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5 Launch System Design for Access to Space

5.1 Design Objective

Design a hybrid launch vehicle which maintains the current crew survivability rate while reducing reliability in favor of lower cost.

5.2 Abstract

Here, a hybrid launch system is developed. The hybrid launch system combines the lower operating cost advantage of an non-man-rated SSTO MLV with the crew survivability advantage of a ballistic escape pod. Ultimately, it was found that a non-man-rated MLV is configured the same as a man-rated MLV and offers no significant savings in operational cost. However, addition of the proposed escape system would increase the crew survivability rate of the SSTO while incurring only a small cost per pound payload penalty.

5.3 Glossary

Term	Definition
DRLS.......	Down Range Launch Site abort
LEO.........	Low Earth Orbit
MLV........	Main Launch Vehicle
NASA......	National Aeronautics and Space Administration
NASP.......	National Aerospace Plane
RTLS.......	Return to Launch Site abort
SSTO.......	Single Stage To Orbit

5.4 Background

The primary needs for the United States space program through the next two decades are to provide access and support for Space Station Freedom , to deploy and service Earth-orbiting satellites, and to deploy deep space exploration satellites. To meet these needs, approximately 900,000 pounds of payload will have to be carried into LEO (OTA[1], 1990). Currently available launch systems can meet these needs.

Launch systems are separated into two categories: man-rated and non-man-rated. Man rated systems are more expensive to design, build, and support because they require redundant life-support systems on board. The cost per pound payload for a man-rated system can reach $20,000 compared to $3,000 for an non-man-rated system (OTA[1], 1990)

5.4.1 Current non-man-rated space vehicles

Currently there are five families of non-man-rated MLV's capable of placing payloads into LEO. Schematics of these systems and their LEO (100 to 350 miles) payload capabilities are shown in Figure 5.1. The overall reliability of these launch systems ranges between 88 and 95 percent (OTA[1], 1990).

failures of the Atlas and Titan systems resulted in their temporary grounding; however, the Scout, and Delta systems still offer flexible payload capacities and serve as economical payload delivery options.

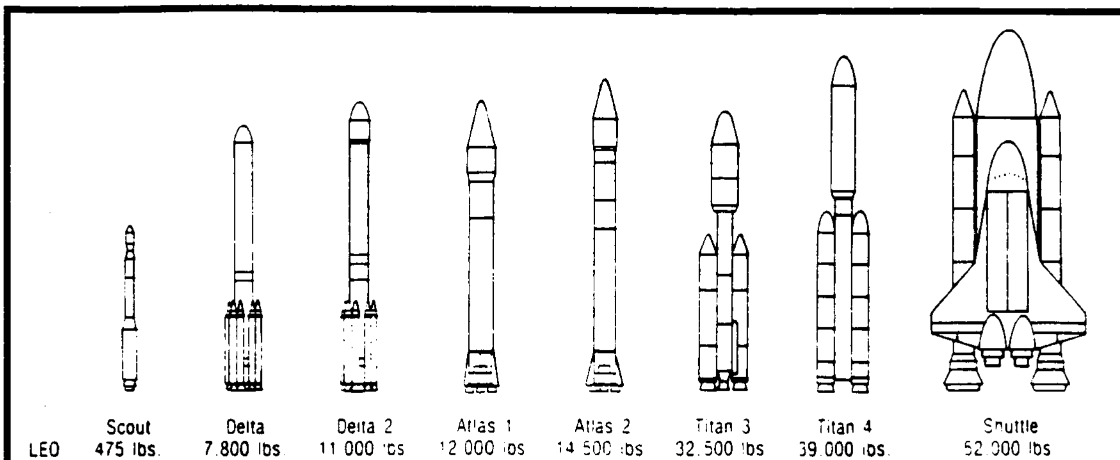

Figure 5.1

5.4.2 Current man-rated space vehicle: Space Shuttle

The Space Shuttle was designed in the early 1970's with its first flight in 1981. Figure 5.2 shows the current Space Shuttle configuration. It is a partially reusable system in that the orbiter glides back to earth after each mission, while parts of the propulsion system are jettisoned during ascension to orbit. The Shuttle can deliver 52,000 pounds of payload and a crew of seven to LEO using liquid-fuel main engines and SRB's.

The major advantage of the Shuttle is its flexibility to be used as a cargo carrier, research platform, and recovery vehicle. One major disadvantage of the Shuttle is its complexity which has driven its operational costs above initial projections. Furthermore, it was anticipated that the turnaround time between missions would be approximately 60 days, but because the Shuttle is only partially reusable, excessive maintenance often requires twice as much time. Another major factor is that safety parameters for hundreds of systems must be satisfied before an orbiter can launch. This system complexity is such that a single malfunction can delay a mission. Launches may also be delayed because of poor weather conditions at the launch site or any of the landing sites (Asker[2], 1993).

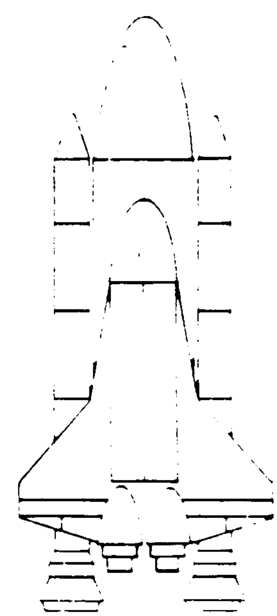
Figure 5.2

5.4.3 Future concepts (Present to 2015)

NASA engineers emphasize the importance of meeting the future (to 2015) United States space program needs, discussed in Section 5.3, with a less expensive, more reliable launch system capable of carrying a payload of 25,000 pounds and a crew of eight to LEO (Brown[3], 1994). Three general concepts have been studied with respect to NASA's future needs: a redesigned Shuttle system, an SSTO transport, and the NASP.

5.4.3.1 Redesigned Space Shuttle

A new shuttle system would use the current design with modifications resulting from technical improvements. Possible improvements are:

- Replace the SRB's with liquid-fuel engines
- Make the Shuttle a totally reusable system
- Replace computers and controllers with new, more reliable systems
- Use state-of-the-art, light-weight materials for the body and engines
- Build an unmanned version of the Shuttle with a payload capacity of 155,000 pounds (Figure 5.3).

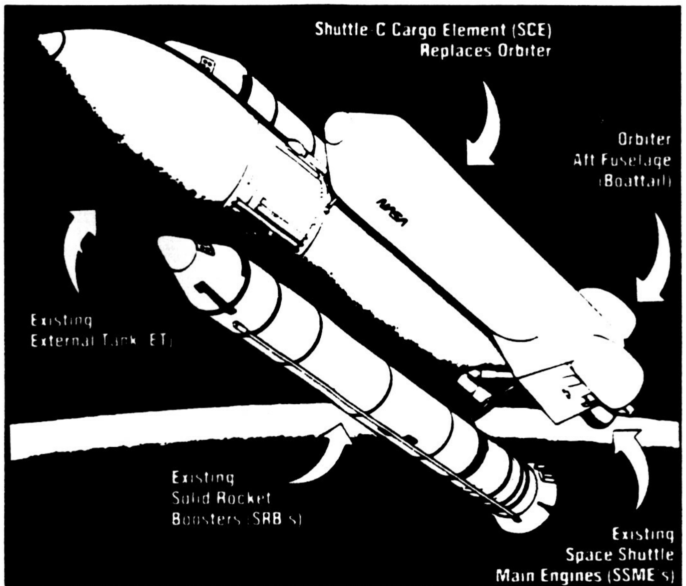

Figure 5.3

Although the modified Shuttle would use proven technology and would take advantage of existing ground support facilities, the man-rated version of the modified shuttle would be as complex and costly as the existing Shuttle.

5.4.3.2 NASA Single Stage To Orbit (SSTO)

The SSTO system is totally reusable, powered by liquid-fueled rocket engines, and capable of reaching LEO. Because the SSTO system is totally reusable, the high maintenance costs of repairing partially reusable parts, like those used in the Space Shuttle (see Section 5.4.2), are eliminated. Two SSTO configurations are the DC-X (Delta Clipper) and the winged SSTO.

5.4.3.2.1 DC-X

The DC-X is a vertical takeoff and vertical landing vehicle that uses existing propulsion technology. A scale model of the DC-X was built and tested during the summer of 1993. Figure 5.4 is a schematic of the DC-X. Anticipated advantages of the DC-X are significant reductions of operating cost and its ability to land on any flat surface. However, researchers have not proven these advantages experimentally, nor has the DC-X demonstrated its ability to deliver a sizable payload.

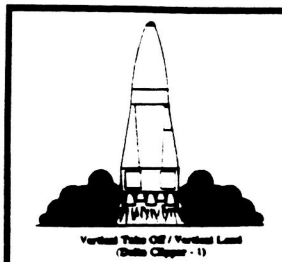

Figure 5.4

5.4.3.2.2 Winged SSTO

The winged SSTO (Figure 5.5) is a vertical takeoff, horizontal landing vehicle with a design payload capacity of 25,000 pounds. The major difference between the SSTO and the Space Shuttle is that the SSTO neither has SRB's nor an external fuel tank. Five liquid-fuel engines supply the necessary thrust to lift the vehicle to LEO.

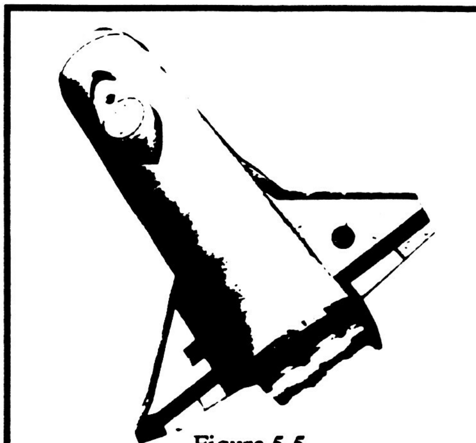

Figure 5.5

5.4.3.3 National Aerospace Plane

The NASP would take off horizontally from a runway, climb to an altitude of 100,000 feet and a speed of Mach 3, and finally switch to supersonic ramjet engines or rocket engines to propel to LEO. However, there have been no successful tests to prove the ramjet engine technology. The following section outlines the customer requirements that any future launch system (i.e. DC-X, winged SSTO, or NASP) will need to meet.

5.4.4 Customer Requirements For Future Launch System

Before any trade studies or design changes were proposed, customer requirements were determined for the future launch system. The customer requirements are used in the selection process for the final launch system. Customer requirements were grouped into five categories: crew safety, system reliability, ability to abort, system robustness, and the overall structure of the system. Some of the customer requirements are only important in the case of catastrophic failure of the MLV (e.g. explosions, multiple engines out, structural failure) which prohibits an RTLS abort or a DRLS abort maneuver. These customer requirements are marked *catastrophic* throughout the following paragraphs. Non-catastrophic failures allow for the MLV to be salvaged through an RTLS or a DRLS maneuver, while catastrophic failures require that the crew escape and sacrifice the MLV.

The safety of the crew during a mission is a major concern to NASA. The major customer requirements for crew safety are:

- Separation of the crew from the MLV (catastrophic)
- Separation of the crew from the MLV without injuries (catastrophic)
- Return of an incapacitated crew if necessary (catastrophic)
- Easy recovery of the crew (catastrophic)
- Backup life-support systems.

The two customer requirements for system reliability are:

- High reliability (i.e. > 0.98) of the MLV
- Mature, proven technology.

The threat of major (e.g. multiple engines out, life-support failure) and minor (e.g. single engine out) system failures, structural failure, and explosions makes it necessary for a crew to be able to abort a mission at any time. The six customer requirements for the ability to abort are:

- Abort at zero-zero (zero altitude and zero velocity)
- Abort in route to orbit
- Abort in orbit
- Abort during re-entry
- Separation of crew from MLV at high speeds (catastrophic)
- Easy separation from the MLV (catastrophic).

The term "system robustness" refers to the MLV's ability to perform many different operations and handle changing circumstances. The overall MLV must be robust so that the need to abort is minimized. The six customer requirements for robustness are:

- The MLV can adjust itself to minor system failures
- The MLV is weather tolerant
- The MLV is modular to allow simple transformation between manned and unmanned missions
- The crew compartment is easily accessed
- The MLV's complexity is lower than current level.

The MLV's structure includes the shape and size of the vehicle and its performance capabilities. The customer requirements for the MLV's structure are:

- Minimal weight and size of the system
- Lower operating costs than the current system.

5.4.5 Determination of the relative importance of customer requirements

Following Ullman[4] (1992), we used a pairwise comparison to determine numeric weightings for each customer requirement. These weightings were used for the final concept selection. Before any comparisons could be made, the mandatory customer requirements were identified as:

- Abort at Zero-Zero
- Abort en route to orbit
- Abort during re-entry
- Get the crew away alive.

Pairwise Comparison	Abort zero zero	Abort in route to orbit	Abort during re-entry	Get crew away alive	Vehicle reliability	Fault recovery	Mature technology	Access to flight controls	Return incapacitated crew	Minimal weight and size	Weather tolerant	Vehicle simplicity	Ease of recovery of crew	Modularity	Self contained life support	Get crew away without injury	Abort at high speeds	Ease of separation	Low cost	Access vehicle easily	Abort in Orbit	Weighting
Abort zero zero																						•
Abort in route to orbit																						•
Abort during re-entry																						•
Get crew away alive																						•
Vehicle reliability						1	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	9.56%
Fault recovery					0		1	1	0	1	1	0	1	1	1	0	0	0	1	1	1	7.35%
Mature technology					0	0		1	0	0	1	0	0	0	1	0	0	0	1	1	0	3.68%
Access to flight controls					0	0	0		0	0	0	0	0	0	1	0	0	0	0	1	1	2.21%
Return incapacitated crew					1	1	1	1		1	1	1	1	1	1	0	1	1	1	1	1	11.03%
Minimal weight and size					0	0	1	1	0		1	1	0	1	1	0	0	0	1	1	1	6.62%
Weather tolerant					0	0	0	1	0	0		0	0	0	1	0	0	0	1	1	1	3.68%
Vehicle simplicity					0	1	1	1	0	0	1		0	1	1	0	0	0	1	1	1	6.62%
Ease of recovery of crew					0	0	1	1	0	1	1	1		1	1	0	0	0	1	1	1	7.35%
Modularity					0	0	1	1	0	0	1	0	0		1	0	0	0	1	1	1	5.15%
Self contained life support					0	0	0	0	0	0	0	0	0	0		0	0	0	1	0	0	0.74%
Get crew away without injury					1	1	1	1	1	1	1	1	1	1	1		0	1	1	1	1	11.03%
Abort at high speeds					0	1	1	1	0	1	1	1	1	1	1	1		1	1	1	1	10.29%
Ease of separation					1	1	1	1	0	1	1	1	1	1	1	0	0		1	1	1	9.56%
Low cost					0	0	0	1	0	0	0	0	0	0	0	0	0	0		1	1	2.21%
Access vehicle easily					0	0	0	0	0	0	0	0	0	0	1	0	0	0	0		0	0.74%
Abort in Orbit					0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1		2.21%
																					Total	100.00%

Figure 5.6.

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5.6.

Because the remaining customer requirements are not mandatory, their relative importance was calculated in the pairwise comparison. The five most important requirements are:

• Return an incapacitated crew	11.03%
• Get crew away without injury	11.03%
• Abort at high speeds	10.29%
• Separate easily	9.56%
• Have high vehicle reliability	9.56%.

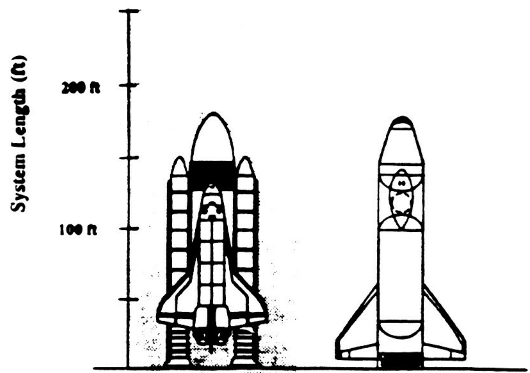
The remaining weightings are listed in Figure 5.6.

5.5 Concept Generation and Recommendation of Final Concept

We chose a hybrid launch system to achieve NASA's future goals as stated by Brown[3] (1994). The two main parts of a hybrid launch system are the MLV and the modular astronaut escape system. Abort techniques such as RTLS and DRLS can be used in single engine out and duel engine out situations. These situations are not classified as catastrophic, thus the astronaut escape system remains in contact with the MLV until the abort maneuver is complete. However, in the case of a catastrophic structural failure, malfunction, or explosion, the astronaut escape module will separate from the MLV and transport crew members to a safe location on Earth. One advantage of the hybrid concept is that system reliability of the MLV can be sacrificed in favor of reduced cost while the crew survivability rating is improved due to the astronaut escape system. Also, the modular astronaut escape system can be removed from the MLV for unmanned missions.

5.5.1 Hybrid launch system: MLV

Following Advanced Technology Team (1993), the NASA winged SSTO concept (see Section 5.4.3.2.2) was selected as the hybrid launch system's MLV. Figure 5.7 shows the proposed SSTO vehicle as it compares to the Space Shuttle, and Figure 5.8 shows the general dimensions of the SSTO vehicle. Key features include:



Vehicle	Shuttle	Single Stage Vehicle
Propulsion	Rocket	Rocket
GLOW	4.5 Mlb	2.5 Mlb
Dry Weight	508 klb	240 klb
Payload to 110 nmi circ@ 28.5°	53.8 klb	45 klb

Figure 5.7

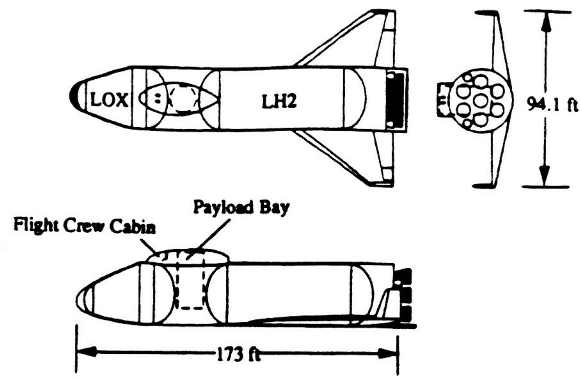


Figure 5.8

Basic shape:	Winged lifting body
Propulsion:	Rocket powered
Takeoff:	Vertical
Landing:	Horizontal
Dry weight:	240,000 pounds

Payload (manned):	25, 000 pounds (@ 28.5° to LEO)
Payload (unmanned):	45,000 pounds (@ 28.5° to LEO)
$/lb payload (manned): $1,995	
$/lb payload (unmanned)	$1,240
Turnaround time:	68 hours
Development cost:	$661.4 Million

The SSTO rocket is designed for:

- Average of 43 flights a year
- Reduced ground support
- Rapid turnaround
- Minimum manpower
- Minimum infrastructure
- Mission flexibility
- Robustness/Automated Flight

5.5.2 Hybrid launch concept: Astronaut Escape Vehicle

With the winged SSTO concept selected as the MLV, concept generation was only necessary for the hybrid launch vehicle's escape system. Accordingly, a more detailed customer requirement list was compiled with respect to the astronaut escape vehicle (Figure 5.9).

Four general escape systems were selected for further evaluation: the ballistic shaped escape pod (Figure 5.10), the lifting body pod (Figure 5.11), the individual capsule (Figure 5.12), and the currently employed pole system (Figure 5.13). The escape system holds a crew of eight astronauts.

Figure 5.10

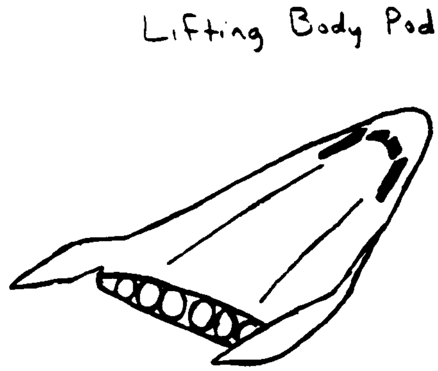


Figure 5.11

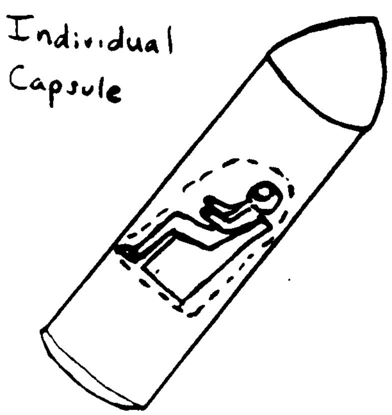


Figure 5.12

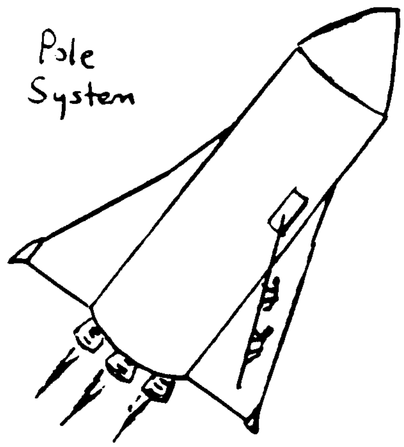


Figure 5.13

Final Concepts

Customer Requirement	Weighting (%)
Vehicle Reliability	9.6
Fault Recovery	7.4
Mature Technology	3.7
Access to Flight Controls	2.2
Return Incapacitated Crew	11
Minimal Weight and Size	6.6
Weather Tolerant	3.7
Vehicle Simplicity	6.6
Ease of Crew Recovery	7.4
Modularity	5.2
Self Contained Life Support	0.7
Get Crew Away Without Injury	11
Abort at High Speeds	10.3
Ease of Separation	9.6
Low Cost	2.2
Access Vehicle Easily	0.7
Abort in Orbit	2.2

Figure 5-9

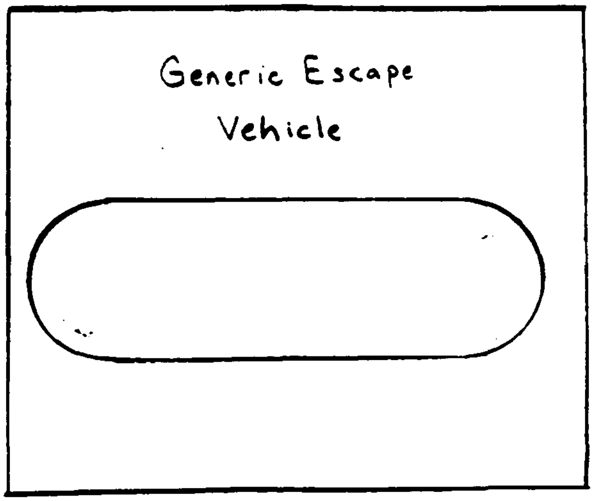


Figure 5-14

5.5.2.1 Discussion of concepts:

The final escape system must be capable of completing five main task:

- Zero-zero abort
- Separation from the SSTO MLV
- Returning to earth
- Landing
- Integration with the SSTO MLV.

Specific concepts were generated to complete each of these tasks. Throughout the following discussion, the shape in Figure 5.14 represents the escape system because the exact appearance and characteristics of the escape system have not yet been determined.

Figure 5.15 illustrates concepts for the zero-zero abort task. Figure 5.15a is a schematic of a zero-zero abort in which the escape system is shot horizontally from the MLV and lands in a body of water. The ocean near the launch pads at Kennedy Space Center and Vandenburgh Air Force Base may serve as the body of water. With the proper orientation and reasonable velocity, the water should dissipate some of the escape system's impact momentum. Figure 5.15b is a schematic of a zero-zero abort in which an inflatable airbag / parachute (Gottschalk[5], 1993) system is used. The parachute slows the descent of the escape system, and the air bag serves as a shock absorber during impact. Figure 5.15c and 5.15d are schematics of zero-zero abort concepts which both require an initial thrust in the vertical direction to give the escape system the extra height necessary for a gliding descent (Figure 5.15c) or a floating descent (Figure 5.15d). Figure 5.15e illustrates a zero-zero abort concept in which a slide is used to move the escape system away from the MLV.

Figure 5.16 illustrates concepts for the task of separating the escape system from the MLV. For all concepts included under the task of separation, the connecting joints between the escape system and the MLV are first severed with pyrotechnics. Figure 5.16a is a schematic of separation using the detonation force of a lumped mass of explosives stored under the bottom side of the escape system. The concept illustrated in Figure 5.16b uses a small solid rocket motor to propel the escape system away from the MLV, while the concept illustrated in Figure 5.16c uses liquid propellant transferred from the MLV prior to separation to power a small engine.

Figure 5.17 illustrates concepts for the task of returning to Earth. Figures 5.17a and 5.17b illustrate the concepts of gliding back to earth with and without propulsion, respectively. Figures. 5.17c and 5.17d illustrate the concepts of floating back to earth with and without propulsion, respectively. Propulsion adds an element of control to the crew on the return trip.

Specific concepts for the landing on land, on water, or in either place. Finally, the concepts for integration of the escape system into the MLV are illustrated in Figure 5.18. Figure 5.18a illustrates the escape system being fully integrated into the MLV. The partially integrated escape system, illustrated in Figure 5.18b, uses the shape of the MLV as well as part of the escape system, with part of the escape system protruding from the MLV body. Figure 5.18c illustrates the non-integrated concept where the escape system rides on the back of the MLV and is in full view.

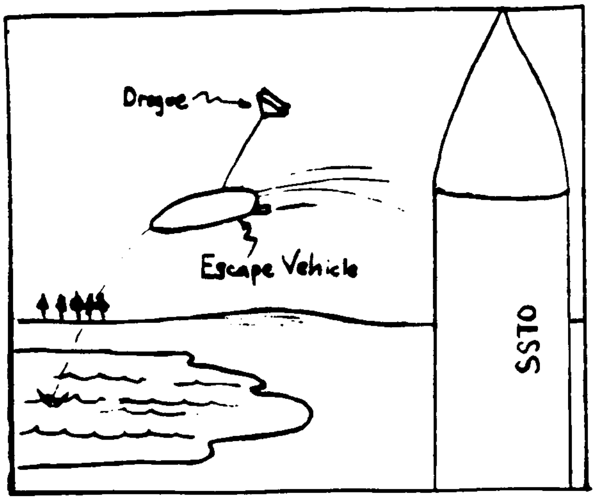


Figure 5-15a

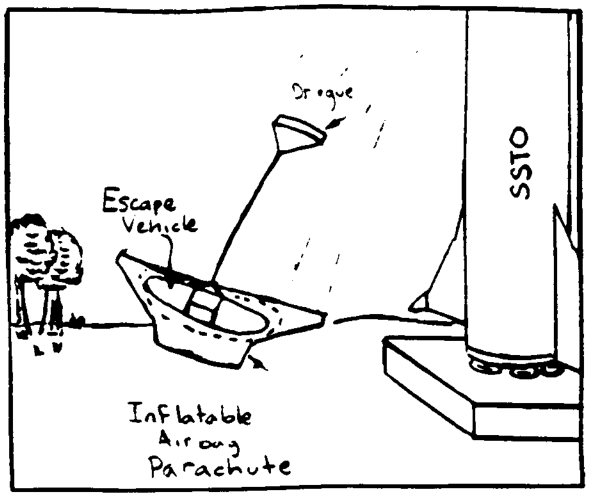


Figure 5-15b

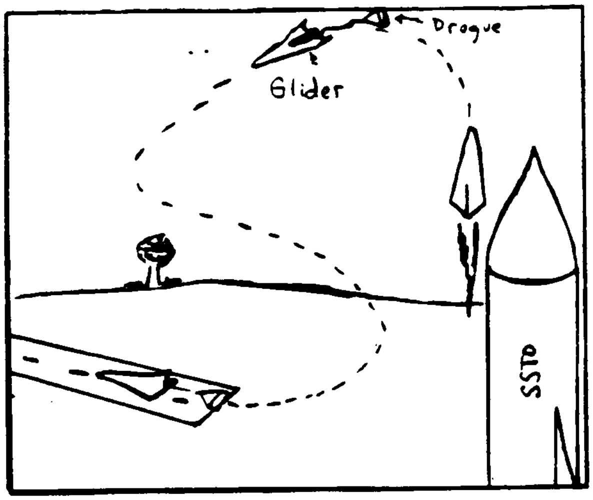


Figure 5-15c

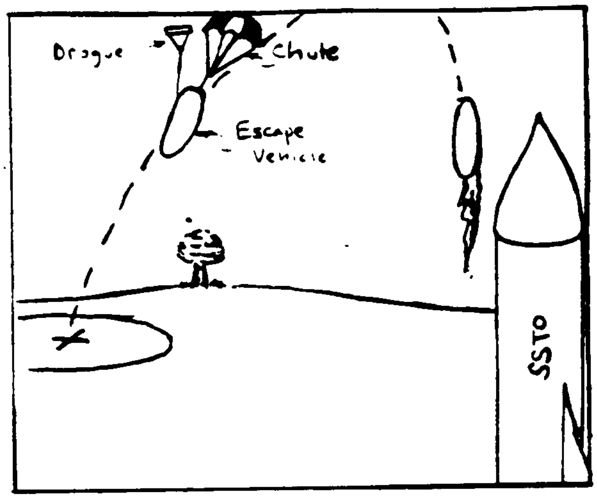


Figure 5-15d

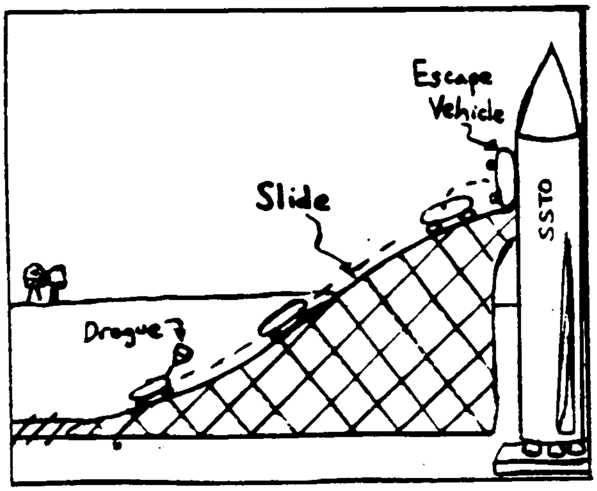


Figure 5-15e

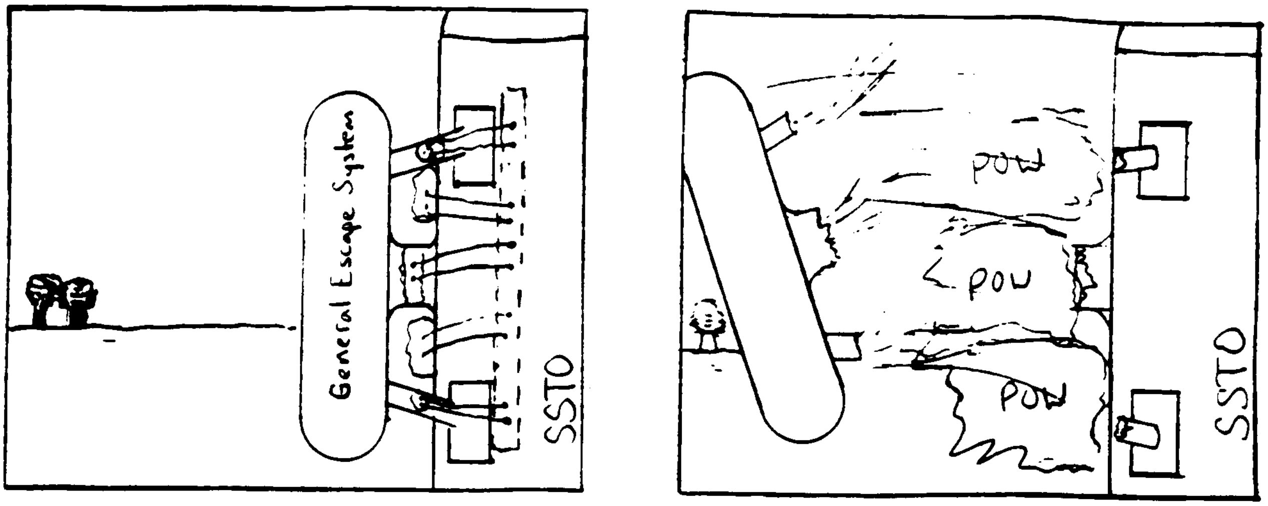


Figure 5-16a

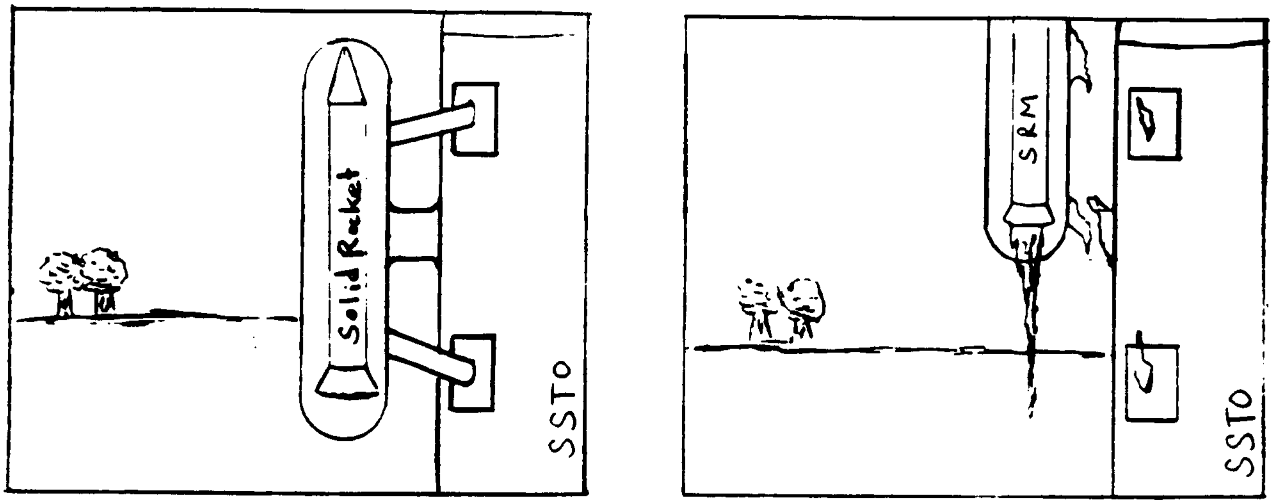


Figure 5-16b

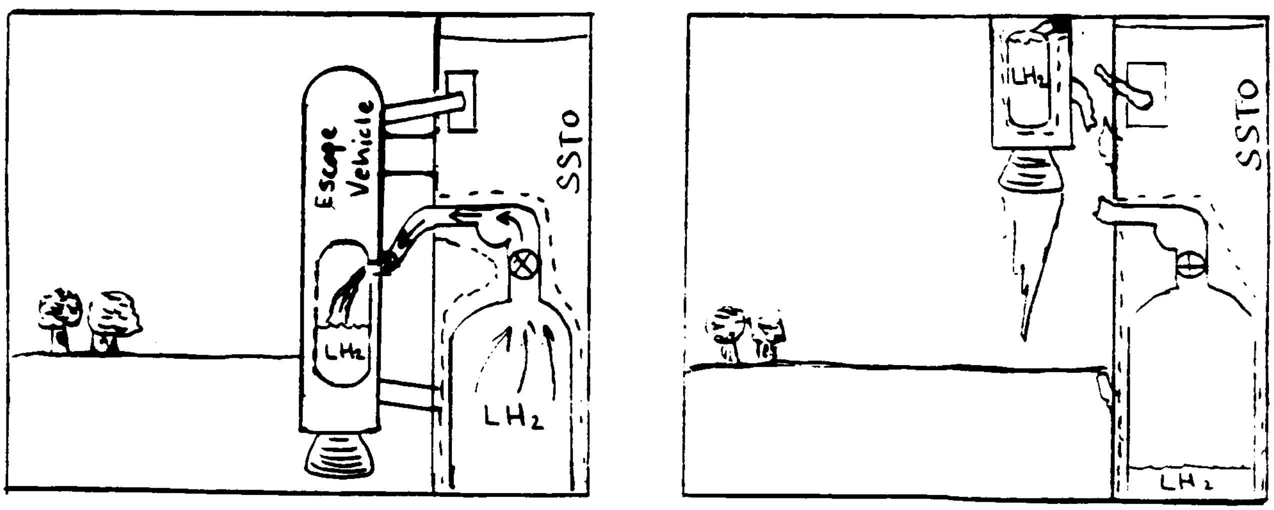


Figure 5-16c

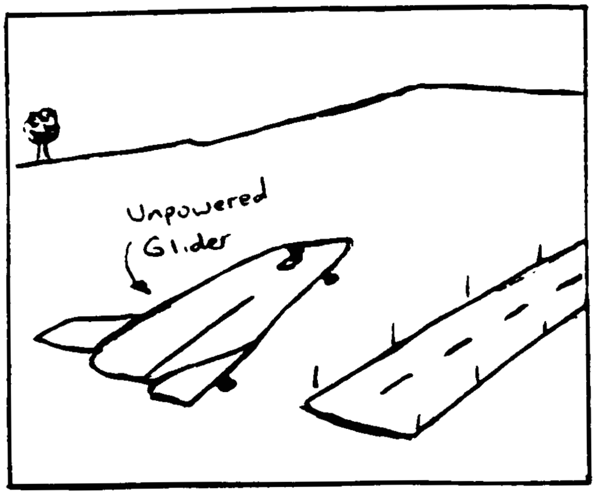


Figure 5-17a

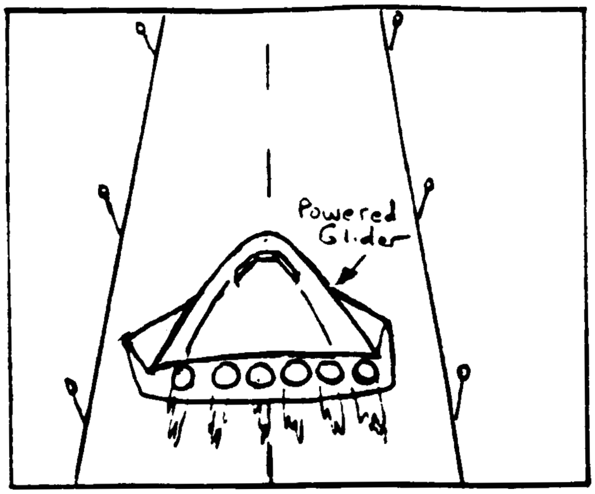


Figure 5-17b

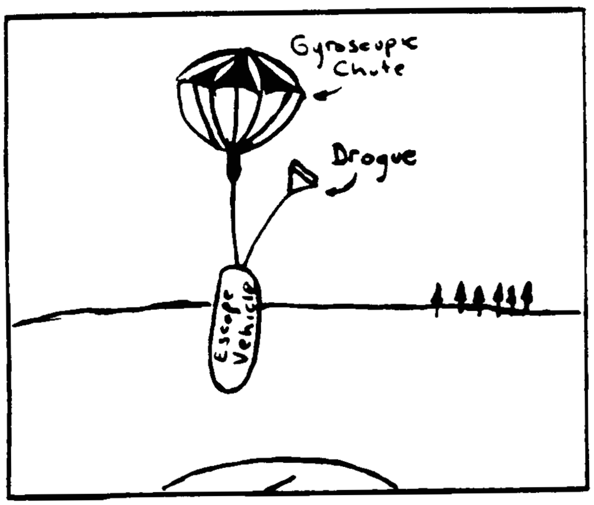


Figure 5-17c

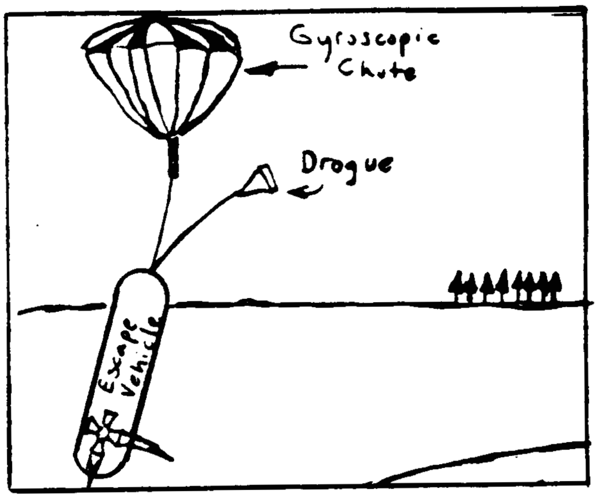


Figure 5-17d

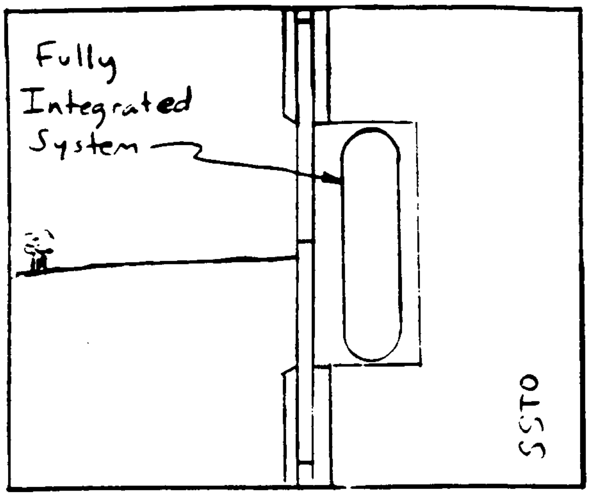


Figure 5-18a

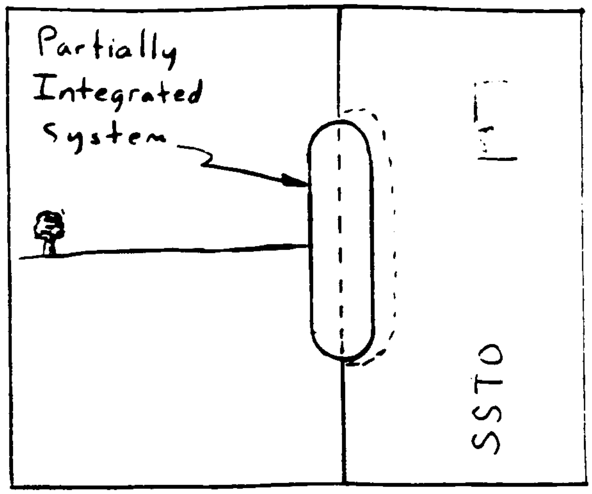


Figure 5-18b

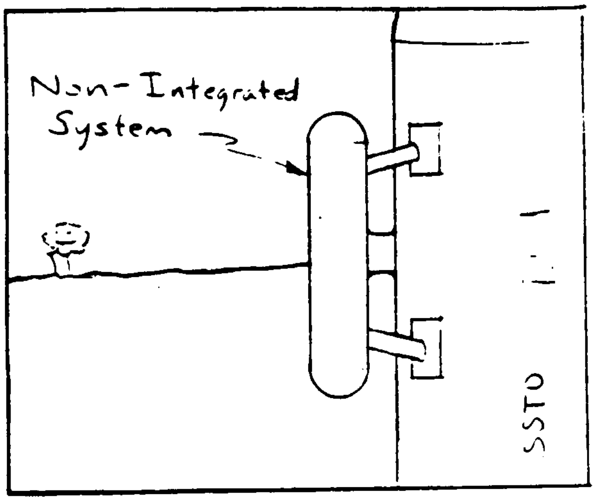


Figure 5-18c

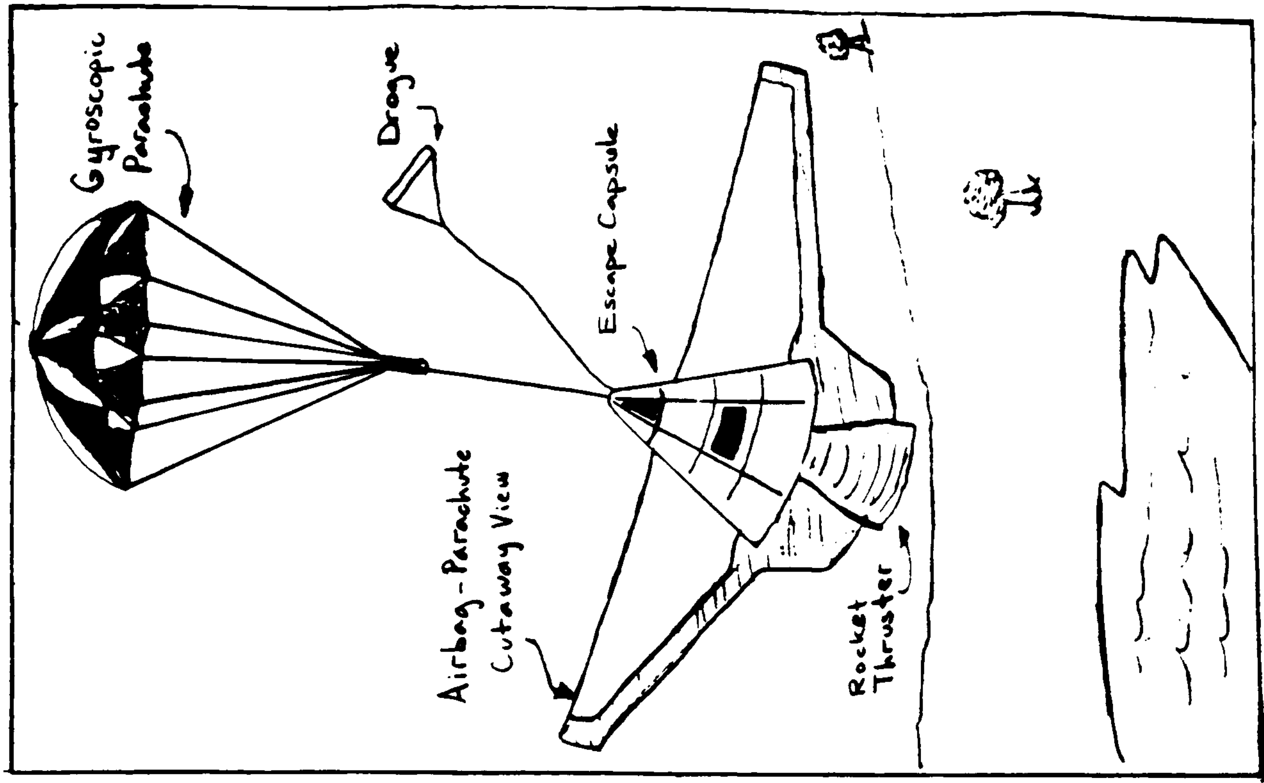


Figure 5-19b

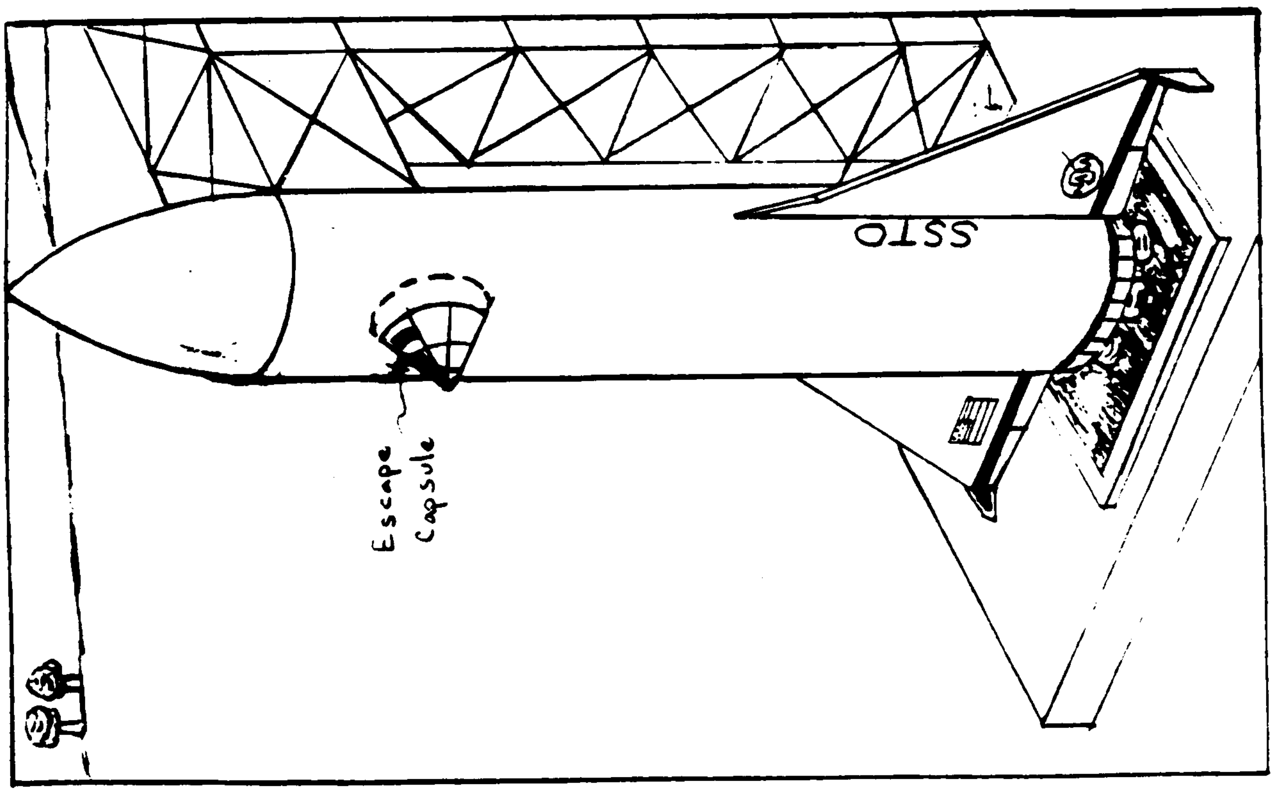


Figure 5-19a

5.5.2.2 Escape system concept selection

The pole escape system concept (see Figure 5.13) was excluded from further evaluation because it cannot realistically satisfy all of the crew safety customer requirements listed in Figure 5.9 for each of eight crew members attempting to escape from the MLV during a catastrophic failure. The remaining three general escape systems (see Figures 5.10, 11, and 12) utilize specific concepts for each of the following tasks: zero-zero abort, separation from the SSTO MLV, return to earth, landing, and integration into the SSTO MLV. These specific concepts for each escape system are listed under their respective tasks in Tables 5.1a, 5.1b, and 5.1c.

For each escape system; the ballistic shaped escape pod, the lifting body pod, and the individual capsule, the specific concepts for completing each task were compared to one another using the decision matrix method (Ullman[4], 1992). The decision matrix provides a means for scoring concepts in their ability to meet the detailed customer requirements for the escape system listed in Figure 5.9. One decision matrix was used to select the best concept for each of the five tasks for each escape system in Table 5.1. The best concepts for each task were combined to give one best configuration for the ballistic shaped pod, lifting body pod, and individual escape capsule systems. These concepts are listed in Table 5.2. Finally, these three configurations were compared in a decision matrix to determine the best overall escape system design. The characteristics of this final escape system are listed in Table 5.3.

5.5.2.3 Configuration of the final escape system (ballistic escape pod)

The ballistic escape pod is illustrated in Figure 5.19. Figure 5.19a shows the pod in its integrated position with the MLV, and Figure 5.19b shows the pod with all of its subsystems exposed. The escape pod uses technology currently employed in the F-111. As with the F-111, the MLV is controlled from the pod which serves as the cockpit.

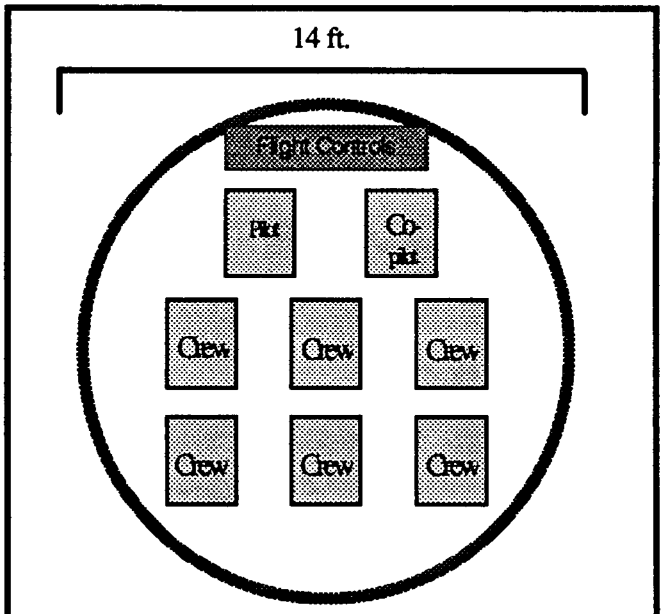


Figure 5-20

The dimensions and weight of the escape pod are the minimum necessary for eight crew members, life-support systems, and flight controls. The pod (see Figure 5.20) has a bottom diameter of 14 feet, top diameter of 8 feet, and height of 5.5 feet. Six crew members sit facing forward in two rows of three while the pilot and co-pilot have access to flight controls. The pod is partially integrated into the MLV and is intended to be occupied only during the flight to orbit and re-entry. Once the astronauts reach orbit, they will leave the escape pod to conduct their mission in other compartments of the vehicle. The escape system weighs approximately 13,000 pounds; this value is based on information in Chacko[8] (1969) and Gottschalk[5] (1993).

Separation from the MLV is accomplished with a small, onboard rocket motor which uses self contained fuel to provide the 13,000 pounds force thrust necessary to propel the escape pod forty feet from the MLV in one second. Forty feet was determined to be a safe distance from the vehicle for any possible MLV orientation during a catastrophic failure. Pyrotechnics, similar to those used by the Space Shuttle for SRB separation, are used to sever the connections between the escape pod and MLV.

The zero-zero abort concept (see Figure 5.15b) uses a deployable drogue and an inflatable airbag / parachute (Gottschalk[5], 1993). The drogue is a two foot diameter, rotating, flexible dragmill parachute. The drogue is made entirely of Kevlar and weighs 0.5 pounds (Design News[7], 1984). The drogue is used to reduce the speed of the escape pod and more importantly to stabilize its descent. The fully inflated airbag / parachute (see Figure 5.21) is forty two feet in diameter, seventeen feet tall, and weighs 500 pounds including the weigh of the inflation system (Gottschalk[5], 1993). The airbag inflates in 1.5 seconds, and its large surface area creates a drag force which slows the descending pod. The airbag reduces the impact between the pod and the ground by venting 180 cubic feet of air through three, eight inch relief valves. Conventional parachutes would not have sufficient time to deploy at an altitude below five hundred feet; therefore, the zero-zero abort concept is also utilized for any aborts within the altitude range of zero to five hundred feet.

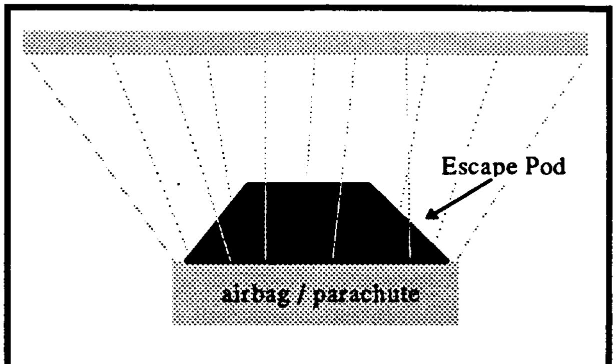


Figure 5.21

For aborts at altitudes greater than five hundred feet, a ringsail parachute is used along with the drogue and the inflatable airbag / parachute (see Figure 5.19c). First, the drogue is used to reduce the pod's speed to Mach 0.46. Upon reaching Mach 0.46, the ringsail parachute is deployed and reduces the pod's speed to 23 feet per second (Phillips[6], 1991). At 500 feet, the airbag / parachute is inflated, and the pod descends to Earth. Air remaining in the airbag after impact allows it to serve as a flotation device in the case of a water landing.

Ballistic Shaped Escape Pod

Zero-zero	Separation	Return to Earth	Landing	Integration
Lake	Detonation	Float	Land	Fully Integrated
Parachute	Stored Propellant	Float with propulsion	Water	Partially Integrated
Airbag/Parachute	Shared Propellant		Both	Fully Exposed
Slide				

Table 5.1a

Lifting Body Escape Pod

Zero-zero	Separation	Return to Earth	Landing	Integration
Lake	Detonation	Glide	Land	Fully Integrated
Glide	Stored Propellant	Glide with propulsion	Water	Partially Integrated
Airbag/Parachute	Shared Propellant		Both	Fully Exposed
Slide				

Table 5.1b

Individual Escape Capsule

Zero-zero	Separation	Return to Earth	Landing	Integration
Lake	Detonation	Float	Land	Fully Integrated
Parachute	Stored Propellant	Float with propulsion	Water	Partially Integrated
Airbag/Parachute	Shared Propellant		Both	Fully Exposed
Slide				

Table 5.1c

Best Configuration For Each Concept

	Final Ballistic Pod Concept	Final Lifting Body Concept	Final Individual Escape Capsule Concept
Zero-zero abort	Airbag/parachute	Airbag/parachute	Lake
Separation	Stored fuel	Stored Fuel	Stored Fuel
Return to Earth	Float back	Glide back	Float with propulsion
Landing	Land and water	Land and water	Land and water
Integration	Partial Integration	Fully exposed	Fully Integrated

Table 5.2

Final Escape System Concept

Overall Shape	Ballistic Escape Pod
Zero-zero abort	Airbag/parachute
Separation	Stored fuel
Return to Earth	Float back
Landing	Land and water
Integration	Partial Integration

Table 5.3

All of the final escape system concepts described for the task of separation, zero-zero abort, landing, and integration are based on mature technology. Mature technology has the advantage of minimal development cost and proven reliability. Furthermore, the escape pod is modular which allows it to be removed from the SSTO MLV for unmanned flights, thus increasing the payload capacity of the SSTO.

5.6 Conclusion

The escape system will take the place of the cockpit in the current NASA SSTO configuration. The volume of the proposed escape pod is 846 cubic feet, while the volume of the current NASA SSTO is estimated to be 1100 cubic feet. Because the volumes of the two cockpits are relatively close, and the current NASA SSTO will have similar surrounding structure, it is valid to assume that the current NASA SSTO cockpit weighs nearly the same as the 13,000 pound proposed escape pod. Therefore, the weight penalty (1000 lbs.) of the escape pod is only due to its parachute, airbag, and propulsion systems. This lowers the payload capacity of the NASA man-rated SSTO to 24, 000 pounds. For unmanned missions, the 14,000 pound modular escape pod is removed from the MLV giving the SSTO a payload capacity of 38,000 pounds. The SSTO vehicle uses a man-rated design for all missions, manned and unmanned, because according to Ryan[9] (1994), no quantitative cost advantage exists for a non-man-rated SSTO over a man-rated SSTO as originally hypothesized in Section 5.3.

Although Ryan[9] (1994) estimates that no cost saving are achievable through non-man-rating the MLV, the final ballistic escape pod system can be integrated into the MLV with a minimal cost per pound of payload penalty and will increase the crew survivability rate of the launch system. The major accomplishment of this study was the development of a ballistic escape pod which can be integrated into the current NASA SSTO configuration. It is possible that the addition of the escape pod to the current NASA SSTO would increase the launch vehicle's crew survivability rate to the desired 0.9999.

5.7 Bibliography

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