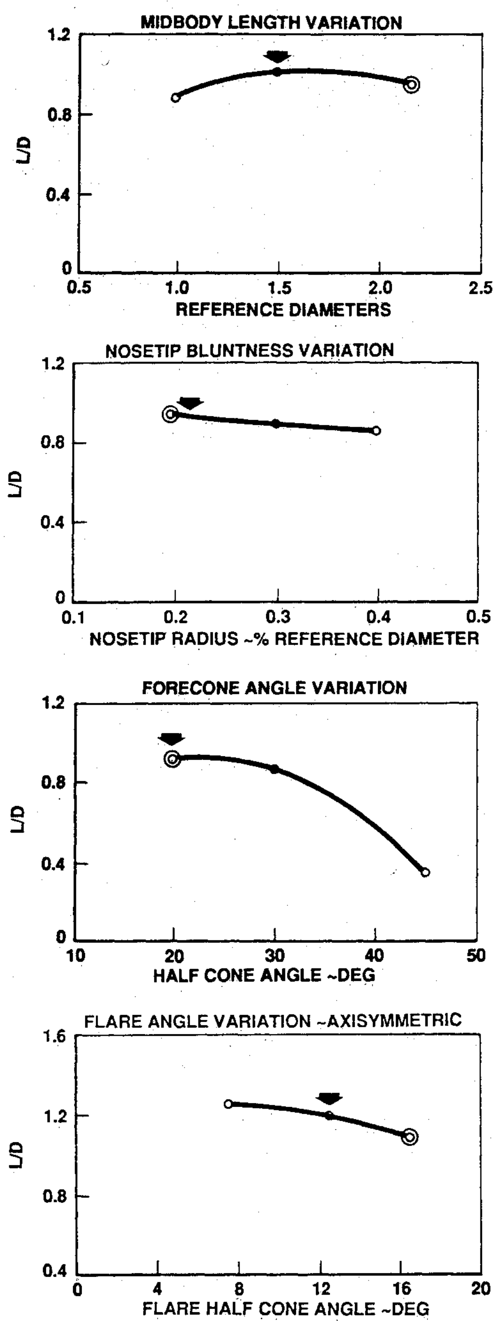


Fig. 7 Configuration sensitivities.

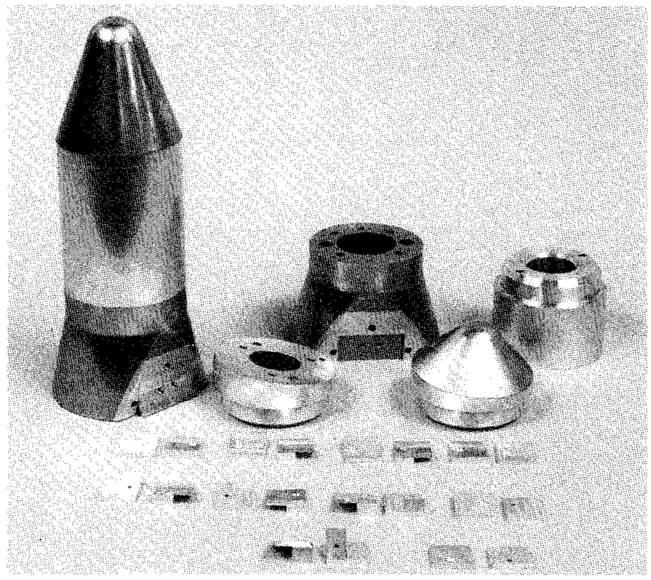


Fig. 8 Wind-tunnel model.

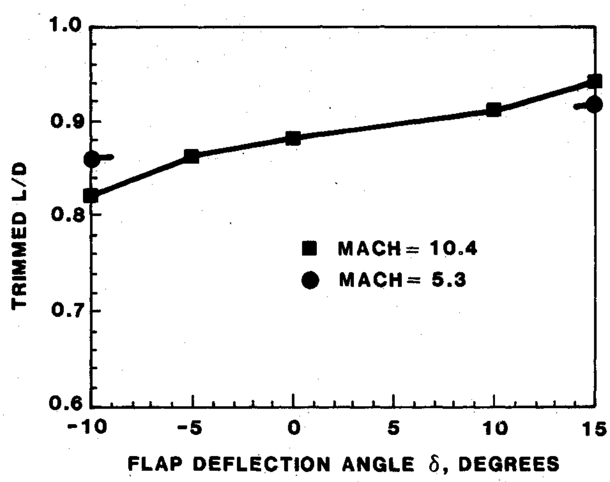


Fig. 9 Flap deflection effects on trimmed L/D.

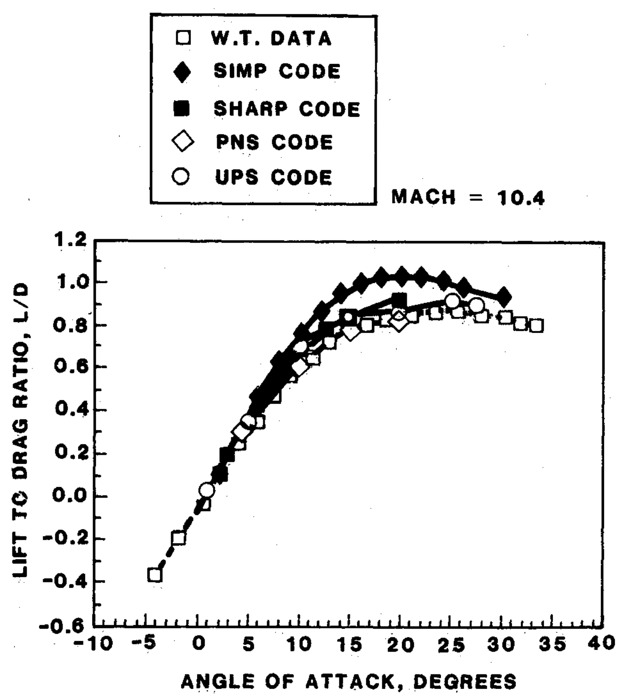


Fig. 10 ACRV L/D code comparison.

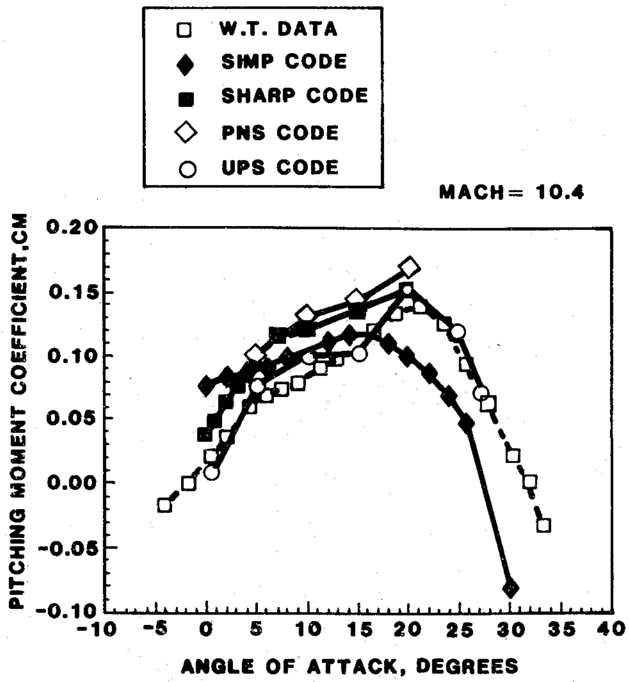


Fig. 11 ACRV pitching-moment code comparison.

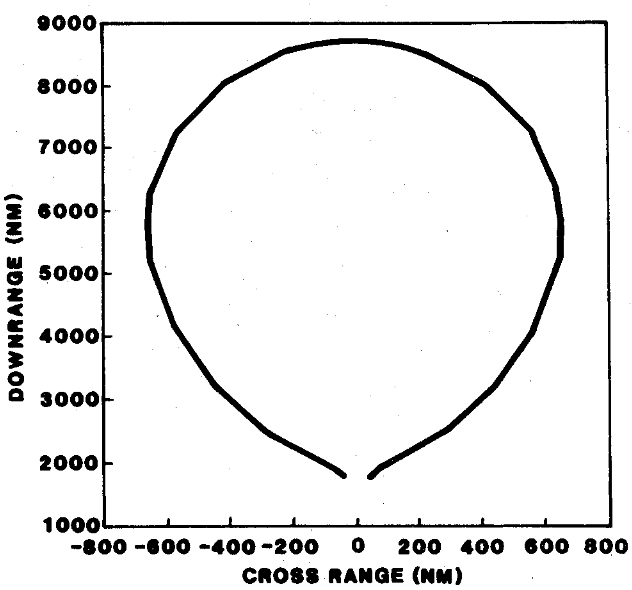
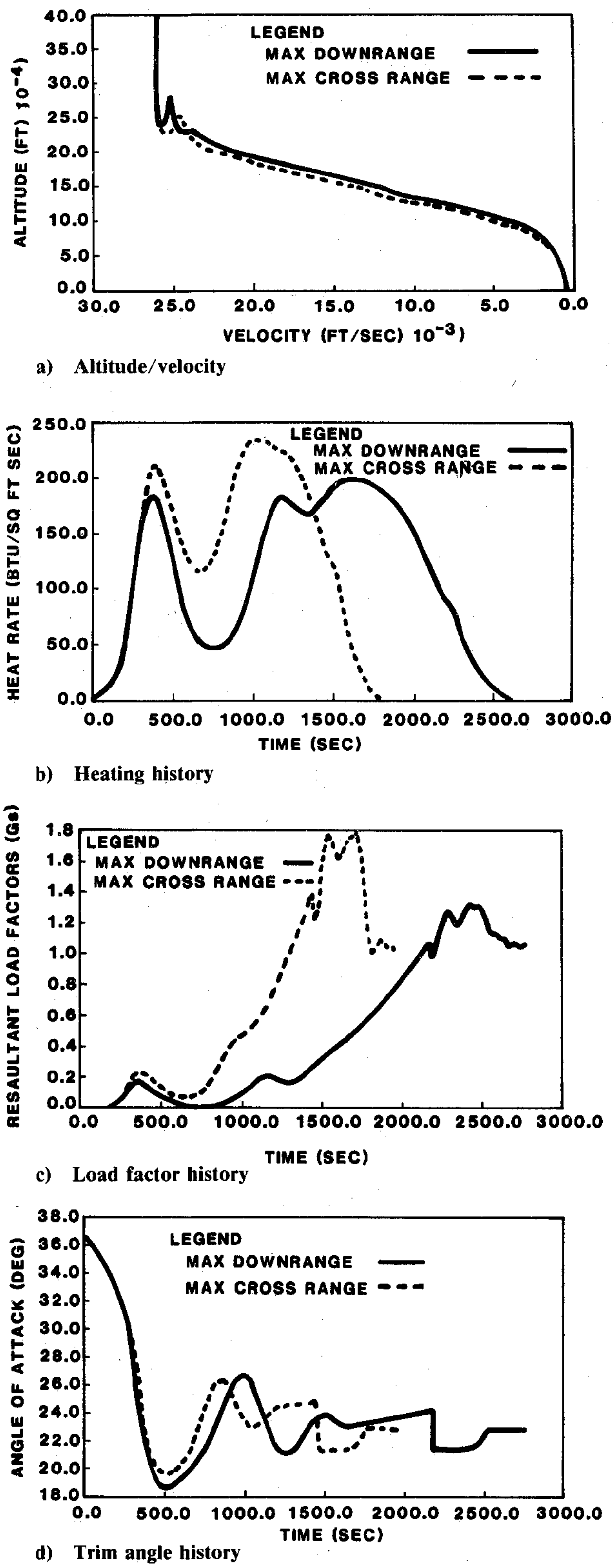


Fig. 12 Downrange/crossrange capability.



a) Altitude/velocity

b) Heating history

c) Load factor history

d) Trim angle history

Fig. 13 ACRV trajectory data.

The wind-tunnel data verify that the flared cylinder achieves the desired performance with a trimmed L/D between 0.8 and 1.0 for the full range of flap deflections tested (Fig. 9).

The data have also been compared to a number of design and flowfield codes [4-8] to aid in the selection of the best codes for generating aerodynamic characteristics over the complete hypersonic/supersonic speed range. Comparisons between wind-tunnel data and the codes for $M = 10$ are shown in Fig. 10 for the fundamental measure of aerodynamic performance, L/D vs α, and in Fig. 11 for the $\delta = 0$ pitching moment. Of the two design codes [SIMP and the Supersonic Hypersonic Aerodynamic Rapid Prediction (SHARP) code], the more sophisticated SHARP code[5] compares best with data. This code combines the Tri-D, inviscid, finite-difference code[6] with the Supersonic/Hypersonic Arbitrary Body code[4] to account for the effects on control surfaces of the nonlinear, inviscid shear flow produced by the highly curved bow shock wave that occurs at hypersonic speeds. Both of the Navier-Stokes flowfield codes, the parabolized Navier-Stokes code (PNS)[7] and the Ames upwind differencing Navier-Stokes code (UPS),[8] do an excellent job in predicting the lift-to-drag ratio (Fig. 10) although the UPS code best predicts the pitching moment (Fig. 11).

Trajectory and Heating Analysis

The initial trajectory analysis used as a first assessment of performance capabilities and Thermal-Protection-System (TPS) requirements were simple three-dimensional trajectories flown at maximum L/D. In subsequent trajectory studies, the angle of attack was modulated to minimize the maximum heat rate realized on the initial plunge into the atmosphere and to minimize altitude oscillations during descent. The maximum heat rate was always kept below 250 Btu/ft^{2}s. Maximum crossrange trajectories were flown at a 45-deg roll angle until a 90-deg change in direction was achieved, then rolled back to zero. Footprint results indicate that a 660 n.mi. crossrange is achieved (Fig. 12). The resulting velocity, heating, angle of attack, the deceleration histories are shown in Fig. 13 for the maximum downrange and crossrange trajectories. They exhibit low re-entry decelerations of less than 1.8 g for maximum crossrange and 1.3 g for maximum downrange. Furthermore,

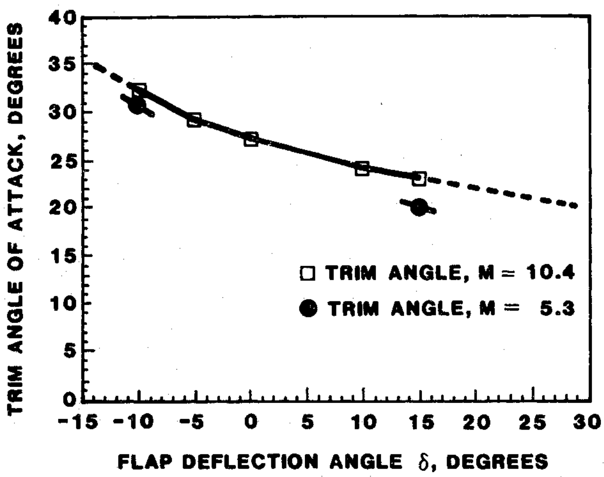


Fig. 14 Flap deflection effects on trim angle of attack.

		MATERIAL				
		AFRSI BLANKET	LI 2200	LI 900	CORK	HTP 16
DENSITY (lb/ft^3)		9	22	9	30	16
THICKNESS (in.) FOR T_{MAX} - 350°F		1.66	1.24	1.08	0.875	1.40
WEIGHT PER AREA (lb/ft^2)	INSULATION	1.25	2.27	0.81	2.19	1.87
	COATING	—	—	—	—	0.03
TOTAL (lb/ft^2) WEIGHT/AREA		1.25	2.3	0.84	2.19	1.9

a) Cylinder insulation/requirements

	MATERIAL				
	AFRSI BLANKET	LI 2200 +0.004 COATING	LI 900 +0.004 COATING	CORK AR	HTP 16 +0.004 COATING
DENSITY (lb/ft^3)	9.00	22	9	30.00	16.00
THICKNESS (in.) FOR T_{MAX} - 390°F	3.53	2.33	2.7	1.28	2.30
WEIGHT PER AREA	2.65	4.22	2.03	3.20	3.07
(lb/ft^2) 0.004 COATING	—	—	—	—	0.03
TOTAL (lb/ft^2) WEIGHT/AREA	2.65	4.30	2.06	3.20	3.10

b) Cone insulation/requirements

Fig. 15 ACRV insulation requirements.

extrapolation of the wind-tunnel data indicates that the required trim range is achievable with a +29-deg to -16-deg flap deflection (compare Figs. 13d and 14).

The mild heating histories shown in Fig. 13b permit a simple state-of-the-art airframe structure and TPS. For example, a variety of thermal-protection materials have been sized for the cylinder that will limit the peak aluminum substrate temperature to 350°F. The lightest solution is the reusable insulation material LI 900 currently in use on the Space Shuttle (Fig. 15a). Likewise, the nosecone (with the exception of the spherical cap) can be insulated to the same structural temperature limit using the same LI 900 insulator (Fig. 15b). Thus, the airframe substructure can be aluminum with a reusable TPS everywhere except possibly the spherical nosetip and the flaps. Carbon phenolic is a good candidate for these components. The airframe structure is, therefore, a well-proven, low-risk technology.

Landing Options

As previously stated, the use of a parachute system allows the ACRV to be optimized for re-entry conditions rather than for landing, thus allowing the compact, low-development risk vehicle just described.

Recovery of this flared-cylinder vehicle would be via parachute for either ground or water landing (Fig. 4). Following successful separation from the Space Station Freedom, deorbit, and re-entry, the vehicle would be slowed by a drogue chute and landed with either a ballistic or glide chute system. Combined parachute retrorocket systems can achieve low touchdown velocities (<5 ft/s vertically and < 10 ft/s horizontally for a 15,000 lb ACRV). The chief concern with a parachute system is being able to acquire a particular landing site with accuracy. If the winds in touchdown area are known 2 h prior to touchdown and re-entry planned accordingly, Fig.

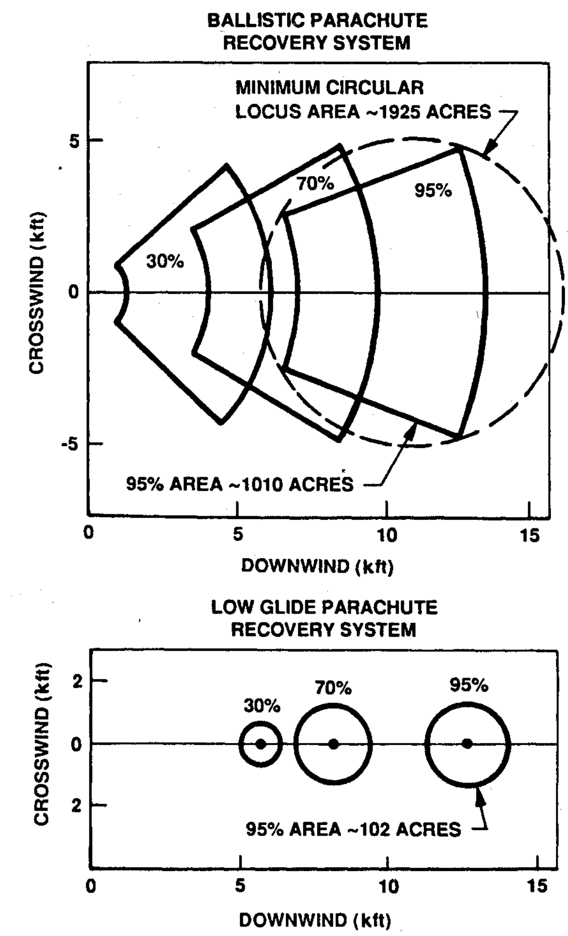


Fig. 16 Touchdown accuracy of ballistic and low-glide systems.

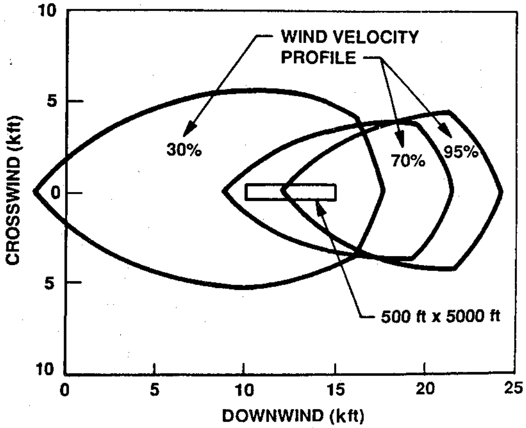


Fig. 17 High-glide recovery system footprint.

16 presents the locus of impact points at Kennedy Space Center (KSC) due to 99% probable variability in the 30, 70, and 95 percentile wind profiles that occur over the 2-h period.[9] It is evident that for a ballistic parachute system an impact area of roughly 2000 acres is required for landing and can be achieved with drogue chute deployment adjustments.

If, on the other hand, a low-glide system with limited guidance, navigation, and control capability is used, it can be steered to land at a point with wind variability causing a dispersion about that point. With proper adjustment of the drogue deployment point, the low-glide system would require an order of magnitude less "real estate" for a landing area than the ballistic system. However, the total downwind distance that must be available for landing due to wind effects is relatively unaffected, but the crosswind area is significantly reduced.

The footprint bounding all points to which a high-glide (parafoil chute) recovery system can steer the ACRV to a landing was estimated as a function of the same KSC wind profiles, variability, and forecast time period described above (Fig. 17). The major advantage of this system is the possibility of acquiring a small landing strip independent of wind velocity profile, provided proper adjustment is made to the drogue deployment point. The high-glide system ($L/D = 3.0$) will allow one to land on a 500 × 5000-ft runway (Fig. 17). Of course, control reliability issues remain to be resolved with high L/D systems but they certainly are attractive for landing accuracy.

Conclusions

A need has been identified to provide an ACRV for Space Station Freedom crews in the event the orbiter would not be available or an emergency occurs at the Station requiring immediate evacuation. An ACRV would provide that capability.

Missions to recover injured or ill crew members from the Space Station Freedom could drive re-entry considerations to landing on a ground base and to low (2 g or less) re-entry decelerations. An aerodynamic configuration has been defined which provides moderate L/D for crossrange capability and low g loads during re-entry to permit time-urgent rescue of ill or injured crew members. This flared-cylinder configuration provides the advantage of moderate lift and will have a technically conservative aluminum substructure with a reusable, proven TPS and can be packaged two to a shuttle for delivery to the space station. Thus, the blunt-cylinder-flare vehicle provides a credible candidate for an ACRV design.

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