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ORBITER EMERGENCY CREW ESCAPE SYSTEM

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SUMMARY

Two conventional ejection seats have been incorporated into the first two Orbiter vehicles to provide the crew with emergency ejection capability during the flight test programs. To avoid extensive development and test costs, existing ejection seats were selected and minimum modifications were made to accommodate the Orbiter application. The new components and modifications were qualified at the component level, and a minimum sled test program was conducted to verify the Orbiter installation and validate the six-degree-of-freedom analysis. The system performance was certified and the orbital flight test capability was established by analysis.

INTRODUCTION

The Orbiter incorporates an "intact abort" philosophy. Problems during launch that compromise the mission success or safety will result in termination of the normal flight plan and return of the Orbiter to the launch site runway or another designated contingency runway. The Orbiter is a high-technology aircraft operating in a range of extreme environments and will have a crew of only two for the first few flights. Therefore, it is prudent and practical to incorporate an individual emergency crew escape capability to protect against those problems or failures that might render the Orbiter incapable of landing safely on a runway.

Originally, ejection seats were added to the first Orbiter vehicle to provide escape capability only for the horizontal flight test program. Off-the-shelf ejection seats were to be used; however, before their selection, it was decided to provide escape capability for portions of the orbital flight test program to be conducted with the second Orbiter. The ejection seats will primarily enhance crew safety during the first demonstrations of launch and landing. Following the orbital flight test programs, the seats will be replaced with operational seats similar to those in commercial air transport vehicles.

The orbital flight test requirement led to the selection of the ejection seat used in the SR 71 aircraft because of its demonstrated high-altitude capability. This ejection seat had been qualified for velocities of 230 m/sec (450 knots equivalent air speed) for the Air Force application and had demonstrated ejection capability at speeds greater than Mach 3 at an altitude of 24 kilometers (78 000 feet). These capabilities exceed the orbital flight test environments for ascent and reentry below approximately 30.5 kilometers (100 000 feet). Early centrifuge tests proved the crewman must be positioned in a tilted-forward attitude during ascent to reach and see all the required controls and displays; however, during ejection, physiological limits require the seat to be in the normal aft position. Although the selected seats would provide escape capability for the horizontal flight test and the entry portions of the orbital flight test programs, the results from the centrifuge test necessitated the addition of a back-angle device to support launch and ascent. Orbiter flammability and toxicity requirements also necessitated a few material changes.

The ejection seat had been qualified to Air Force requirements and installed in their aircraft for some time. The Air Force qualification of the basic seat was accepted as satisfactory for the Orbiter application. The energy transfer and sequencing system and the modifications to the ejection seats were each qualified at the component level and in breadboard tests. Finally, the complete system operation was verified and the six-degree-of-freedom (DOF) analysis program was validated during a minimum sled test program. The crew escape system was then certified by evaluation of the results of the six-DOF analysis. Likewise, system performance under adverse conditions and during ascent was established using this analysis.

SYSTEM DESCRIPTION

Since the Orbiter was not designed specifically to accommodate ejection seats, several unique features had to be incorporated to facilitate the Crew Escape System installation (fig. 1). A structure was added between the floor and the ceiling of the inner crew station to support the ejection rails. Both the inner structure and the outer skin must be severed, without injuring the crew, and then thrust clear before the seats are ejected. To allow ejection at higher altitudes, an Air Force-type pressure suit was included for the orbital flight tests and the supporting ventilation and oxygen supply was incorporated into the Orbiter.

The Orbiter Crew Escape System consists of ejection seats; the ejection escape suit; guide rails and support structures; the escape-panel severance and jettison system; and the energy transfer and sequencing system. Operation of the escape system is accomplished through state-of-the-art pyrotechnic devices, many of which are off the shelf or only slightly modified for the Orbiter application. The pre-ejection functions of crew positioning (including the back-angle change) and restraint and the post-ejection functions of drogue deployment, seat/man separation, and main parachute deployment are accomplished through a self-contained gas-operated pyrotechnic system. The energy transfer and sequencing system controls the ejection from the Orbiter and consists of shielded mild detonating cord (SMDC), confined detonating cord (CDC) initiators, time delays, inner and outer panel severance systems, thrusters, safe and arm sequencers, and gas generators. A schematic of the Crew Escape System is shown in figure 2.

Ejection Seat

A conventional ejection seat from the SR 71 aircraft was procured off the shelf for use in the Orbiter. This system includes the rocket catapult, seat adjustment actuator, survival kit container, crew restraint, stabilization drogue parachute, recovery parachute, and Orbiter interface components. To accommodate the unique application in the Orbiter of launching in the vertical position, remaining in orbital flight for some time, and then gliding to a more or less conventional landing, the ejection seat had to satisfy the requirements for positioning of the crew while fitting in a limited space in the Orbiter. These requirements, together with considerations of material flammability and toxicity for spacecraft applications, necessitated the following changes to the basic ejection seat.

1. A two-position seat-back subsystem was added to provide a crewman back angle of 2° forward of vertical (X_O axis) for launch to improve reach and vision. The seat back was mechanized to return to the aft position automatically before ejection or manually for the on-orbit and approach-and-landing mission phases.

2. The ejection seat vertical adjustment was changed to be compatible with Orbiter physical and anthropometric requirements.

3. The cushions were revised to improve comfort and positioning during prelaunch and launch but still satisfy ejection safety requirements.

4. Material changes were made and shielding was added to meet Orbiter fire protection requirements.

5. Parachute holddown straps and survival kit forward-edge holddown clips were added to reduce upward movement of the seat occupant during the prelaunch and launch phases.

6. The timing of the seat drogue deployment and of seat/man separation was changed to improve stabilization and seat/man separation trajectories.

7. Oil damping was added to the crew positioning inertial reel to reduce acceleration during repositioning.

8. To improve ascent survivability, the aneroids were changed to initiate the low-altitude mode below 3 kilometers (10 000 feet) rather than at 4.5 kilometers (15 000 feet).

A survival kit, packaged in a fiberglass box assembly, is installed in the ejection seat pan. The survival kit contains an emergency supply of breathing oxygen in the back compartment and worldwide survival equipment in the front compartment.

The Orbiter ejection seat has two modes of operation that are automatically selected by the aneroids depending on altitude. If ejection occurs below 3 kilometers (10 000 feet), seat/man separation and main parachute deployment occur immediately after separation from the Orbiter. If ejection occurs above 3 kilometers (10 000 feet), seat/man separation is inhibited and the crewman descends on a drogue parachute to 3 kilometers (10 000 feet) altitude, at which time separation occurs and the main parachute deploys. The sequence of events during ejection is shown in table I. For emergency ground egress, either the flight crew or the ground crew can jettison the escape panels without ejecting the seats.

The salient features of the Orbiter ejection seat are shown in figure 3.

Ejection Escape Suit

The ejection escape suit (EES) is a modified off-the-shelf Air Force full-pressure suit. The Air Force unit has been modified by adding medical monitoring of the crewman and anti-g protection for the entry phase of the orbital flight test program.

The EES (fig. 4) consists of a torso assembly, separable helmet, gloves, retainer assembly, urine collection system, anti-g protection, and biomedical monitoring. The suit has separate breathing and ventilation gas inlets, each with independent plumbing and ducting systems. When the helmet visor is down, a dual demand breathing regulator supplies breathing oxygen to the helmet face area, which is separated from the rest of the suit assembly by the face barrier. Ventilation air is supplied to the torso assembly for body cooling during pressurized cabin flight. The differential pressure is controlled by a valve that regulates the exhaust of the ventilation air from the EES. This valve also controls the pressure after ejection, and makeup pressure for the exhausted air comes from the oxygen that escapes from the face area barrier into the torso assembly.

Suit ventilation system.- Two ventilator assemblies, each including a compressor, the associated electronics, and a check valve, are enclosed in a housing located immediately behind each ejection seat. Conditioned air is pulled from the environmental control life-support system duct and discharged from each compressor into a common manifold assembly. Two manifold discharge ports are each connected to a plenum located under each ejection seat. Each plenum in turn is connected to the pressure suit by a flexible hose that supplies the ventilation air. The air flows through the suit to provide body cooling and then is returned to the cabin atmosphere. Either ventilator assembly can provide adquate cooling for the crew.

Regulated oxygen system.- The regulated oxygen system uses a dual oxygen regulator to convert the 5860-kN/m^2 (850 psi) oxygen to the 414- to 620-kN/m^2 (60 to 90 psi) oxygen required for the pressure suit and the anti-g suit. The regulator assembly also has an 862-kN/m^2 (125 psig) relief valve downflow from the regulator. The regulated oxygen is delivered to manifolds located on the right side of the rail support structure and then through the survival kit to the EES.

Guide Rails and Support Structures

Since the Orbiter is primarily designed to operate similarly to a commercial air transport with four crewmembers on the flight deck, the flight deck area is open and there is no bulkhead on which to mount the ejection seat guide rails in the conventional manner. Therefore, a special support structure with integral guide rails (fig. 5) was incorporated to provide ejection seat support during normal operations and guidance during ejection. This structure also transmits both the normal flight loads and the loads from the panel jettison and ejection into the Orbiter structure. Components from the pyrotechnic system, the interface wire harness for seat adjustment power, communications, biomedical monitoring, the oxygen system manifold, suit ventilation system blowers, and ducting are also mounted on this structure.

Escape Panel Severance and Jettison

The outer structure of the Orbiter is designed to carry flight loads; it also provides a mounting surface for the thermal protection system tiles. The pressure vessel that provides the habitable workspace and living area for the crew is supported within the outer structure of the Orbiter. This arrangement does not provide the normal canopy or hatch arrangements to facilitate emergency ground egress or ejection. Therefore, a panel severance and jettison system was incorporated to cut openings in the surfaces above each seat and thrust the panels clear of the Orbiter during emergency procedures. The escape panels are shown in figure 6.

The outer structure is severed by mild detonating fuse (MDF) as is done in numerous other aircraft and spacecraft applications. The MDF system severs the panel primarily by shock effects. To protect the crew from dangerous hot gases and debris, the inner structure is severed by an expanding tube assembly (XTA). The XTA consists of one strand of MDF encased in lead and inserted in a stainless steel tube. The assembly is flattened and fitted to the structure around each inner panel, and the voids around the XTA are filled with silicone rubber. Upon firing, the tube expands and severs the panel from the crew module structure in a prescribed section around each panel. The XTA is retained in the support structure by stainless steel straps that do not inhibit its expansion.

As the panels are severed, thrusters mounted between each seat support structure and the inner panels provide propulsion for jettison of the panels. Both cabin pressure and aerodynamic forces assist panel jettison under some conditions. The energy applied to the inner panels by the thrusters is transmitted to the outer panels through a system of attenuator pads and cable attenuators as shown in figure 6. The expended thruster barrel is removed from the ejection path by the thruster retractor and guillotines sever the panel-to-Orbiter wire harnesses. The escape panels are automatically jettisoned during ejection but can be manually jettisoned from the center console or the lower right side of the Orbiter for emergency ground egress.

Energy Transfer and Sequencing System

The energy transfer and sequencing system controls the sequencing and initiation of each element of the Crew Escape System. The initiation signal is transmitted to the various elements by the energy transfer system, which uses SMDC between fixed paths and CDC between elements requiring relative motion. Both the SMDC and the CDC use MDF for transmission of the initiation signal. Since the ejection seat incorporates a hot-gas system, initiators and hot-gas generators are used to transmit the signal to and from the seat system. Through-bulkhead initiators transmit the signal between the pressurized and unpressurized compartments, and one-way transfer devices prevent the initiation of the ejection seat when the escape panels are jettisoned with either of the manual controls.

The energy transfer system provides the initiation signals to the Crew Escape System elements so fast that several of the operations cannot be completed without additional time delays. One-half-second delay initiators are included to delay the ejection of the right seat to allow time for the jettisoned panels to clear; another is included to delay the ejection of the left seat to avoid collision with the right seat. Safe and arm sequencing devices are provided to ensure that the escape panels have been jettisoned before the actuation of the ejection seats. These sequences require a pyrotechnic input from the energy transfer system and a mechanical signal from the rotating inner panel before the initiation signal is transmitted to the ejection seat propulsion system.

TEST PROGRAM

To reduce development costs, maximum utilization of off-the-shelf components was made throughout the Crew Escape System. Where necessary, existing items were modified to meet the Orbiter requirements; only as a last resort were new items developed. For example, the basic ejection seat is used in the SR 71 aircraft and the one-way transfer device is used in the F-14 aircraft, but the inner panel XTA severance system was developed for the Orbiter. Maximum use of previous test data and qualification test experience was made in the certification of the Orbiter Crew Escape System. The new hardware and the modified existing hardware were first qualified at the component level and then portions of the system were operated in breadboard tests. Finally, the installation of the system was verified in a minimum sled test program.

The ejection seats, rail support structures, overhead panel structures, and energy transfer and sequencing system were installed in a sled vehicle that simulated the Orbiter crew module. The system was then realistically tested throughout the Orbiter velocity range. The sled test program consisted of the following tests.

1. Two panel-jettison tests using previously severed panels

2. One panel severance and jettison test

3. One dual-ejection test with a complete system at zero velocity

4. Four dynamic tests at various velocities throughout the flight envelope (two complete dual-ejection tests and two single-ejection tests)

The sled test program verified the installation and operation of the Crew Escape System in the Orbiter. The six-DOF analysis developed to predict system performance was updated during the sled test program such that it gave excellent correlation between the predicted and actual system performance. As a result, the six-DOF analysis was validated during this program.

PERFORMANCE

The capabilities of the Crew Escape System during each phase of the orbital flight test program were established using the six-DOF analysis. During ascent, the plumes from the Space Shuttle main engines (SSME) and the solid rocket booster engines and reasonable deviation of the Orbiter from its nominal trajectory in pitch, roll, and yaw were considered. Based on this analysis, the system will provide escape capability from approximately 3 seconds after launch to about 3.7 kilometers (12 000 feet) altitude. From approximately 3.7 to 9 kilometers (12 000 to 30 000 feet), the crew will intersect the SSME plumes at a location where the temperature and/or dynamic pressure exceed human limits. From approximately 9 to 30.5 kilometers (30 000 to 100 000 feet), the crew will pass through the plumes at a location where the environment is acceptable. During descent, escape capability exists from approximately 30.5 kilometers (100 000 feet) through landing and rollout. The estimated and demonstrated ejection seat capabilities for the orbital flight test ascent and reentry conditions are shown in figure 7.

This analysis considered adverse Orbiter body rates about a nominal trajectory but did not consider such factors as the actual body rate resulting from anomalies, vehicle breakup and explosion, or engine-out conditions. When anomalous vehicle performance is considered, the performance capabilities will change.

CONCLUDING REMARKS

The Orbiter Crew Escape System, initially installed to provide escape capability during horizontal flight, has made maximum use of existing components and prior qualification programs. The system has been qualified at the component level and verified at the system level, and the analysis has been validated. The analysis indicates that the system also offers substantial escape system capabilities during portions of the ascent phase and of the descent and landing phases during the orbital flight program.

TABLE I.- ESCAPE SYSTEM SEQUENCE[a]

Time from initiation, sec	Sequence of events below 3 km (10 000 ft)	Sequence of events above 3 km (10 000 ft)
0.0	D-ring pulled, escape panels jettison, shoulder harness reel and foot actuators retract, back positioner retracts,[b] faceplate heater activated	Same
0.5	Sequencers ignite the catapult	Same
0.7	Drogue gun deploys drogue parachute	Same
0.95	Drogue parachute full open	Same
1.2	Rocket burns out	Same
1.5	Separation occurs; lap belt releases; shoulder straps, foot cables, and D-ring cable cut; separator actuates	Separation initiator armed but blocked by aneroid device
1.8	Upper drogue parachute risers cut	
2.1	Drogue gun deploys main parachute	
3.6	Main parachute full open	
11.5	Lower drogue parachute risers cut	Lower drogue parachute risers cut Aneroid unblocks, initiating complete separation sequence, deploying main parachute 0.6 sec later and cutting upper drogue parachute risers after 0.3 sec

[a] The sequence shown is for the right seat; the sequence for the left seat is the same except there is an 0.5-sec time delay before the sequencers ignite the catapult.

[b] During launch only; already retracted during reentry.

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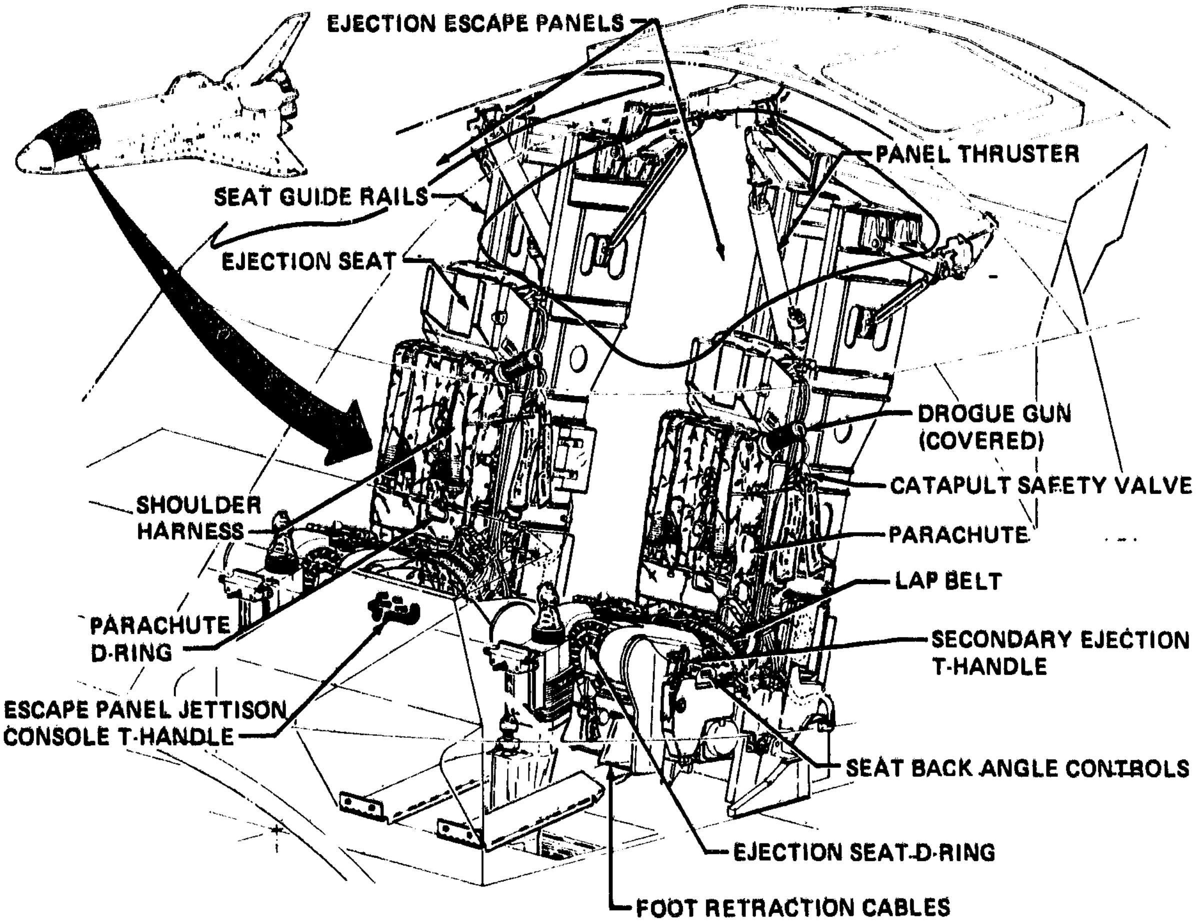


Figure 1.- General arrangement of the Crew Escape System.

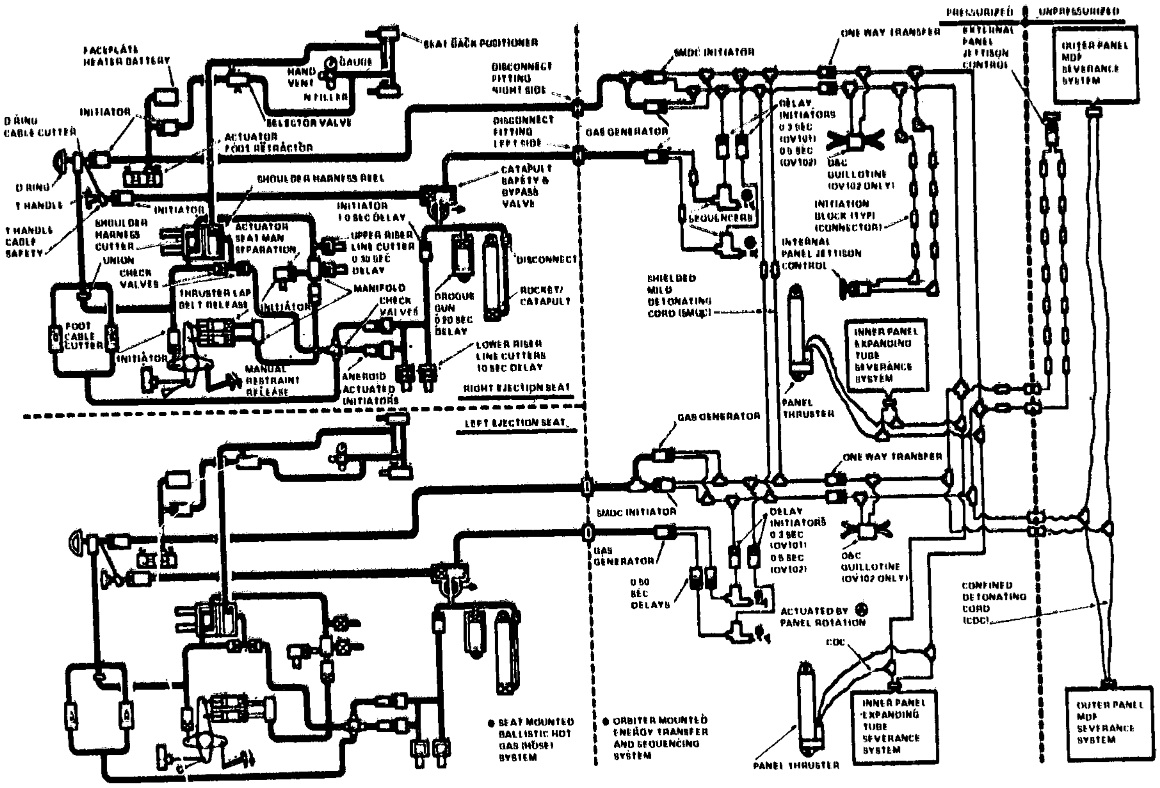


Figure 2.- Crew Escape System schematic.

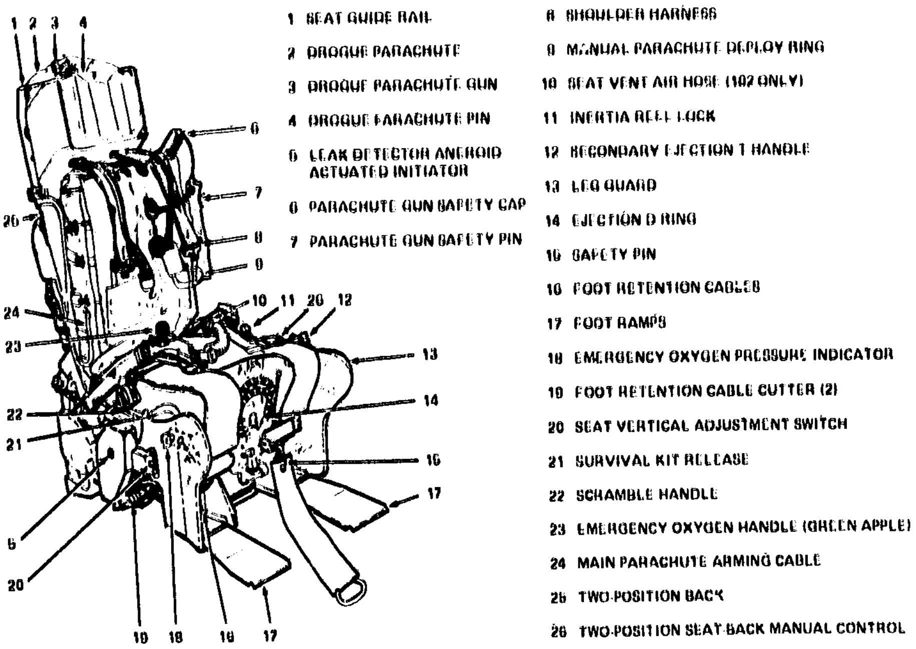


Figure 3.- Orbiter ejection seat.

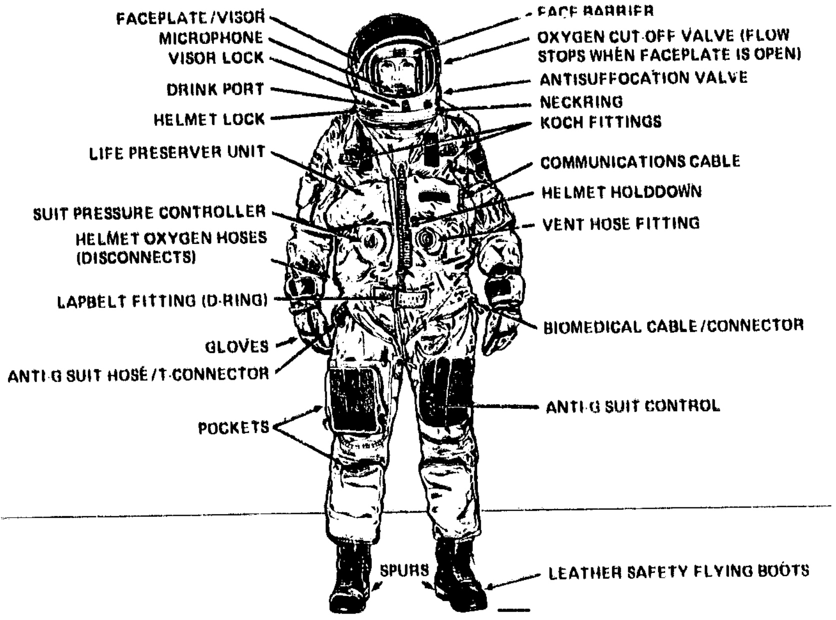
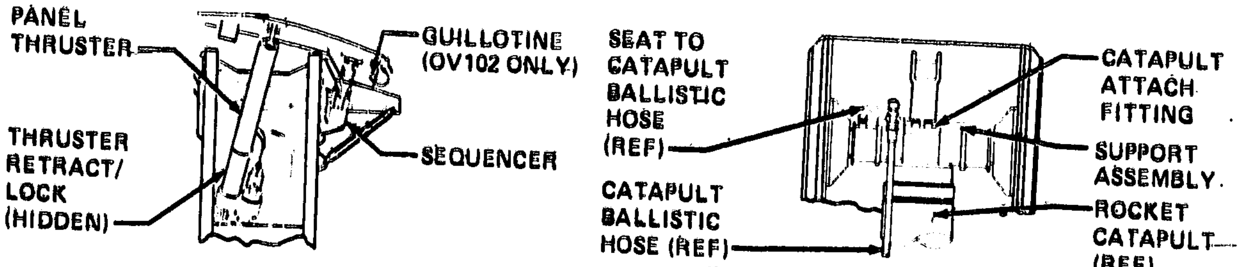
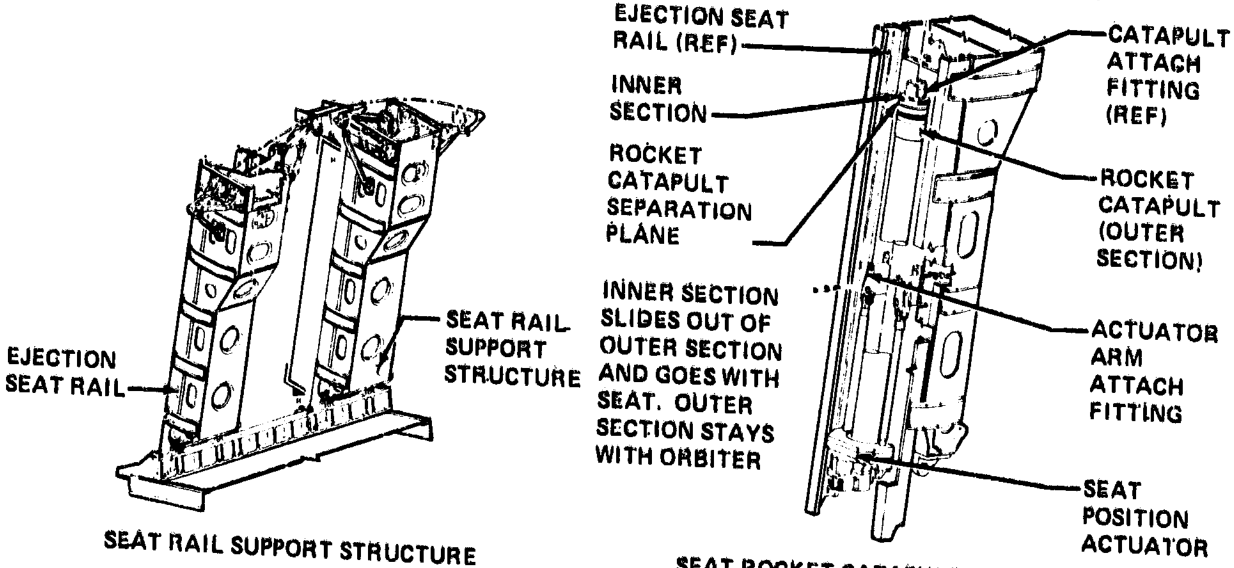


Figure 4.- Ejection escape suit (modified Air Force pressure suit).



ESCAPE PANEL THRUSTER INSTALLATION

ROCKET CATAPULT/SEAT INTERFACE - (DROGUE PARACHUTE BRIDLE AND COVER OMITTED FOR CLARITY)



SEAT RAIL SUPPORT STRUCTURE

SEAT ROCKET-CATAPULT INSTALLATION

Figure 5.- Guide rails and support structure.

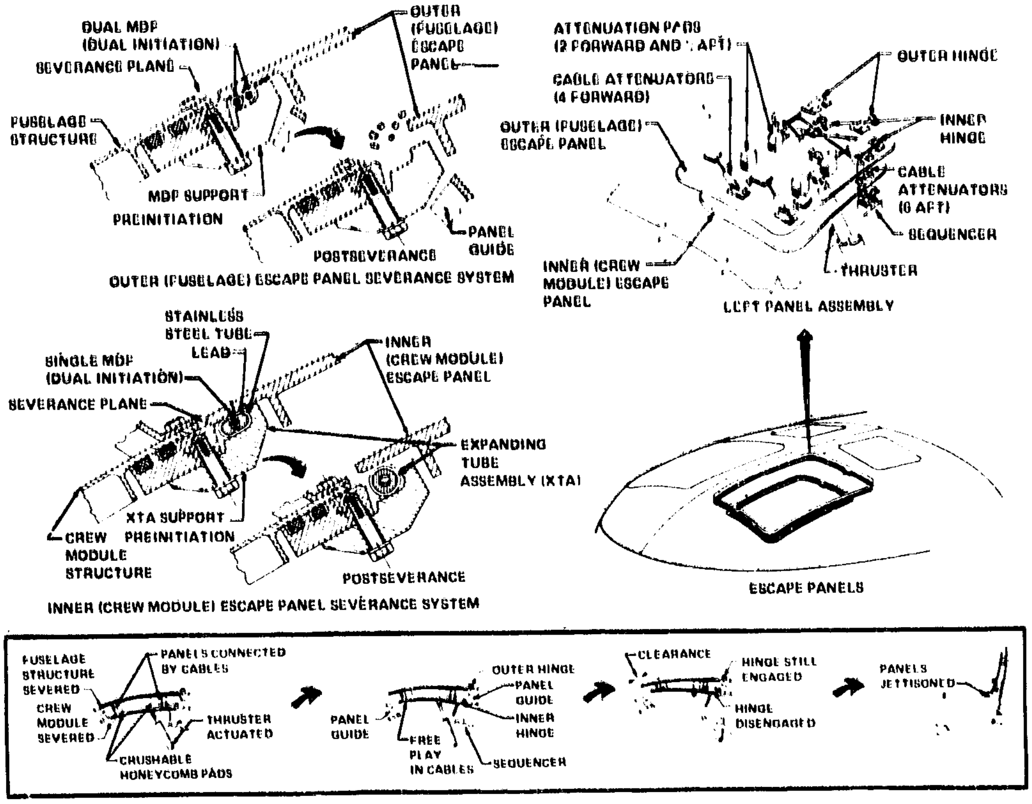


Figure 6.- Escape panel severance and jettison system.

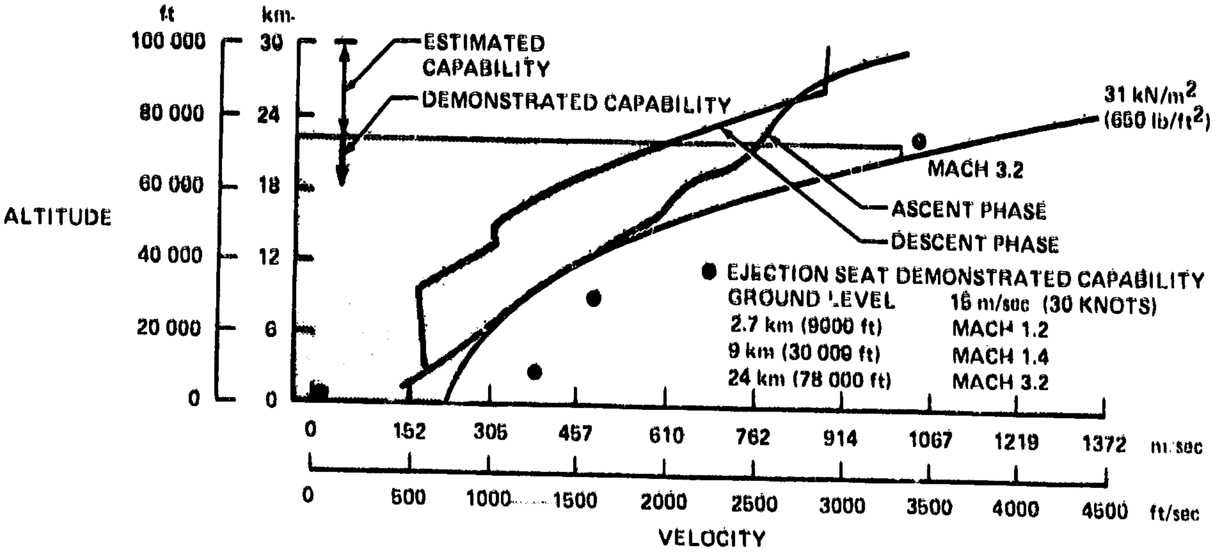


Figure 7.- Ejection seat capability.