N88-17280

HYPERVELOCITY TECHNOLOGY (HVT) CREW ESCAPE

Lanny A. Jines, P.E.
Aerospace Engineer
Air Force Wright Aeronautical Laboratories
Flight Dynamics Laboratory
Crew Escape and Subsystems Branch
Air Crew Escape Group
WPAFB, OH 45433

ABSTRACT The Flight Dynamics Laboratory is currently conducting a research and development effort investigating conceptual designs for escape systems applicable to hypervelocity technology class aerospace vehicles. The contractor, Boeing Military Airplane Company, has recently completed Task I, Concept Definitions and Preliminary Evaluation; and Task II, Enabling Technology Identification; of contract F33615-86-C-3410 (Reference 1). The concepts selected for further development through out the effort will provide survivable escape and recovery throughout all phases of flight including launch, upper atmospheric hypervelocity, orbit, atmospheric entry, terminal approach, and landing. The specific objective for Task I was to conduct conceptual development of the candidate escape system concepts which meet the various crew escape and protection requirements. The contractor initially identified sixteen (16) conceptual escape systems. Of the sixteen, there were two viable options. The study vehicles included a horizontally launched vehicle (HLV) and a vertically launched vehicle (VLV). The contractor has developed graphic computer aided design models of the candidate escape systems with Zenith 248 computers utilizing the CADC IIc software package (Reference 2). During Task II the contractor has identified the necessary state-of-the-art or near-term enabling technologies; i.e., propulsion, life support, thermal protection, deceleration, etc.; that would allow for the implementation of the conceptual designs. The contractor in Task III, Trade Studies, shall prepare performance simulation models of the conceptual designs using the EASY5/EASIEST Computer Program (Reference 3) software with the escape system component and analysis input files appropriately modified for configurations of interest to conduct an in-depth trade study of the candidate concepts.

INTRODUCTION The aerospace vehicles of the future will incorporate hypervelocity technologies, providing the capability of flying at much higher altitudes and much faster speeds than the current' military aircraft. These vehicles will have the capability to be in orbit from one to three revolutions around the earth. Appropriately, the escape systems for such vehicles will require an expanded flight envelope when compared to the existing escape system performance envelopes of current military aircraft. Presently, open ejection seats provide inadequate performance for hypervelocity class vehicles. The ejection trajectory range is cannot provide for safe escape from the launch pad or for the initial phase of ascent. State-of-the-art open ejection seats are also inadequate for high speed or high altitude escape conditions. During a seven (7) year period from 1973 to 1979, the statistics from non-combat ejections of open ejection seats at airspeeds between 400 and 500 keas showed that 57% of the crew members sustained major or fatal injuries. From 500 to 600 KEAS, the major injury and fatality rate was approximately 70% and above 600 KEAS, the probability of major or fatal injury was 100% (Reference 4,p.27). Pressurization is required for protection when ejection occurs above 50,000 feet altitude. Attempts to provide emergency escape capability for high velocity atmospheric aircraft has led to the development of enclosed ejection seat escape systems (B-58) and B-70) and crew escape modules (F-111 and prototype B1). The problems posed by these types of escape systems have been: accelerations imposed on the crew during separation from the aircraft and upon landing impact, increased time to full recovery parachute inflation due to larger recovery parachute systems, weight penalty, and high life cycle costs. Various concepts and techniques for providing escape capability for the crew of space vehicles have been studied in significant detail since before the first United States (U.S.) Manned Space Program, Project Mercury. The reason for the numerous space escape study efforts in the 1960's and 1970's are obvious; practically all aspects of manned space flight were unknown. The United States was "in a hurry" to establish space superiority. And, of course, all space flights were done in view of the entire world. The greatest concern for crew safety in the early space projects was the on-the-pad or launch phase of the mission. The Mercury and Apollo escape systems were for the on-the-pad and early boost phases only (the rocket powered escape towers were jettisoned shortly after launch). Gemini employed ejection seats for the crew, therefore it had a post

* C-7

atmospheric entry escape capability which Mercury and Apollo did not have. Sky Lab astronauts utilized the Gemini-B during launch and atmospheric entry thus they had the same escape capability as the Gemini system. Sky Lab astronauts also had an escape capability in space. They could enter the Gemini-B that was docked to the Lab, separate from the Lab, and subsequently return to earth in the capsule. The Space Shuttle used ejection seats for atmospheric escape capability in early flights, however NASA deactivated the seats when the crew manifest was expanded beyond two individuals. Of the many space escape studies performed in the past, the separable atmospheric entry escape capsule/module seems to have been the most prevalent. The goal in most escape studies was to provide a single escape concept/technique which would provide the crew with escape capability at any phase of the mission. Another escape concept which has received much attention is a non atmospheric entry separable capsule or module, which would separate from a disabled orbiting space vehicle and remain in orbit until recovered in space by another space vehicle. During mission phases other than the orbit phase of such a vehicle the escape system designer relied upon techniques as used on Mercury, Gemini, and others.

DISCUSSION The statement of work (SOW) requires the contractor to postulate single and dual place escape system concepts for contractor defined HVT aerospace vehicles. The selected vehicles are to be representative of the class designed for transatmospheric capabilities which include missions of one to three orbits plus upper atmospheric brakemaneuvering for at least one orbital plane change. The selected hypervelocity vehicles for which the escape systems are to be conceptualized include one that is vertically launched and one that is horizontally launched. Figure 1 shows a range of applicable similarity parameters for the atmospheric entry of the selected vehicles.

SIMILARITY PARAMETERS

FOR ATMOSPHERIC REENTRY

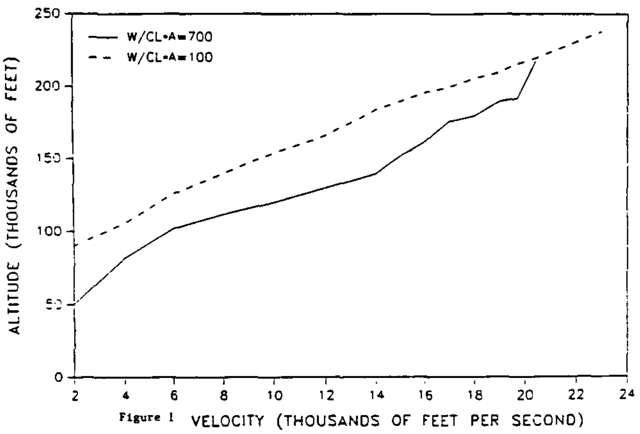


Figure 1

The corridor between W/CL*A = 100 and W/CL*A = 700 (W = Weight, CL = Coefficient of Lift, and A = Reference Area) is representative of the range of flight parameters for HVT aerospace vehicles. The lower value corresponds to a vehicle typical of the NASA Space Shuttle design yielding an entry trajectory that has a higher angle of attack, higher altitude approach, minimum heating, and minimum aerodynamic loading. The higher value represents a vehicle with a maximum Lift-to-Drag ratio (L/D) providing an entry path yielding greater range or crossrange flight capability which is more characteristic of desired military performance in the HVT class vehicles. The vehicles allow for a payload approximately equal to 1% of the total takeoff weight which is estimated to be 1.3 to 1.6 million pounds. The Air Force SOW Task I requires the contractor to postulate escape system concepts to provide for survivable escape and recovery throughout the phases of flight allowed by the selected VLV or HLV performance envelopes; i.e. 1) launch, 2) upper atmospheric hypervelocity flight, 3) orbit, 4) atmospheric entry, 5) terminal approach, and 6) landing. Initially the contractor is to develop basic escape system concepts which provide for crew escape from initial conditions within the selected vehicle's flight performance envelope that result in final crew landing within the continental United States (CONUS) from orbital flight, or anywhere on earth for all other flight conditions. Subsequently, the contractor shall separately consider advanced escape system concepts for each of the selected vehicles. These advanced escape system concepts shall possess sufficient performance capabilities to: 1) allow for recovery within the CONUS for escape initiated from orbit, 2) allow for extended cross range flight for escape initiated during upper atmospheric hypervelocity flight, and 3) allow for immediate recovery anywhere on earth for all other escape conditions. Within these requirements the desired goal of achieving escape system concepts exhibiting minimum weight and minimum volume shall be sought. During Task II the contractor is required to investigate promising technologies in the fields of aerodynamics, thermodynamic protection, propulsion, materials, structures, flight controls, life support and human protection that are necessary to implement the various concepts with maximum escape performance and minimal weight penalty to the overall vehicle performance. The identification of alternative technologies for implementing each fundamental functional requirement as well as the preliminary sizing designs of each alternative technology is required. SOW Task III involves a comparative trade study of the concepts defined in Task I and their associated technologies investigated in Task II to select the best alternative technology to implement each fundamental functional requirement identified in Task I. Volume, cost, weight, risk, compatibility with the gross concept and development requirements are to be used as trade criteria with suitable merit weights selected by the contractor. The contractor shall evaluate performance of the various proposed escape systems throughout the vehicles' operational envelopes with attention to minimal impact to the overall added weight of the vehicle; crew station integration; crew mobility; vision; comfort; ingress and egress in normal and emergency situations; and potential R&D problems. The contractor is to develop FORTRAN IV Extended computational component models of the selected escape concepts compatible with the EASY5 Computer Program. These models are used to compute vehicle accelerations, angular rates, trajectories, and thermal loads for the purpose of evaluating the selected escape concepts in terms of state-of-the-art human protection design criteria with emphasis given to short term (less than one second) and long term acceleration, vibration, thermal energy, and atmospheric pressure. The short term acceleration exposure limits have been specifically developed by the Harry G. Armstrong Aerospace Medical Research Laboratory (Reference 1, Appendix A).

The contractor has selected the designs shown in Figure 2 and Figure 3 for the the HLV and VLV, respectively.

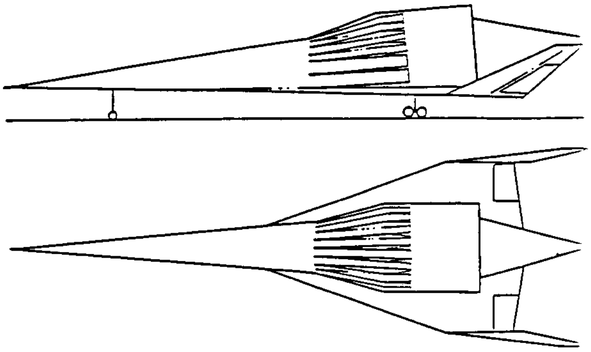


Figure 2 Selected Horizontally-Launched HVT Vehicle Configuration

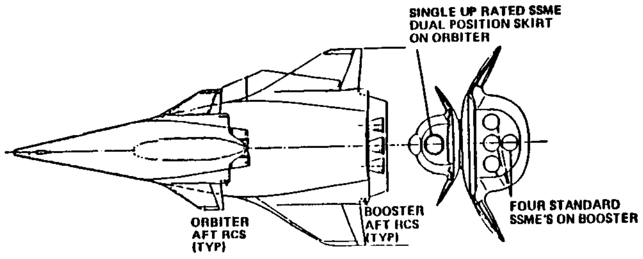


Figure 3 Selected Vertically-Launched HVT Vehicle Configuration

The HLV is a single-stage-to-orbit vehicle which makes extensive use of combined cycle airbreathing propulsion. Its takeoff launch weight is approximately 1.6 million pounds and the design has provisions for a crew of two. The VLV, which is approximately a 1.3 million pound launch weight design, is a two-stage launch vehicle consisting of a single crewmember orbiter and an unmanned booster. For both vehicle configurations, active cooling of critical areas and compartments is required during flight at high Mach number or during atmospheric entry. During launch, the HLV cruise climbs a dynamic pressure launch profile of 1200 lbs/sq.ft. until Mach 12 is reached. At this condition the flight path steepens to gain altitude. Airbreathing propulsion ceases at 200,000 feet (ft) altitude and Mach 25. A transition is made to rocket propulsion to achieve a higher orbital altitude of 100 to 300 nautical miles. For atmospheric hypersonic flight the vehicle will operate between 125,000 and 180,000 feet altitude at Mach 20. The VLV experiences a traditional vertical launch followed by a slight pitchover, a gravity turn, and then a phase which uses pitch to maintain a flight-path angle of zero (0) degrees until the desired velocity is achieved. The maximum dynamic pressure during the ascent is 400 pounds per square foot (psf) which occurs at 40,000 ft and 90 seconds after liftoff. The vehicle reaches 80,000 ft at 125 seconds after liftoff and continues to 300,000 ft in an additional 150 seconds.

The crew escape and protection requirements as specified in the SOW are the applicable military specifications MIL-S-9479B (Reference 6), MIL-C-25969B (Reference 7), and the Air Force Systems Command Design Handbook 1-3, Human Factors Engineering (Reference 8). For brevity only the modifications to these requirements necessary for HVT escape systems will be discussed. The low altitude performance requirements for escape capsules in MIL-C-25969B are essentially the same as required for ejection seats in MIL-C-9479B. Applied to HVT vehicles, the following Table 1 has been proposed by the contractor as the low altitude requirements:

TABLE 1. Low level Escape Performance Requirements for HVT Escape

Cond. No.	Pitch Angle, deg	Roll Angle, deg	Flight Path Angle, deg	Velocity, knots	Altitude Required, feet
1	0	0	0	0	0
2 *	90	0	90	0	0
3	-10	180	-10	250	600

* Applicable to vertically-launched vehicle only. Not applicable to horizontally-launched vehicle.

The HVT escape system range requirements are as previously discussed. Standard explosive hazard design requirements in terms of safe distances as a function of TNT equivalent explosives are utilized. It is noted that the main dangers due to explosion are: shockwave, peak and duration, thermal radiation, shrapnel, and fireball. The contractor has considered a complete array of crew protection requirements which must be satisfied by the designed escape systems to ensure no or minimal injuries to the crewmenbers, i.e. accelerations, angular rates, total pressure, oxygen partial pressure, carbon dioxide, environmental temperature, ionizing radiation, windblast, exposure to shock waves, flashblindness protection, space motion sickness, and waste management. The contractor has initially investigated 16 escape system concepts of various capabilities which exhibited possibilities to satisfy the crew escape and protection requirements for escape during part of the HVT vehicle flight envelopes. These concepts are:

1. Extraction system
2. Open ejection seat
3. Encapsulated seat with thermal protection
4. Separable nose capsule with thermal protection
5. Pod-type capsule with thermal protection
6. Inflatable capsule with reentry capability
7. Paracone with reentry capability
8. Mating with orbiting space rescue station
9. Rocket-pack escape to space rescue station
10. Rocket-pack escape to a reentry rescue capsule
11. Mating with rescue vehicle
12. Non-reentry capsule escape to rescue vehicle
13. Ejection seat with orbital rescue
14. Extraction system with orbital rescue
15. Ejection seat with inflatable re-entry capsule
16. Ejection seat with rocket-pack transfer to rescue capsule

The results of a trade study of the features of these concepts against the desired SOW requirements identified that only the concepts numbered 3 and 5 were determined to be feasible for all phases of flight.

The contractor has conducted detailed design of the candidate escape concepts including definition of the operational escape sequence. The advanced encapsulated seat designs for hypervelocity vehicles is shown in Figure 4, 5, and 6.

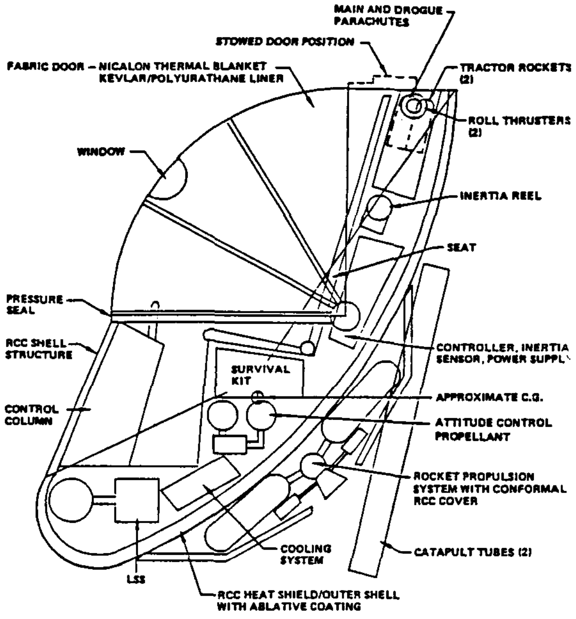
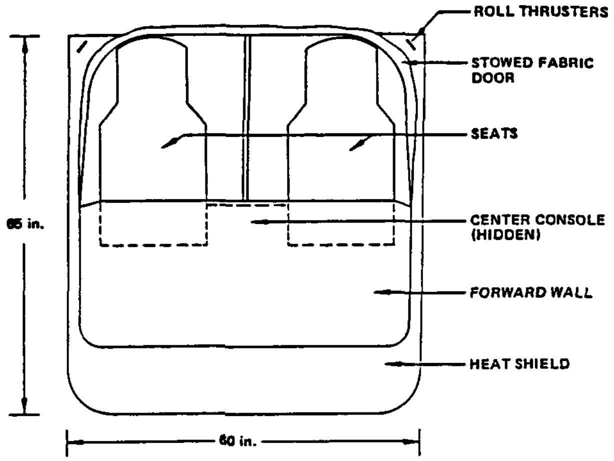


Figure 4 Encapsulated Seat Design for Hypervelocity Vehicles



- SIDE VIEW SIMILAR TO SINGLE PLACE SEAT
- CATAPULT AND PROPULSION MODULE IN REAR

Figure 5 Front View of 2-Place Encapsulated Seat

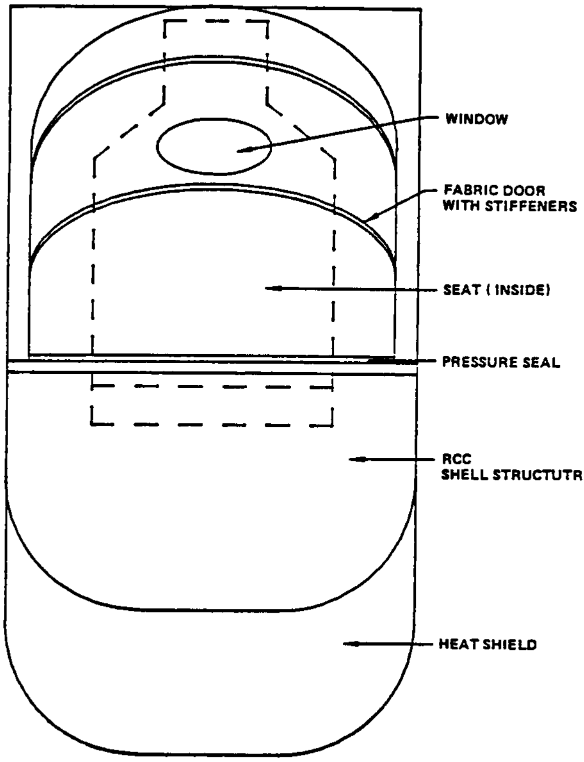


Figure 6 Front View of Single Place Encapsulated Seat

Figure 4 shows basically a modified B-58 ejection seat with doors to shield the crew member from the environment during escape and to provide emergency life support environment. It includes a heat shield, solid-propellant retrorocket engine, reaction control jets, life support system and a control system. A front view of a two place side by side version of the encapsulated seat for the HLV is shown in Figure 5 while a single place version for the VLV is shown in Figure 6. The emergency escape sequence and system operation for the encapsulated seat which follows after a crewmember pulls the ejection handle initiating the digital control sequencer is summarized below (Figure 7):

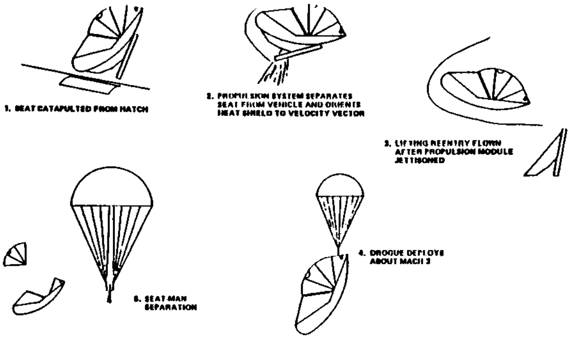


Figure 7 Encapsulated Seat Escape Sequence (Hypersonic/Reentry Flight Phase)

1. Escape condition evaluated based on information from the vehicle data bus and seat-mounted sensors, and life threat assessment conducted (start at 0.010 sec, complete at 0.020 sec after initiation).
2. Thermal batteries initiated (0.010 sec start, 0.050 sec complete).
3. Crewmember haulback devices initiated (0.030 sec start, 0.200 sec complete).
4. Limb capture devices initiated (0.030 sec start, 0.200 sec complete)
5. Close and lock seat door (0.200 sec start, 0.250 sec complete)
6. Initiate seat oxygen and pressurization system (0.200 sec).
7. Jettison ejection hatch (0.200 sec start, 0.300 sec complete)
8. Initiate catapult (0.300 sec)

The following events depend upon the initial flight condition occurring at the time of escape:

Atmospheric Flight below Mach 3 (includes zero altitude/zero airspeed)

9a. Propulsion system ignites after catapult stroke (0.5 seconds)
10a. Deceleration drogue parachute deployed if airspeed is between 300 and 500 KEAS.
11a. Main recovery parachute deployed if airspeed is below 300 KEAS and the altitude is below 15,000 feet altitude. Note: fabric door and drogue are jettisoned.
12a. Restraints severed and crewmember removed with survival kit.
13a. Crewmember makes conventional parachute landing.

Hypersonic flight (including atmospheric entry)

9b. Propulsion system ignites after catapult stroke (0.5 seconds) Seat is positioned with heat shield forward.
10b. Propulsion module is jettisoned (1.5 seconds)
11b. With inertial sensing unit and attitude control thrusters, the seat varies its lift vector orientation to control aerodynamic heating rate and to provide cross range capability (1.5 sec - 20 mins)
12b. After velocity decreases below Mach 3 sequence 10a to 13a occurs.

Orbital flight

9c. Following catapulting from vehicle the seat orbits until appropriate time to deorbit (0.5 sec - 12 hrs)
10c. Attitude thrusters orient seat for deorbit (10 secs)
11c. Propulsion deorbit burn (10 sec)
12c. The heat shield is positioned forward.
13c. Proceed with 10b to 12b.

The single place encapsulated seat, shown in Figure 6, for the VLV varies in the design details of the thickness of ablative coating and attitude control system capability due to the differences in maximum dynamic pressure (400 psf for VLV compared with 2000 psf for HLV) and aerodynamic drag area anticipated. The escape sequencing and operation of the single place VLV encapsulated seat is the same as previously described for the dual place HLV system.

Figures 8 and 9 show Concept 5, the pod-type capsules with thermal protection.

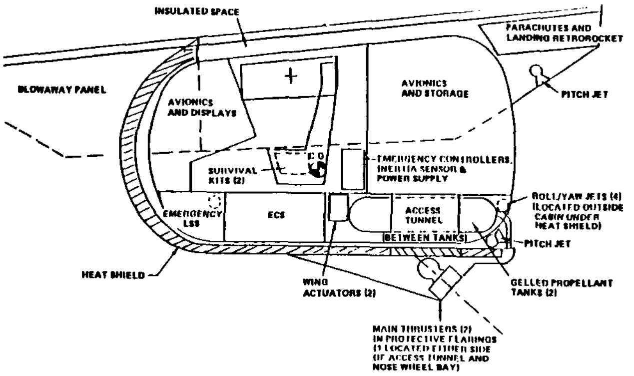


Figure 8. Pod-Type Capsule for Horizontally-Launched Hypervelocity Vehicle

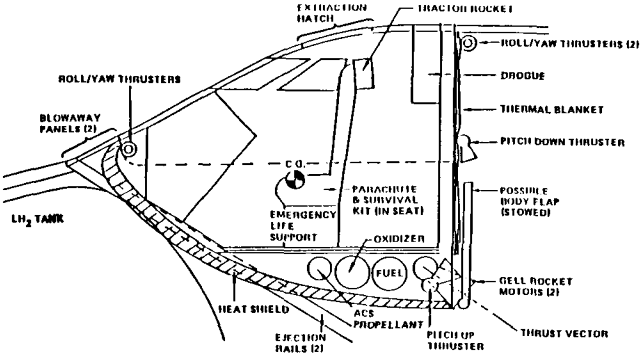


Figure 9. Pod-Type Capsule for Vertically-Launched Hypervelocity Vehicle

These capsules share basic structure with the crew cabin. The figures depict the detailed side views featuring the component subsystems.

The HLV pod capsule utilizes folding wings as shown in Figure 10.

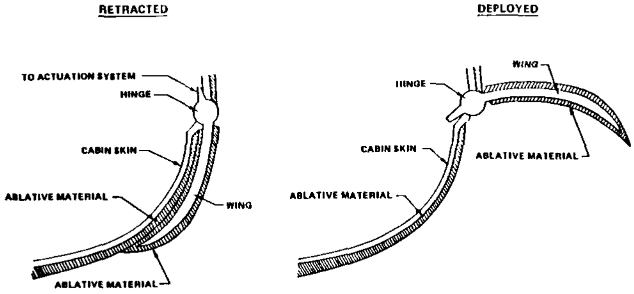


Figure 10. Pod Capsule Wings in Retracted and Deployed Position

These deploy to achieve lift to drag ratio of 2 to 4. This capability coupled with a typical roll maneuver yields a side force for cross range requirements. The escape sequence and operation following initiation is (Figures 11):

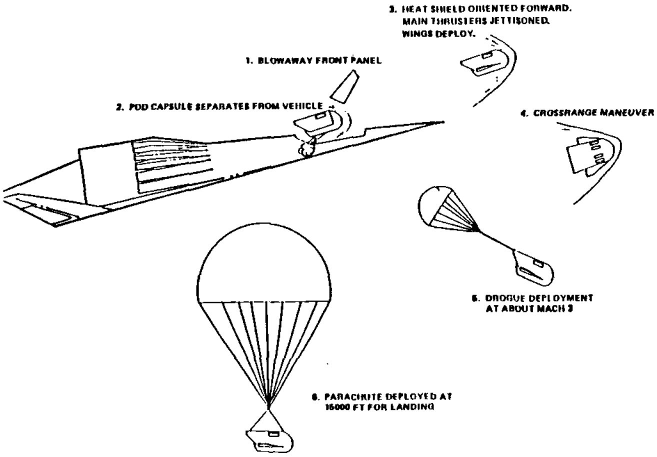


Figure 11 Escape Sequence for HLV Pod Capsule During Upper Atmospheric Escape

1. Initial condition evaluation (0.010 sec start, 0.020 sec complete).
2. Initiate thermal batteries (0.010 sec start, 0.050 sec complete).
3. Initiate crewmember haulback (0.030 sec start, 0.200 sec complete).
4. Initiate oxygen and pressurization (0.030 sec).
5. Severe capsule structure (0.050 sec).
6. Initiate propulsion system (0.2 sec start, 0.4 sec end)

The subsequent sequence depends upon escape initial conditions:

Atmospheric flight below Mach 3

7a. Propulsion system stabilizes flight, steers, and reduces deceleration (0.4 sec start, 1,2 sec end).

8a. Propulsion cut off and drogue deployed. When velocity and altitude are below 300 KEAS and 15,000 feet, or during low speed low altitude escapes the recovery parachute is deployed.

9a. Retrorockets attenuate ground impact.

Hypersonic flight (including atmospheric entry)

7b. Propulsion continues for thrust, stabilization,deceleration, and rolling (0.4 - 1.2 sec)

8b. Wings deployed and main nozzles jettisoned (0.4)

9b. Pod attitude control used to orient lift vector for the desired deceleration and cross range (up to 20 min).

Orbital Flight

7c. Pod remains in orbit until appropriate time to deorbit (0.5 sec. - 12 hrs)

8c. Thrusters orient pod for deorbit (10 sec).

9c. Deorbit maneuvers (2.0 sec)

10c. Thrusters reorient pod for heat shield positioning.

11c. Follow sequence 7b to 10b.

Figure 9 shows the pod-type capsule as designed for the VLV. The figure illustrates the location of various subsystems and components. This pod capsule design is considered a hybrid system in that it utilizes a rocket extraction system to remove the crewmembers for final recovery under personal parachutes. The escape sequence and operation following initiation is (Figure 12):

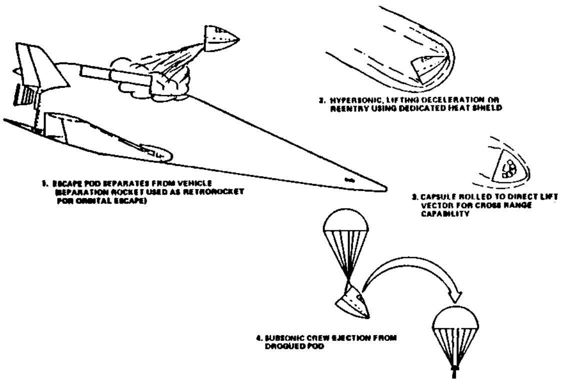


Figure 12 Recovery Sequence Diagram for Vertically-Launched Vehicle Capsule

1. Initial conditions evaluated (0.010 sec start, 0.020 sec complete).
2. Thermal batteries initiated (0.010 sec start, 0.050 sec complete).
3. Crewmember haulback (0.030 sec start, 0.200 sec complete)
4. Initate oxygen and pressurization (0.03 sec).
5. Severe capsule structure (0.050 sec)
6. Propulsion initiation (0.2 sec start, 0.4 sec complete)

The subsequent sequence depends upon escape initial conditions:

Atmospheric flight below Mach 3.

7a. Propulsion system continues (0.4 sec start, 1.2 sec complete).
8a. Drogue deployed except at low altitude the extraction of crew occurs immediately. Below 300 KEAS and 15,000 feet altitude the ejection hatch blows.
9a. Extraction tractor rocket for each crewmember fires.
10a. Crewmembers make conventional parachute landing.

Hypersonic flight including atmospheric entry.

7b. Propulsion system continues (0.4 sec start, 1.2 sec complete).
8b. Pod lift vector controlled for desired deceleration profile and cross range (up to 20 minutes).
9b. Below Mach 3 follow 8a through 10a.

Orbital flights

7c. Pod remains in orbit until appropriate time for deorbit maneuver (0.5 sec - 12 hours).
8c. Thrusters orient pod for deorbit (10 sec).
9c. Deorbit burn (2.0 sec)
10c. Thrusters reorient pod for forward-facing heat shield position.
11c. Follow sequence 7b through 9b.

During Task II, the contractor investigated emerging technologies in the structures, materials, thermal protection, propulsion, aerodynamics, flight controls, sensors, crew station integration, and life support to the extent that the selected escape concepts could be developed within minimum weight and volume constraints yet be capable of meeting SOW requirements. The results of Task II is presented as a weight summary in Table 2.

Table 2. Weight Summary

Concept	Weight (lbs)
Dual Encapsulated Seat	1741
Single Encapsulated Seat	1055
HLV Pod Capsule	5576
VLV Pod Capsule	2972

CONCLUSIONS Conceptual designs of escape systems for hypervelocity technology class aerospace vehicles have been identified with state-of-the-art or near term state-of-the-art enabling technologies. The initial weight estimates for the selected subsystem components provide sufficient confidence for further development of the concepts. The development of computer models of the selected concepts for performance studies is being pursued by the contractor as a part of Task III. Additionally, a detailed study of the escape system weights compared to necessary common structural weights of the airframe crew station will be performed to identify the actual escape system weight penalty to the HLV and VLV.

REFERENCES

1. Statement of Work, "Hypervelocity Technology Escape System Concepts," USAF Contract No. F33615-86-C-3410, February 1986.

2. Evers, John E., CIMS CADC IIc User's Guide, Computer Intergrated Manufacturing Systems (CIMS), 20859 Old Spanish Trail, New Orleans, LA, 70129.

3. West, Christopher L., Brian R. Ummel, Roger F. Yurczyk, Analysis of Ejection Seat Stability Using Easy Program (EASIEST), AFWAL-TR-80-3014, Vol. I and II., September 1980.

4. White, B.J., USAF Crew Escape State-of-The-Art Requirements For Technology Advancement, AFWAL-TR-82-3089, December 1982.

5. Interim Technical Report For Hypervelocity Technology Escape System Concepts, Boeing Military Airplane Company, Seattle, Washington, USAF Contract No. F33615-86-C-3410, May 1987.

6. MIL-S-9479B (USAF), General Specification for Seat System, Upward Ejection, Aircraft, March 1971.

7. MIL-C-25969B (USAF), General Requirements for Capsule Emergency Escape Systems, March 1970.

8. AFSC Design Handbook, Series 1-0 General - Design Handbook DH 1-3 Human Engineering, Volumes 1 and 2, ASD/ENESS, WPAFB, OH, January 1977.