MOSES (Manned Orbital Space Escape System)—A Hypothetical Application

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Extensive experience acquired over more than 20 years in the design and operation of unmanned recoverable satellite vehicles is directly applicable for the economical development of escape systems for a variety of present and planned manned orbital programs. The manned orbital space escape system (MOSES) described herein is a direct outgrowth of these unmanned vehicles. It employs a thoroughly flight-proven aerodynamic configuration, a currently operational heat protection system for vehicles of this type, and functional procedures which have resulted in outstanding reliability over hundreds of successful flights and recoveries. As a media for illustrating the significant physical and operational aspects of integrating the MOSES into a primary manned orbital system, a hypothetical application to an early space operations center configuration is defined and discussed.

Introduction

INITIAL introduction of the concept of a manned orbital space escape system (MOSES) at a 1979 AIAA/NASA conference[1] presented a basic vehicle design and rationale but lacked focus in the specifics of a system application. Since the interface requirements imposed by a particular orbital system will significantly dictate the physical and functional characteristics of the escape vehicle, the specifics of this interrelationship should be understood in considering a particular application. To best illustrate this influence a hypothetical application of the MOSES concept to an early version of the space operations center (SOC) is developed and described here.

As a long-duration, low-Earth-orbit space station with an eight-man crew, this SOC configuration is representative of low-orbit systems now under consideration and provides an ideal application for a case study. Further, it has been sufficiently defined in published NASA documentation[2,3] to allow realistic interfacing on a physical and operation level.

Background, Rationale, and Philosophy

Systems and techniques for retrieving payloads from orbit were first developed over 20 years ago and have been progressively improved since then. Hundreds of flights and successful recoveries have been achieved with improvements in reliability and accuracy carried to a point of 100% success over the past decade with dispersion errors reduced to a fraction of the 3 σ limits initially considered acceptable. While manned programs have received the most attention in this area, unmanned satellite recovery vehicles (SRV) have, in fact, accumulated the overwhelming bulk of flight experience.

From the standpoint of simplicity, reliability, and low cost felt to be mandatory for an escape system, it is this extensive SRV background that is most applicable. A representative 33 in. diam SRV is shown in Fig. 1. A somewhat larger unit (40 in.) was flown (circa 1968-70) as BIOS in the recoverable orbital laboratory series which included a fully autonomous attitude control system for retrofire alignment.

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The MOSES concept was developed as a single-function, short-duration device, which must achieve high reliability through simplicity and exhibit a cost significantly below that of a primary space system. Consequently, it employs an enlarged version of a thoroughly proven SRV configuration with minimum added accommodations for a passive human payload and maximum use of proven SRV functions.

The basic technology required to develop such a system has been fully established and demonstrated. The major engineering challenge lies in its adaptation for use with a specific orbital system and avoidance of the natural inclination to overcomplicate a basically simple device. To this end the design philosophy originally proposed is repeated here:

1) The vehicle is not a conventional spacecraft but an escape device similar in nature and function to the many SRVs flown. As such, it should retain their simplicity of design and function and employ their proven components and procedures wherever possible.

2) An escape capsule is a short-lived device with a total operational life of a few hours of which the entry phase takes little more than 30 min. The design should reflect this fact to its advantage.

3) As an escape system, all considerations of crew safety or danger to ground facilities and populace should defer to the emergency nature of its function, wherein risks found acceptable for similar devices such as aircraft escape systems should likewise be tolerable in space escape.

4) Rescue of man is the over-riding system objective. Design accommodation should be made to accomplish this reliability. Comfort and well-being are not mandatory and excessive design compromises to serve these secondary needs must be avoided.

5) Vehicle simplicity demands minimum integral life support. Every possible use should be made of the EVA-type gear already developed with self-contained life support systems.

Basic Vehicle Discussion

The generic satellite recovery vehicle, which is recommended as the configuration base for MOSES, is shown as an exploded isometric in Fig. 2. Its inherent simplicity is compatible with the limited function and short period of operation required of these vehicles. The sphere/cone shape employed is fully characterized through extensive flight experience, and has proved to be well behaved and insensitive to disturbances common to deorbit and low-angle re-entry. It also lends itself well to human payload accommodation, mounting, and crew access. A number of other configurations may ultimately contend for application in this area. For example, when controllable lifting bodies have reached an equivalent level of development, they may offer greater mission flexibility and versatility. From the standpoint of simplicity, low cost, and near-term availability, however, the economy of dealing with a "known quantity" favors employing the proven SRV configuration and concentrating effort on problems of application.

Thus, the vehicle presented is basically a scaled-up SRV with provisions for a human payload and autonomous deorbit capability. Life support is assumed integral with the escape suits worn by the individuals entering the capsule.

In total, the generic MOSES vehicle consists of the following major elements:

1) The basic recoverable capsule including crew accommodations such as contoured couches and retention harness, an ingress hatch, power supply, communication equipment, etc., and supplemental consumables (if desired).

2) A retardation system consisting of a parachute with associated drogue, refining, and deployment devices.

3) The re-entry heat shield comprised of an elastomeric ablative material (ESM) bonded to a structural substrate with provisions for mechanical attachment external to the recoverable capsule and accommodation for pyrotechnic separation. The heat shield would also include a covering of similar material over the aft face of the vehicle and any protrusions in the area.

4) The deorbit module which accommodates all sensing, command, and processing equipment, attitude control plumbing and tankage, and the retrorocket subsystem. Concentrated in an annual ring mounted on the aft face of the re-entry vehicle, it is pyrotechnically separated following the retro fire sequence and prior to re-entry.

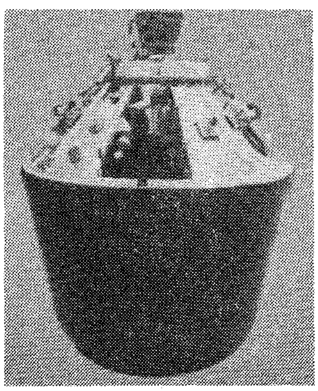
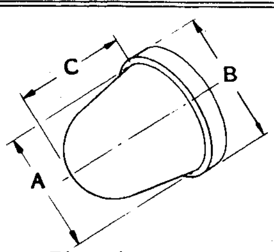


Fig. 1 Satellite recovery vehicle, 33 in. base diameter.

Table 1 Basic MOSES configuration size and weight



No. of men	Dimensions, cm A	B	C	Gross weight, kg
1	165	175	135	513
2	183	193	150	900
3	216	216	175	1180
4	254	254	208	1406

Relative overall dimensions and gross weights are provided for one-, two-, three-, and four-man systems in Table 1. Within reason larger systems appear feasible but will be limited, in the near term, to a size which can be conveniently transported to orbit in the Shuttle.

SOC/MOSES Configuration

A four-man capacity MOSES vehicle specifically configured for a SOC-type application is presented in Fig. 3 with an accompanying weight breakdown provided in Table 2. Tangential seating around a central console provides a relatively compact crew arrangement without the need to fold back equipment for ingress. It allows semiprone crew positioning for good g tolerance and conforms ideally to the proven SRV shape. For crew ingress, the top of the console also provides a convenient step for entering the vehicle.

Functionally, there is a strong family resemblance to the basic unmanned SRV in Fig. 1, and all major subsystems can trace their lineage to thoroughly flight-proven equivalents used on unmanned SRVs.

Thermal Protection

The thermal protection subsystem consists of a layer of elastomeric ablative material covering all surface areas exposed to re-entry heating. The main heat shield is bonded to a metallic substrate to makeup a forebody which is separated and discarded after re-entry. A similar layer of shielding material protects the back end of the vehicle and all local protrusions.

The ESM heat shield is a foamed silicon rubber material in which density can be varied in the fabrication process and

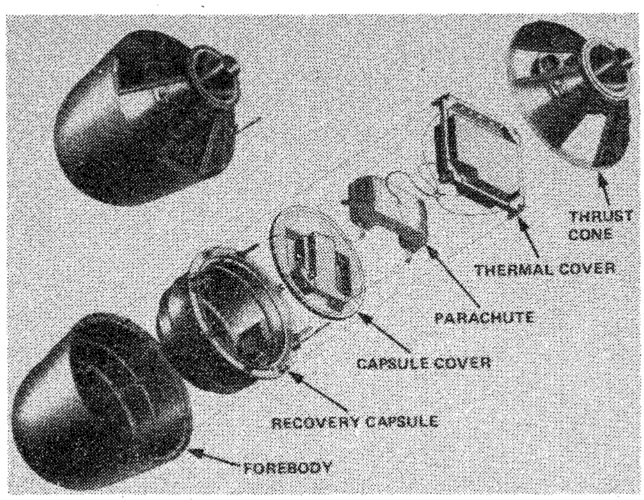


Fig. 2 Typical satellite recovery vehicle (SRV).

Table 2 Weight breakdown of four-man MOSES/SOC application

Subsystem	Mass, kg
Men and suits	508.0
Structure	249.5
Thermal protection system	204.1
Attitude control system	33.1
Propulsion	150.1
Electrical	78.0
Recovery	77.6
Landing attenuation	26.3
Separation	21.8
Ballast	57.6
Deorbit mass	1406.1
Re-entry mass	1130.0
Chute suspension mass	1043.3
$Diam_A/area_B$	259 cm/5.06 m^2
W/C_DA	307.63 kg/m^2

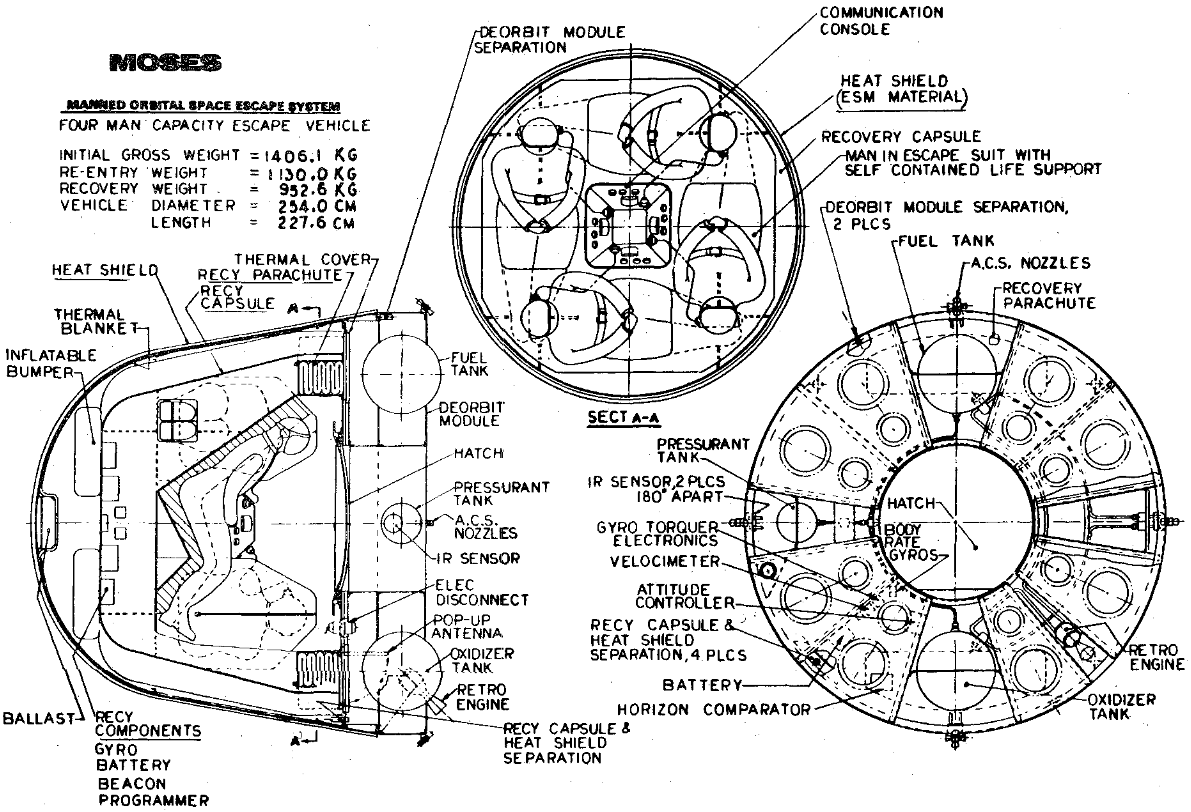


Fig. 3 MOSES four-man capacity vehicle.

reinforcement added for char retention in high-erosion areas. A detailed presentation of its development, testing, and material properties is provided in Ref. 4. In this particular application, the spherical nose cap would employ a 2.70 cm thickness of 0.879 g/cm^3 density material with imbedded char retention elements. The conical portion of the forebody would use 1.53 cm of 0.561 g/cm^3 density material without reinforcement and the aft surface of the vehicle a 1.3 cm thick layer of 0.368 g/cm^3 density material with char retention.

Primary Structure

The basic structure of the vehicle consists of two nested semimonocoque aluminum shells of conventional design connected through an aft bulkhead which is the primary load transfer element in the system. The droppable heat shield (forebody) dictates this duplex arrangement where all functional components and payloads are mounted off the inner capsule or aft bulkhead while the outer shell supports only the heat shield and sustains the aerodynamic loading. With land recovery as the primary operating mode, the space between the forebody and the recovery capsule is ideal for stowage of shock attenuation and locator-type gear which is uncovered at forebody separation.

Attitude Control

System autonomy dictates design of an attitude sensing and control subsystem which assumes that the MOSES vehicle could separate from the SOC in an uncontrolled manner and be randomly tumbling along its orbital track. Dependence on the crew to stabilize the system is not considered viable on the premise that escaping individuals might be incapacitated or unqualified to fly the vehicle.

Thus, a fully automated three-axis attitude sensing and control system of conventional design is provided. It employs infrared horizon sensing, rate gyros and associated control system elements and will determine vehicle attitude and behavior after separation, automatically stabilize and orient the vehicle, and position it properly for retro fire. Attitude control thrust is provided by an array of 12 nozzles distributed at selected locations on the deorbit module structure and working off a N_2O_4/N_2H_4 bipropellant hot-gas system in common with the retrorocket. Selection of the hybrid attitude control and retro system provides the efficiency of common tankage, and its continued use to maintain pointing accuracy throughout retro fire is preferable to adding separate spin stabilization. Further, the precise cutoff achievable with a liquid retrorocket will serve to minimize re-entry dispersion. Re-entry data for the four-man MOSES system is presented in Fig. 4.

Command

There are two basic commands associated with currently planned MOSES operation: separation from the primary vehicle and retro fire. All other functions are either automatic or occur passively. A number of combinations for primary and backup commands are possible, however, between the onboard crew, ground control, or personnel remaining on the SOC.

The operational plan for MOSES calls for the escaping personnel in the vehicle to initiate separation, with a command link to the SOC serving as a backup alternative. This would accommodate a situation of complete incapacitation among the escapees in one MOSES vehicle.

Conversely, retrorocket ignition for deorbit is commanded from the ground where the tracking network provides the best information to determine the proper timing for touchdown in a preferred landing zone. They are also best able to consider such contributing factors as weather, terrain conditions, recovery force disposition, etc. Backup capability in this case would be provided by the escapees in the capsule.

Communications

A number of communication alternatives were also evaluated with consideration given to both functional need

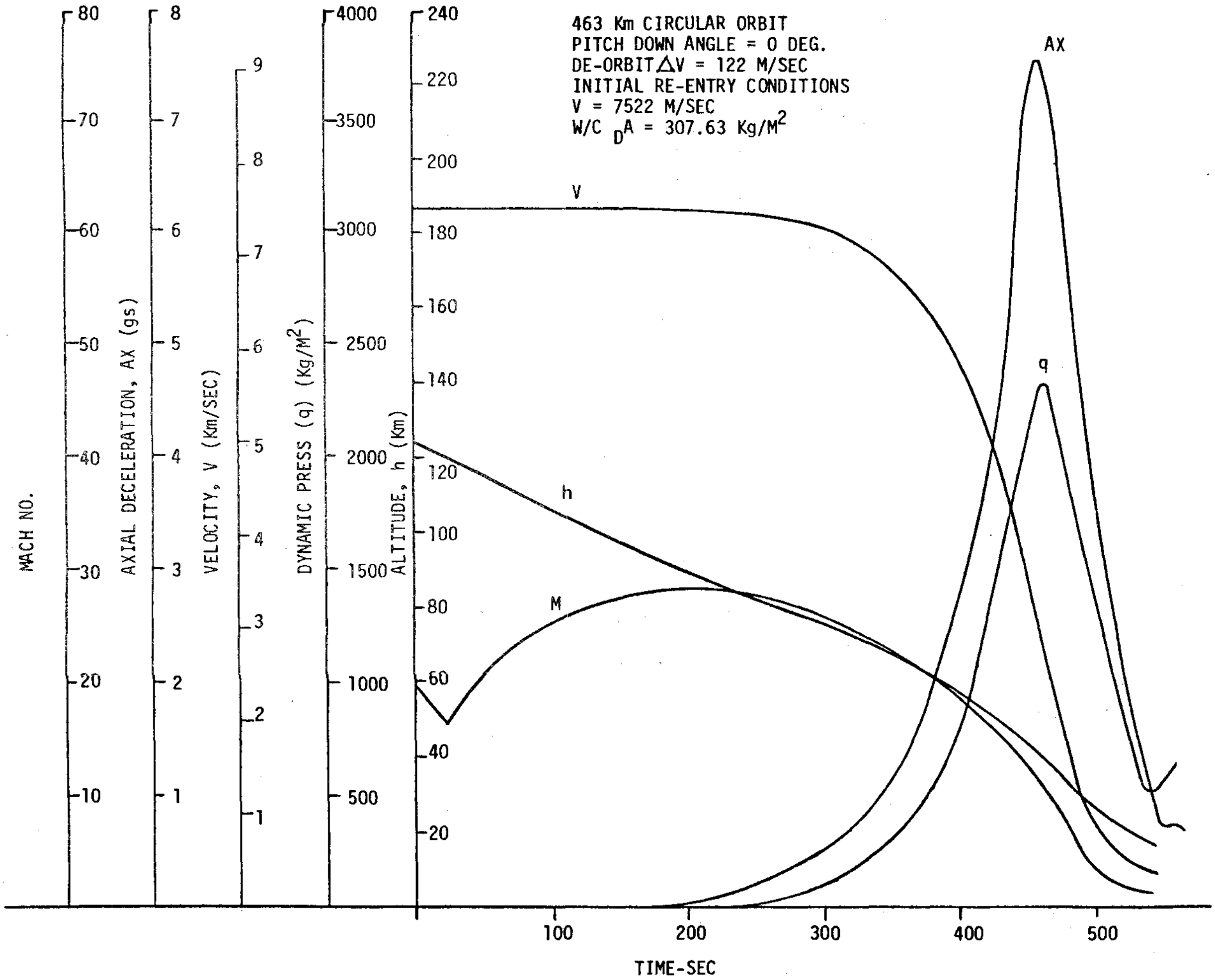


Fig. 4 Four-man MOSES re-entry data.

and the psychological well-being of the crew. Automatic tracking and locator beacons are included as basic equipment in the escape vehicle. Additionally, however, voice communication is provided between the escape vehicle, the SOC command center, and ground command, both before and after separation. This arrangement allows for both two- and three-way escape planning and coordination before and during the return flight, and contributes to the psychological well-being of the crew by allowing them to stay in touch during the escape.

Deorbit Module

The deorbit module contains all attitude sensing and control components, the retrorocket, tankage, plumbing, valving, and other miscellaneous items associated with these subsystems, which operate off a common fuel and oxidizer supply. A toroidal configuration of box beam construction was found to be most compatible with the backface of the MOSES re-entry vehicle. Associated interfacing requirements include the physical accommodation of the central access hatch and mounting of the attitude control and retro system components with their special requirements of location, alignment, and rigidity. The module must also provide the mating interface with the docking port of the SOC and be ejectable as a unit from the basic re-entry body, when the retro fire function has been completed.

Life Support

In the event of orbital emergencies, it is anticipated that the crew would immediately don protective garments with integral life support. Continued use of these systems for the relatively short duration of the escape seems reasonable. The low crew exertion level facilitated by complete automation and solar shielding provided by the vehicle itself impose minimum requirements on the life support system. A duration of 4-6 h suggested by earlier escape garment concepts and the present extravehicular maneuvering unit (EMU) appear adequate to support a complete escape sequence including 40 min from retro fire to landing and allowances for orbital dwell, attitude stabiliztion, and a contingency reserve. Auxiliary consumables could be readily added to the vehicle if an extension of operational life is desired.

Terminal Descent

Terminal descent for the MOSES recovery capsule commences at approximately 15 km with the deployment of a conventional parachute system. Attenuation of the shock loads associated with land recovery is provided by an inflated bumper which is deployed after it has been uncovered by separation of the forebody.

An alternative recovery system now under development employs a controllable gliding parachute and offers a number of attractive advantages, including less weight and packaging volume and the ability to maneuver directionally. This maneuverability offers the prospect of terminal correction of re-entry dispersion errors and wind drift. At touchdown, it also provides a positive means of obstacle avoidance and, most significantly, a controlled flare-out which insures the soft landings required for a manned capsule. It is anticipated that this terminal descent control recovery system will ultimately be incorporated as the primary mode for landing MOSES capsules.

MOSES/SOC Interface

A suggested mounting for the MOSES vehicles is presented in Fig. 5. This arrangement places the escape vehicles out of the main work area, locates them at structurally convenient points on the major thoroughfare between habitats, allows for easy crew access, and provides a reasonably clear path for separation from the primary system.

Two four-man vehicles are mounted as a matched set, providing an escape option for the full eight-man SOC crew, or discriminate abandonment of the station in the event that only one of the double habitats sustains damage.

The mounting interface is similar to a docking port with the capability for repeated separation and reattachment of replacement MOSES vehicles. This provision assumes that an emergency requiring escape will not necessarily preclude refurbishment and reuse of the platform.

Primarily, separation will be initiated by command from within the MOSES vehicle and from that point on it would be autonomous and independent of the platform.

As stated earlier, suited access to the escape vehicle is anticipated with continued employment of the emergency garment for life support.

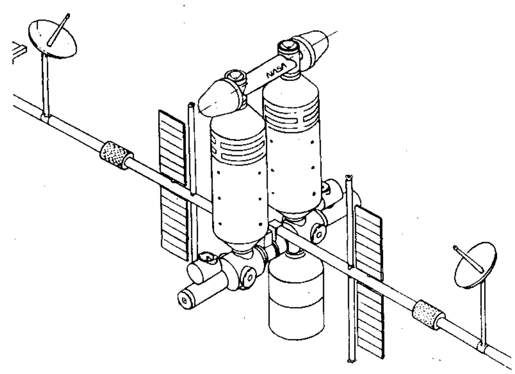


Fig. 5 MOSES/SOC installation.

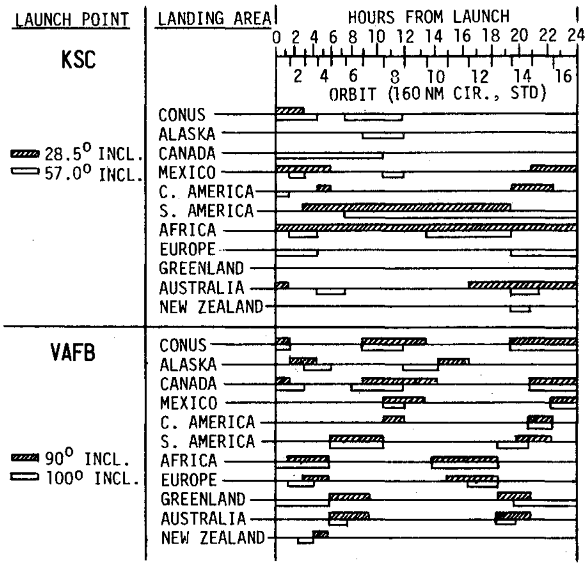


Fig. 6 Potential recovery zones.

Threats, Timing, and Effects

With heavy equipment on board and the strenuous activities involved, a broad spectrum of orbital accidents are possible in the normal operation of the platform. These threatening situations are categorized as follows and it should be recognized that there is a broad range of severity associated with each: fire, explosion, environmental control failure, electrical power and distribution failure, habitat contamination, consumables loss, habitat rupture/leak, crew illness/injury, and Earth return vehicle incapacitation.

Most situations would normally result in low-urgency threats allowing a well-organized departure from the SOC which is fully coordinated with ground command. Extreme cases, however, could demand immediate evacuation where all coordination with the ground would take place from the MOSES vehicle in free orbit after separation.

In cases where the crew can remain with the SOC until a convenient deorbit point is reached, a high degree of landing site selectivity is possible. In the more urgent situations, this selectivity could still be obtained by providing auxiliary consumables in the escape vehicle to allow for extended orbital dwell time.

The planned Space Shuttle orbits and associated global land masses shown in Fig. 6 are fairly representative of SOC operations. They give a reasonable indication of the maximum orbital dwell times involved for recovery in both the continental United States (CONUS) and other worldwide sites where hospitable terrain would exist and mobile rescue teams could find ready access. The time interval from any point in these representative orbits to an acceptable recovery area is generally a few hours. A worst-case CONUS recovery would require a 21 h maximum dwell time.

For a number of reasons, both operational and political, recovery in the continental United States is highly desirable. Fortunately, in the case of the SOC with its dual habitats and other emergency features, CONUS recovery appears reasonable in virtually all conceivable situations. The preferred procedure would have the crew remain aboard the SOC, living off its consumable supply and then entering and activating the MOSES when the desired deorbit point is approached.

Typical Escape Scenario

By way of illustration, a hypothetical escape scenario might proceed as follows. Assume an explosion and fire occurs in one of the dual SOC habitats which causes significant damage to the interior, rendering it unuseable without refurbishment. Four crew members have sustained injuries ranging from minor burns and abrasions to severe facial burns and eye damage. All four have escaped to the other habitat and sealed the damaged zone behind them.

A decision is made, in conjunction with ground command, to return the injured crew members to Earth employing one of the onboard MOSES escape vehicles. The four uninjured crew men will remain aboard the SOC to clear debris, initiate repairs, and prepare for refurbishment.

Contact with the ground tracking network has indicated an interval of several hours before reaching a point where deorbit of the escape vehicle would insure landing at a hospitable CONUS recovery area. At a reasonable time before this deorbit point, the departing crew members don escape garments with the aid of their uninjured companions and enter the escape vehicle. On command from within the capsule, the MOSES vehicle is then ejected from its mounting on the SOC in sufficient time to stabilize itself and align properly for retro fire. From this point to recovery on the surface, the following sequence as depicted in Fig. 7 would ensue:

1) At a safe distance from the SOC, the vehicle would initiate a programmed search mode to acquire the Earth horizon. It would then stabilize its motion and attitude and properly point itself for retro fire.

2) Ground tracking establishes the exact timing for retro fire and initiates the ignition command to deorbit the vehicle.

3) Throughout retro fire the three-axis attitude control system maintains pointing accuracy.

4) Following retro rocket cutoff, the attitude control system performs a final pitching maneuver to achieve a nose-first entry attitude and then imparts a low spin rate to the

vehicle (approximately 10 rpm) to compensate for minor c.g. offsets.

5) At this point, the deorbit module (including attitude control and retro systems) is jettisoned, reducing the vehicle to its re-entry configuration.

6) Atmospheric re-entry commences at approximately 122 km where vehicle velocity is in the 7620 m/s range and is essentially complete by 18.3 km where the vehicle has slowed to approximately Mach 1.

7) The mechanical tie between the forebody (heat shield plus substructure) and the rest of the vehicle is now pyrotechnically servered and the drogue chute deployed. This added drag extracts the recovery capsule from the forebody, discarding the spent heat shield in the process.

8) After a further period of deceleration, the main chute is released in a reefed condition and shortly thereafter disreefed to a fully deployed configuration.

9) At this point, locator equipment and a landing shock attenuation system uncovered by forebody separation are activated.

10) Terminal descent under the parachute system culminates with touchdown in a preselected zone where an alerted recovery force is waiting to administer to the injured crew members.

Alternative Applications

The MOSES concept has been examined for application to a number of existent or potentially existent systems. Figure 8 depicts a four-man unit as it might be installed in the present Shuttle orbiter with direct access by way of the air lock and egress tunnel. A variety of other mountings and accessabilities are possible along with combinations of one or more vehicle sizes to fit specific needs. This family of applications would be feasible for the inevitable Shuttle growth models, heavy lift transports, etc., currently in the preliminary study stages. The SOC application is, of course, representative of a broad spectrum of Earth-orbiting platforms. Except for variations peculiar to individual physical interfaces, the basic MOSES vehicle could serve them all.

At the other extreme of the performance envelope, a feasibility study has been conducted on application of a MOSES-type system for escape from GEOS and other deep-space orbits where the solar storm threat adds considerably to an already impressive list of hazards. No significant changes to the basic vehicle were found necessary. A more precise attitude control is required to negotiate the narrower re-entry corridor and additional consumables must be added to accommodate a longer flight time, but neither impose undo strain on present capabilities.

In view of the very high reliability being achieved in recovering vehicles from orbit, the prospects of employing a MOSES under other than emergency conditions seems feasible. There would appear to be a number of nonemergency occasions when it may be desirable to return personnel from orbit without the preplanning and cost associated with use of a Shuttle or other orbital transport vehicle. This option seems worthy of further examination at a later date.

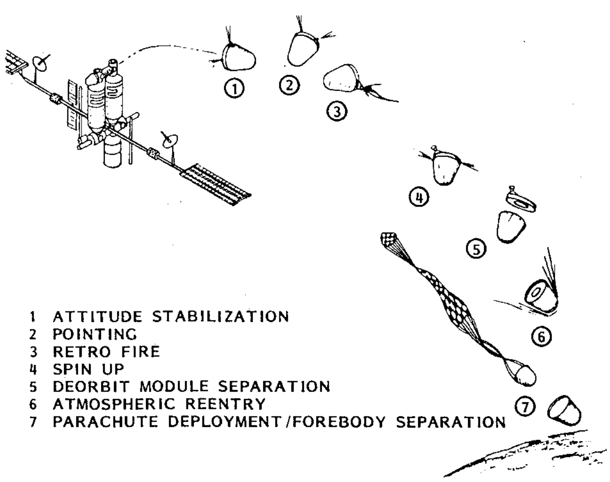


Fig. 7 Deorbit sequence MOSES/SOC application.

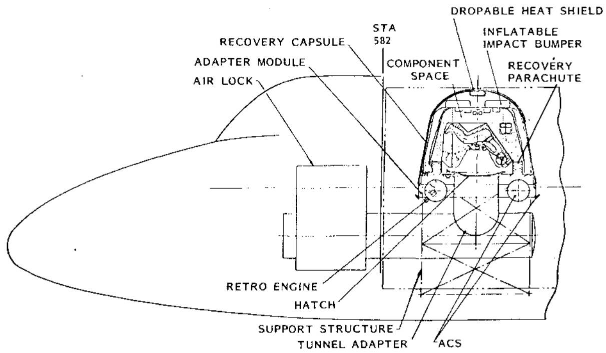


Fig. 8 Four-man MOSES: Shuttle application.

Summary

The intensive manned activities now being planned for the Shuttle and post-Shuttle eras emphasize a growing need to provide an orbital escape option to protect space crews from life-threatening occurrences in orbit. The MOSES concept ideally fills this need and through the use of thoroughly demonstrated satellite recovery vehicle technology can offer high reliability, minimum development costs, and availability in the shortest possible time.

Acknowledgments

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