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INVESTIGATION OF CREW ESCAPE CONCEPTS FOR VTOL AND LOW-ALTITUDE DASH VEHICLES

John O. Bull
Edward L. Serocki
Jakob Schor, et al.

THE BOEING COMPANY, RENTON, WASHINGTON, P.O. BOX 707,

TECHNICAL REPORT AFFDL-TR-66-149

FEBRUARY 1967

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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ISSUE NO. ________

FOREWORD

The research work in this report was performed by The Boeing Company, Renton, Washington, for the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, under AF Contract No. AF33(615)-2378. This research work is part of an effort to determine the crew escape design requirements for VTOL and low-altitude dash vehicles; investigate various crew escape concepts such as ejection seats, encapsulated seats, nose and pod type escape capsules; study the associated escape problems such as stability, critical timing, automatic initiation, high-dynamic forces, low-altitude and VTOL escape performance, etc.; and determine the theoretical feasibility of the techniques and concepts that will meet the vehicle requirements. The Project number is 1362, "Crew Escape for Flight Vehicles" and the Task number is 136203, "Crew Escape Techniques Research." The Air Force program monitor was Mr. Marvin C. Whitney, office symbol FDFR, Recovery and Crew Station Branch. The research was conducted from February 1965 to August 1966.

Mr. John O. Bull of The Boeing Company, Product Development Technology Section was the project leader responsible for the study organization and technical direction of the work performed. Other Boeing personnel contributing to the study and participating in the preparation of the report were Jakob Schor, Larry J. Nolan, Edward L. Serocki, Bernie C. Mackey, George A. Dowling, George W. Milner, Claud Hendry, Liale R. Towner, and Michael D. Terry.

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The manuscript was released by the authors in August 1966 for publication as a technical report.

This technical report has been reviewed and is approved.

GEORGE A. SOLT, JR.
Chief, Recovery & Crew Station Branch
Vehicle Equipment Division
AF Flight Dynamics Laboratory

ABSTRACT

This report covers the results of a study to define crew escape requirements and criteria for selection, evaluation, and design of crew escape systems for VTOL and low-altitude dash vehicles. Escape concept performance, survival, pressurization, restraint, crew comfort and efficiency, and development and qualification testing requirements are defined. Representative open ejection seat, encapsulated ejection seat, cockpit pod, and separable nose capsule escape concepts and vehicle configurations are defined. Escape concept performance capabilities with respect to altitude, speed, and descent angle are presented and results of analyses of escape concept effectiveness for VTOL hover and transition, conventional takeoff and landing, low-altitude dash, and high-speed and high-altitude flight regimes are presented. Also, the results of an investigation of automatic emergency detection and escape initiation are presented. Escape concept trade data relative to escape and survival potential, reliability, cost, weight, volumetric penalty, availability, crew comfort and efficiency, and crew safety were developed and are presented in a form useful as a guide in the selection, evaluation and design of escape concepts for advanced VTOL and low-altitude dash vehicles.

CONTENTS

CONTENTS (Cont)

CONTENTS (Cont)

ILLUSTRATIONS

ILLUSTRATIONS (Cont)

ILLUSTRATIONS (Cont)

ILLUSTRATIONS (Cont)

ILLUSTRATIONS (Cont)

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TABLES

SECTION I

INTRODUCTION

The objectives of this study are to define crew escape requirements and criteria for selection, evaluation and design of escape systems for VTOL and low-altitude dash vehicles. Crew escape requirements were defined in terms of escape concept performance, survival after landing, emergency pressurization, restraint, crew comfort and efficiency, and crew compartment integration. Test requirements for development, qualification, and verification of escape performance capability also were defined. Representative open ejection seat, encapsulated ejection seat, cockpit pod capsule, and separable nose capsule escape concepts and vehicle configurations were established. Basic escape concept performance capabilities with respect to vehicle altitude, descent angle, and speed were calculated. Special analyses and evaluations of escape concept effectiveness for VTOL hover and transition, conventional take-off and landing, and low-altitude dash flight regimes were accomplished. Also, analyses to evaluate automatic emergency detection and initiation were accomplished.

Escape concept trade data pertaining to escape capability, survival capability, reliability, cost, weight, volumetric penalty, availability, crew comfort and efficiency, and crew safety were developed. A summary of the trade data is presented and a rank order rating of the escape concepts with respect to each trade factor is provided. This will be useful as a guide in the selection, evaluation, and design of escape concepts for future advanced VTOL and low-altitude dash vehicles.

SECTION II

PRELIMINARY INVESTIGATION

1. ESCAPE SYSTEM GOALS AND REQUIREMENTS

Escape system goals and requirements with respect to escape capability, survival equipment, emergency pressurization, restraint, crew comfort and efficiency, and crew compartment integration have been defined for use as guidelines for the establishment of design criteria and the evaluation of crew escape concepts. Three types of vehicles were considered in this study: (1) subsonic VTOL vehicle; (2) supersonic low-altitude dash vehicle; and (3) combined capability vehicle, having both VTOL and supersonic dash capability.

a. Escape System Capability

(1) VTOL Vehicle

The current state-of-the-art of VTOL technology does not permit a precise prediction of landing and take-off techniques or emergency escape conditions for advanced VTOL vehicles. Further, attitude control is sensitive to vehicle configuration, and numerous power and control alternatives are currently being considered. Thus, variations in control characteristics make it difficult to generalize emergency escape requirements. However, present VTOL design philosophy relating to flight safety and vehicle attitude control in the event of power failure may be used as a basis for establishing certain escape system goals. Current design philosophy will provide lift engine configurations that will minimize asymmetric thrust in the event of power failures. Also, compensation for asymmetric thrust will be provided by automatic actuation of the control system and by automatic termination of thrust on opposing lift engines. Ideally a power failure would result in the VTOL vehicle crashing in a controlled level attitude. A minimum acceptable design would be a vehicle capable of maintaining sufficient attitude control for a limited period of time to permit emergency escape. Based on preliminary estimates of control requirements and VTOL vehicle dynamics, it is reasonable to presume that vehicle pitch and roll rates can be limited so as not to exceed 0.5 radian per second. Therefore, for the purposes of this preliminary analysis, pitch and roll rates of 0.5 radian per second are used as a basis for defining limiting escape conditions for VTOL vehicles.

Escape system capability requirements for the VTOL vehicle are defined as follows:

- During level flight for all combinations of airspeed and altitude as shown on Fig. 1 for the VTOL vehicle.
- At ground level from zero speed to the maximum speed capability of the vehicle (Mach 0.9 at sea level).
- During all phases of conventional takeoff and landing.
- During all phases of the representative normal vertical takeoff as defined in Fig. 2.
- During all phases of the representative normal vertical landing as defined in Fig. 3.

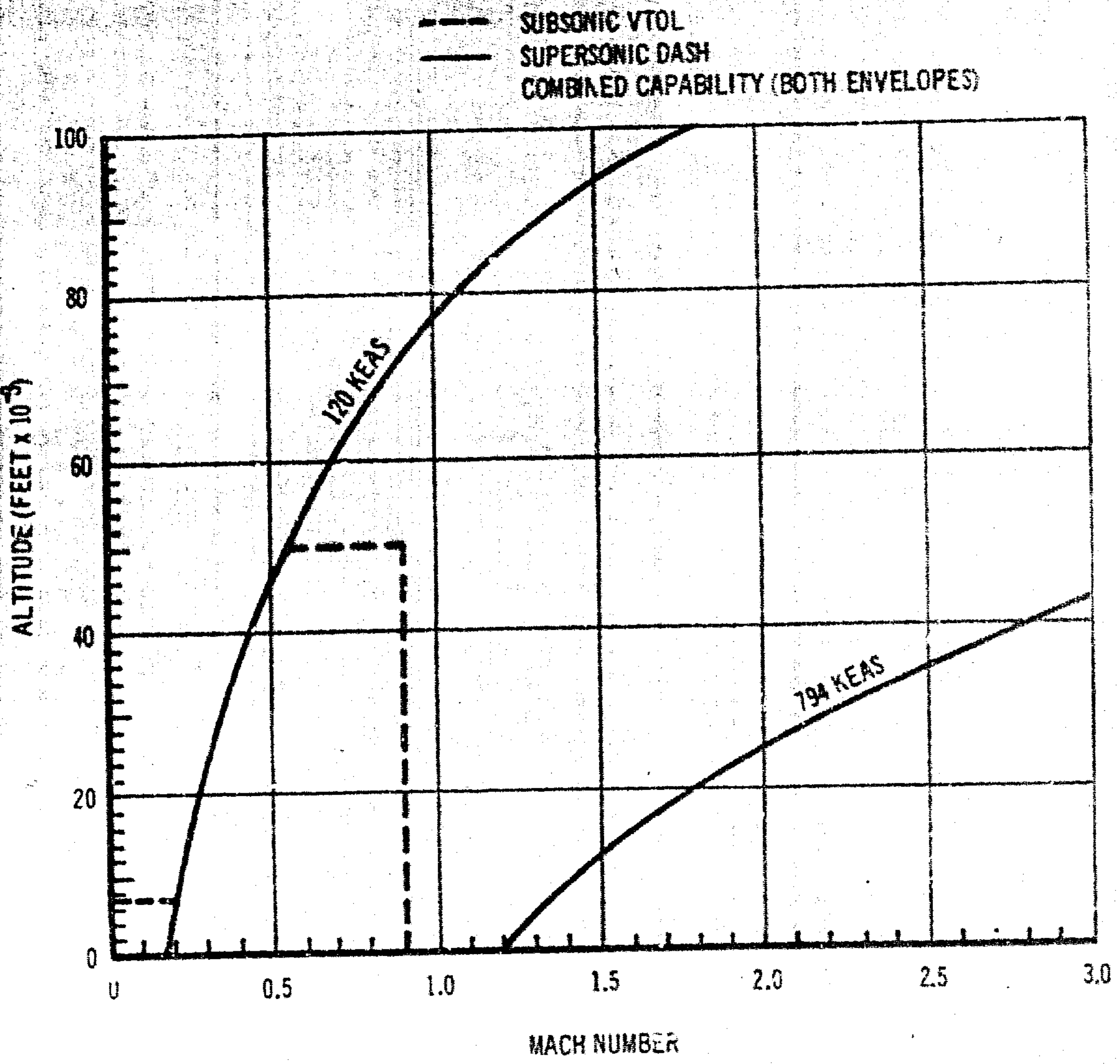


Figure 1. Flight Envelopes

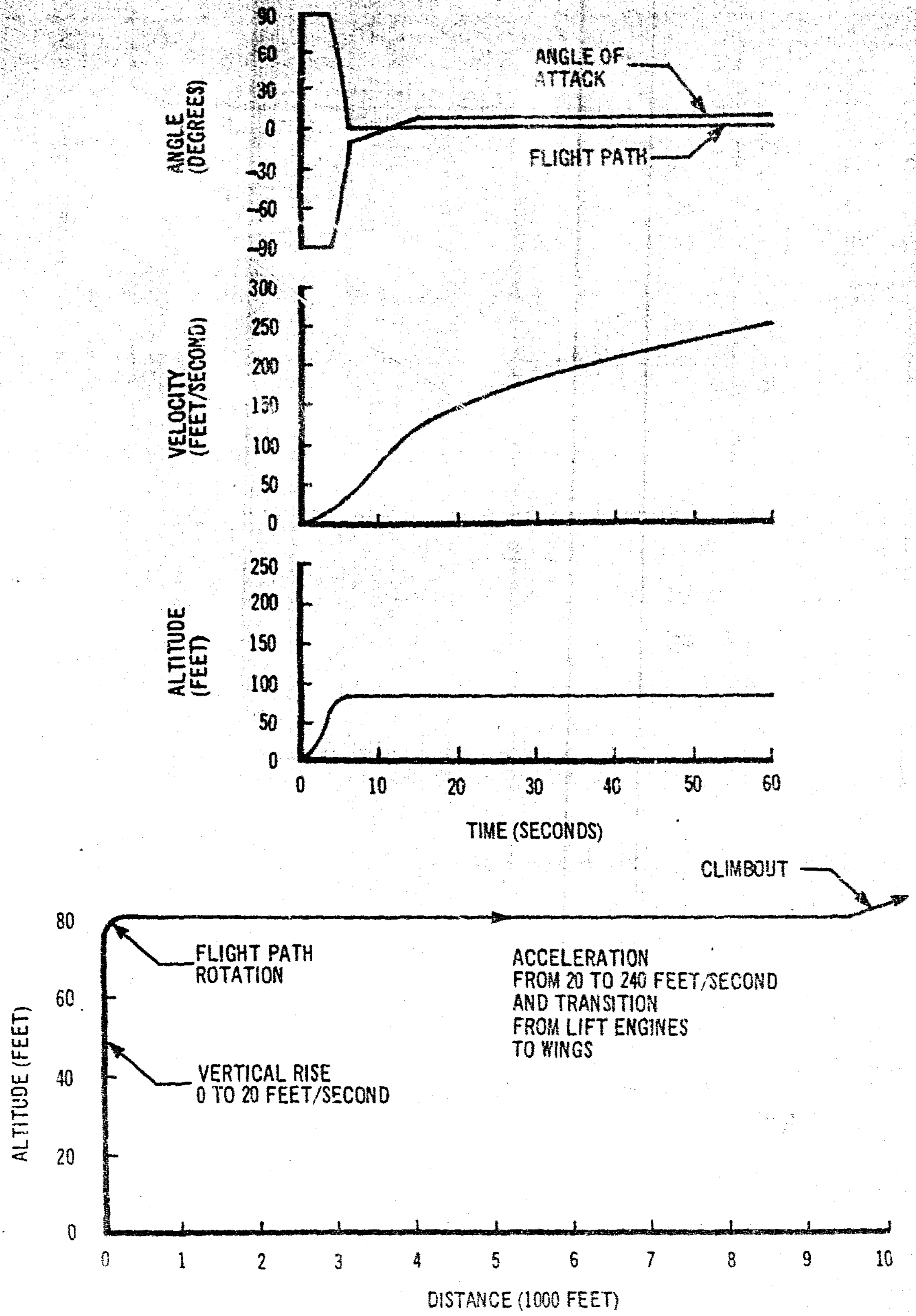


Figure 2. Normal Vertical Takeoff

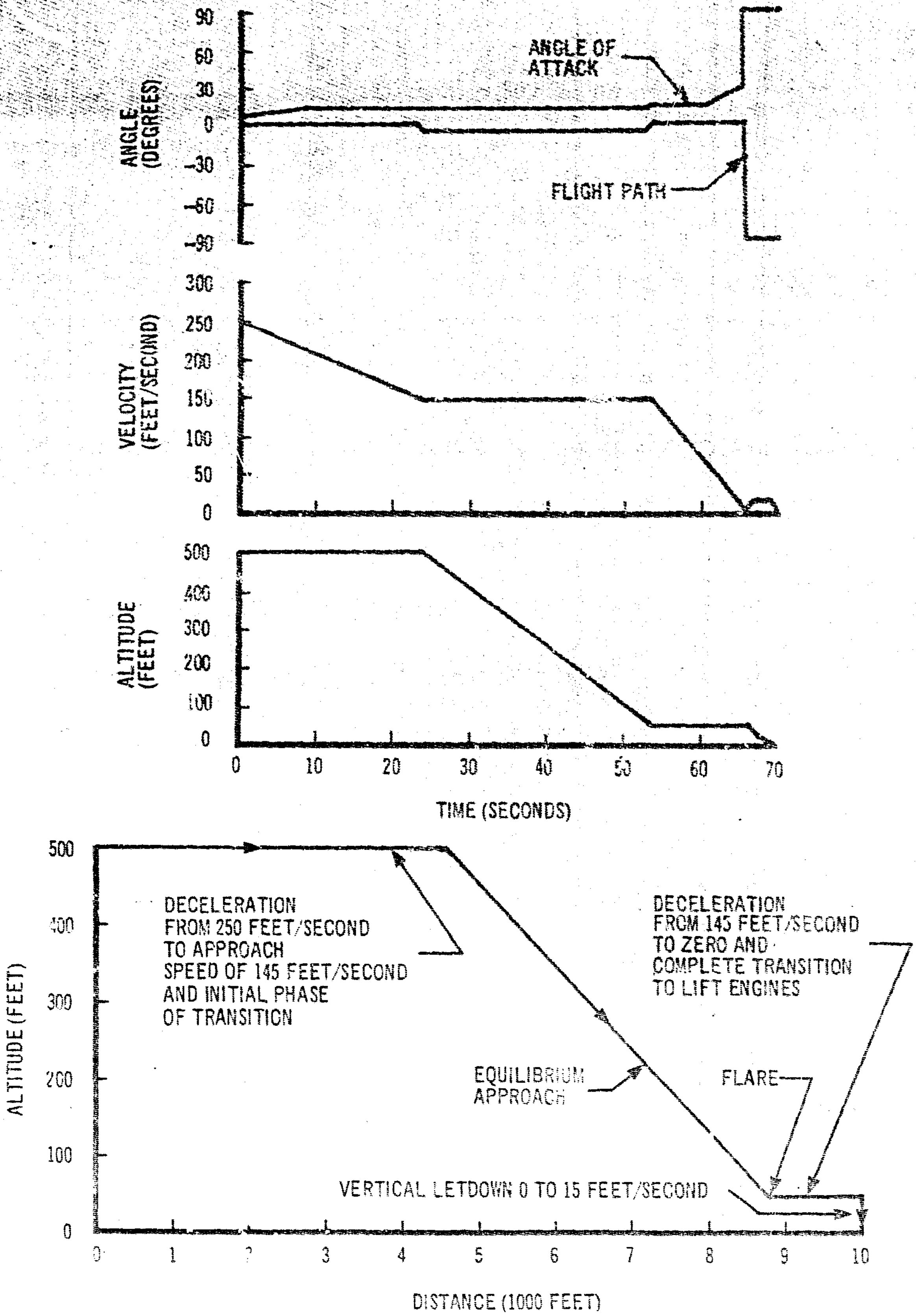


Figure 3. Normal Vertical Landing

- **During the vertical takeoff and landing emergency conditions shown on Figs. 4 and 5: free-fall conditions for level attitude, rolling, and pitching during descent as defined on the accompanying graphs; and maximum push-over conditions as defined in the flight path angle and velocity graphs.**

  NOTE: The free-fall and maximum pushover emergency conditions are believed to represent the limiting or most severe escape conditions that might be expected to occur during vertical takeoff or landing and during transition. However, the escape system must be capable of providing successful escape and recovery, during emergency conditions, that might be defined as combinations or interpolations between the free-fall and maximum pushover conditions.

- **During inflight emergencies that result in escape at combinations of altitude, dive angles, and airspeeds (up to Mach 0.9) shown on Fig. 6.**

(2) Low-Altitude Dash Vehicle

Escape system capability requirements for the low-altitude dash vehicle are defined as follows:

- **During level flight at all combinations of airspeed and altitude within the flight envelope (as shown in Fig. 1) for the low-altitude dash vehicle.**
- **At ground level from zero speed up to the maximum speed capability of the vehicle (Mach 1.2 at sea level).**
- **During all phases of conventional takeoff and landing.**
- **During inflight emergencies that result in escape at combinations of airspeed, altitude, and dive angles as shown in Fig. 6.**

The escape system must be capable of providing safe escape at the minimum possible altitude during the emergency conditions represented by the maximum pushover maneuver capability of the vehicle as shown in Fig. 7. Sustained flight at transonic speeds 200 feet above the terrain must be considered a design criteria.

(3) Combined Capability Vehicle

The escape system capability requirements for the combined capability vehicle include all the conditions defined for both the VTOL and low-altitude dash vehicles.

b. Survival Equipment

Survival equipment must provide for: survival and rescue on land or water during environmental extremes, keeping survivors afloat in water, temporary emergency shelter on land or water, emergency rations and a means for obtaining food and water, survival clothing and equipment to assist the survivor in keeping as comfortable as possible and in good physical and

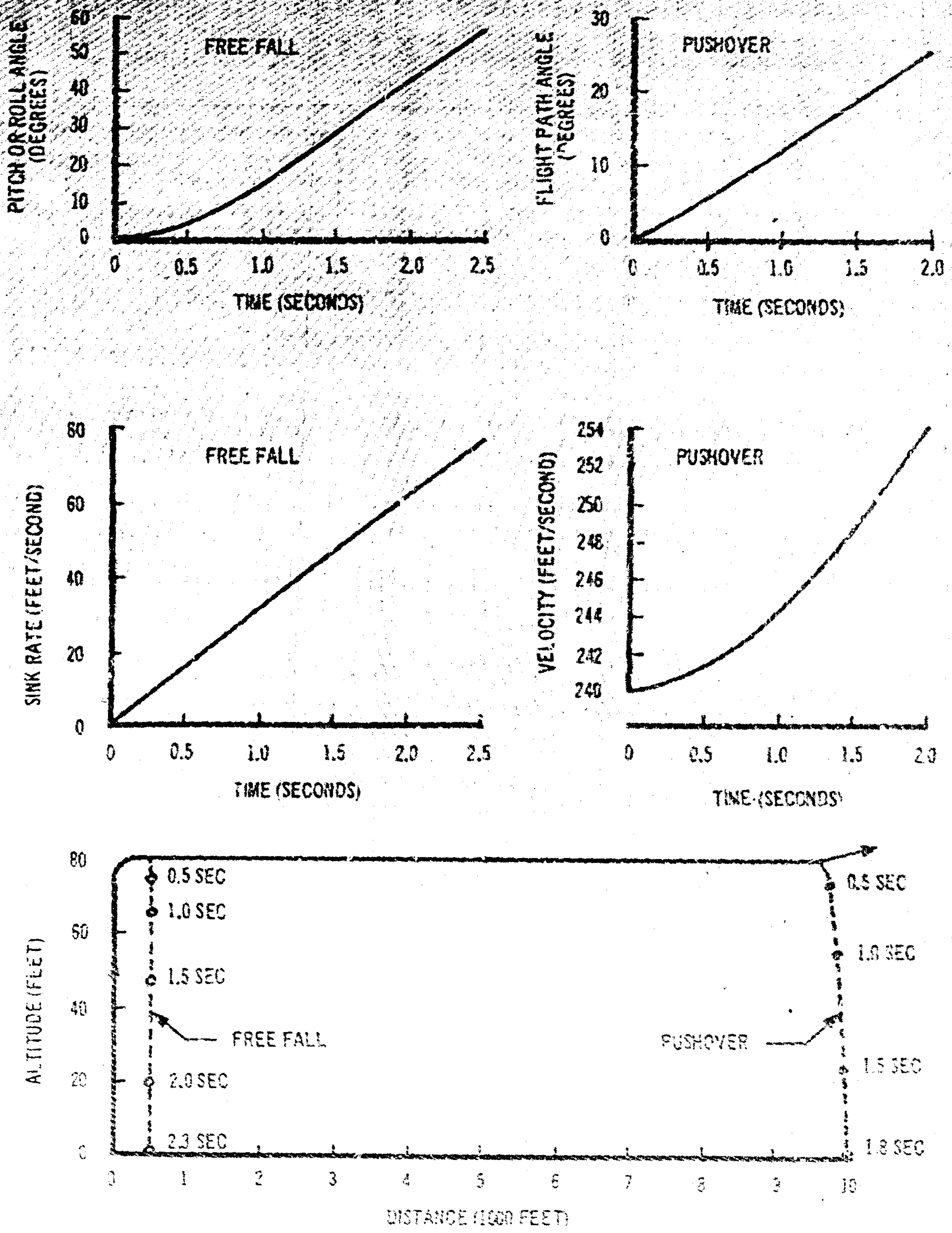


Figure 4. Vertical Takeoff Emergency Conditions

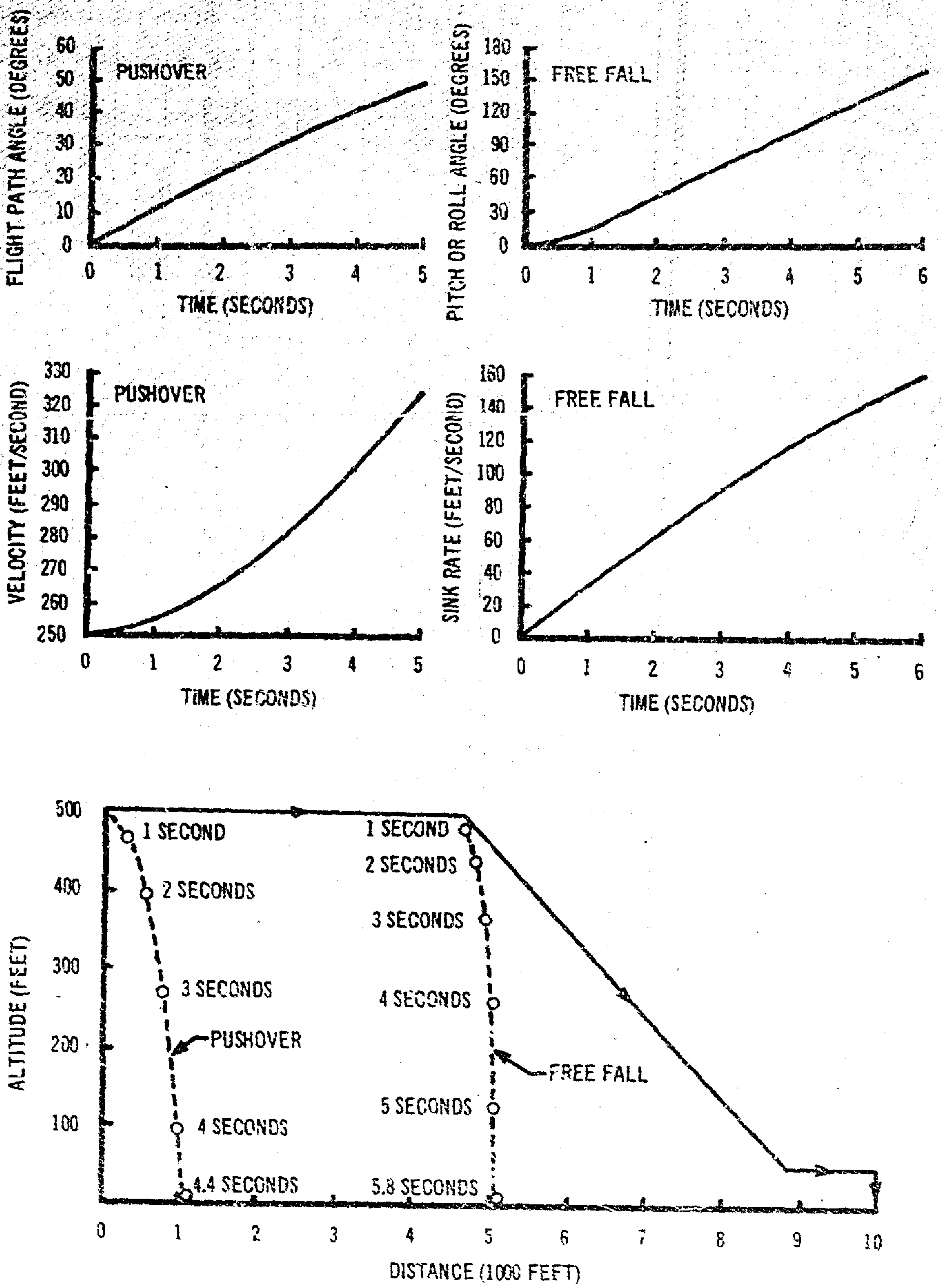


Figure 5. Vertical Landing Emergency Conditions

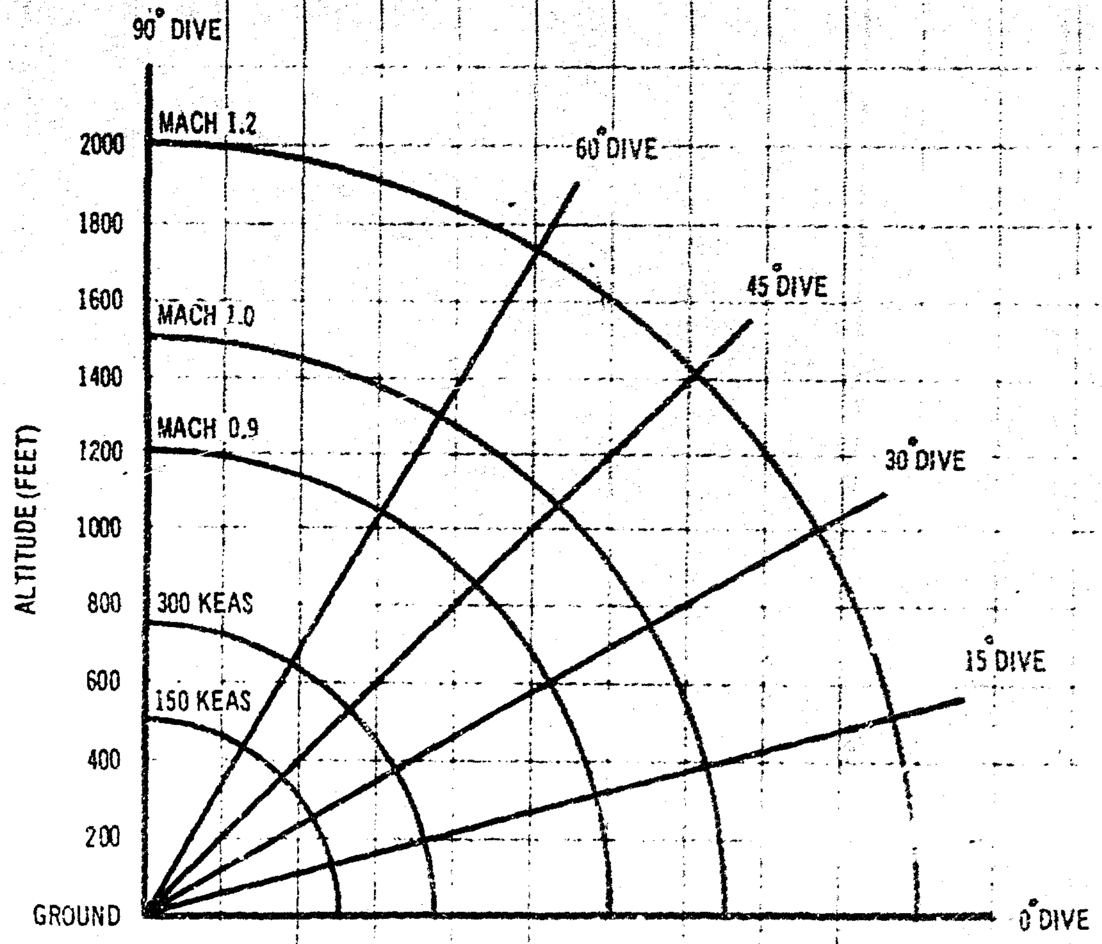
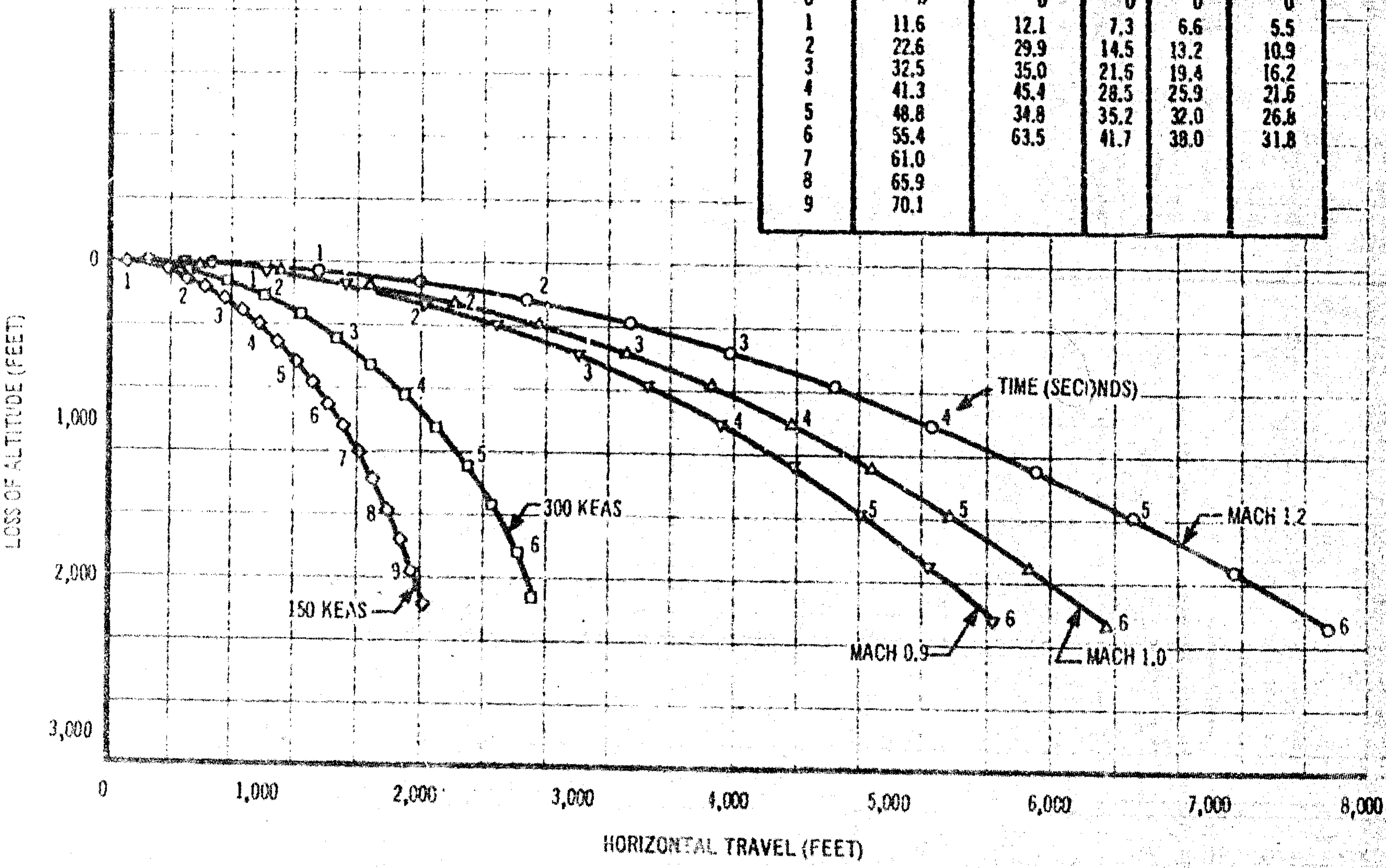


Figure 6. Altitude, Dive Angle, and Airspeed Escape Criteria



TIME (SECONDS)	DIVE ANGLE (DEGREES)				
	150 KEAS	300 KEAS	M 0.9	M 1.0	M 1.2
0	0	0	0	0	0
1	11.6	12.1	7.3	6.6	5.5
2	22.6	29.9	14.5	13.2	10.9
3	32.5	35.0	21.6	19.4	16.2
4	41.3	45.4	28.5	25.9	21.6
5	48.8	34.8	35.2	32.0	26.8
6	55.4	63.5	41.7	38.0	31.8
7	61.0				
8	65.9				
9	70.1				

Figure 7. Airplane Trajectories for Pushover at Sea Level

mental condition, a means for assisting the survivor in taking evasive measures to prevent capture by the enemy, and communication through automatic or manual signalling or tracking devices to facilitate location of survivors during rescue operations.

c. Emergency Pressurization and Breathing Atmosphere

A survivable pressure level and breathing atmosphere must be maintained by either mechanical backup systems or pressure suit during inflight emergencies such as ejection, cabin depressurization, or oxygen system failure.

Emergency pressurization and oxygen must be provided to operate automatically and be capable of providing a survivable pressure level and breathing oxygen during escape and descent from the maximum altitude capability of the vehicle. Emergency pressurization also must be provided to protect the crewmember in the event of primary pressurization failure when emergency escape from the aircraft is not mandatory.

A system must be incorporated to actuate emergency pressurization that is separate and independent of automatic pressure regulation.

d. Restraint

Adequate restraint during flight, emergency escape, and crash landing must be provided.

The head, limbs, and torso must be supported and restrained from any movement which could cause injury during aircraft launching, normal flight involving high accelerations, uncontrolled flight, crash landing, and throughout an emergency escape operation.

Restraint must be adequate to sustain the combined forces of deceleration, tumbling, and windblast that could be experienced under the most adverse escape conditions.

The restraint system must be capable of integrating into a "shirt-sleeve" environment and must not appreciably compromise crew comfort, efficiency, or effectiveness, and must be manually adjustable to suit individual requirements. It must be automatic during adverse acceleration load conditions and during the escape sequence. Simultaneous release of all restraints must be accomplished by a single action (manual and automatic), and must provide for ingress to and egress from the seat without assistance and with a minimum of motions. It must be easy to operate, lightweight, and allow freedom of movement when restraint is not required.

e. Crew Comfort and Efficiency

A comfortable and livable environment must be achieved for optimum efficiency and effectiveness of the aircrew throughout the performance envelope of the vehicle. The aircrew must be relieved of as many protective encumbrances as possible, and minimum restrictions must be imposed by the escape system on efficient use of cockpit space, and must allow the aircrew to operate all required equipment in an efficient manner with minimum restriction of aircrew movement during normal flight. It must also provide for adequate cushioning and energy absorption which will result in maximum comfort and support.

f. Crew Compartment Integration

The escape system must be designed to be completely integrated and compatible with the design of the parent aircraft, must not compromise the aircrew station nor the operator's function, and must not adversely affect the performance or mission capability of the aircraft.

The integrity of the parent aircraft must not be penalized by the addition of emergency escape capabilities within the crew compartment. Escape system space requirements must be minimized to provide for greater flexibility of displays and controls location and arrangement, and must allow for location of controls and instrument consoles that are compatible with arm reach requirements of 5 to 95 percentile crewmen. The maximum practicable vision must be provided for crewmembers.

2. AUTOMATIC DETECTION AND ESCAPE INITIATION

The primary cause of unsuccessful utilization of escape systems in current aircraft is the failure of the crewmember to actuate the escape system in time for successful recovery prior to ground impact. This will become even more critical for the hazardous flight conditions of future VTOL and low-altitude dash vehicles.

Airplane trajectories for maximum hard nose-over from low-level flight are shown in Fig. 8 for a -3g structural limit at Mach 0.9, 1.0, and 1.2, and an aerodynamic capability limit of -2.38g at 300 KEAS and -0.6g at 150 KEAS. This illustrates limiting conditions from which escape might be required for a representative low-altitude dash vehicle. The 1.8-second time line represents the time required for a crewmember to sense the emergency (0.10 second), decide to escape (1.5 seconds), and actuate the escape system (0.20 second). These times are based on trained personnel, simple stimulus, simple decision alternatives, and negligible delay attributed to mental duress. Under actual emergency conditions the human reaction time is expected to be significantly greater. As illustrated, the time required for human initiation of the escape system precludes the possibility of successful escape for a maximum hard nose-over emergency occurring at the prescribed vehicle dash capability of transonic speed at 200 feet above the terrain. For even significantly less severe low-altitude dash emergencies, it is extremely unlikely that a crewman would be capable of actuating the escape system in time to effect successful escape. Examination of the escape conditions for the VTOL vehicle (Figs. 4 and 5) reveals that escape initiation time for the vertical takeoff and landing emergencies is also extremely critical. For emergencies occurring within 200 feet of the ground, human reaction time would essentially preclude the possibility of successful escape. At slightly higher altitudes escape must be initiated on a timely basis to preclude the possibility of escape initiation at an undesirable attitude.

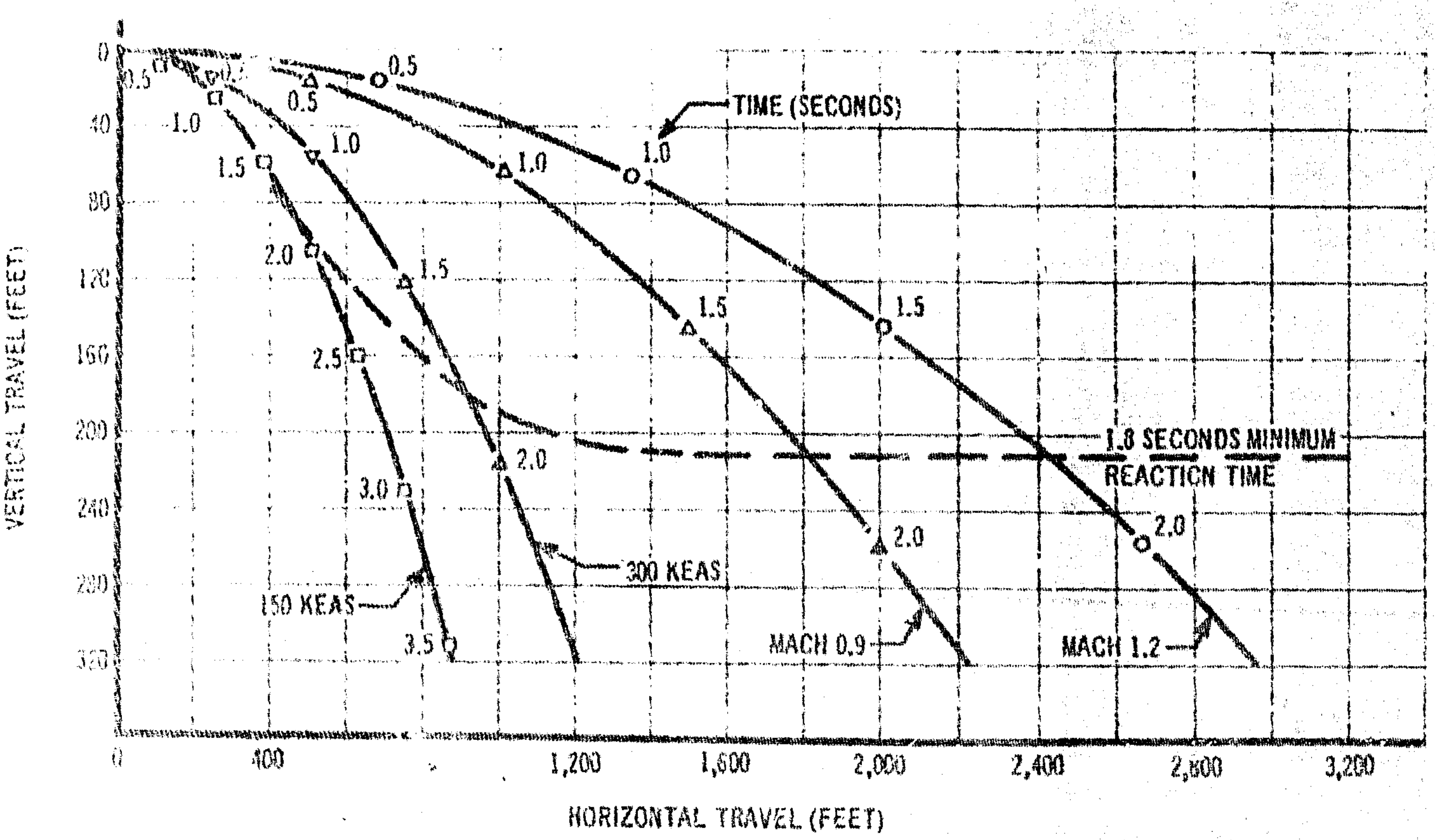


Figure 8. Airplane Trajectories for Hard Pushover Maneuver

A preliminary analysis of a basic automatic escape initiation system was accomplished to provide background and insight into the feasibility of such a system. Figure 9 is a block diagram showing the air vehicle systems required for data input and the logic diagram for the escape initiation computer. For this initial investigation, the escape variables were limited to vehicle speed, altitude, and dive angle. Automatic escape initiation is signalled at the time the vehicle flight factors indicate that the vehicle has reached a nonrecoverable flight condition.

Vehicle systems required for inflight measurements of airspeed and height above terrain are provided in military airplanes by an air data computer and radar altimeter. The measurement of dive angle is more restricted in the sense that flight instruments, such as the artificial horizon, yield approximate values for display to the pilot; no provision is made for an output to other systems. A measurement of dive angle can be provided for use by the other systems only in airplanes equipped with a stable reference. This measurement is achieved by an algebraic combination of the pitch angle from the pitch reference and the true angle of attack from the air data computer.

Functionally, the air data computer requires input data from the pitot-static system, outside air temperature sensor, and the angle of attack sensor. The measured air data, static pressure, dynamic pressure, stagnation temperature, and indicated angle of attack are used by the computer in solving standard air data equations. This computer is generally an analog mechanization and, typically, furnishes calculated values of Mach number, true airspeed, indicated airspeed, and air density ratio for display to the pilot or use by other systems. For the application outlined the indicated airspeed, true angle of attack, and air density ratio are obtainable with maximum errors of ±6.5 knots, ±0.1 degree, and ±0.10, respectively.

The radar altimeter is a special-purpose radar using fixed antennas to provide a measure of the range to the nearest terrain. The simplest and most accurate radar altimeters are pulse-type radars. The radar altitude is obtained by measuring the time delay between the transmitted pulse and the pulse reflected into the receiving antenna by the terrain below the airplane. At low altitude the accuracy is a function of the pulse width and altitude, being typically 50 ±0.01H feet, where H is the altitude to be measured.

Stable platforms are generally restricted to use in airplanes using a complex weapon delivery system, stability augmentation or inertial navigation systems. The stable reference is obtained by the use of gyros and a gimbal system. The gyros maintain a vertical reference, and, as the aircraft pitches or rolls, the gimbals make it possible to measure the magnitude of the excursion about the pitch and roll axes. The accuracy of measuring the pitch angle is typically to within three to five minutes of arc.

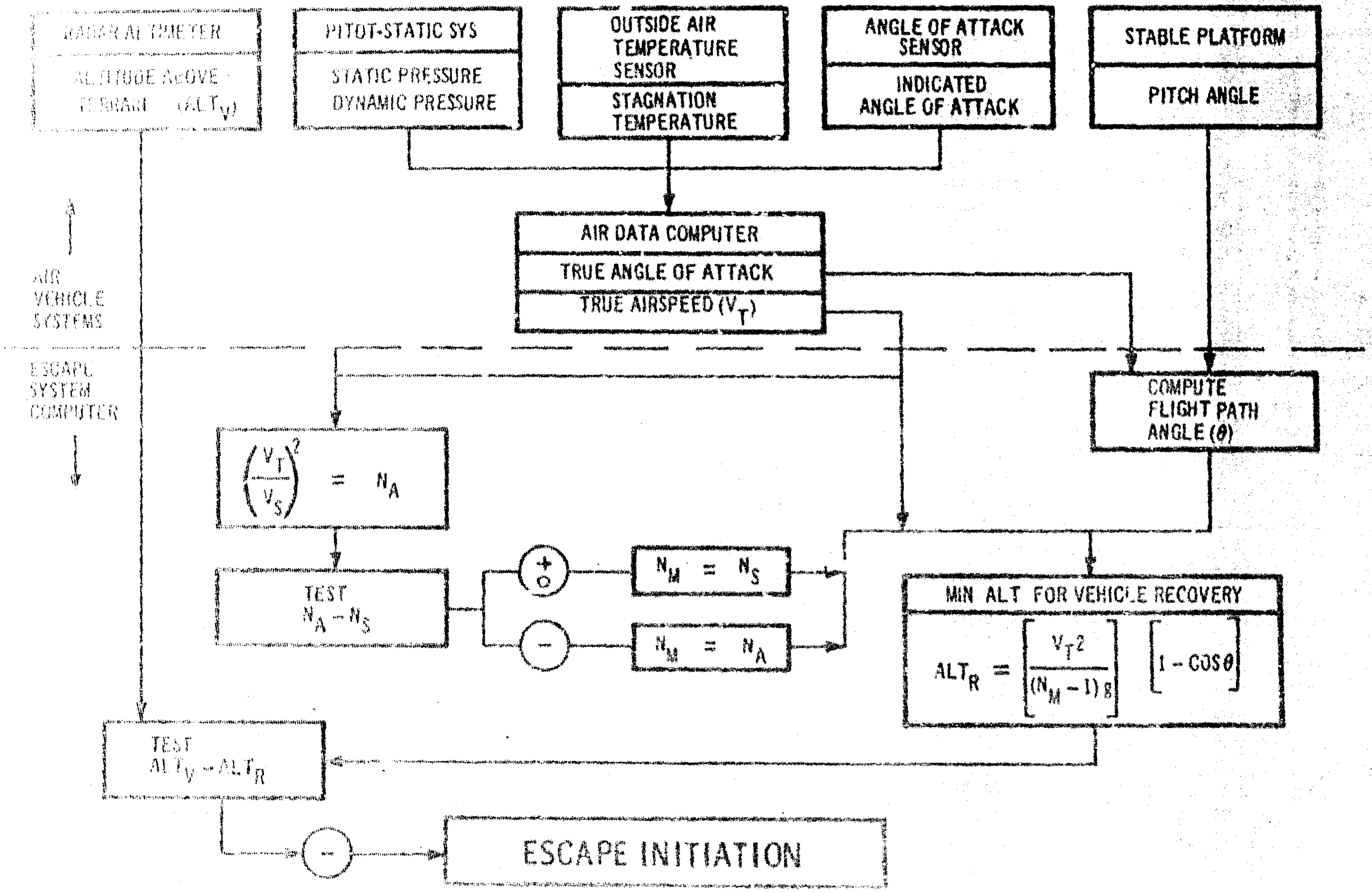


Figure 9. Automatic Escape Initiation System

Definition of Terms for Automatic Escape Initiation Computer:

V_T = Vehicle true airspeed.

V_S = Vehicle stall speed (120 knots for study).

N_A = Approximation of maximum positive load factor capability of vehicle based on aerodynamic lift.

N_S = Maximum positive load factor capability of vehicle based on structural limit (+5g for study).

N_M = N_A or N_S, whichever is less, selected by computer.

θ = Vehicle flight path angle, computed from vehicle pitch angle and true angle of attack.

ALT_R = Minimum altitude above terrain required for vehicle recovery.

ALT_V = Vehicle altitude above terrain.

g = Acceleration due to gravity.

Figures 10 and 11 show the altitude versus dive angle at which the prescribed automatic system would initiate escape for vehicle speeds of Mach 1.2 at sea level and 300 KEAS. Also plotted on the graphs is the predicted altitude needed for successful recovery of the crew with a cockpit capsule escape system. As is apparent from Figure 10, the automatic system would initiate escape at an altitude sufficient for successful escape for an escape situation occurring at a speed of Mach 1.2. However, Figure 11 indicates that the prescribed automatic initiation system would initiate escape at an altitude too low for successful escape at the lower speed of 300 KEAS. Therefore, the prescribed system would not be appropriate for the entire speed range considered. Additional logic could be programed into the escape initiation signal to limit the vehicle speed range during which the automatic escape initiation system would function. This would provide automatic escape only during the hazardous low altitude high speed dash flight regime. Evaluations of automatic escape initiation systems which would be appropriate for other flight regimes or types of emergencies is beyond the scope of this preliminary investigation. However, a more detailed analysis of the need for and benefits of automatic detection and escape initiation is presented in Section V.

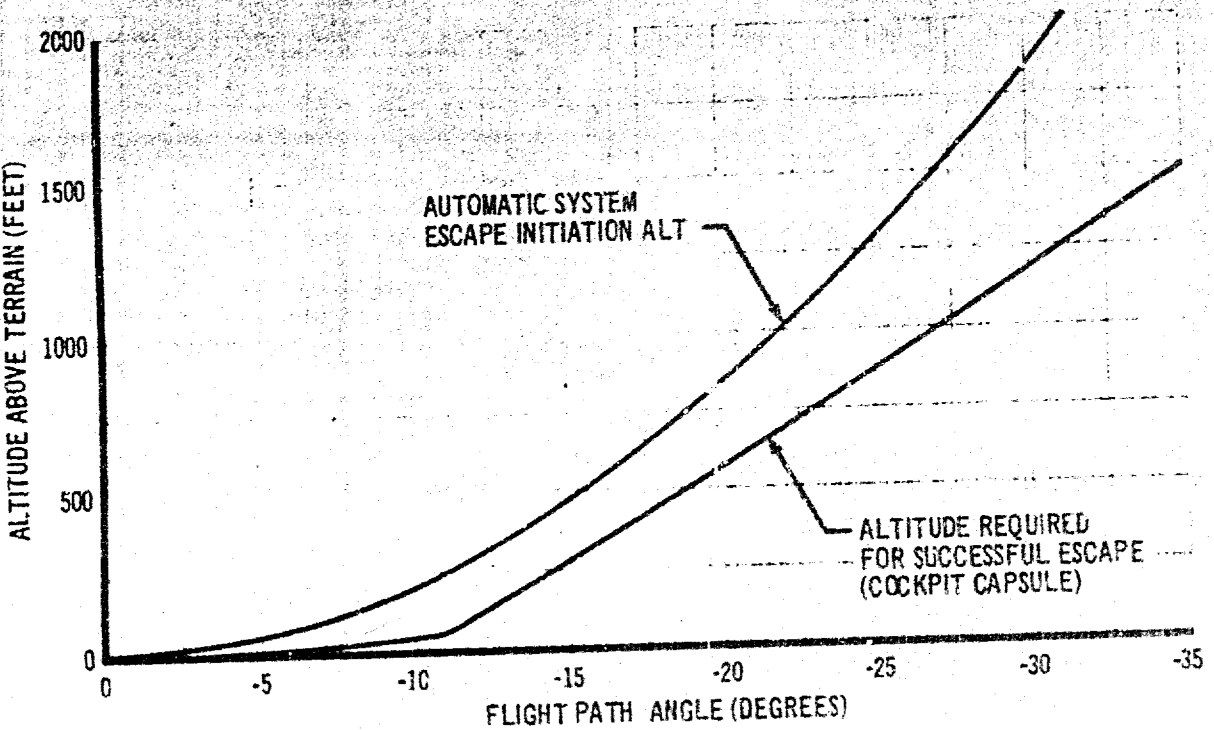


Figure 10. Automatic Escape Initiation Altitude Vs Dive Angle for Vehicle Speed Mach 1.2

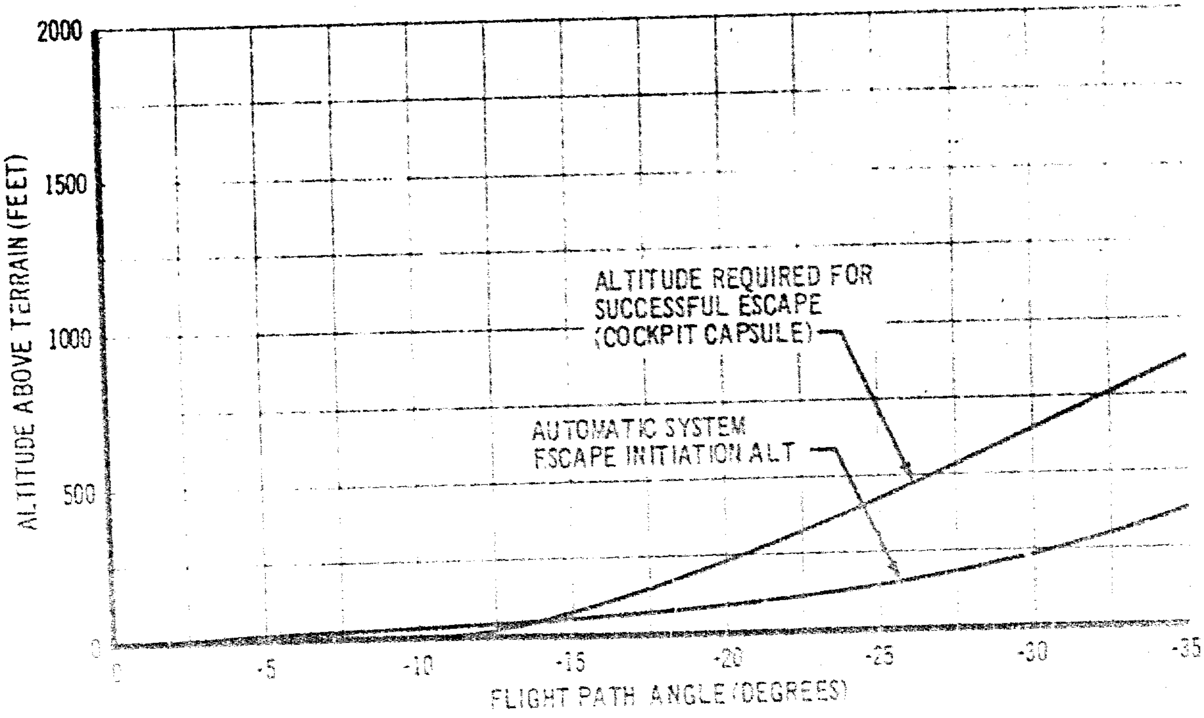


Figure 11. Automatic Escape Initiation Altitude Vs Dive Angle for Vehicle Speed 300 KEAS

SECTION III

ESCAPE CONCEPT/VEHICLE CONFIGURATIONS AND CAPABILITIES

This section describes escape concepts and vehicle configurations, and basic escape concept capabilities for VTOL and supersonic dash vehicles. Three types of vehicles were considered: 1) subsonic VTOL vehicles; 2) supersonic low altitude dash vehicles; and 3) combined capability vehicles having both VTOL and supersonic dash capability. For this study, low-altitude dash capability is defined as the ability of sustained flight at transonic speeds 200 feet above the terrain. Crew size variations of two, three, or four crewmembers were considered for each vehicle. Escape concepts considered are open ejection seats, encapsulated ejection seats, cockpit pod capsules, and separable nose capsules.

Twelve escape concept/vehicle combinations, representative of the range of possible combinations of vehicles, crew size, and escape concepts, were selected for detailed study. The selected combinations are:

Vehicle	Crew Size	Escape Concept
Subsonic VTOL	2-man	Open ejection seat (OES)
Subsonic VTOL	2-man	Encapsulated ejection seat (EES)
Subsonic VTOL	2-man	Cockpit pod capsule (CPC)
Subsonic VTOL	2-man	Separable nose capsule (SNC)
Supersonic dash	4-man	Open ejection seat
Supersonic dash	4-man	Encapsulated ejection seat
Supersonic dash	4-man	Cockpit pod capsule
Supersonic dash	4-man	Separable nose capsule
Combined capability	3-man	Open ejection seat
Combined capability	3-man	Encapsulated ejection seat
Combined capability	3-man	Cockpit pod capsule
Combined capability	3-man	Separable nose capsule

The most effective escape system for each of the twelve representative escape concept/vehicle combinations was established. These systems are defined in terms of refinements and/or projections of current systems and preliminary designs of advanced systems. The most suitable subsystems for each application were selected and incorporated into particular designs. Subsystem considerations included functional adequacy, complexity, weight, cost, and developmental status. Preliminary design drawings are presented to show escape equipment installation requirements and typical crew compartment arrangements. System operation and time sequence is defined by schematic drawings and written descriptions.

A three-degrees-of-freedom digital computer program was used to optimize escape configuration parameters (such as boost rocket or catapult thrust, thrust angle, thrust excentricity, stabilization, deceleration and recovery parachute sizes, event timing sequence, etc.) to give maximum escape capability. The computer program also was used to compute performance of the final escape systems. The program is capable of computing horizontal and vertical travel and pitch rotation for escapes utilizing any of the escape concepts considered herein. Program inputs include: aerodynamic force and moment characteristics from wind tunnel tests; boost rocket thrust characteristics; deployment, filling, and drag characteristics of stabilization, deceleration, and recovery parachutes; timing and system sequence data; geometry and mass data; and airplane flight conditions at initiation of the escape sequence. Program outputs are printed as a function of elapsed time, and include aerodynamic coefficients and forces of the basic escape vehicle and each parachute, filling times of each parachute, and escape vehicle deceleration, velocity, displacement, pitch angle, angle of attack, and trajectory relative to the airplane. For this study, the most pertinent computer outputs were considered to be travel relative to the ground to establish minimum escape altitudes, and accelerations to define speed limitations of the different escape concepts. Basic capabilities of the escape concepts with respect to speed, descent angles, and altitude are presented in this section. More detailed analyses and evaluation of escape concept effectiveness for various emergency situations and flight regimes are presented in Section V.

1. OPEN EJECTION SEAT CONFIGURATIONS

a. Configurations

The open ejection seat system configurated for this study consists of existing subsystems and those being developed. The system described is considered a feasible configuration and the optimum open ejection seat system operable within established human tolerance limits.

The system was designed to provide safe escape from zero speed to 600 KEAS at ground level and up to 50,000 feet altitude.

Major subsystems and components of the system are: 1) canopy/hatch jettison system; 2) initiation and eject sequence installation; 3) rocket-catapult (5,500 pound average thrust); 4) survival kit; 5) restraint system consisting of lap belt, shoulder harness and a ballistic powered inertia reel; 6) directional automatic realignment of trajectory (DART) system; and 7) drogue gun deployed 5-foot diameter stabilization/deceleration parachute and a 29.7-foot diameter Skysail recovery parachute. The seat also has screw-type electromechanical actuators for vertical, fore and aft, and tilt adjustments. The maximum horizontal and vertical travel is approximately three and five inches respectively, and the seat can be tilted through a maximum range of ten degrees.

The system is initiated by operation of the arm rest ejection control or the D-ring located on the front of the seat bucket. After initiation, the sequence of operation is completely automatic; however, provisions are made to allow the seat occupant to manually override the events necessary for recovery. When the system is initiated the canopy/hatch is jettisoned and the crewman is automatically positioned and restrained in the seat. After time delays to permit the completion of pre-ejection events and to provide sequenced ejection of the crewmembers, the catapult ignites. As the seat clears the ejection rails, the DART system supplies force to initially stabilize the seat. At rocket burnout, the deceleration/stabilization parachute becomes effective and continues to stabilize and decelerate the seat, allowing deployment of the recovery parachute within minimum elapsed time.

The recovery parachute time delay is established by a speed sensor operated by the airplane pitot-static system when the escape system is initiated. The system event sequence for the high- and low-speed mode of operation for ejections below 15,000 feet is shown in Figure 12. The high-speed mode timing sequence is selected by the speed sensor when ejection is initiated at an airspeed of more than 200 KEAS. If escape is accomplished at high altitude, the man-seat is stabilized and descends to 15,000 feet before separation and deployment of the recovery parachute.

For this study, it was assumed that the airplane escape system would incorporate a command-select sequencing system that would permit the pilot or copilot to eject the entire crew at predetermined intervals.

The two-man subsonic VTOL vehicle cockpit seating arrangement selected for this study is shown in Fig. 13. The tandem arrangement will require the aft seat to clear the airplane 0.5 second before ejecting the forward seat. This time-delay will be sufficient to avoid possible injury, due to rocket-catapult effects, to the aft seat occupant, and will prevent collision and possible parachute entanglement. The above sequence will occur only if escape is initiated by the forward seat occupant. If escape is initiated by the aft seat control, the forward seat may or may not be ejected depending on the position of the command sequence control, which is located in the forward cockpit. The minimum elapsed time from escape initiation until both crewmen clear the airplane is 1.06 seconds.

The three-man combined capability vehicle seating arrangement is shown in Fig. 14. The escape system and command sequence for ejection is similar to the two-man airplane. When the escape system is initiated at the pilot's position, the aft seat is ejected, followed at 0.5 second intervals by the copilot and pilot seats. The minimum elapsed time for the entire crew to clear the airplane is 1.56 seconds after system initiation by the pilot.

The seating arrangement for the four-man supersonic dash vehicle is shown in Fig. 15. In this crew arrangement, escape initiation by the pilot or copilot will automatically eject the entire crew; however, either aft seat can be ejected individually and the pilot can elect to remain with the airplane. The systems function as described above and differ only in the command ejection control. When the escape system is initiated by the pilot, the time required for the entire crew to clear the airplane is 2.06 seconds. The order of ejection is the seat aft of the copilot, the seat aft of the pilot, and the seats of copilot and pilot. By allowing the ejection of the two aft seats before either forward seat, injury due to rocket-catapult blast (pressure and fire) is eliminated.

b. Performance

The dynamic performance of the open ejection seats was analyzed for each vehicle for speeds from zero to 600 KEAS. The calculated trajectories shown in Figures 16, 17 and 18 for the two-, three- and four-man vehicles indicates that after ground level ejections during level flight at speeds from zero to 600 KEAS, all crewmembers would be recovered well above the ground. The trajectories shown are for the last man to be ejected in the command sequence modes as defined in the preceding paragraphs and include the time spent in the aircraft prior to seat/airplane separation for pre-separation functions and ejection sequence time delays. Escape sequence initiation occurs at the origin of the graphs and the time lapse from initiation until the last man clears the aircraft is 1.06 seconds for the two-man vehicle, 1.56 seconds for the three-man vehicle, and 2.06 seconds for the four-man vehicle.

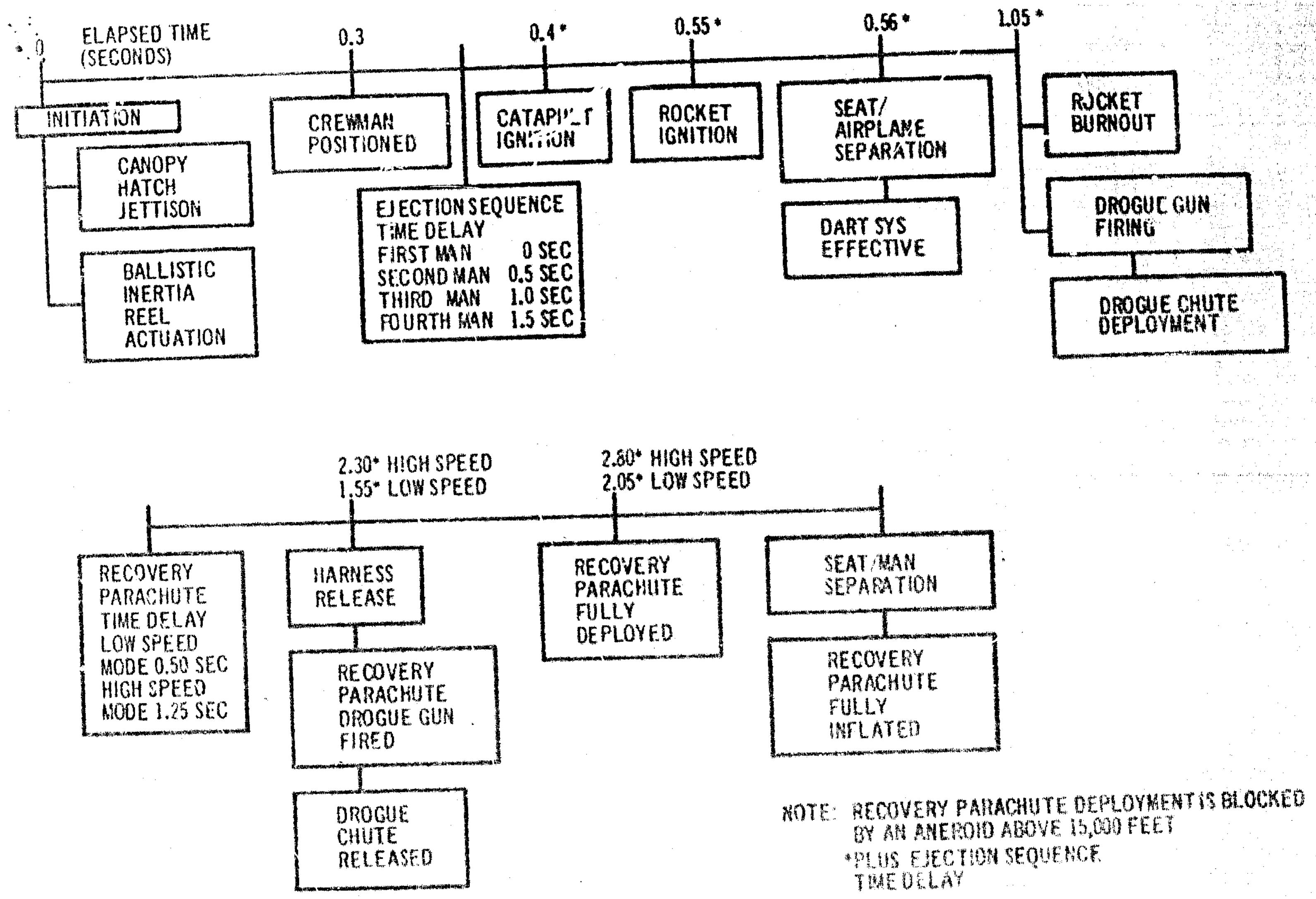
Figures 19 through 24 show the open ejection seat trajectories for escape during diving flight at 200 and 600 KEAS for each vehicle. These data are also for the last man to be ejected in the command sequence and include pre-separation functions and sequence time delays.

Figures 25, 26, and 27 show, for each vehicle, the altitude at which the escape sequence must be initiated for successful recovery of the entire crew versus airplane dive angle for various airspeeds.

A computer plot of the horizontal and vertical accelerations imposed on the crewman during escape at an airspeed of 600 KEAS at 15,000 feet is shown in Fig. 28. The parachute system deployment time sequence and parachute sizes were established to provide a maximum deceleration of 30g on the crewman during ejections occurring up to 600 KEAS. For 600 KEAS ejections at lower altitudes, the timing sequence results in a more rapid velocity decay and in lower deceleration loads when the recovery parachute deploys. See Fig. 29. The maximum peak g experienced during escapes from zero to 600 KEAS is shown in Fig. 30. Due to the low-speed event time sequence, the deceleration loads imposed during a 200 KEAS ejection approach the generally accepted human tolerance limits.

c. Weight Penalty

Table I shows the weight breakdown for the open ejection seat escape concept. Weight penalties shown for the two-, three-, and four-man vehicles include the ejection seat installations, plus escape hatches, less the weight of basic nonejection seats.



NOTE: RECOVERY PARACHUTE DEPLOYMENT IS BLOCKED
BY AN ANEROID ABOVE 15,000 FEET
*PLUS EJECTION SEQUENCE
TIME DELAY

Figure 12. Block Diagram – Open Ejection Seat Event Sequence

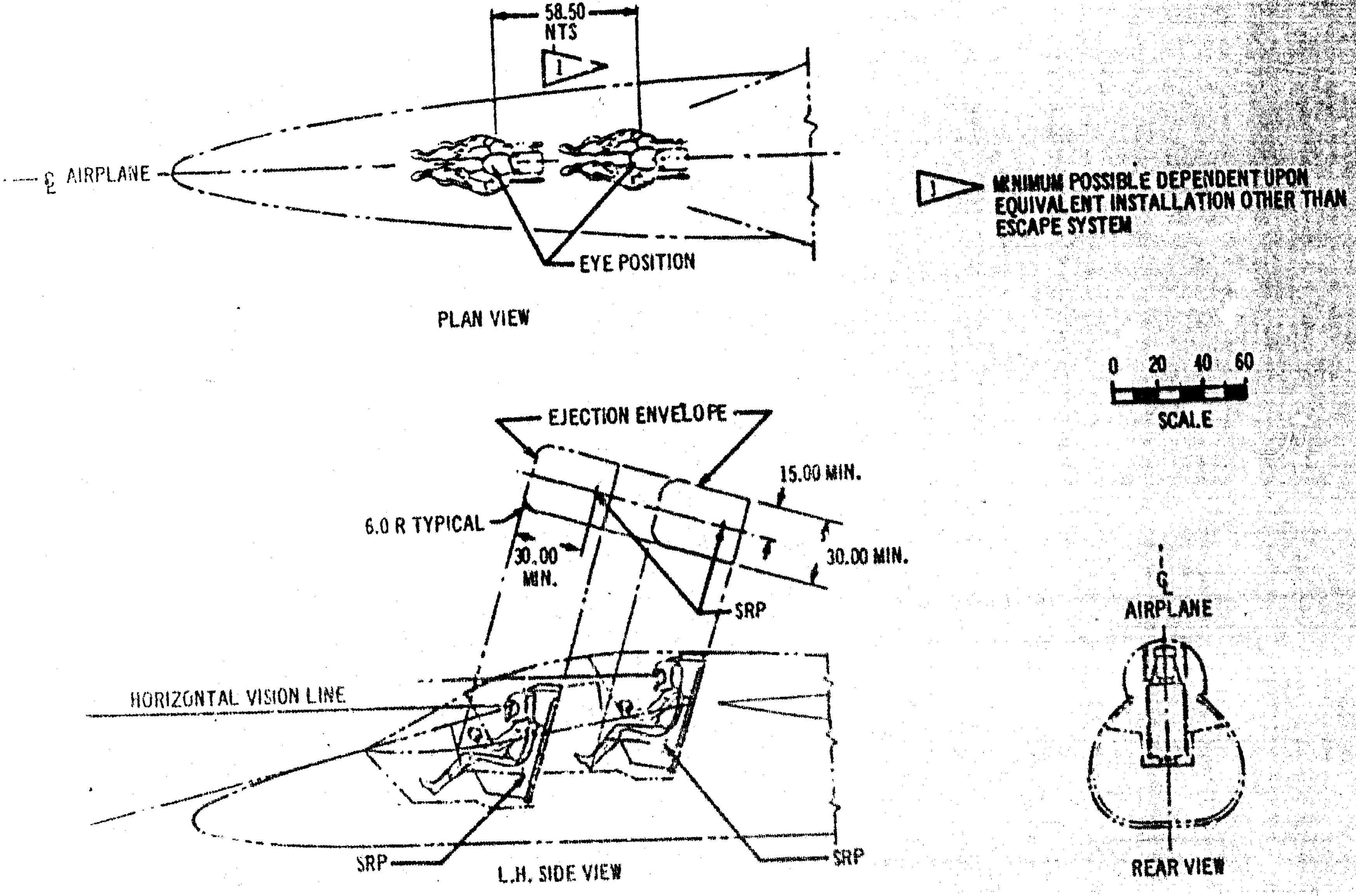


Figure 13. Two-Man Subsonic VTOL Vehicle Open Ejection Seat Configuration

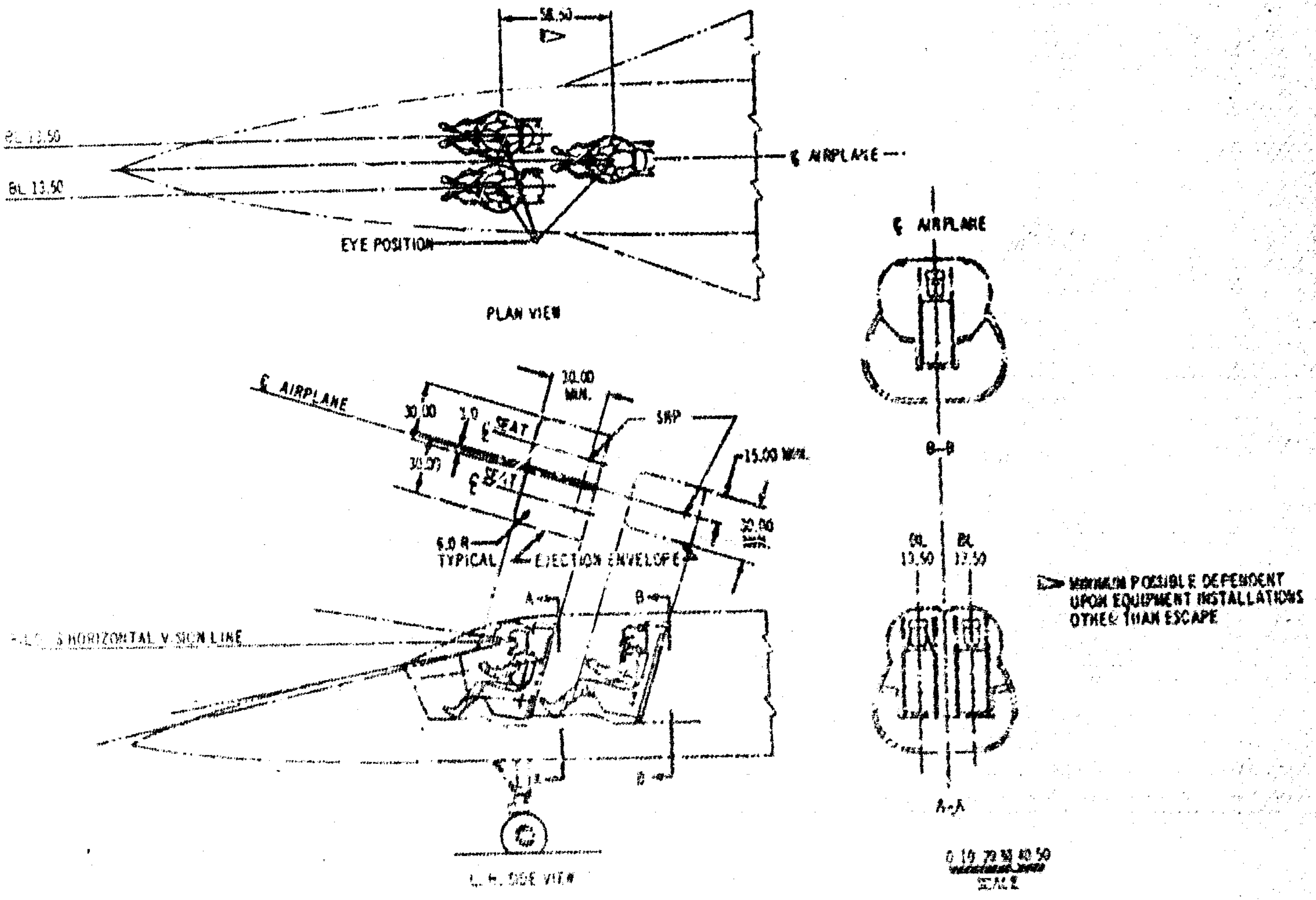


Figure 14. Three-Man Combined Capability Vehicle Open Ejection Seat Configuration

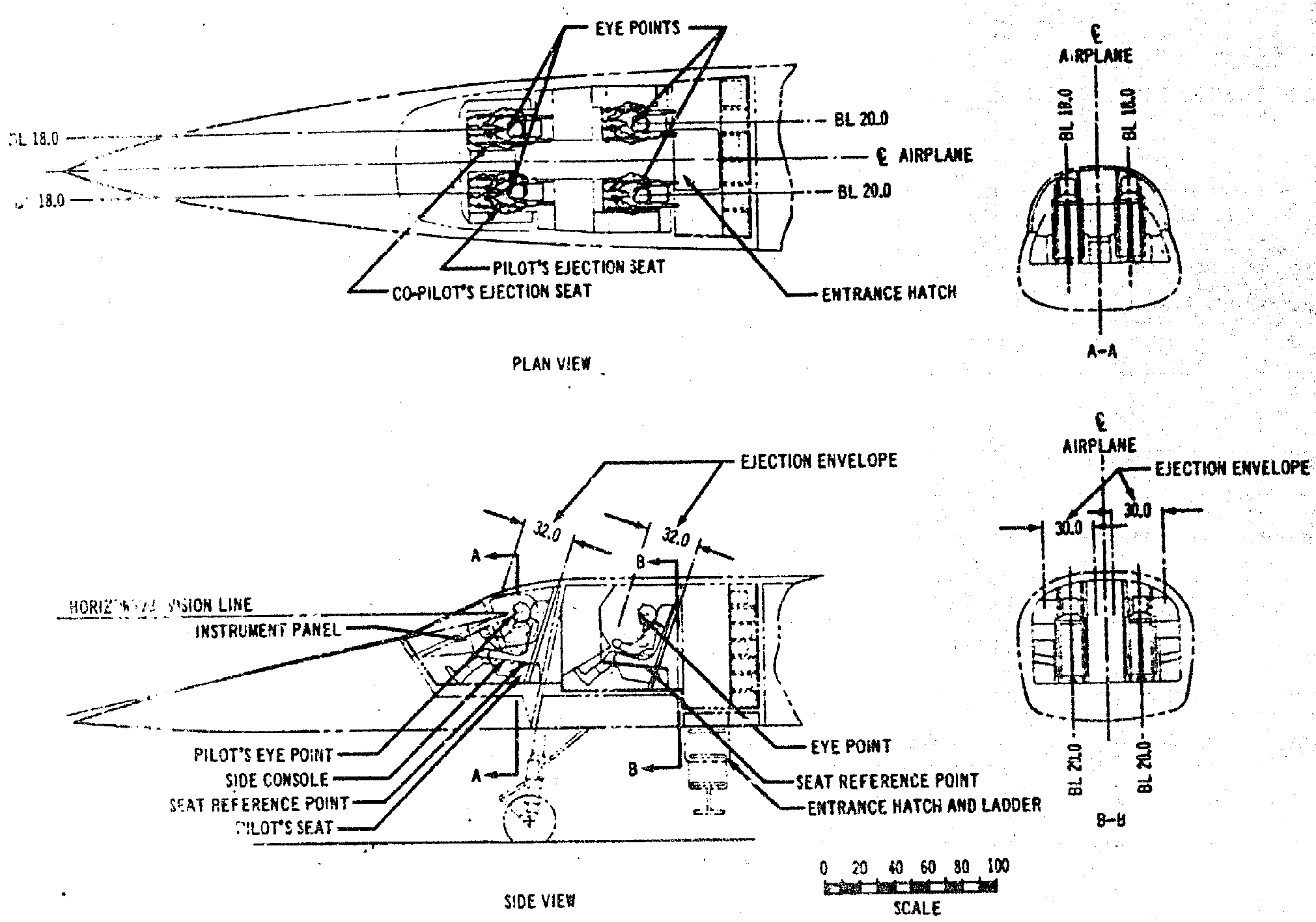


Figure 15. Four-Man Supersonic Dash Vehicle Open Ejection Seat Configuration

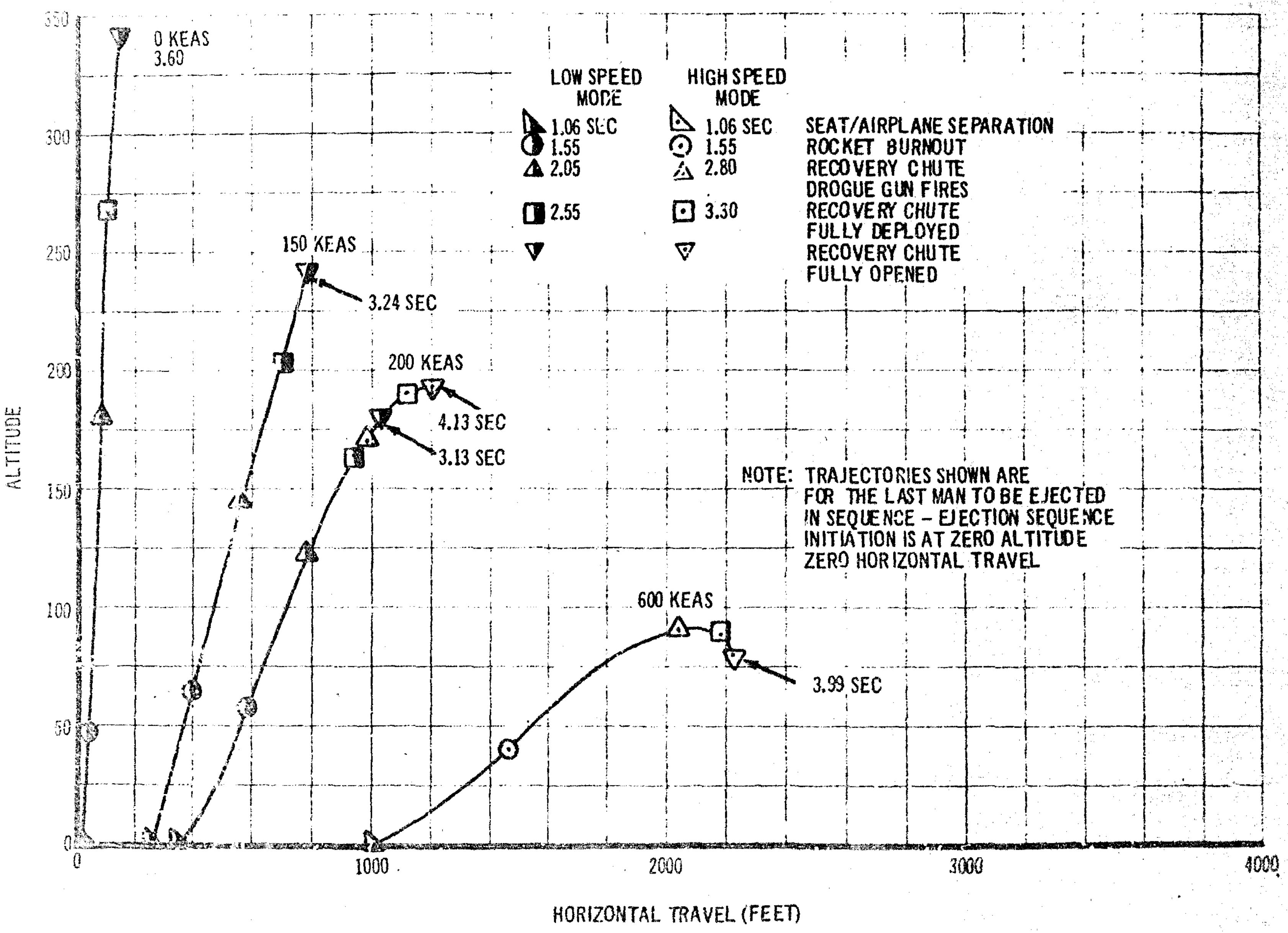


Figure 16. Two-Man Vehicle Open Ejection Seat Level Flight Trajectories

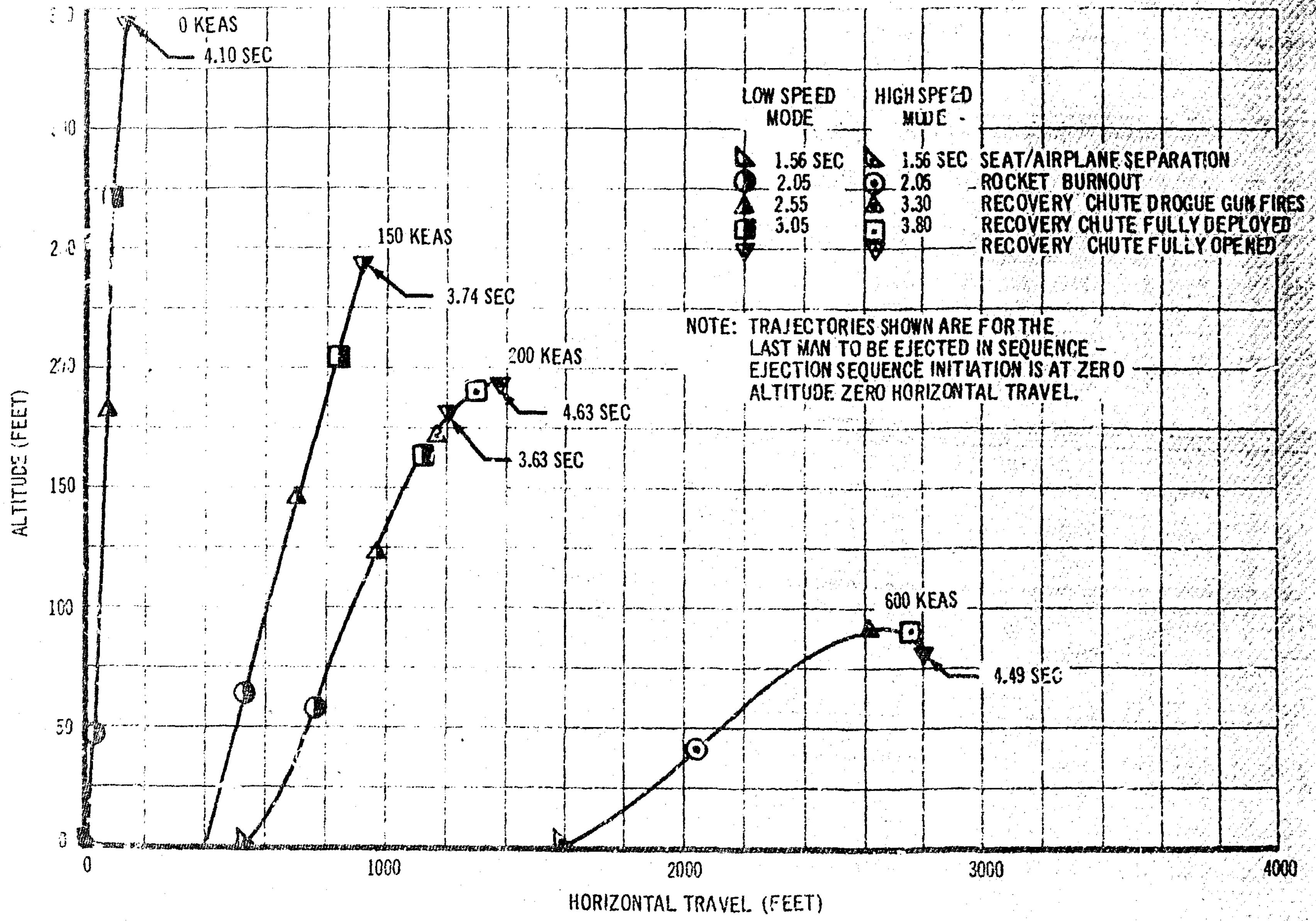


Figure 17. Three-Man Vehicle Open Ejection Seat Level Flight Trajectories

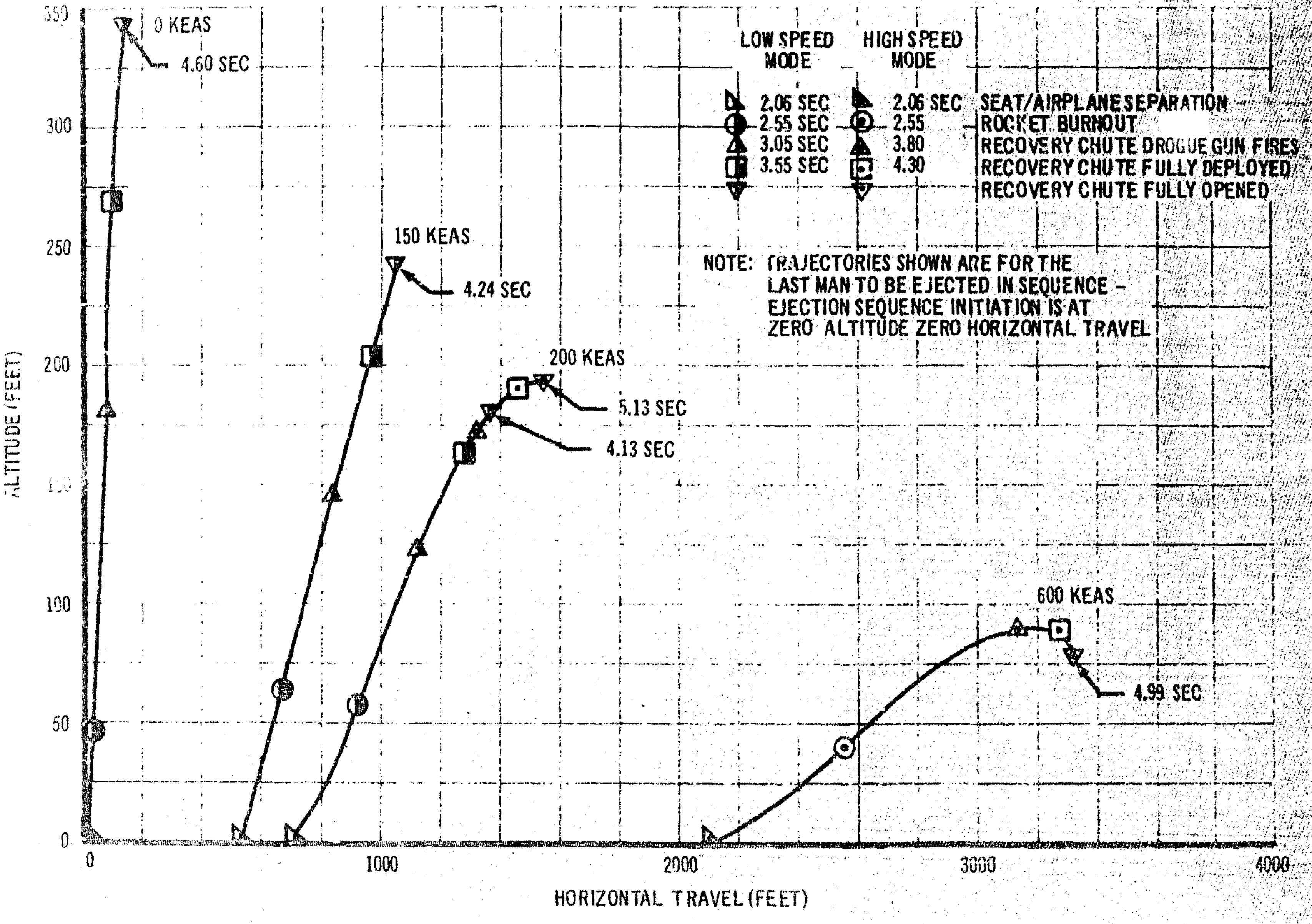


Figure 18. Four-Man Vehicle Open Ejection Seat Level Flight Trajectories

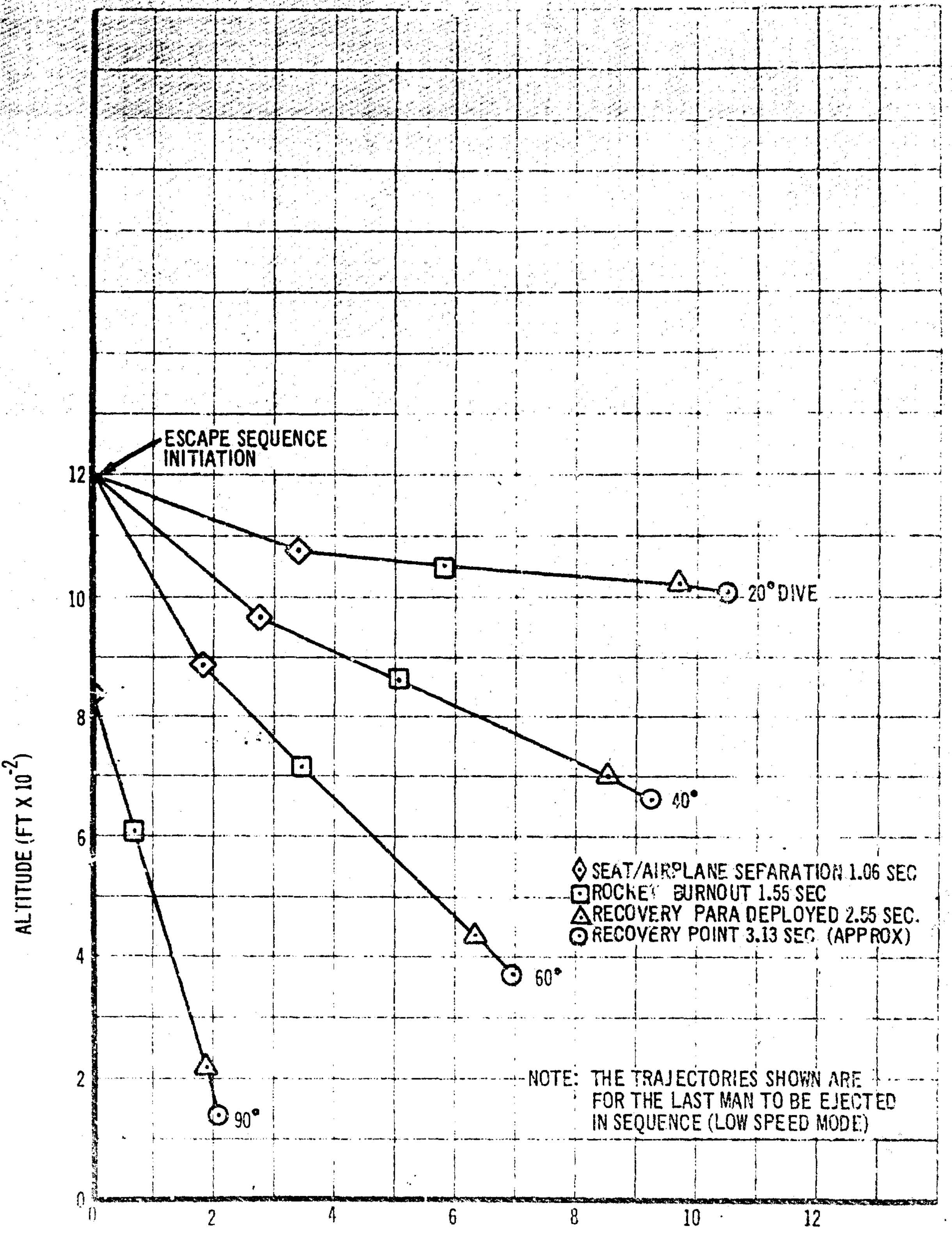


Figure 19. Two-Man Vehicle Open Ejection Seat Dive Trajectories, 200 Knots

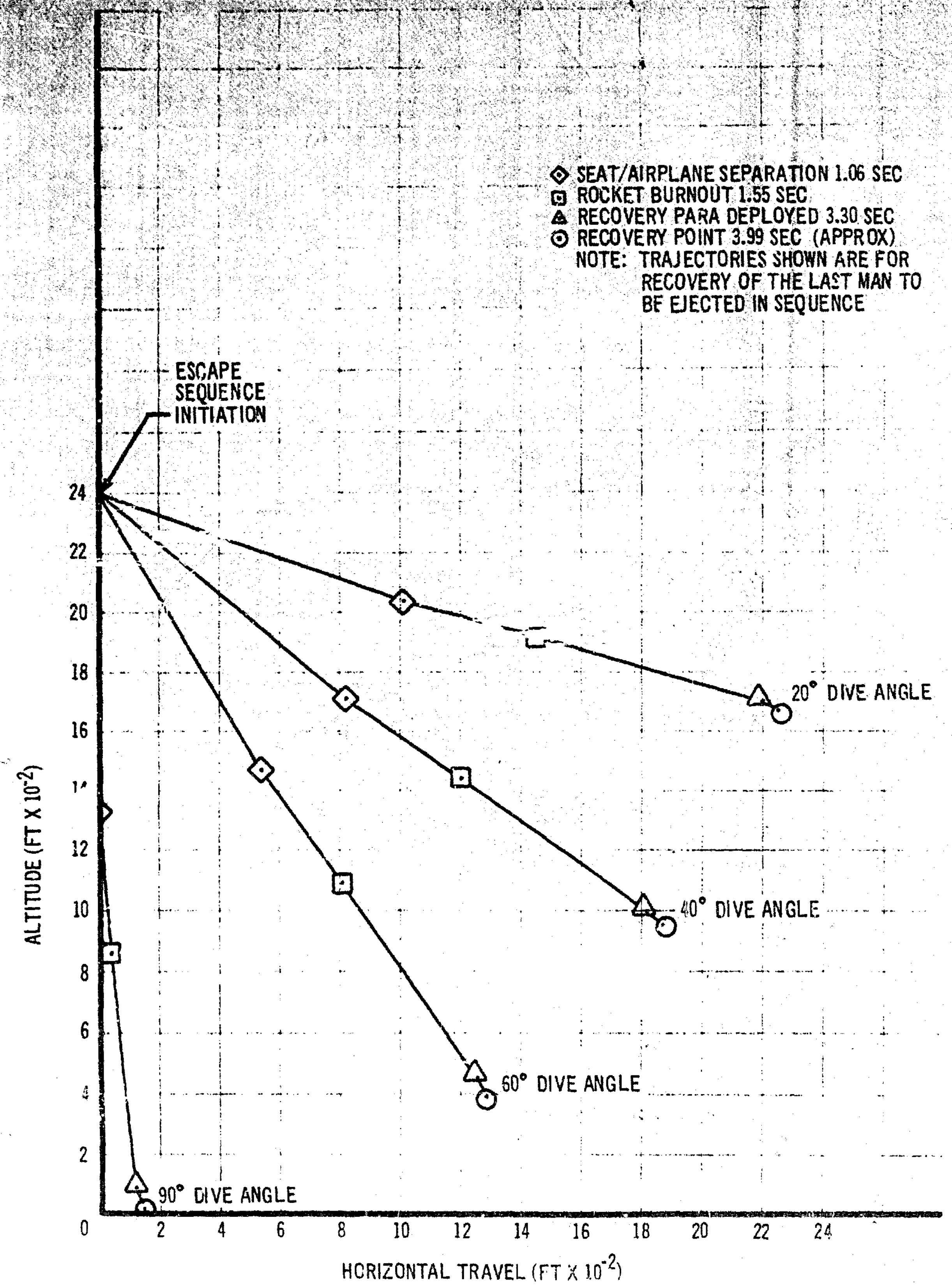


Figure 20. Two-Man Vehicle Open Ejection Seat Dive Trajectories, 600 Knots

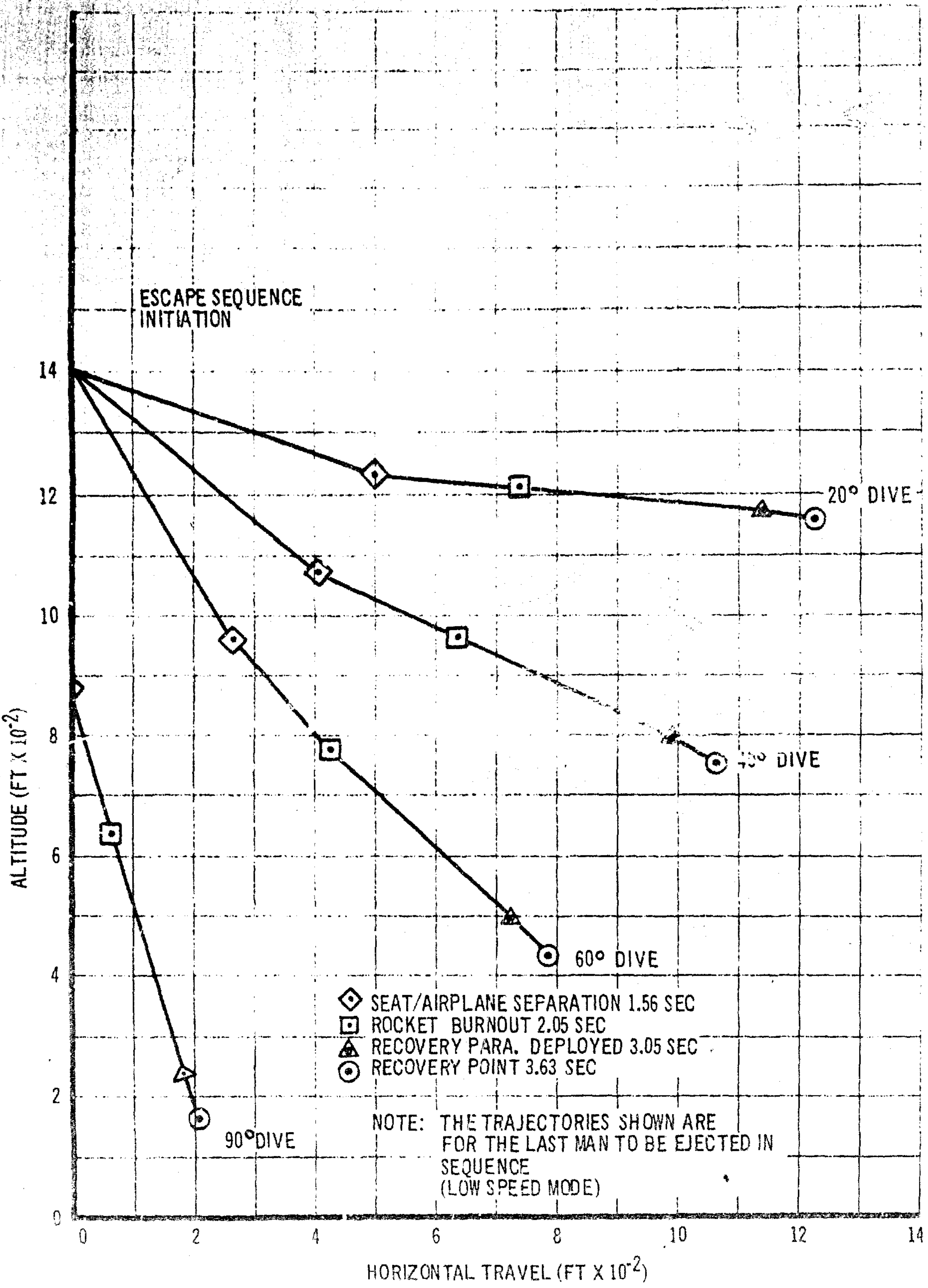


Figure 21. Three-Man Vehicle Open Ejection Seat Dive Trajectories, 200 Knots

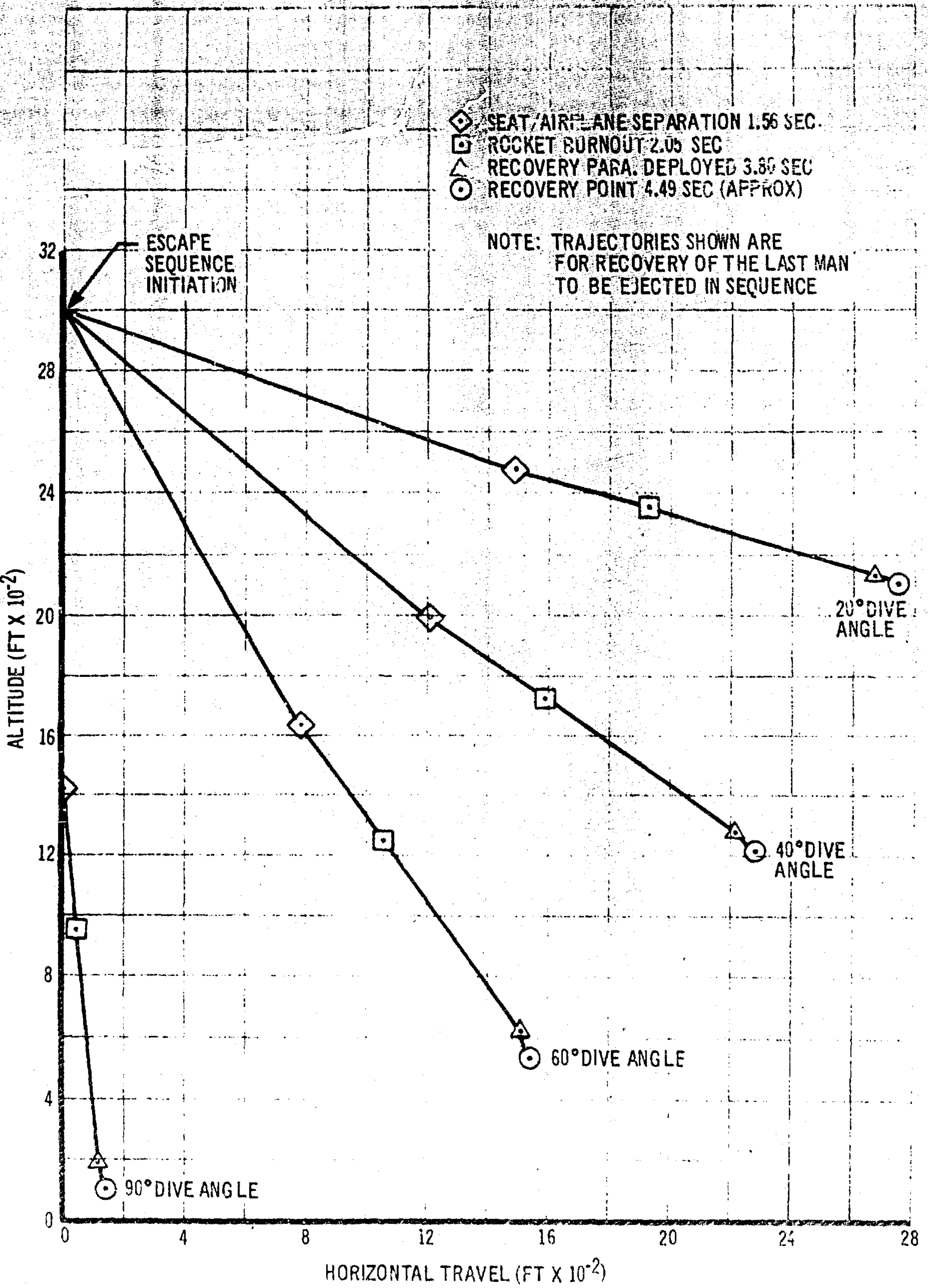


Figure 22. Three-Man Vehicle Open Ejection Seat Dive Trajectories, 600 Knots

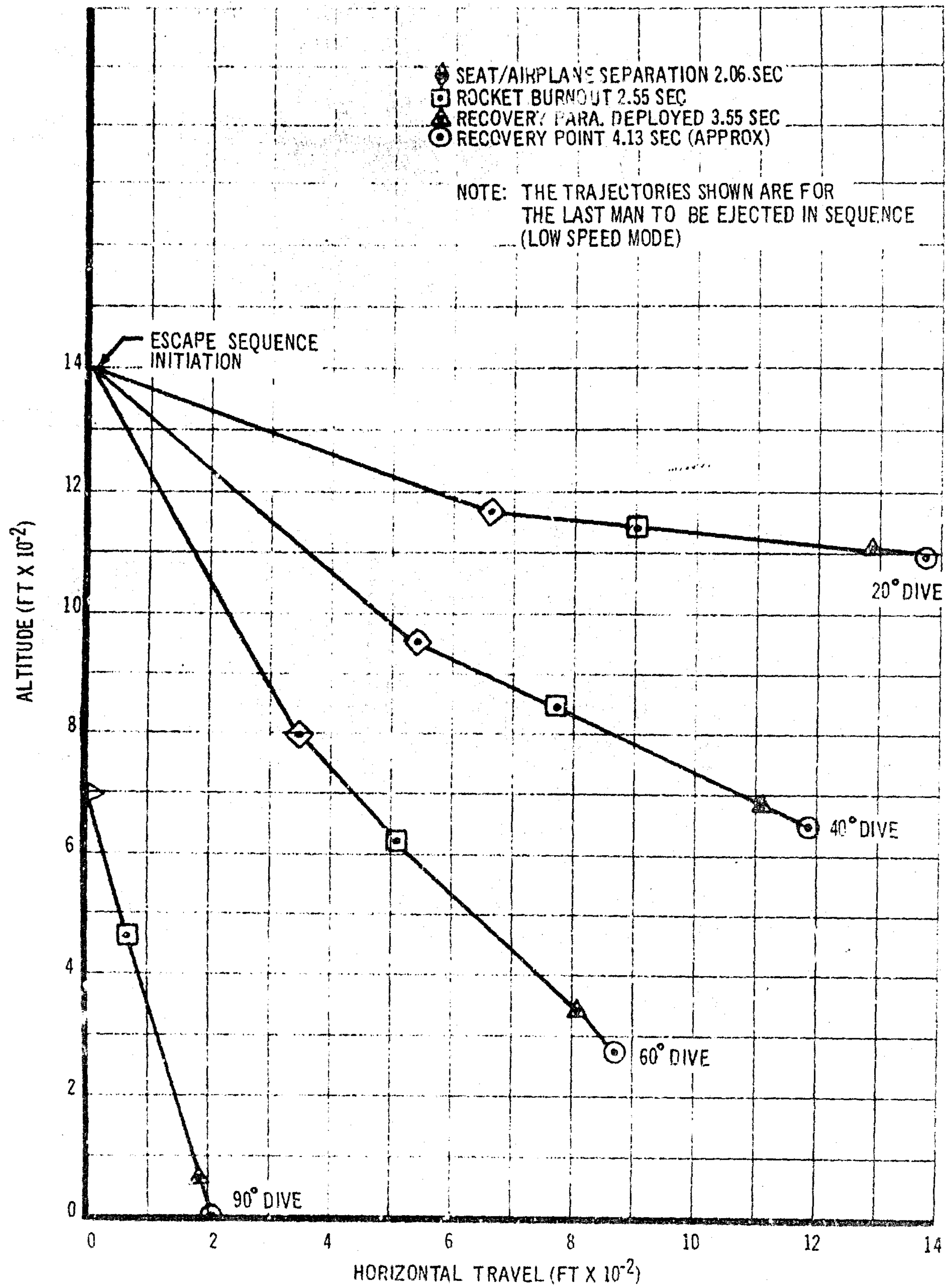
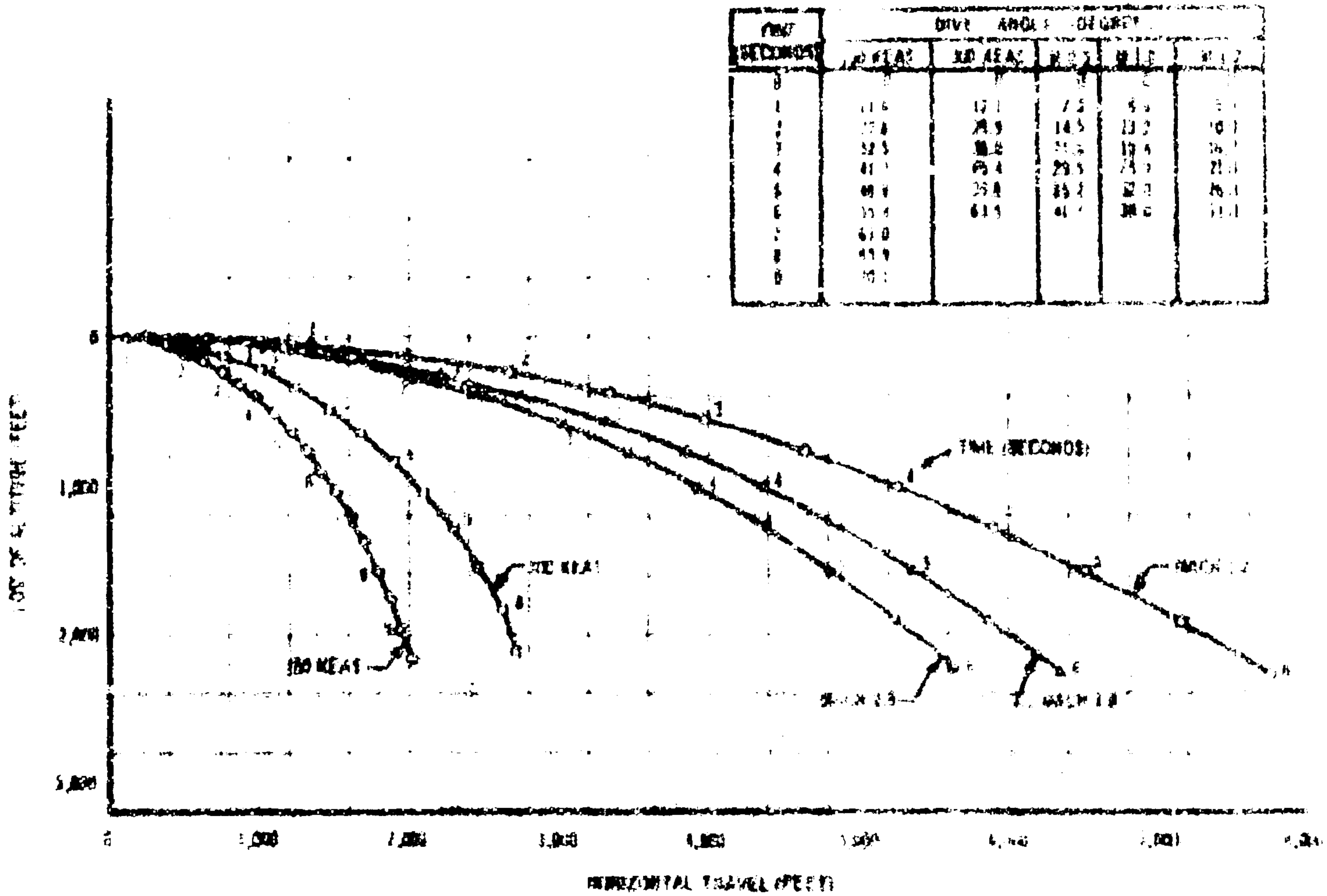


Figure 23. Four-Man Vehicle Open Ejection Seat Dive Trajectories, 200 Knots



TIME (SECONDS)	DIVE ANGLE - DEGREE				
	180 KEAS	300 KEAS	M 0.9	M 1.0	M 1.2
0	0	0	0	0	0
1	11.6	15.1	7.5	5.5	[illegible]
2	[illegible]	28.9	14.5	13.2	10.1
3	32.5	[illegible]	[illegible]	19.6	[illegible]
4	41.[illegible]	45.4	29.5	[illegible]	21.[illegible]
5	49.9	[illegible]	35.2	32.0	26.[illegible]
6	[illegible]	61.5	41.[illegible]	38.6	31.1
7	61.0				
8	65.9				
9	70.1				

Figure 7. Airplane Trajectories for Pushover at Sea Level

manual ejection [illegible] of assisting the survivor [illegible] means to prevent capture by the enemy, and communication through [illegible] of means signalling and locating devices to facilitate location of survivors during rescue operations.

c. Emergency Pressurization and Breathing Atmosphere

A survivable pressure level and breathing atmosphere must be maintained by either mechanical backup systems or pressure suit during inflight emergencies such as ejection, cabin depressurization, or oxygen system failure.

Emergency pressurization and oxygen must be provided to operate automatically and be capable of providing a survivable pressure level and breathing oxygen during escape and descent from the maximum altitude capability of the vehicle. Emergency pressurization also must be provided to protect the crewmember in the event of primary pressurization failure when emergency escape from the aircraft is not mandatory.

A system must be incorporated to actuate emergency pressurization that is separate and independent of [illegible] pressure regulator.

d. Restraint

Adequate restraint during flight, emergency escape, and crash landing must be provided.

The head, limbs, and torso must be supported and restrained from any movement which could cause injury during aircraft launching, normal flight involving high accelerations, uncontrolled flight, crash landing, and throughout an emergency escape operation.

Restraint must be adequate to resist the combined forces of deceleration, tumbling, and windblast that could be experienced under the most severe escape conditions.

The restraint system must be capable of integrating into a "shirt-sleeve" environment and must not appreciably compromise crew comfort, efficiency, or effectiveness, and must be manually adjustable to suit individual requirements. It must be automatic during adverse acceleration load conditions and during the escape sequence. Simultaneous release of all restraints must be accomplished by a single action (manual and automatic), and must provide for ingress to and egress from the seat without assistance and with a minimum of motions. It must be easy to operate, lightweight, and allow freedom of movement when restraint is not required.

e. Crew Comfort and Efficiency

A comfortable and livable environment must be achieved for optimum efficiency and effectiveness of the aircrew throughout the performance envelope of the vehicle. The aircrew must be relieved of as many [illegible] encumbrances as possible, and minimum restrictions must be imposed by the escape system on efficient use of cockpit space, and so as to allow the aircrew to operate all [illegible] provide for adequate cushioning [illegible] maximum comfort and [illegible]

Crew Compartment Integration

The escape system must be designed to be completely integrated and compatible with the design of the parent aircraft, must not compromise the aircrew station nor the operator's function, and must not adversely affect the performance or mission capability of the aircraft.

The integrity of the parent aircraft must not be penalized by the addition of emergency escape capabilities within the crew compartment. Escape system space requirements must be minimized to provide for greater flexibility of displays and controls location and arrangement, and must allow for location of controls and instrument consoles that are compatible with arm reach requirements of 5 to 95 percentile crewmen. The maximum practicable vision must be provided for crewmembers.

2. AUTOMATIC DETECTION AND ESCAPE INITIATION

The primary cause of unsuccessful utilization of escape systems in current aircraft is the failure of the crewmember to actuate the escape system in time for successful recovery prior to ground impact. This will become even more critical for the hazardous flight conditions of future VTOL and low-altitude dash vehicles.

Airplane trajectories for maximum hard nose-over from low-level flight are shown in Fig. 5 for a -3g structural limit at Mach 0.9, 1.0, and 1.2, and an aerodynamic capability limit of -2.5g at 300 KEAS and -0.8g at 150 KEAS. This illustrates limiting conditions from which escape might be required for a representative low-altitude dash vehicle. The 1.4-second time line represents the time required for a crewmember to sense the emergency (0.16 seconds), decide to escape (1.0 seconds), and actuate the escape system (0.25 seconds). These times are based on trained personnel, simple stimulus, simple decision alternatives, and negligible delay attributed to mental duress. Under actual emergency conditions the human reaction time is expected to be significantly greater. As illustrated, the time required for human initiation of the escape system precludes the possibility of successful escape for a maximum hard nose-over emergency occurring at the prescribed vehicle dash capability of transonic speeds at 200 feet above the terrain. For even significantly less severe low-altitude dash emergencies, it is extremely unlikely that a crewman would be capable of actuating the escape system in time to effect successful escape. Examination of the escape conditions for the VTOL vehicle (Figs. 4 and 5) reveals that escape initiation time for the vertical takeoff and landing emergencies is also extremely critical. For emergencies occurring within 300 feet of the ground, human reaction time would essentially preclude the possibility of successful escape. At slightly higher altitudes, escape must be initiated in a timely manner to preclude the possibility of escape initiation at an undesirable attitude.

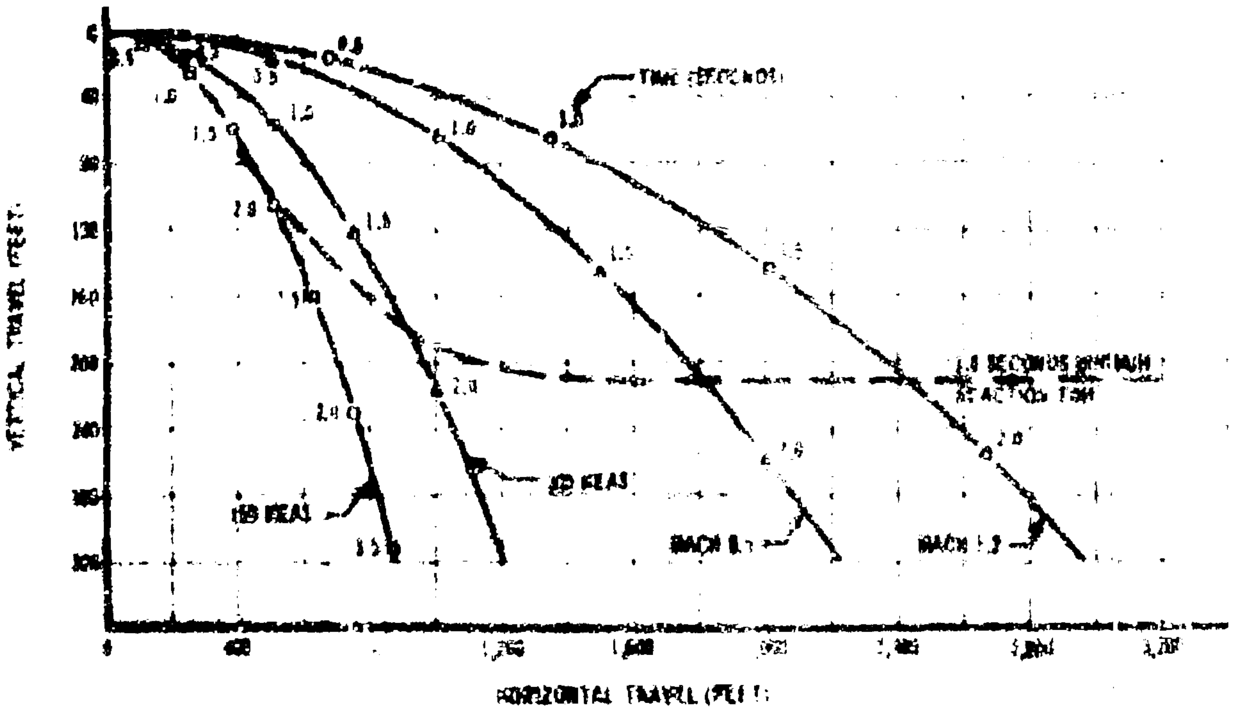


Figure 8. Airplane Trajectories for Hard Pushover Maneuvers

[illegible] This system was [illegible] such a system. Figure 3 is a block diagram of the air vehicle systems required for data input for the flight reaction for the escape initiation computer. For this initial investigation, the escape variables were limited to vehicle speed, altitude, and dive angle. Automatic escape initiation is signalled at the time the [illegible] flight factors indicate that the vehicle has reached a nonrecoverable flight condition.

Vehicle systems required for making measurements of airspeed and height above terrain are provided in military airplanes by an air data computer and radar altimeter. The measurements of dive angle is more restricted in the sense that flight instruments, such as the artificial horizon, yield approximate values for display to the pilot, as precise as is needed for an output to other systems. A measurement of dive angle can be provided for use by the other systems only in airplanes equipped with a stable reference. This measurement is achieved by an algebraic combination of the pitch angle from the pitch reference and the true angle of attack from the air data computer.

Functionally, the air data computer requires input data from the pitot-static system, outside air temperature sensor, and the angle of attack sensor. The measured air data, static pressure, dynamic pressure, stagnation temperature, and indicated angle of attack are used by the computer in solving standard air data equations. This computer is generally an analog mechanization and, typically, furnishes calculated values of Mach number, true airspeed, indicated airspeed, and air density ratio for display to the pilot or use by other systems. For the application outlined the indicated airspeed, true angle of attack, and air density ratio are obtainable with maximum errors of ±1.5 knots, ±0.1 degree, and ±1%, respectively.

The radar altimeter is a special-purpose radar using fixed antennas to provide a measure of the range to the nearest terrain. The simplest and most accurate radar altimeters are pulse-type radars. The radar altitude is obtained by measuring the time delay between the transmitted pulse and the pulse reflected into the receiving antenna by the terrain below the airplane. At low altitude the accuracy is a function of the pulse width and altitude, being typically 50 ±0.01H feet, where H is the altitude to be measured.

Stable platforms are generally restricted to use in airplanes using a complex weapon delivery system, stability augmentation or inertial navigation systems. The stable reference is obtained by the use of gyros and a gimbal system. The gyros maintain a vertical reference, and, as the aircraft pitches or rolls, the gimbals make it possible to measure the magnitude of the excursion about the pitch and roll axes. The accuracy of measuring the pitch angle is typically to within three to five minutes of arc.

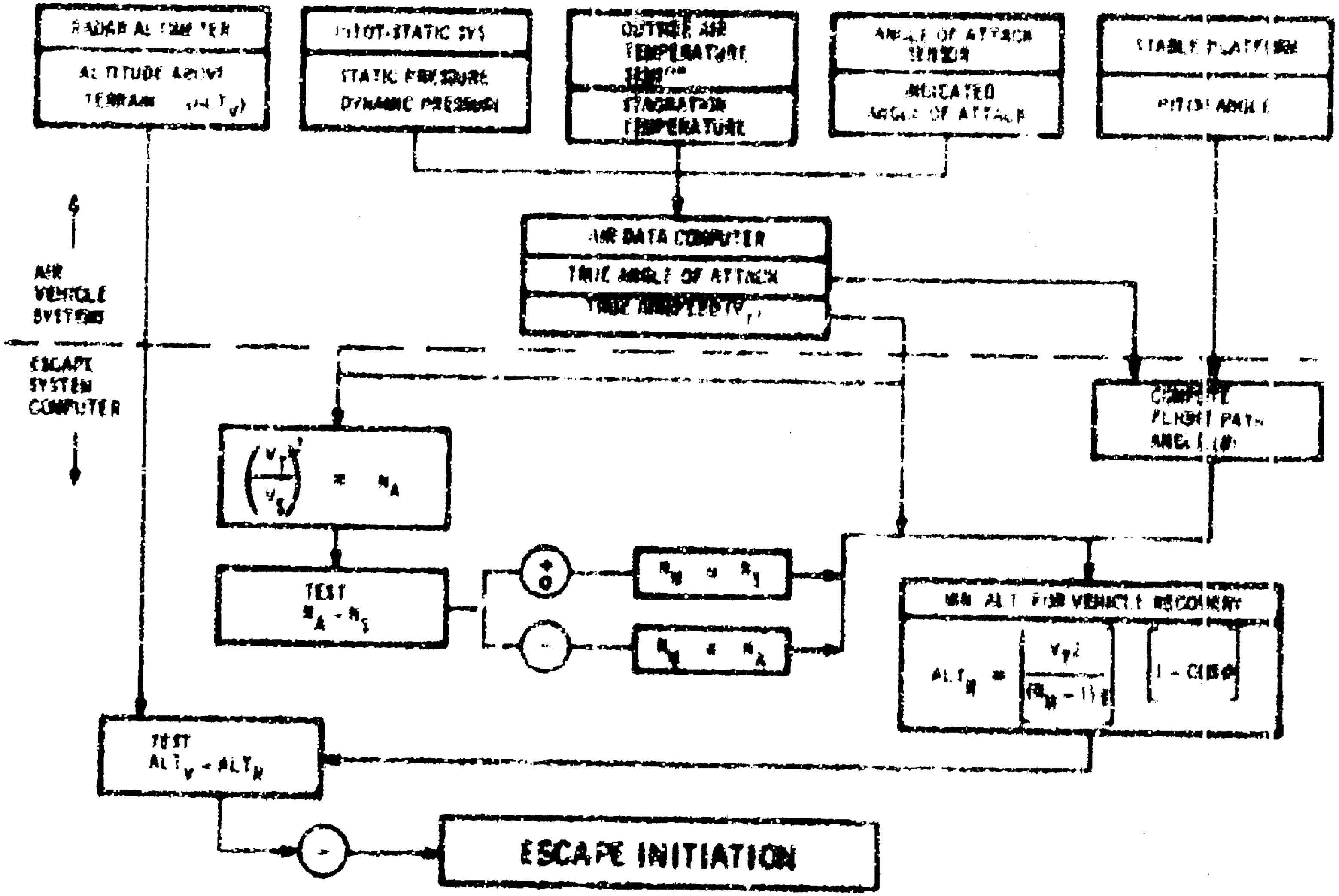


Figure 9. Automatic Escape Initiation System

Definition of Terms for Automatic Escape Initiation Computer

V_T	Vehicle true airspeed.
V_S	Vehicle stall speed (1[illegible] knots for study).
N_A	= Approximation of maximum positive load factor capability of vehicle based on aerodynamic lift.
N_S	Maximum positive load factor capability of vehicle based on structural limit (8g for study).
N_M	N_A or N_S whichever is less, selected by computer.
γ	= Vehicle flight path angle, computed from vehicle pitch angle and true angle of attack.
ALT_R	Minimum altitude above terrain required for vehicle recovery.
ALT_V	Vehicle altitude above terrain.
g	= Acceleration due to gravity.

Figures 10 and 11 show the altitude versus dive angle at which the prescribed automatic system would initiate escape for vehicle speeds of Mach 1.2 at sea level and 300 KEAS. Also plotted on the graphs is the predicted altitude needed for successful recovery of the crew with a zero-zero capable escape system. As is apparent from Figure 10, the automatic system would initiate escape at an altitude sufficient for successful escape for an escape situation occurring at a speed of Mach 1.2. However, Figure 11 indicates that the prescribed automatic initiation system would initiate escape at an altitude too low for successful escape at the lower speed of 300 KEAS. Therefore, the prescribed system would not be appropriate for the entire speed range considered. Additional logic could be programmed into the escape initiation signal to limit the vehicle speed range during which the automatic escape initiation system would function. This would provide automatic escape only during the hazardous low altitude high speed dash flight regime. Evaluations of automatic escape initiation systems which would be appropriate for other flight regimes or types of emergencies is beyond the scope of this preliminary investigation. However, a more detailed analysis of the need for and benefits of automatic detection and escape initiation is presented in Section V.

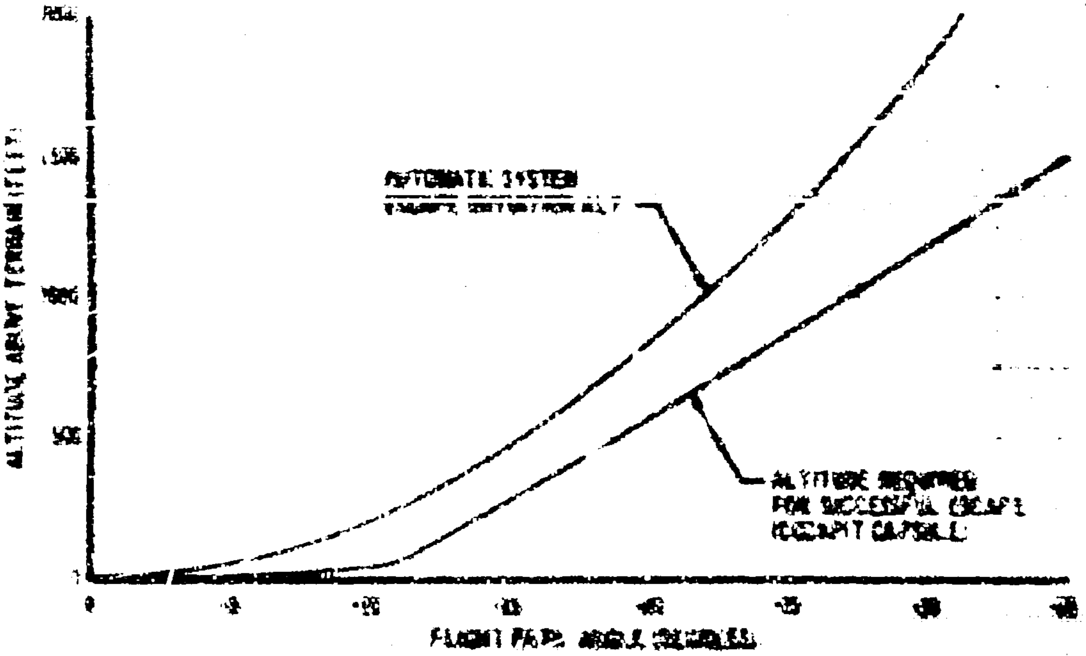


Figure 10. Automatic Escape Initiation Altitude Vs Dive Angle for Vehicle Speed Mach 1.2

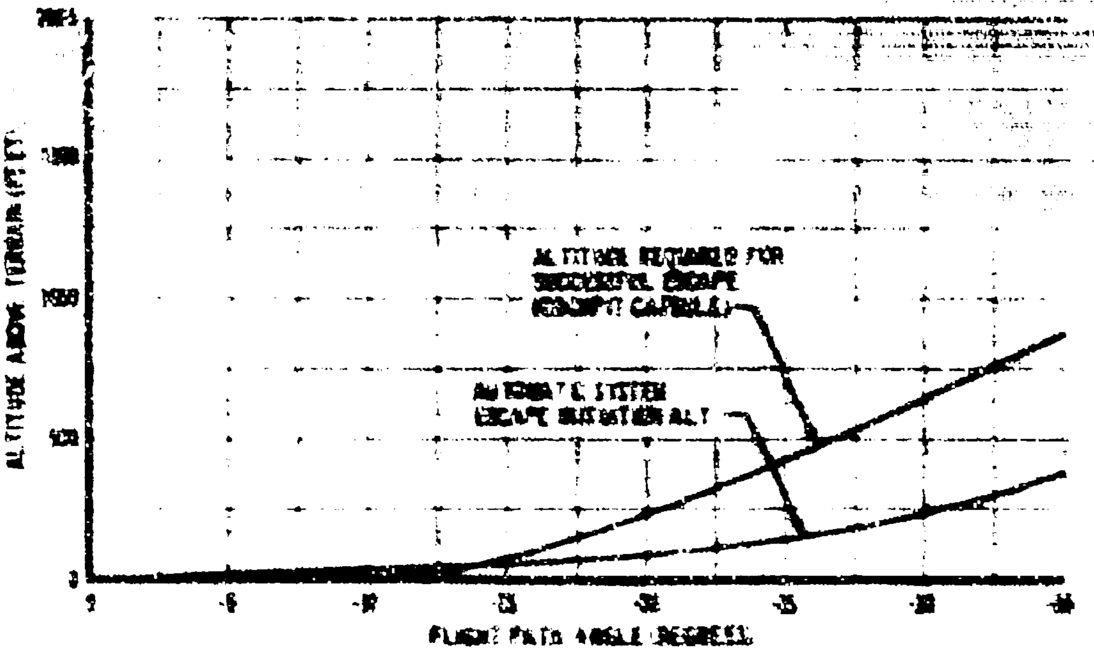


Figure 11. Automatic Escape Initiation Altitude Vs Dive Angle for Vehicle Speed [illegible] KEAS

SECTION III

ESCAPE CONCEPT VEHICLE CONFIGURATIONS AND CAPABILITIES

This section describes escape concepts and vehicle configurations, and basic escape concept capabilities for VTOL and supersonic dash vehicles. Three types of vehicles were considered: 1) subsonic VTOL vehicles, 2) supersonic low altitude dash vehicles, and 3) combined capability vehicles having both VTOL and supersonic dash capability. For this study, low altitude dash capability is defined as the ability of sustained flight at supersonic speeds 200 feet above the terrain. Crew size variations of two, three, or four crewmembers were considered for each vehicle. Escape concepts considered are open ejection seats, encapsulated ejection seats, cockpit pod capsules, and separable nose capsules.

Twelve escape concept vehicle combinations, representative of the range of possible combinations of vehicles, crew size, and escape concepts, were selected for detailed study. The selected combinations are:

Vehicle	Crew Size	Escape Concept
Subsonic VTOL	2-man	Open ejection seat (OES)
Subsonic VTOL	2-man	Encapsulated ejection seat (EES)
Subsonic VTOL	2-man	Cockpit pod capsule (CPC)
Subsonic VTOL	2-man	Separable nose capsule (SNC)
Supersonic dash	4-man	Open ejection seat
Supersonic dash	4-man	Encapsulated ejection seat
Supersonic dash	4-man	Cockpit pod capsule
Supersonic dash	4-man	Separable nose capsule
Combined capability	3-man	Open ejection seat
Combined capability	2-man	Encapsulated ejection seat
Combined capability	3-man	Cockpit pod capsule
Combined capability	3-man	Separable nose capsule

The most effective escape system for each of the twelve representative escape concept vehicle combinations was established. These systems are defined in terms of refinements and/or projections of current systems and preliminary designs of advanced systems. The most suitable subsystems for each application were selected and incorporated into particular designs. Subsystem considerations included functional adequacy, complexity, weight, cost, and developmental status. Preliminary design drawings are presented to show escape equipment installation requirements and typical crew compartment arrangements. System operation and time sequence is defined by schematic drawings and written descriptions.

A three-degrees-of-freedom digital computer program was used to optimize escape configuration parameters (such as basic rocket or catapult thrust, thrust angle, thrust eccentricity, stabilization, deceleration and recovery parachute sizes, event timing sequence, etc.) to give maximum escape capability. The computer program also was used to compute performance of the final escape systems. The program is capable of computing horizontal and vertical travel and pitch rotation for escapes utilizing any of the escape concepts considered herein. Program inputs include: aerodynamic force and moment characteristics from wind tunnel tests, rocket thrust and force curves, deployment, filling and drag characteristics of stabilization, deceleration and recovery parachutes; escape system sequence data; geometry and mass data; and airplane flight conditions at initiation of the escape sequence. Program outputs are printed as a function of elapsed time and include aerodynamic coefficients and forces of the basic escape vehicle and each parachute, filling times of each parachute, and escape vehicle deceleration, velocity, displacement, pitch angle, angle of attack, and trajectory relative to the airplane. For this study, the most pertinent computer outputs were considered to be trajectories relative to the ground to establish minimum escape altitudes, and accelerations to define speed limitations of the different escape concepts. Basic capabilities of the escape concepts with respect to speed, descent angles, and altitude are presented in this section. More detailed analyses and evaluation of escape concept effectiveness for various emergency situations and flight regimes are presented in Section V.

1. OPEN EJECTION SEAT CONFIGURATIONS

a. Configurations

The open ejection seat system configuration for this study consists of existing subsystems and those being developed. The system described is considered a feasible configuration and the optimum open ejection seat system operable within established human tolerance limits.

The system was designed to provide safe escape from zero speed to 600 KEAS at ground level and up to 50,000 feet altitude.

Major subsystems and components of the system are: 1) canopy/hatch jettison system; 2) initiation and eject sequence installation; 3) rocket-catapult (5,500 pound average thrust); 4) survival kit; 5) restraint system consisting of lap belt, shoulder harness and a ballistic powered inertia reel; 6) directional automatic realignment of trajectory (DART) system; and 7) drogue gun deployed 5-foot diameter stabilization/deceleration parachute and a 28.7-foot diameter Skysail recovery parachute. The seat also has screw-type electromechanical actuators for vertical, fore and aft, and tilt adjustments. The maximum horizontal and vertical travel is approximately three and five inches respectively, and the seat can be tilted through a maximum range of ten degrees.

The system is initiated by operation of the arm rest ejection control or the D-ring located on the front of the seat bucket. After initiation, the sequence of operation is completely automatic; however, provisions are made to allow the seat occupant to manually override the events necessary for recovery. When the system is initiated the canopy/hatch is jettisoned and the crewman is automatically positioned and restrained in the seat. After time delays to permit the completion of pre-ejection events and to provide sequenced ejection of the crewmembers, the catapult ignites. As the seat clears the ejection rails, the DART system supplies force to initially stabilize the seat. At rocket burnout the deceleration/stabilization parachute becomes effective and continues to stabilize and decelerate the seat, allowing deployment of the recovery parachute within minimum elapsed time.

[illegible] the airplane [illegible] escape system is initiated. The [illegible] In the high speed mode [illegible] is selected by the speed sensor when ejection is initiated at an airspeed of more than [illegible] KEAS. If escape is not initiated at high altitude, the [illegible] is stabilized and descends to 15,000 feet before separation and deployment of the recovery parachute.

In this study it was assumed that the airplane escape system would incorporate a command select sequencing system that would permit the pilot or copilot to eject the entire crew at predetermined intervals.

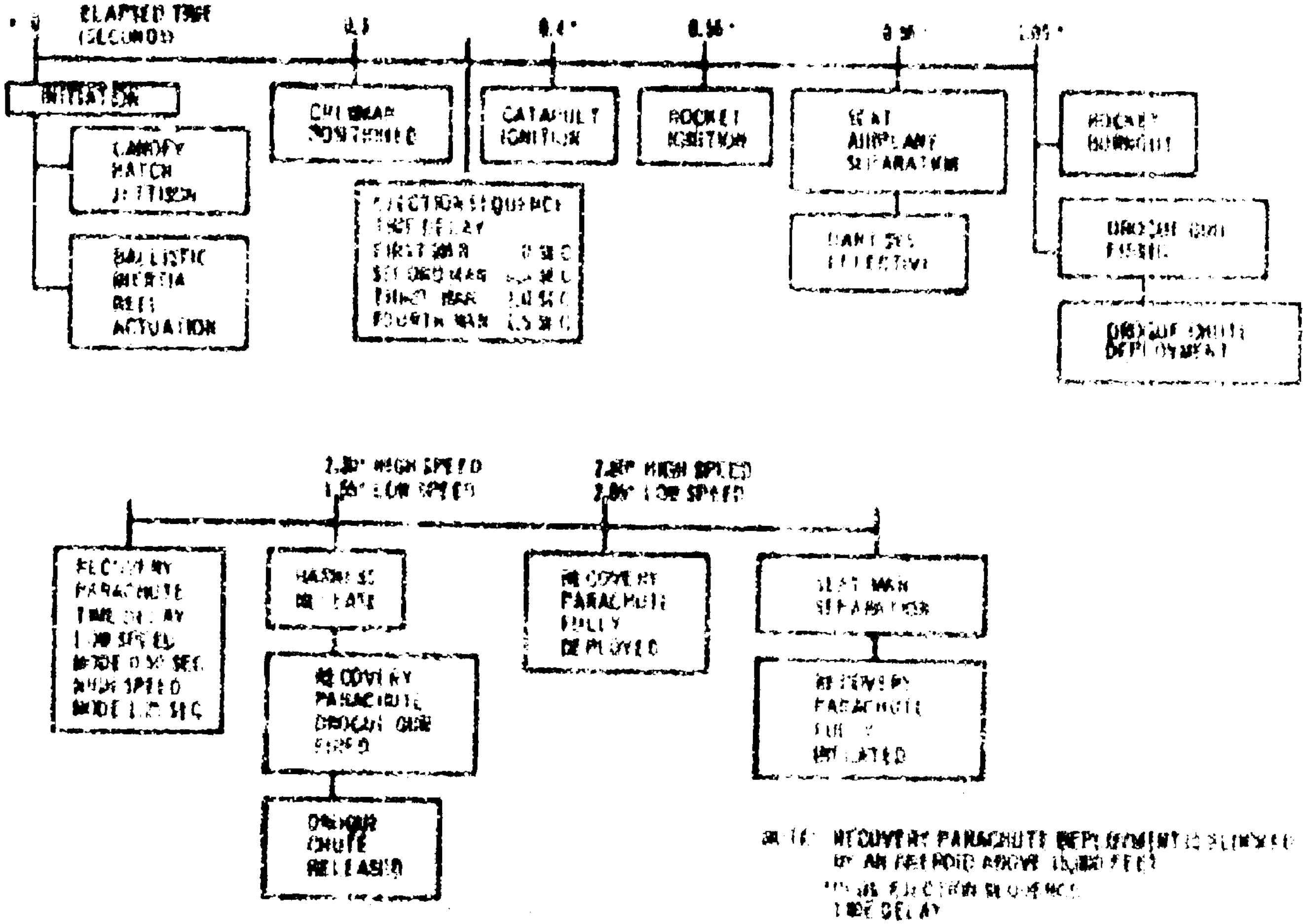
The two-man subsonic VTOL vehicle cockpit seating arrangement selected for this study is shown in Fig. 13. The tandem arrangement will require the aft seat to clear the airplane [illegible] second before ejecting the forward seat. This time delay will be sufficient to avoid possible injury due to rocket-catapult effects to the aft seat occupant and will prevent collision and possible parachute entanglement. The above sequence will occur only if escape is initiated by the forward seat occupant. If escape is initiated by the aft seat occupant, [illegible] depending on the position of the command sequence control, which is located in the forward cockpit. The minimum elapsed time from escape initiation until both crewmen clear the airplane is 1.06 seconds.

The three-man combined repair [illegible] vehicle seating arrangement is shown in Fig. 14. The escape system and command sequence for ejection is similar to the two-man airplane. When the escape system is initiated at the pilot's position, the aft seat is ejected, followed at 0.5 second intervals by the copilot and pilot seats. The minimum elapsed time for the entire crew to clear the airplane is [illegible] seconds after system initiation by the pilot.

The seating arrangement for the four-man supersonic dash vehicle is shown in Fig. 15. In this crew arrangement, escape initiation by the pilot or copilot will automatically eject the entire crew; however, either aft seat can be ejected individually and the pilot can elect to remain with the airplane. The systems function as described above and differ only in the command ejection control. When the escape system is initiated by the pilot, the time required for the entire crew to clear the airplane is 2.06 seconds. The order of ejection is the seat aft of the copilot, the seat aft of the pilot, and the seats of copilot and pilot. By allowing the ejection of the two aft seats before either forward seat, injury due to rocket-catapult blast pressure and fire is eliminated.

b. Performance

The dynamic performance of the open ejection seats was analyzed for each vehicle for speeds from zero to 600 KEAS. The calculated trajectories shown in Figures 16, 17 and 18 for the two-, three- and four-man vehicles indicate that at ground level conditions during level flight at speeds from zero to 600 KEAS all crewmembers would be recovered well above the ground. The trajectories shown are for the last man to be ejected in the



NOTE: RECOVERY PARACHUTE DEPLOYMENT IS DELAYED BY AN ANEROID ABOVE 15,000 FEET

*PLUS EJECTION SEQUENCE TIME DELAY

Figure 12. Block Diagram – Open Ejection Seat Event Sequence

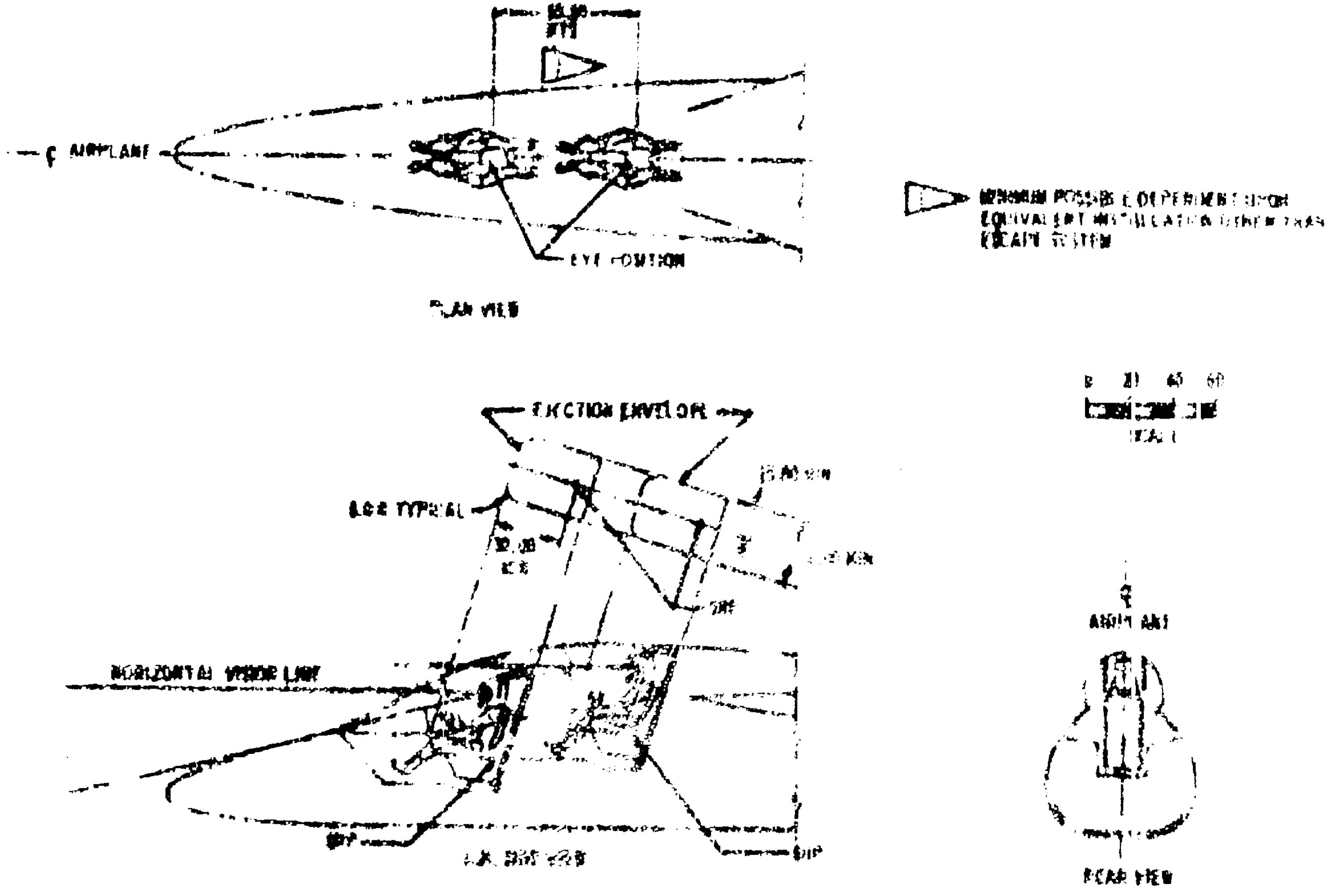


Figure 13. Two-Man Supersonic VTOL Vehicle: Open Ejection Seat Configuration

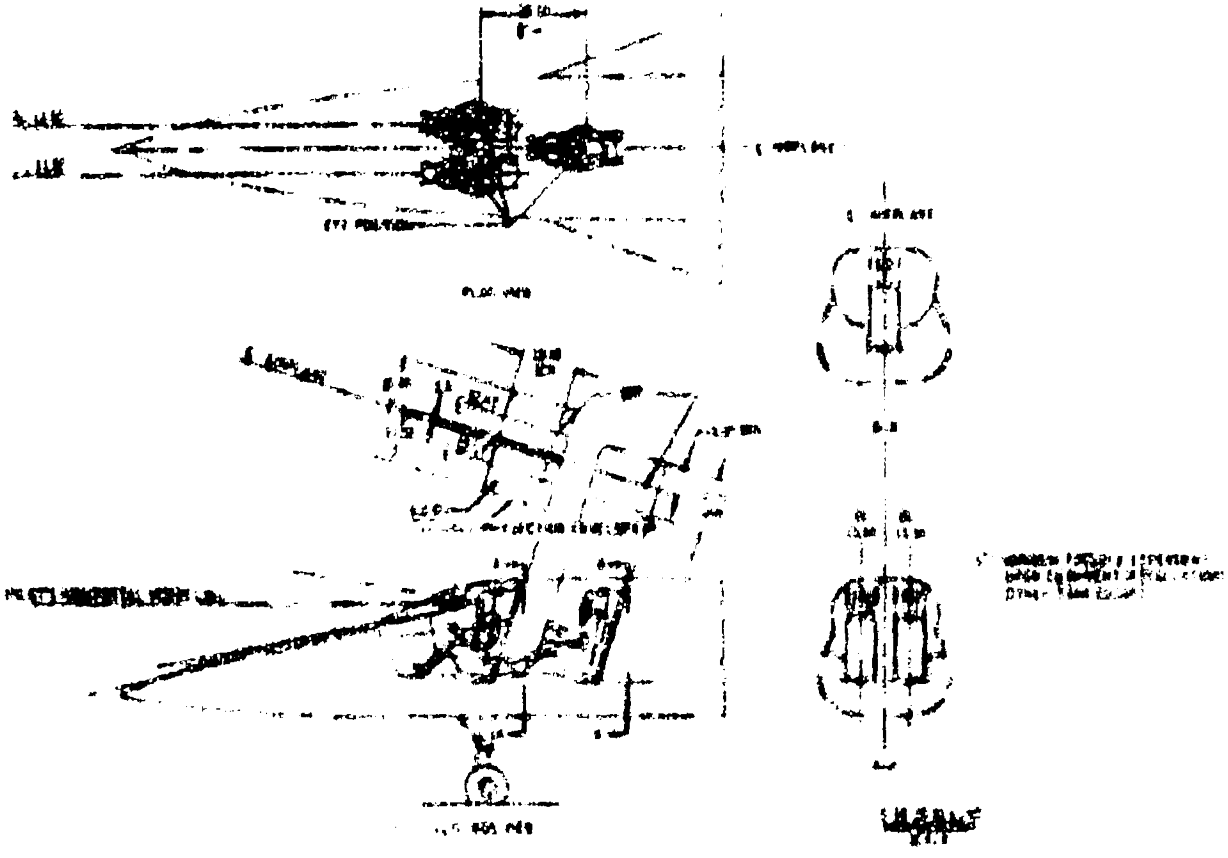


Figure 14. Three-Axis Combined Capability Vehicle Open Ejection Seat Configuration

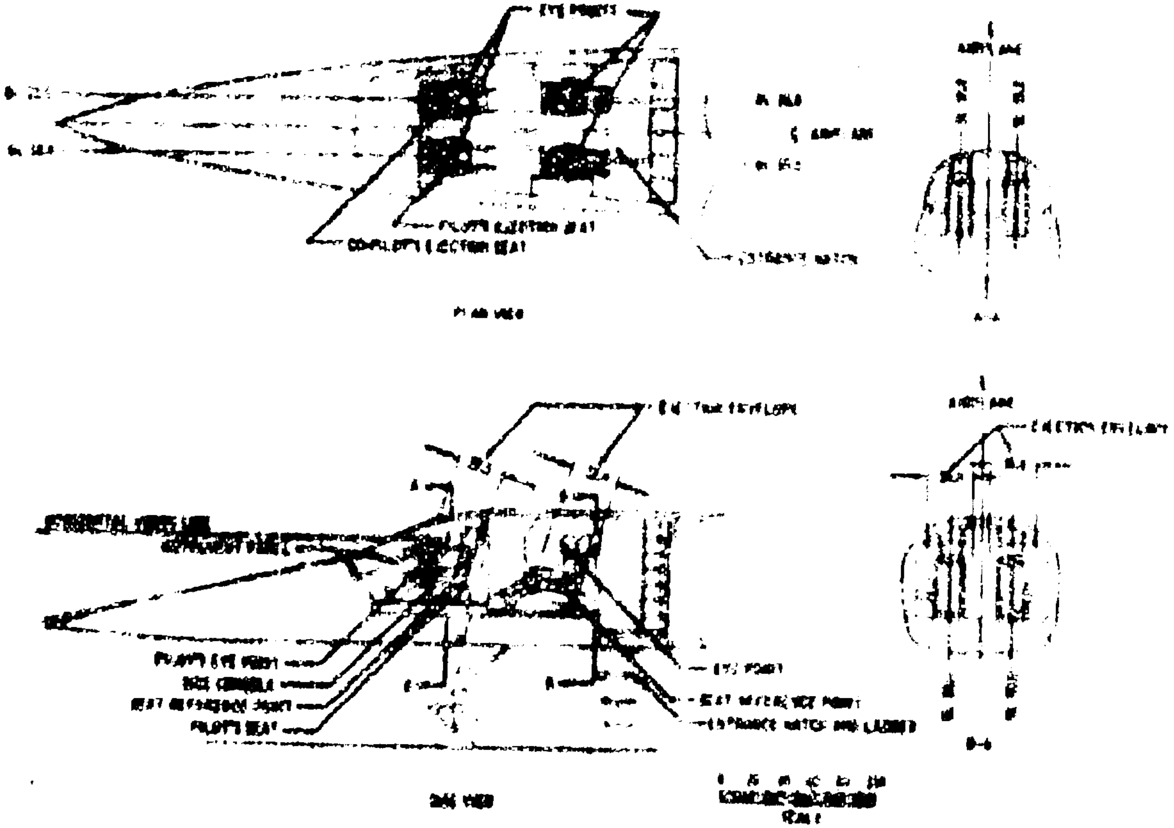
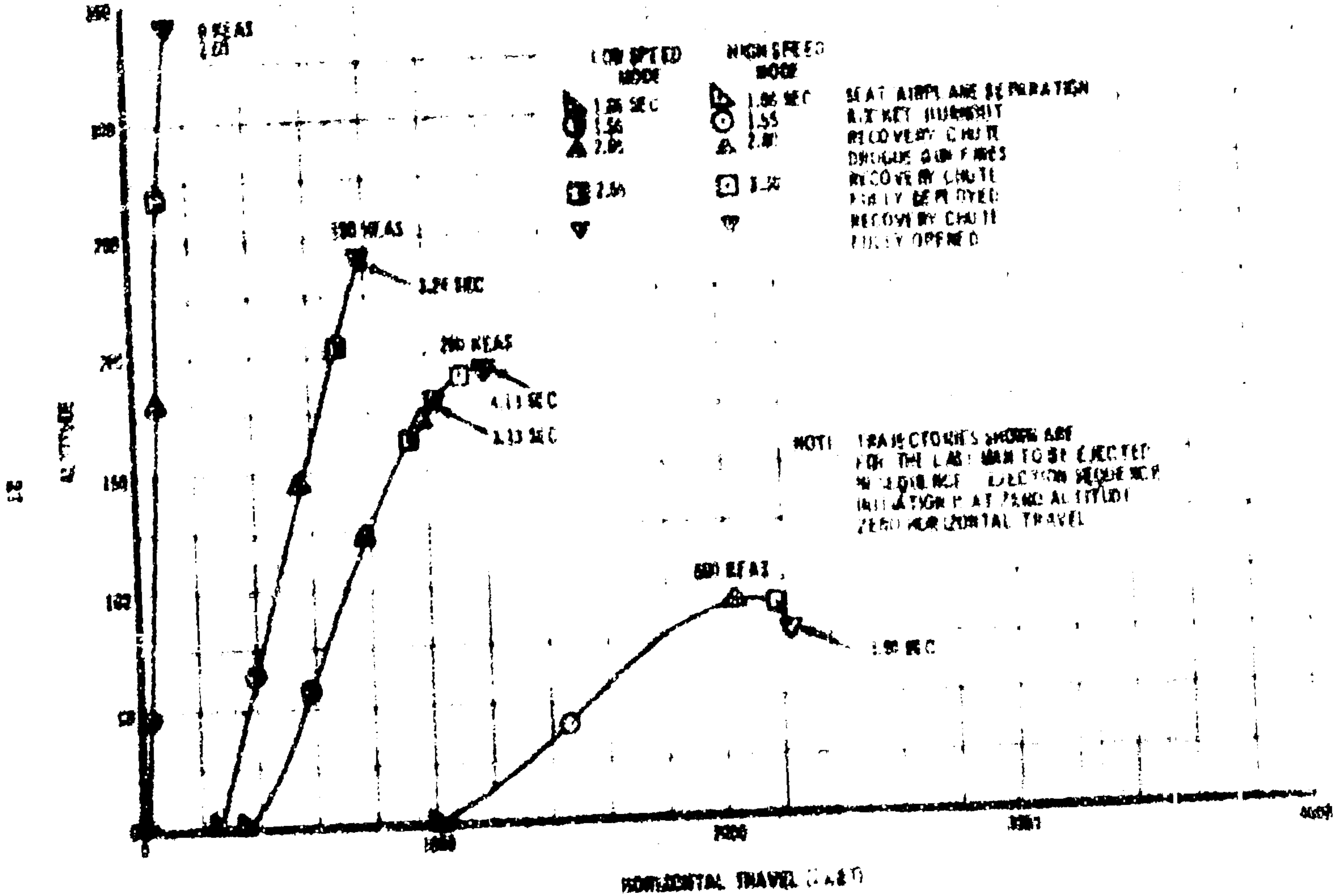
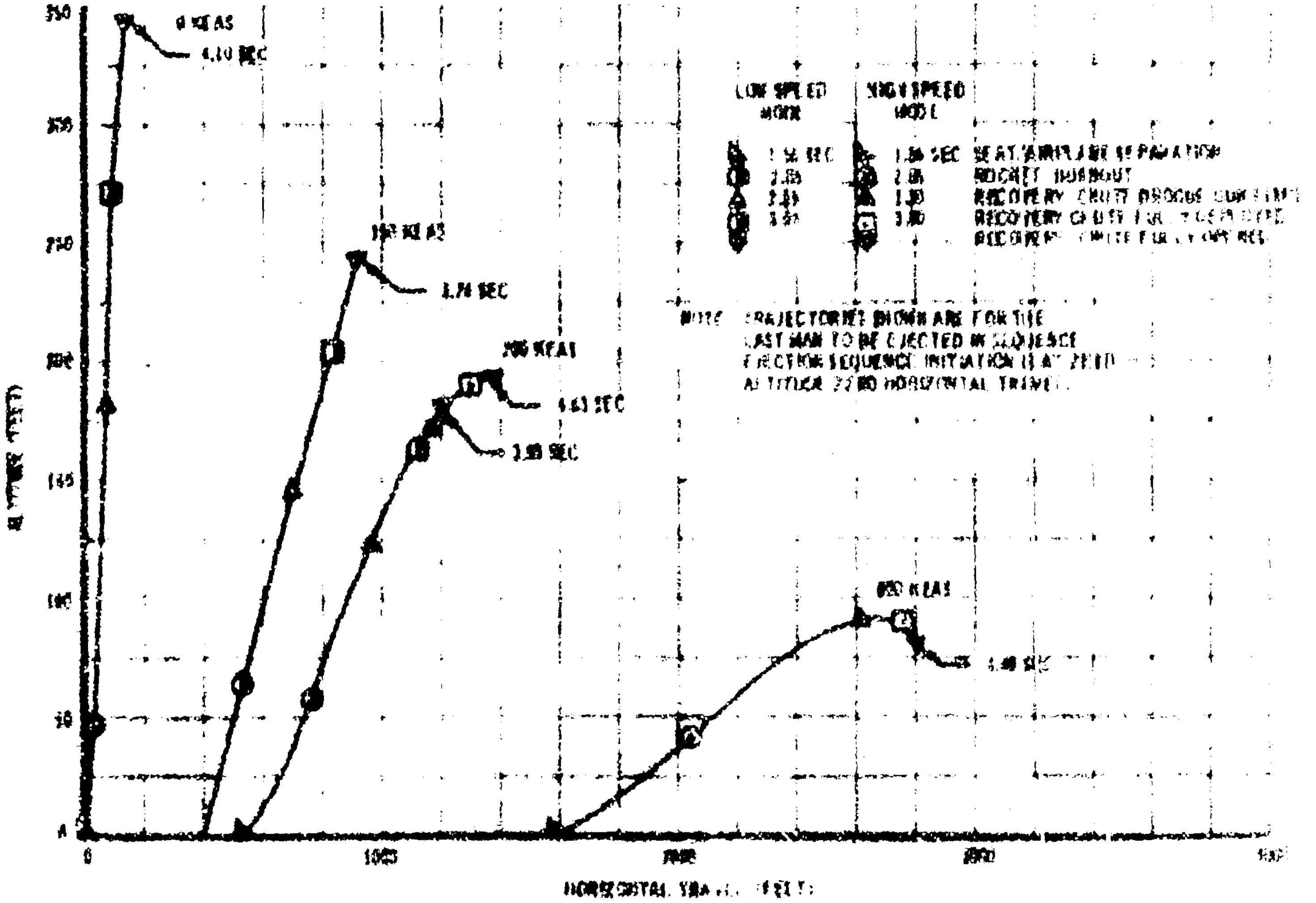


Figure 12. Four-Man Supersonic Dash Vehicle Open Ejection Seat Configuration



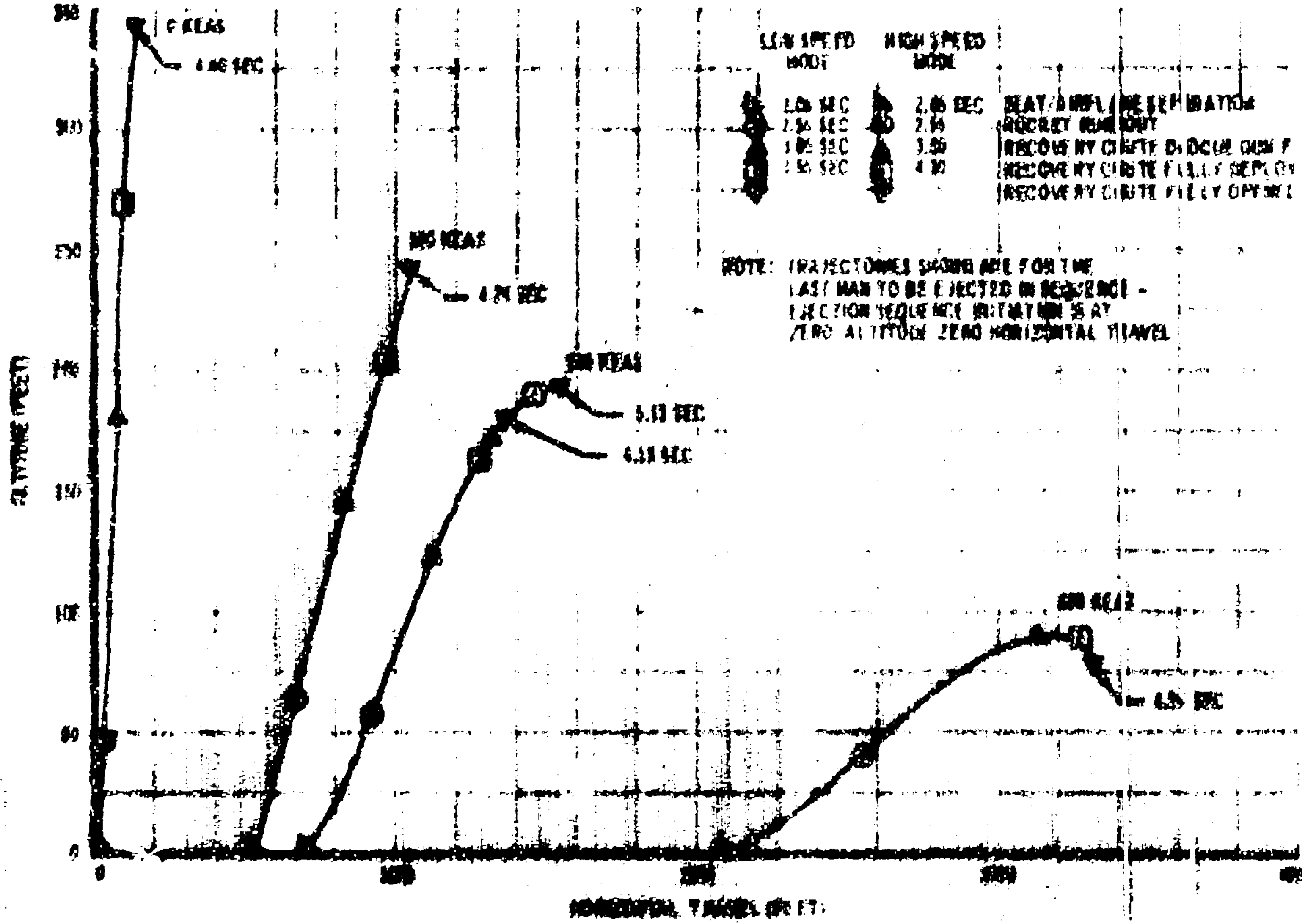
NOTE: TRAJECTORIES SHOWN ARE FOR THE LAST MAN TO BE EJECTED IN SEQUENCE. EJECTION SEQUENCE INITIATION AT ZERO ALTITUDE ZERO HORIZONTAL TRAVEL

Figure 15. Tandem Vehicle Open Ejection Sea Level Flight Trajectories



NOTE: TRAJECTORIES SHOWN ARE FOR THE LAST MAN TO BE EJECTED IN SEQUENCE. EJECTION SEQUENCE INITIATION IS AT ZERO ALTITUDE, ZERO HORIZONTAL TRAVEL.

Figure 17. Three-Man Vehicle Open Ejection: Sea Level Flight Trajectories



NOTE: TRAJECTORIES SHOWN ARE FOR THE LAST MAN TO BE EJECTED IN SEQUENCE - EJECTION SEQUENCE INITIATION IS AT ZERO ALTITUDE ZERO HORIZONTAL TRAVEL

Figure 16. Flotation Vehicle Open Ejection Sea Level Flight Trajectories

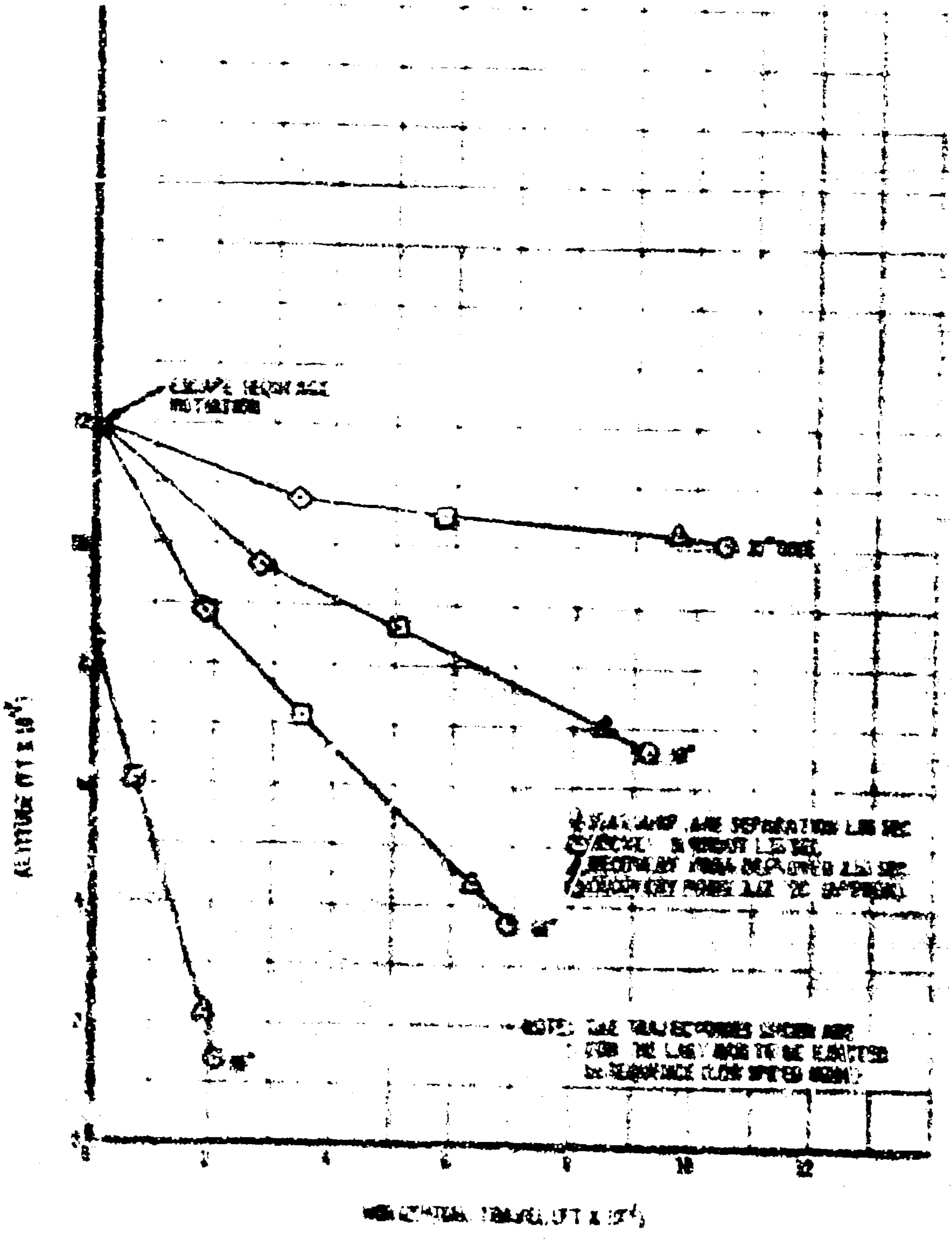


Figure 15. Two-Man Vehicle Crew Ejection Seat Glide Trajectories, 250 Knots

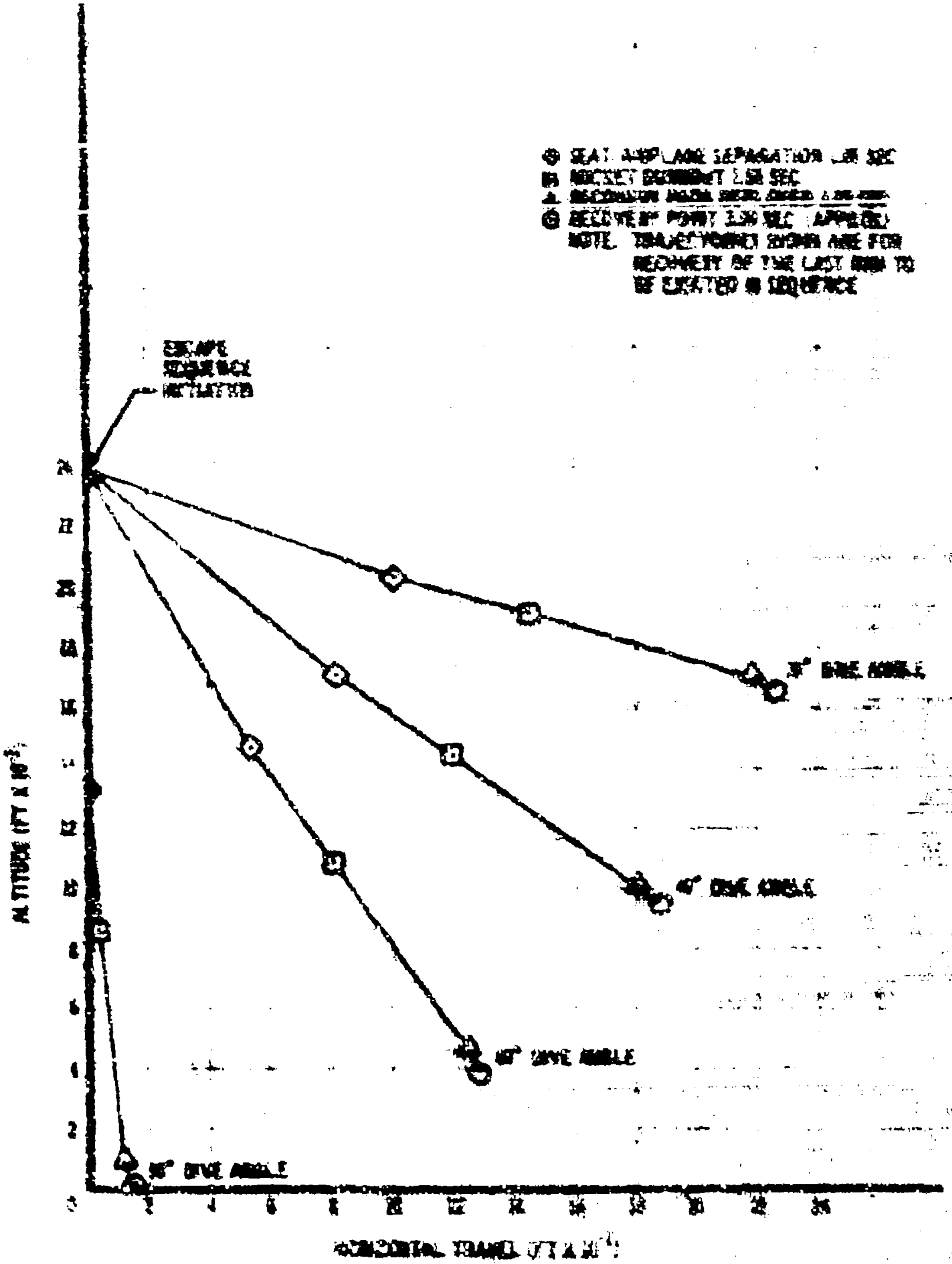


Figure [illegible]. [illegible] Vehicle Open Ejection Seat Dive Trajectories, [illegible]

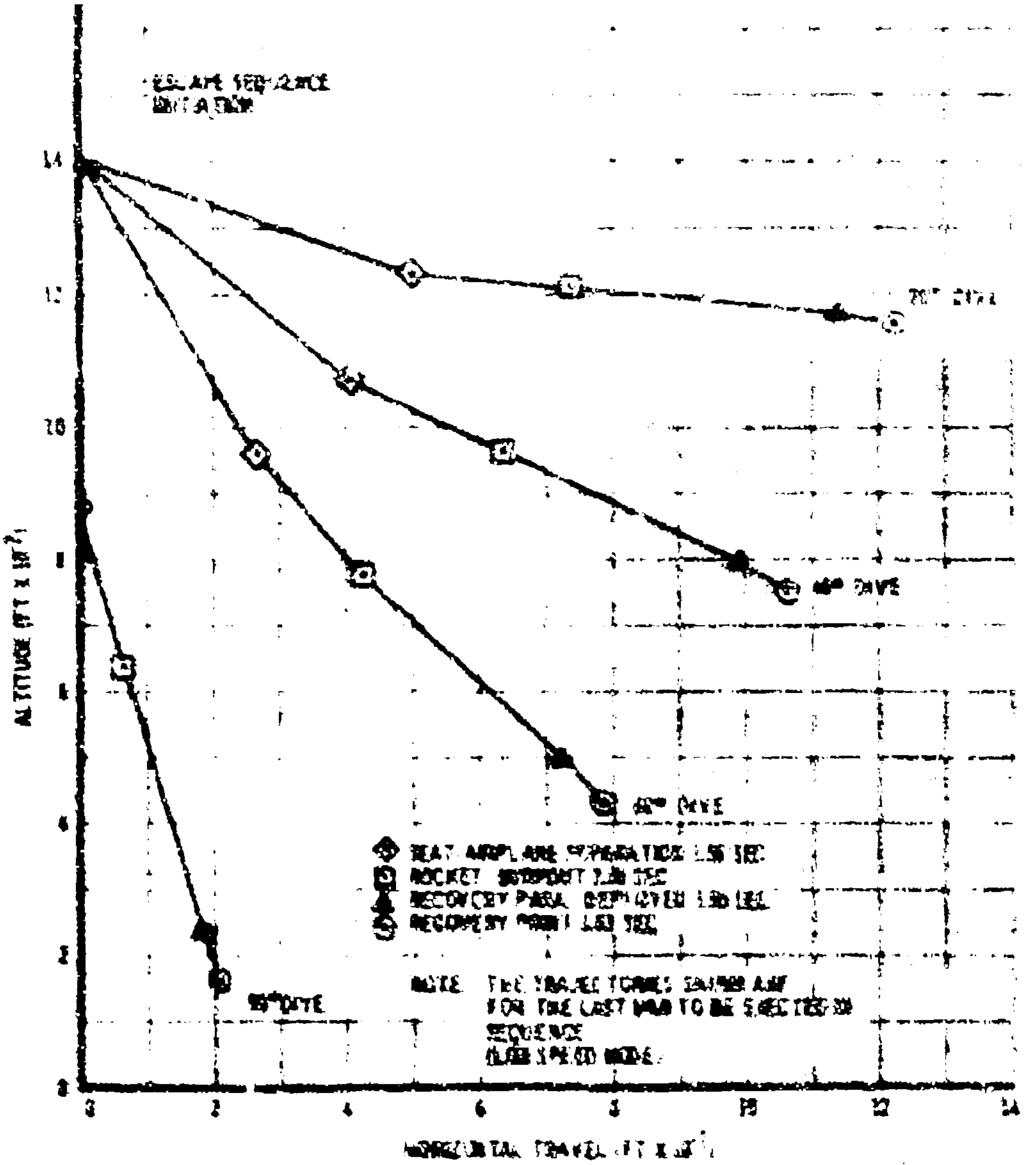


Figure 21. Three-Man Vehicle Open Ejection Low Dive Trajectories, 300 Knots

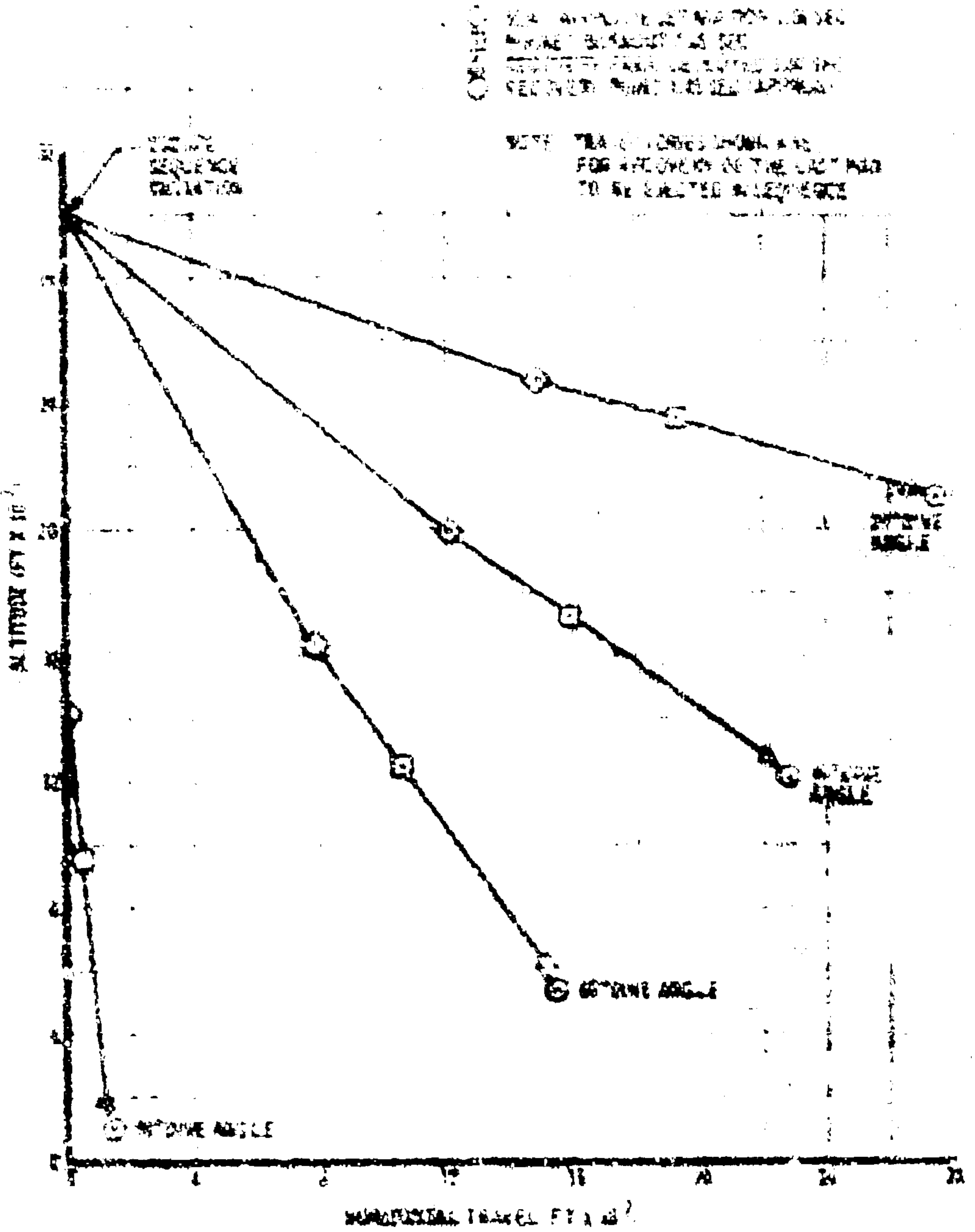


Figure 22. Three-Man Vehicle Crew Ejection Seat Crew Trajectories, 400 Knots

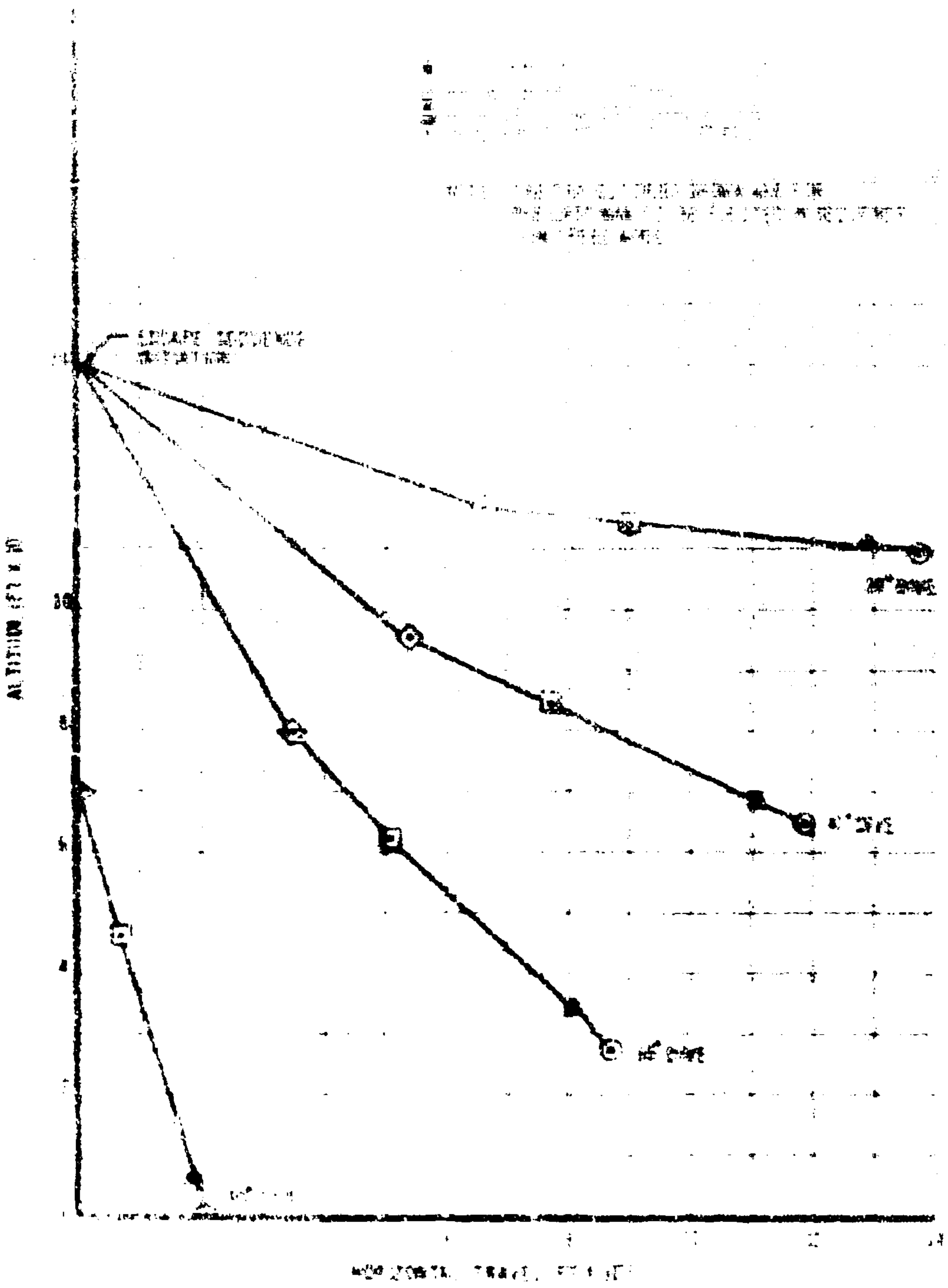


Figure [illegible] [illegible] Open Ejection Seat Dive Trajectories, [illegible] Knots

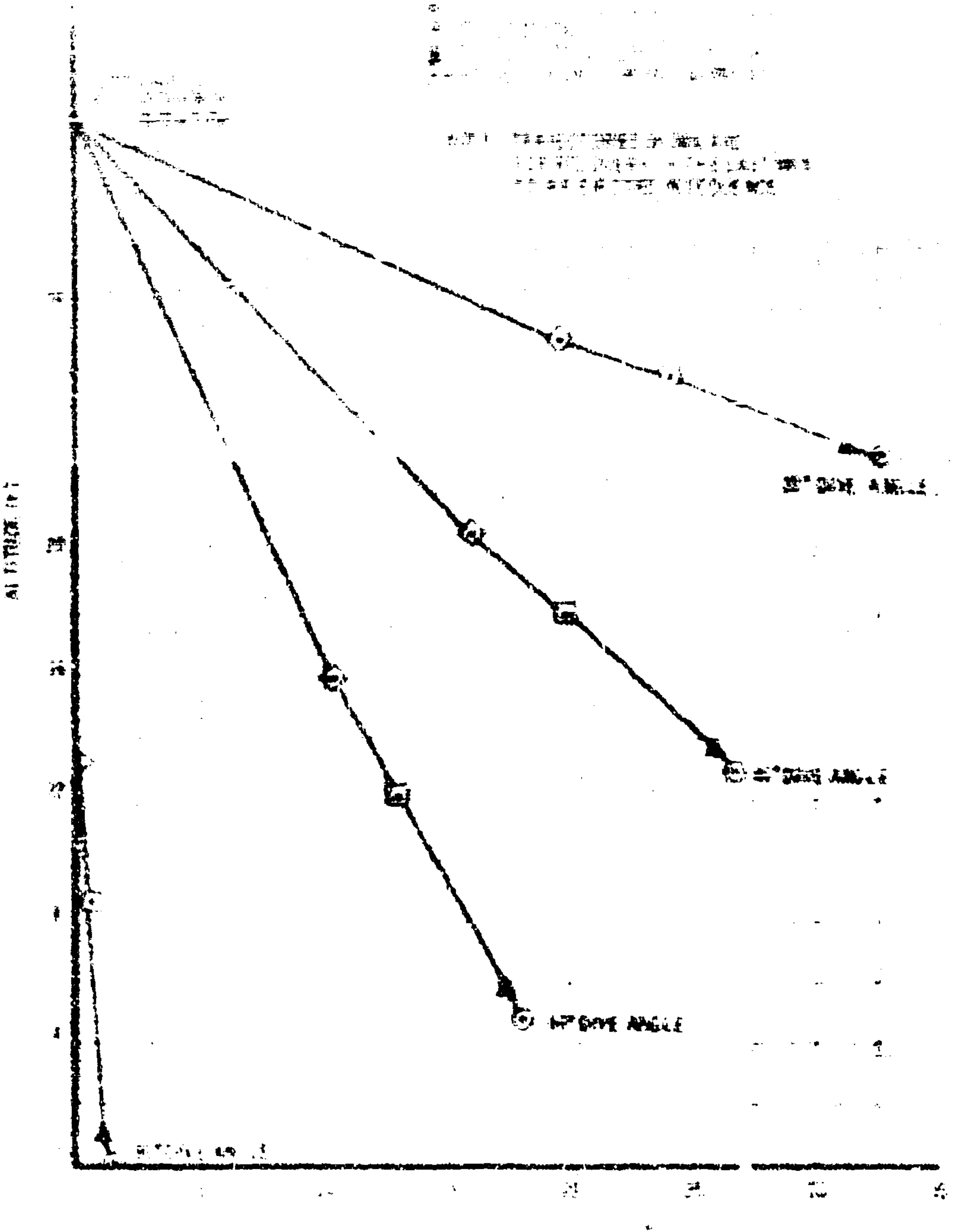


Figure [illegible] [illegible] Vehicle [illegible] Ejection [illegible] Dive Trajectories at [illegible] Knots

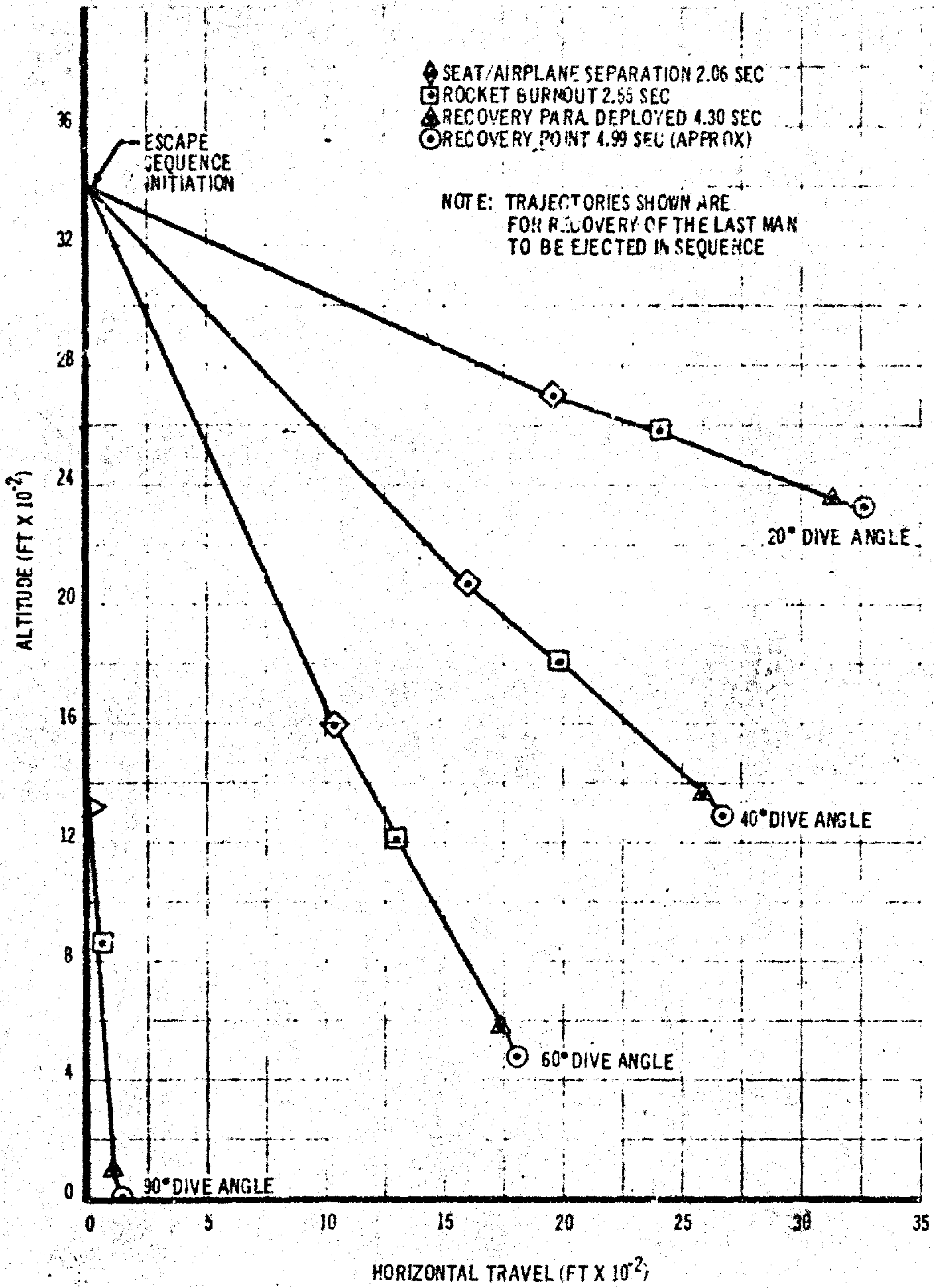


Figure 24. Four-Man Vehicle Open Ejection Seat Dive Trajectories, 600 Knots

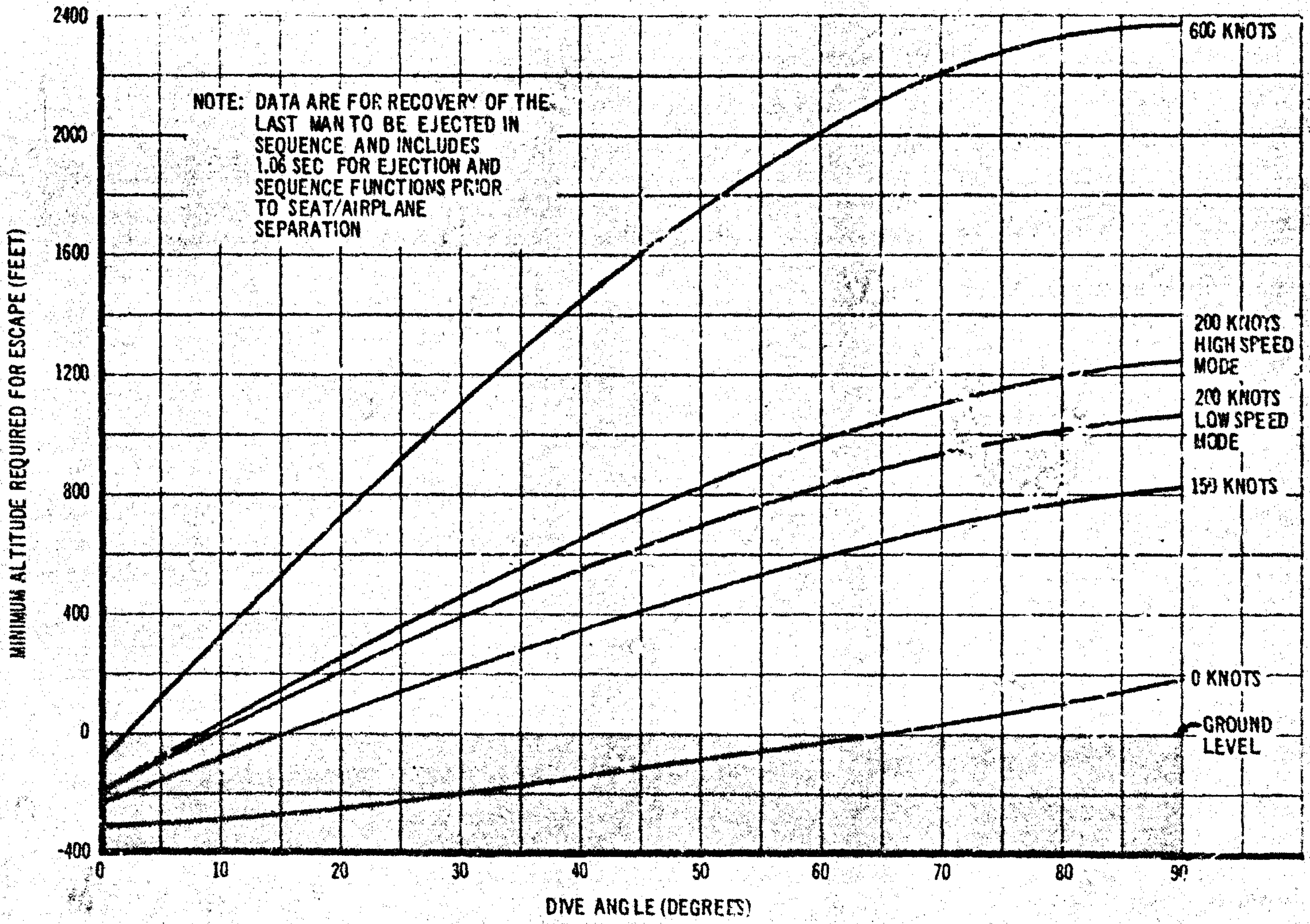
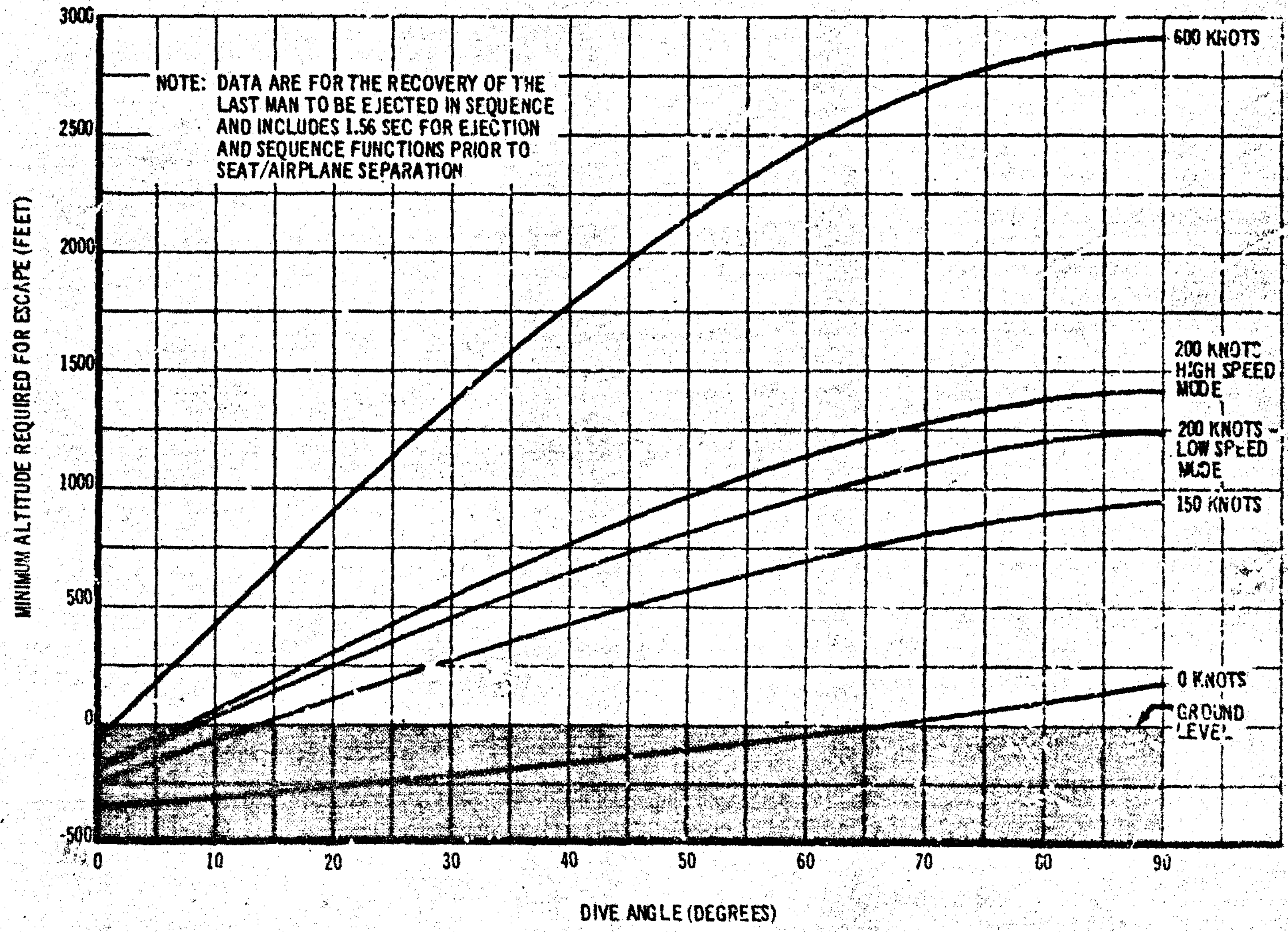


Figure 25. Two-Man Vehicle Open Ejection Seat Escape Altitude Required



NOTE: DATA ARE FOR THE RECOVERY OF THE LAST MAN TO BE EJECTED IN SEQUENCE AND INCLUDES 1.56 SEC FOR EJECTION AND SEQUENCE FUNCTIONS PRIOR TO SEAT/AIRPLANE SEPARATION

Figure 26. Three-Man Vehicle Open Ejection Seat Escape Altitude Required

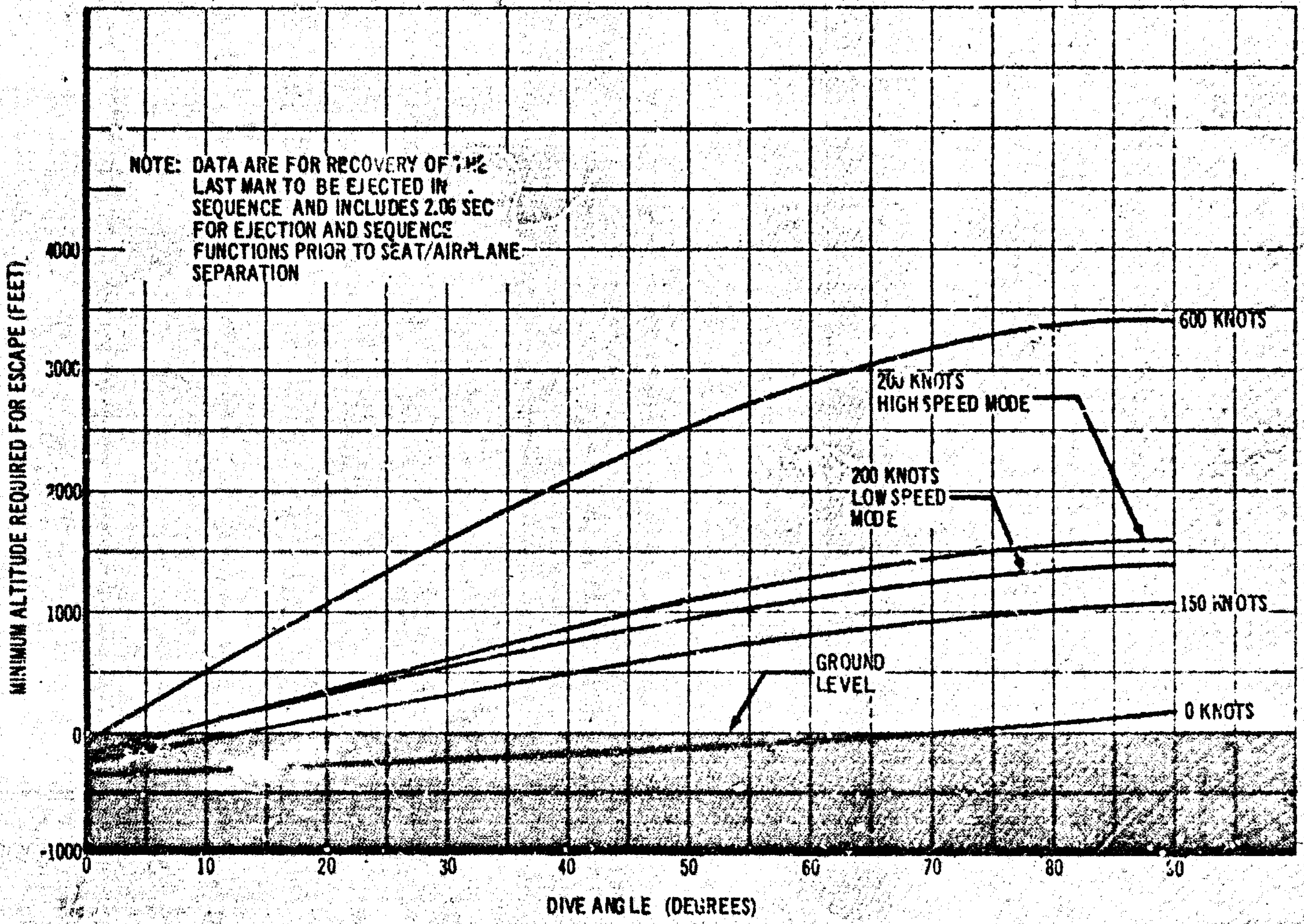


Figure 27. Four-Man Vehicle Open Ejection Seat Escape Altitude Required

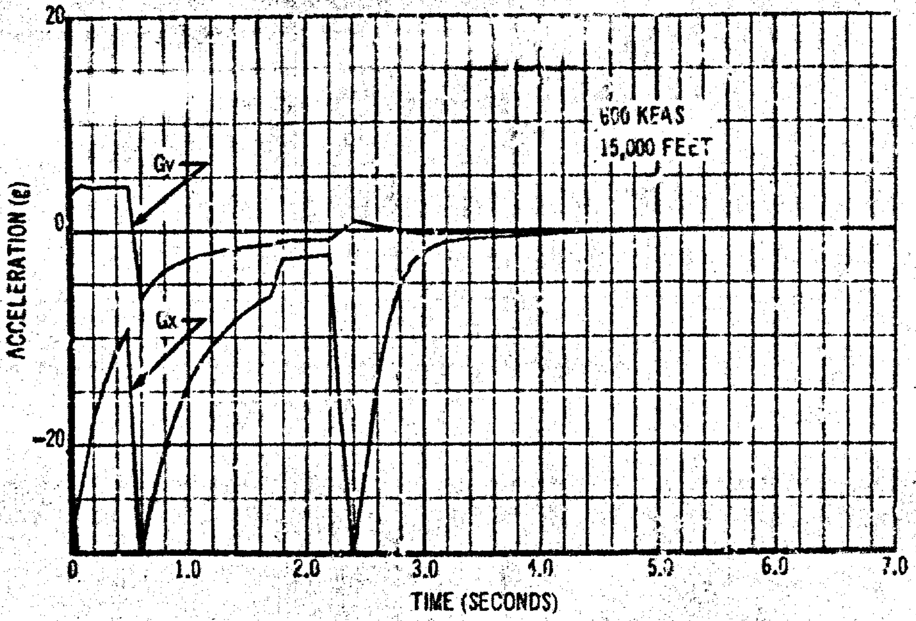


Figure 28. Open Ejection Seat – Computer Plot of Acceleration

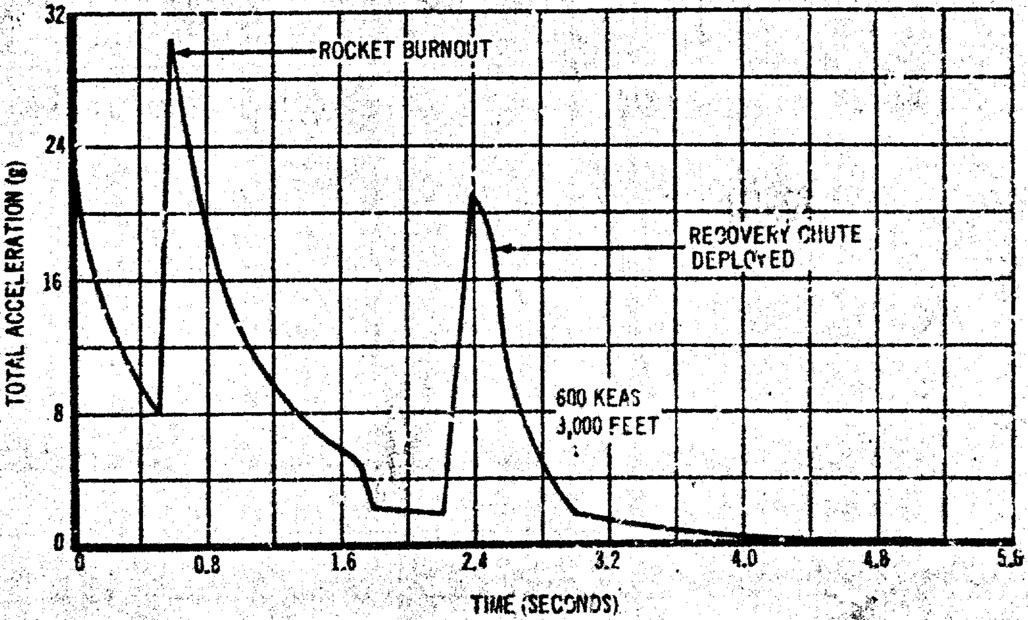


Figure 29. Open Ejection Seat – Acceleration Versus Time

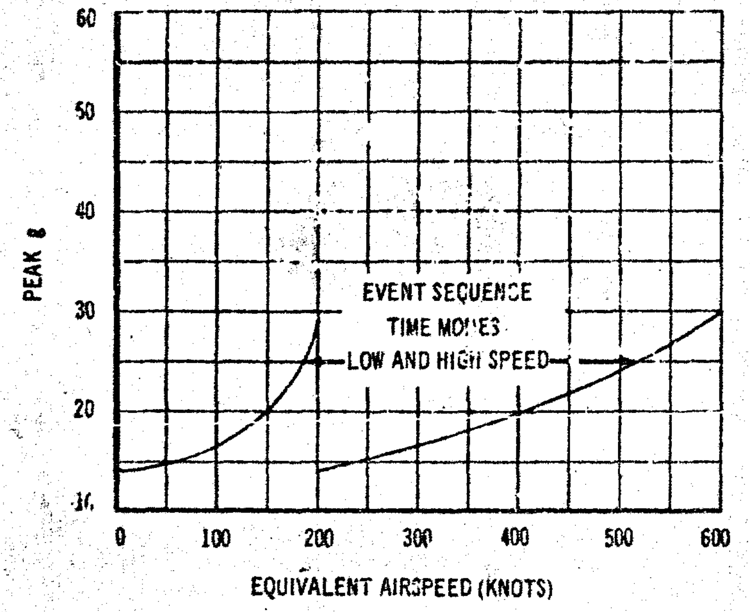


Figure 30. Open Ejection Seat – Peak g

Table I. Open Ejection Seat Weight Breakdown

	Weight (Pounds)	
	Installed	Ejectable
Basic seat structure	40.0	40.0
Rocket-catapult	28.0	21.0
Survival kit and equipment	40.0	40.0
Ballistic inertia reel	4.0	4.0
Drogue gun assembly	2.0	2.0
Stabilization/deceleration parachute	5.0	5.0
Back headrest assembly	16.0	18.0
Skysail parachute and drogue gun	26.0	26.0
Seat adjustment actuators	12.0	12.0
Ejection guide rails and fittings	8.0	---
Emergency oxygen	6.0	6.0
Speed sensor	1.0	---
Total Seat Weight	191.0	174.0
Escape Hatch	50.0	
	241.0	
Less Weight of Nonejection Seat	-45.0	
Weight Penalty Per Seat	196.0	
Total Weight Penalty		
2-man vehicle	392.0	
3-man vehicle	588.0	
4-man vehicle	784.0	

2. ENCAPSULATED EJECTION SEAT CONFIGURATIONS

a. Configurations

The encapsulated ejection seat configurated and analyzed during this study consists of subsystems used in past development programs and those currently in use. The system, as described, is considered the optimum encapsulated ejection seat system, and will have capabilities exceeding those of current systems.

The system was designed to provide safe escape from zero to 800 KEAS from ground level up to 42,000 feet, and to Mach 3.0 from 42,000 to 100,000 feet.

Major subsystems and components of the system are: 1) canopy/hatch jettison system; 2) initiation and ejection sequence installation; 3) restraint system consisting of a lap belt, leg retraction thruster, shoulder harness and powered inertia reel; 4) survival equipment; 5) rocket-catapult (12,000 pound average thrust); 6) drogue gun deployment of 5-foot diameter stabilization/deceleration parachute; 7) drogue gun deployed 36-foot diameter Skysail recovery parachute; 8) stabilization booms and chutes; 9) pressurization system; 10) landing impact system; and 11) flotation system. The seat also is provided with electromechanical actuators for vertical adjustment through five inches. Actuators also are used to position the seat-man forward of the capsule shell (in one capsule version) during flight which may be desirable for some airplane crew arrangements. However, the dynamic performance and safe escape capability for each encapsulated seat design are identical.

Operation of either handgrip located on the seat arm rests retracts the crewman's legs (seat-man if required), closes the clam shell doors, and pressurizes the capsule. From this position, the pilot can monitor the instrument panel and control the airplane or initiate ejection by squeezing the trigger in either handgrip. When the ejection system is initiated, the canopy/hatch is jettisoned and the crewman is positioned and restrained in the seat. Just before capsule separation from the rails, the stabilization/deceleration parachute is deployed (reefed) and the catapult rocket motor is ignited. Immediately after separation, the stabilization booms are extended to stabilize the capsule. At rocket burnout, the stabilization/deceleration parachute is disreefed and continues to stabilize and decelerate the capsule to allow deployment of the recovery parachute within the minimum elapsed time. The recovery parachute deployment time delay is established by a speed sensor operated by the airplane pitot-static system when the escape system is initiated. The system event sequence operates a low-speed (below 300 KEAS) or a high-speed (above 300 KEAS) mode, as shown in Fig. 31, for ejections below 15,000 feet. If escape occurs at high altitude, the capsule is stabilized and descends to 15,000 feet before deployment of the main recovery parachute.

The escape system incorporates a command-select sequencing system that permits the pilot or copilot to eject the entire crew at predetermined intervals. The following events require 1.65 seconds after system initiation: 1) retract legs and/or seat-man; 2) close doors; 3) pressurize capsule; 4) jettison canopy/hatch; 5) position and restrain crewman; and 6) propel capsule up the rails. In multiplace airplanes, pre-ejection events are concurrent, and time delays are provided for ejection of the crewmembers in a pre-determined sequence. This will permit all crewmembers to clear the airplane within the minimum elapsed time.

The two-man subsonic airplane tandem seating arrangement is shown in Figs. 32 and 33. The capsule in Fig. 33 positions the seat forward of the capsule shell during normal flight and retracts the seat-man when the escape system is initiated. If escape is initiated by the forward seat control, the aft seat ejects 0.5 second prior to the forward seat to avoid collision and possible parachute entanglement. The forward seat occupant has the option of being ejected if escape is initiated by the aft seat control, or to remain with the airplane depending on the position of the command sequence control. The minimum elapsed time from escape initiation until both crewmen clear the airplane will be 2.15 seconds.

The three-man combined capability vehicle crew arrangement is shown in Fig. 34. The escape system and command sequence for ejection will be similar to the two-man vehicle. When escape is initiated by the pilot, the order of ejection is the aft seat followed at 0.5 second intervals by the copilot and pilot seats. The minimum elapsed time from escape initiation until the entire crew clears the airplane is 2.65 seconds.

The crew arrangement for the four-man supersonic dash vehicle is shown in Fig. 35. In this crew arrangement, escape initiation by either of the forward seats automatically ejects the entire crew. However, either aft seat can eject individually and the pilot can elect to remain with the airplane. The systems function as described above and differ only in the command ejection control. The time required to eject the entire crew after escape initiation is 3.15 seconds. The order of ejection is the seat aft of the copilot, the seat aft of the pilot, the copilot and pilot seats. By allowing the aft capsules to be ejected prior to the forward capsules the possibility of collision and parachute entanglement is reduced without increasing the minimum elapsed time required.

5. Performance

The dynamic performance of the encapsulated ejection seats was analyzed on the computer for speeds from zero to 800 KEAS. Figures 36, 37, and 38 show the level flight ejection trajectories and indicate that for level flight ground level ejections throughout the speed range considered for each vehicle, the capsule will be recovered well above the ground. The trajectories shown for each vehicle are for the last man to be ejected in the command sequence and include the time spent in the aircraft prior to seat/airplane separation for pre-separation functions and ejection sequence time delays.

Escape sequence is initiated at the origin of the graphs and the time lapse from initiation until the last man clears the aircraft is 2.15 seconds for the two-man vehicle, 2.65 seconds for the three-man vehicle, and 3.15 seconds for the four-man vehicle.

Figures 39 and 40 show capsule trajectories for escape during diving flight at 200 and 600 KEAS for the two-man vehicle. Figures 41 and 42 show the dive trajectories at 200 and 800 knots for the three-man vehicle and Figs. 43 and 44 show the dive trajectories at 200 and 800 knots for the four-man vehicle. These data are also for the last man to be ejected in the command sequence and include the time required for pre-separation functions and ejection sequence time delays.

Figures 45, 46, and 47 show, for each vehicle, the altitude at which escape must be initiated for successful recovery of the entire crew versus airplane dive angle for various airspeeds.

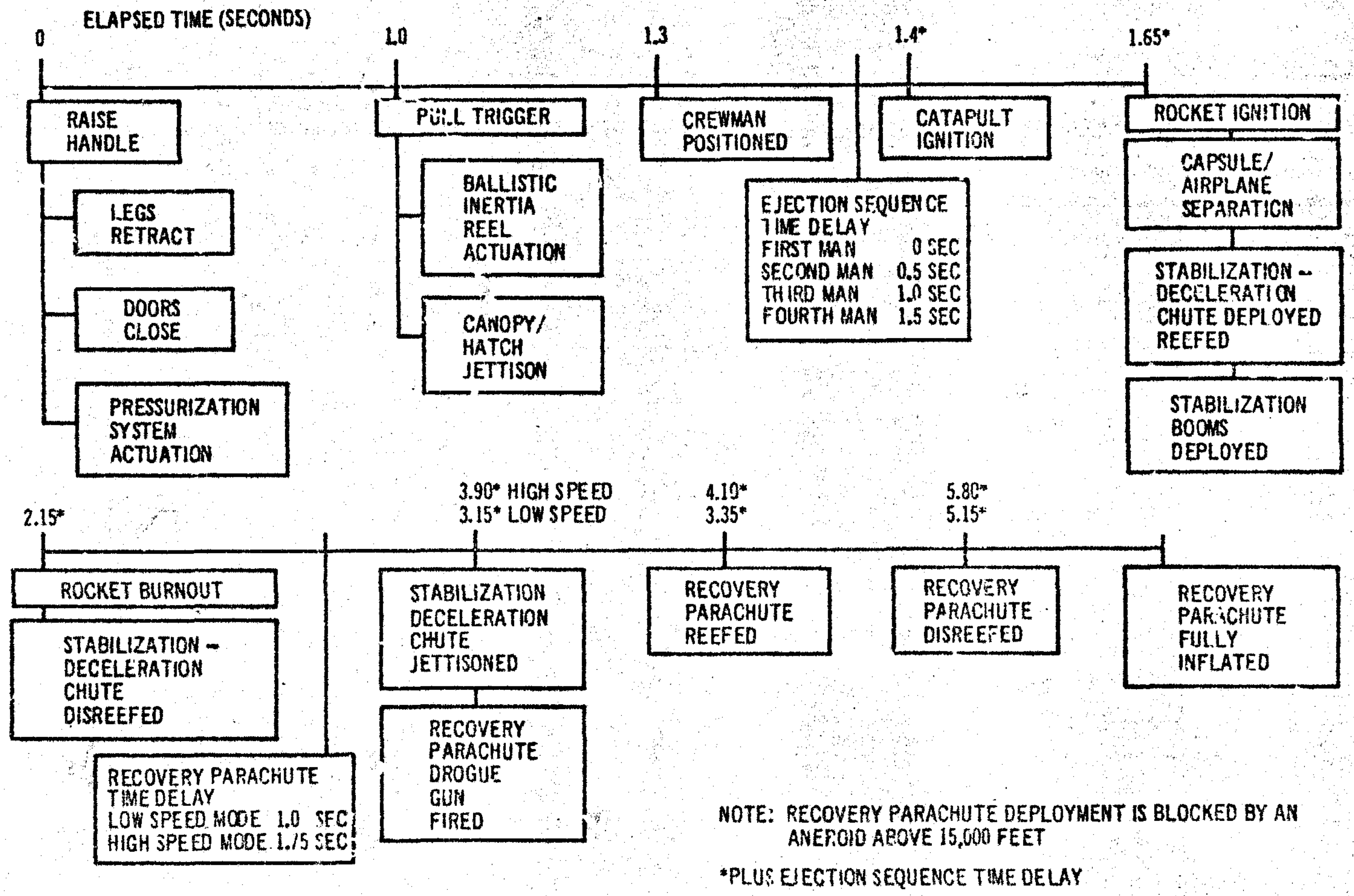
A computer plot of the horizontal and vertical accelerations that will be imposed on the crewman during escape at a speed of 800 KEAS at 15,000 feet are shown in Fig. 48. Figure 49 shows the total deceleration load experienced by the crewman during escape at 800 KEAS at a lower altitude. Due to the more rapid velocity decay caused by the deceleration parachute prior to recovery parachute deployment at lower altitudes, the deceleration loads are less than those at 15,000 feet. The maximum peak g calculated for escapes from zero to 800 KEAS for both the high- and low-speed event sequence modes are shown in Fig. 50. The rocket motor, deceleration parachute and the event time sequence were designed to keep the acceleration loads on the crewman within the accepted human tolerance limits during ejections from zero to 800 KEAS.

c. Weight Penalty

Table II shows the weight breakdown for the encapsulated ejection seat. Weight penalties shown for the two-man, three-man, and four-man vehicles include weights of the seat installation and escape system, less weight of non-ejection seats.

Table II. Encapsulated Seat Weight Breakdown

	Ejectable (Pounds)	Nonejectable (Pounds)
Capsule structure	200.0	
Seat including restraint system	60.0	
Seat actuators	20.0	
Rocket-catapult	36.0	
Survival gear	45.0	
Oxygen system	27.0	
Stabilization booms and chutes	80.0	
Stabilization/deceleration parachute	20.0	
Recovery parachute system	45.0	
Impact bag and gas generator	15.0	
Flotation system	10.0	
Speed sensor		1.0
Catapult outer tube		15.0
Ejection rails and fittings		40.0
Ejectable	558.0	
Nonejectable		56.0
Total Seat Weight	614.0	
Escape Hatch Weight	50.0	
	664.0	
Less Weight of Nonejection seat	-45.0	
Weight Penalty Per Seat	619.0	
Total Weight Penalty		
2-man vehicle	1238.0	
3-man vehicle	1857.0	
4-man vehicle	2476.0	



NOTE: RECOVERY PARACHUTE DEPLOYMENT IS BLOCKED BY AN ANEROID ABOVE 15,000 FEET

*PLUS EJECTION SEQUENCE TIME DELAY

Figure 31. Block Diagram – Encapsulated Ejection Seat Event Sequence

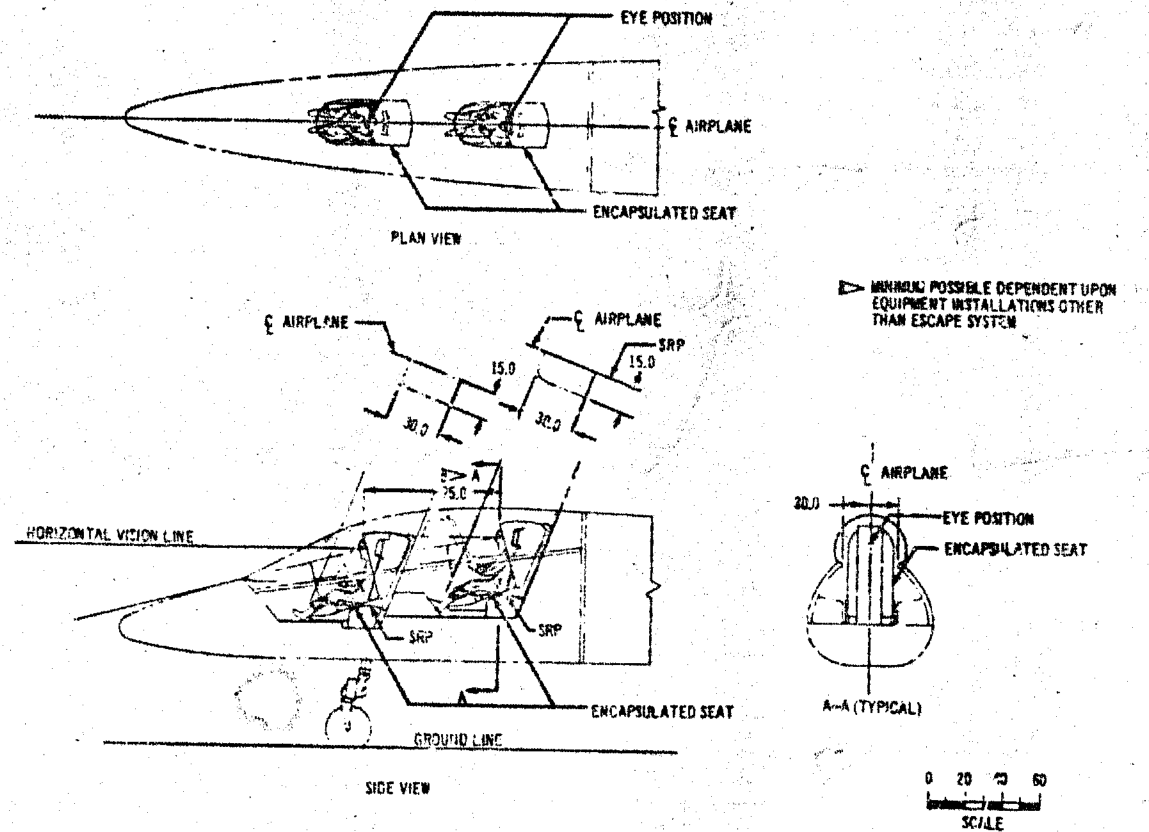


Figure 32. Two-Man Subsonic VTOL Vehicle Encapsulated Ejection Seat Configuration

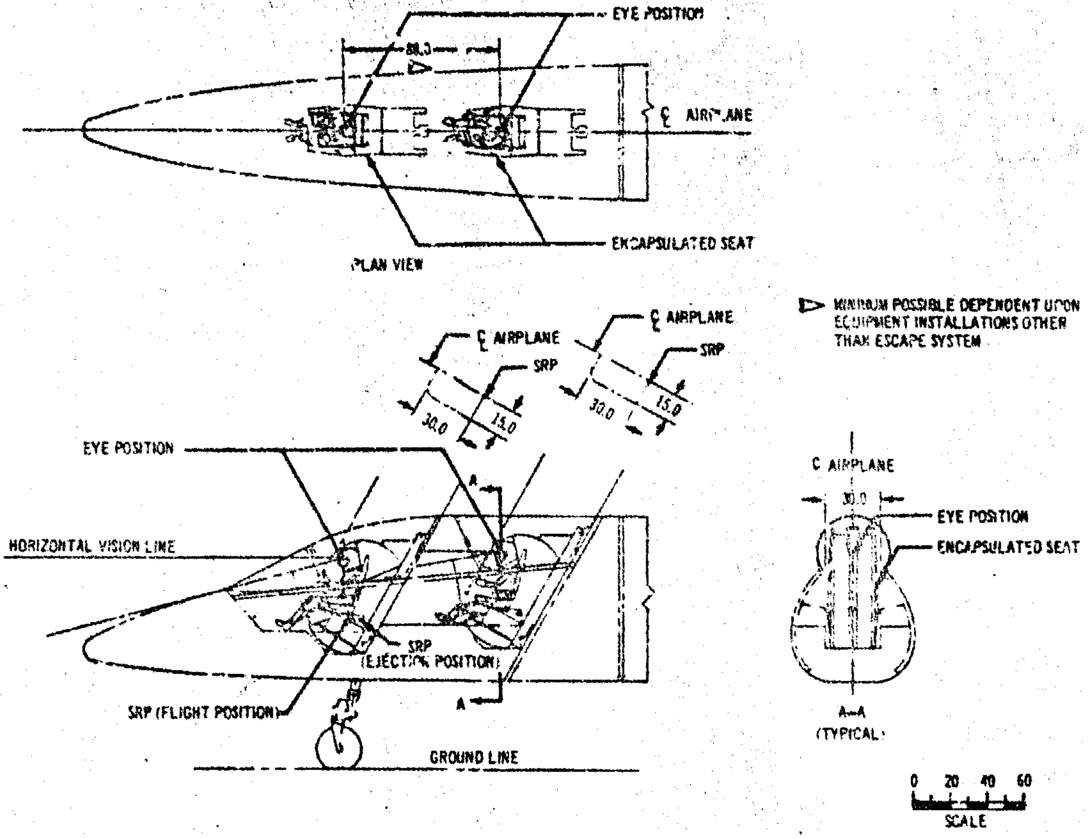


Figure 32. Two–Man Subsonic VTOL Vehicle Encapsulated Ejection Seat Configuration (Seat Positioning Type)

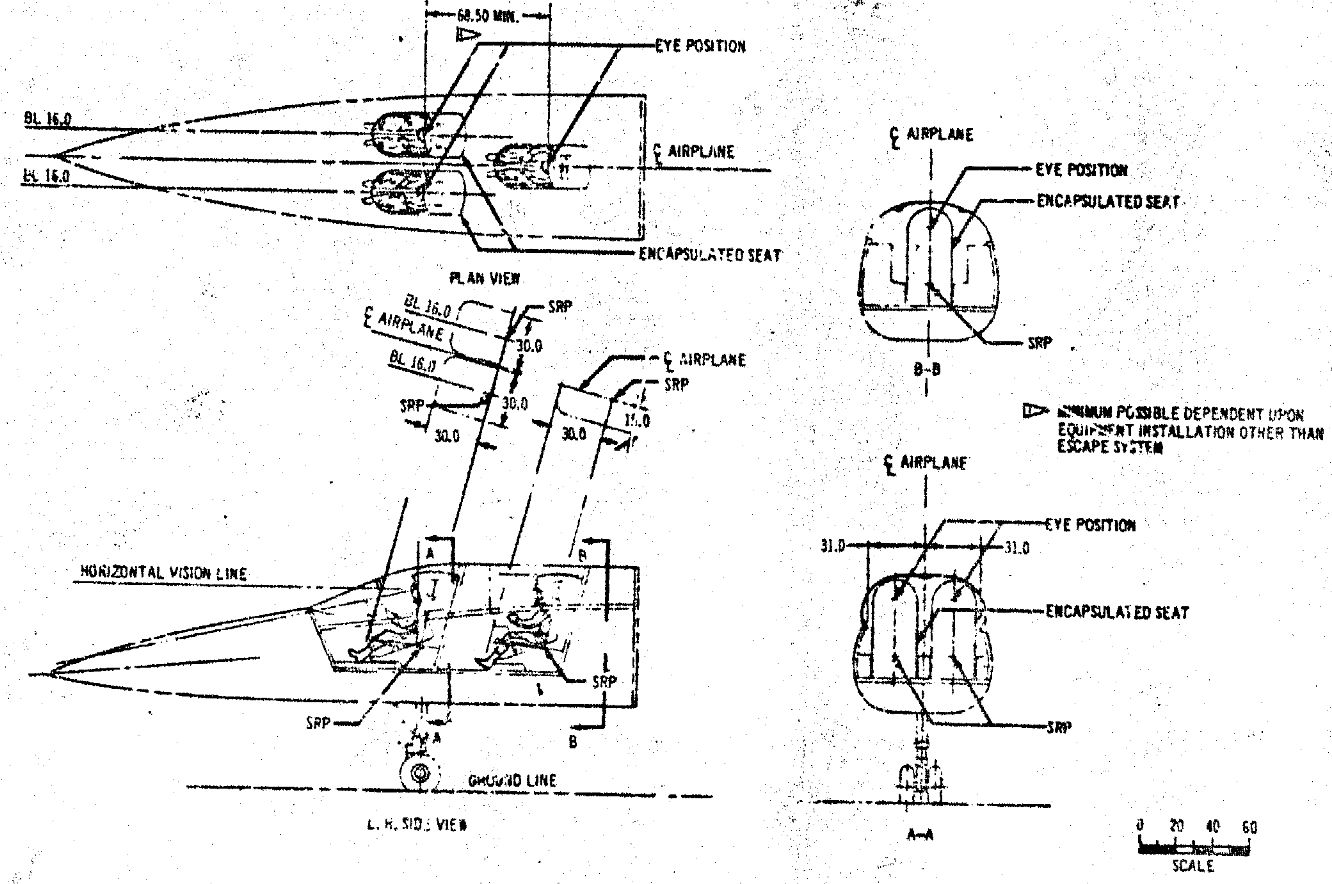


Figure 34. Three–Man Combined Capability Vehicle Encapsulated Ejection Seat Configuration

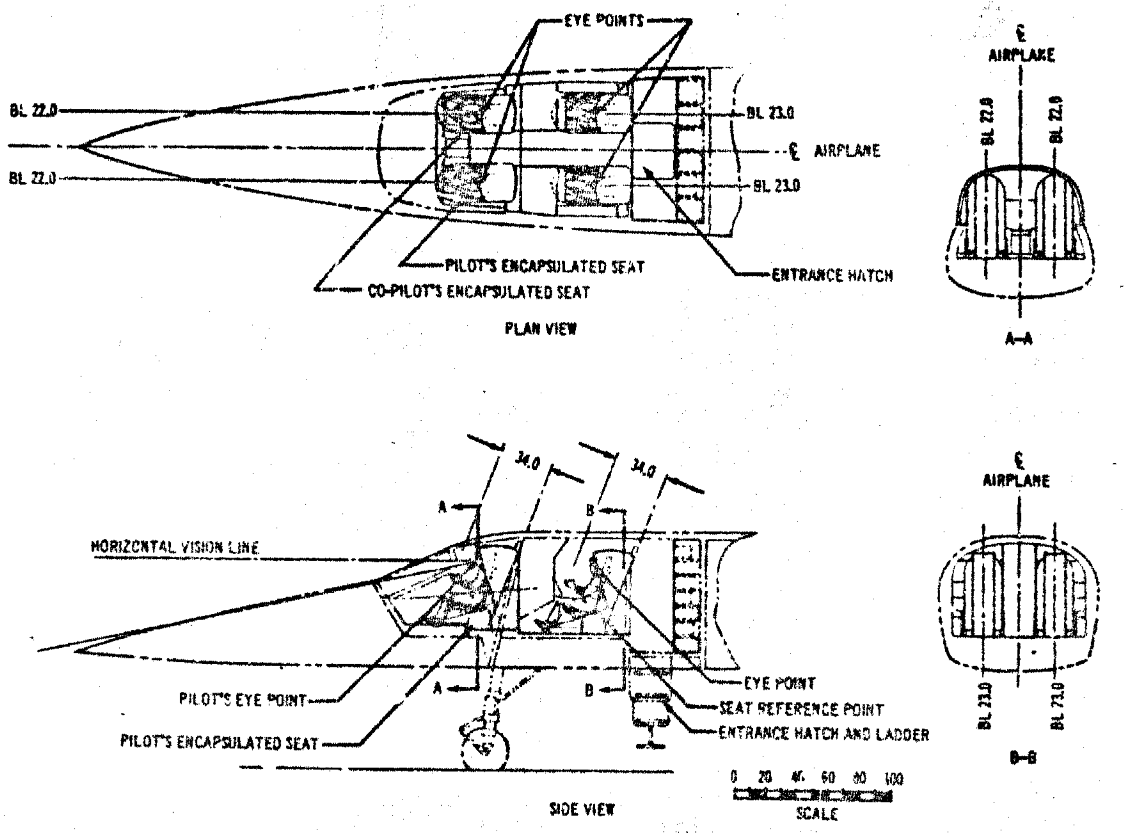


Figure 35. Four-Man Supersonic Dash Vehicle Encapsulated Ejection Seat Configuration

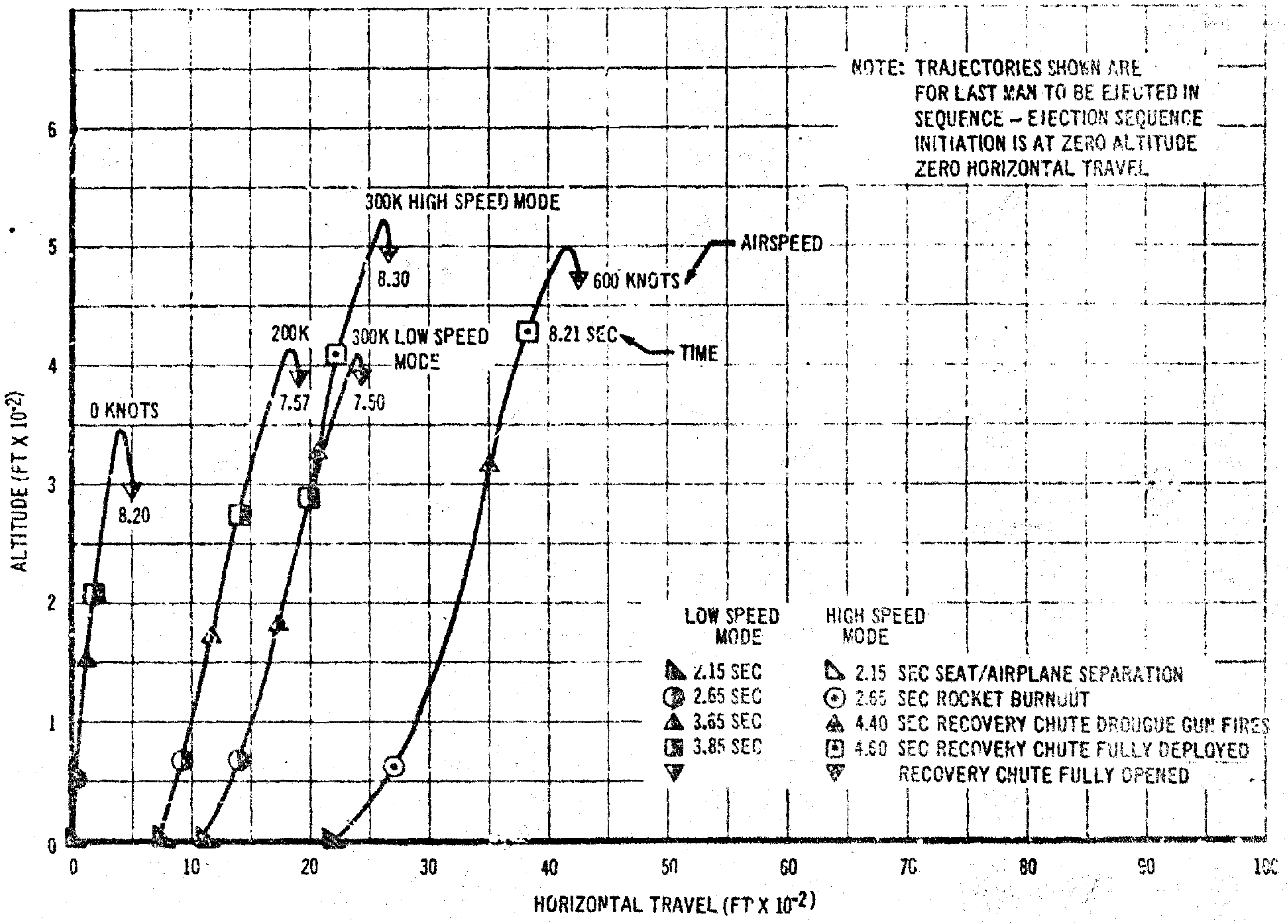


Figure 36. Two-Man Vehicle Encapsulated Ejection Seat Level Flight Trajectories

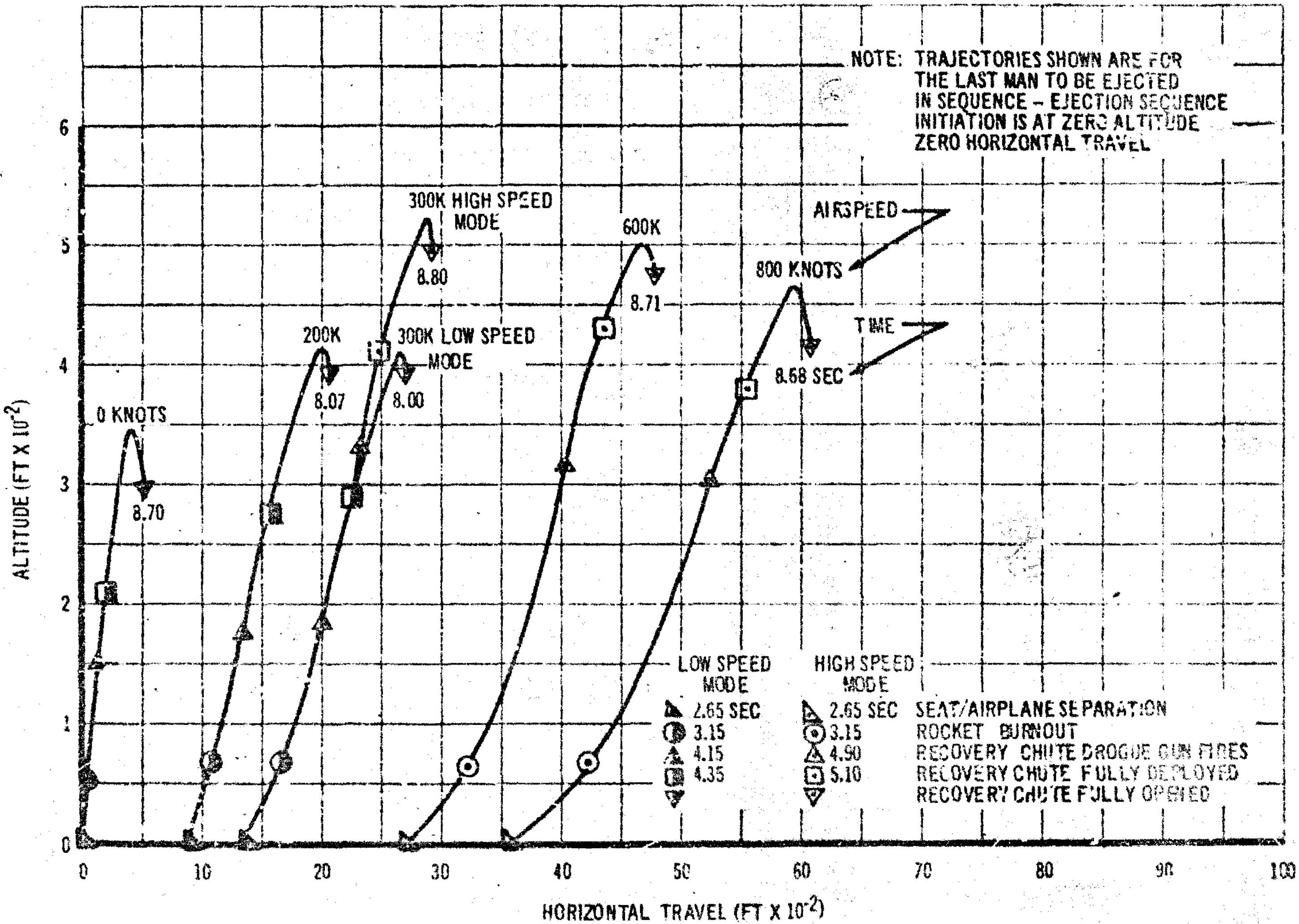


Figure 37. Three-Man Vehicle Encapsulated Ejection Seat Level Flight Trajectories

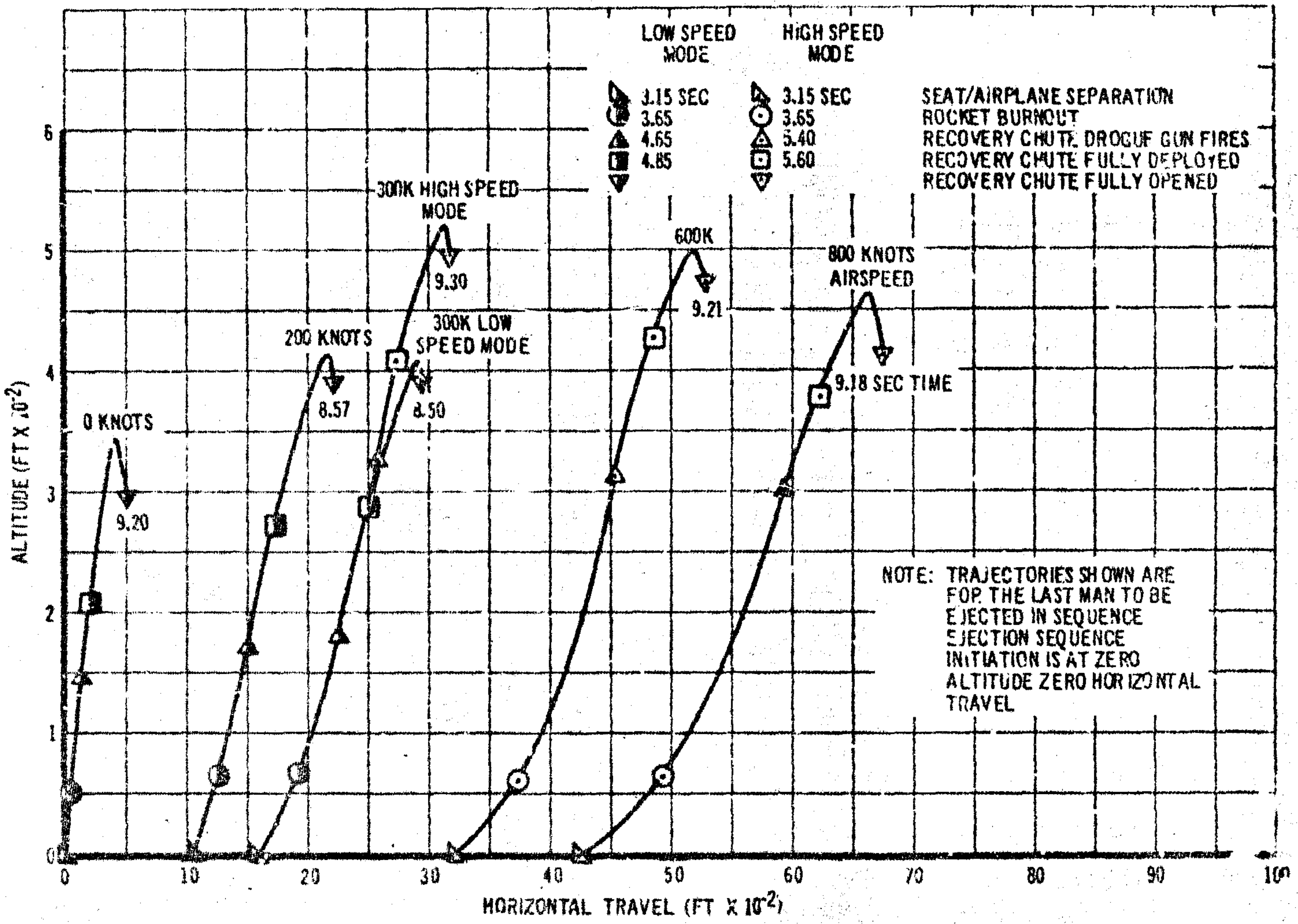


Figure 38. Four-Man Vehicle Encapsulated Ejection Seat Level Flight Trajectories

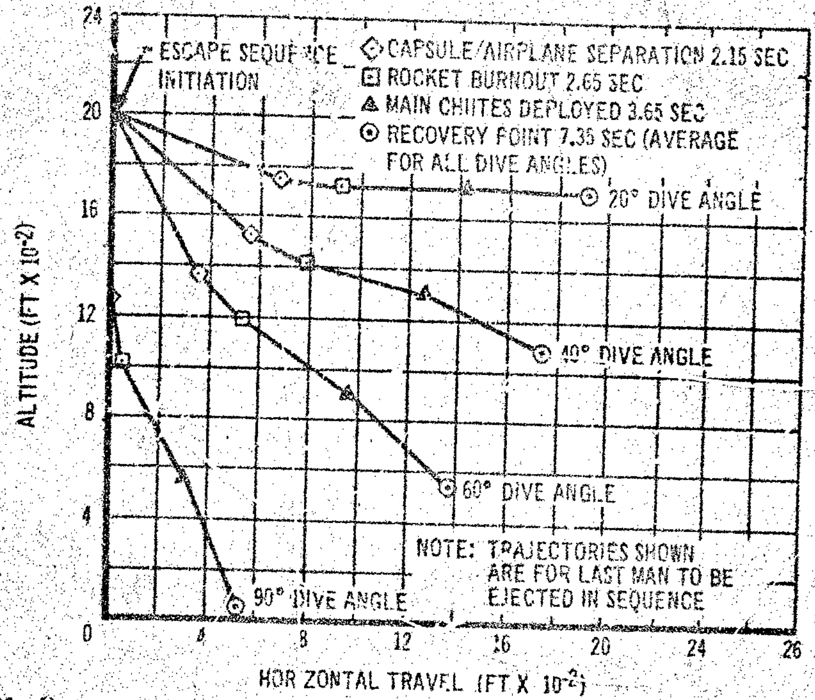


Figure 39. Two-Man Vehicle Encapsulated Ejection Seat Dive Trajectories, 200 Knots

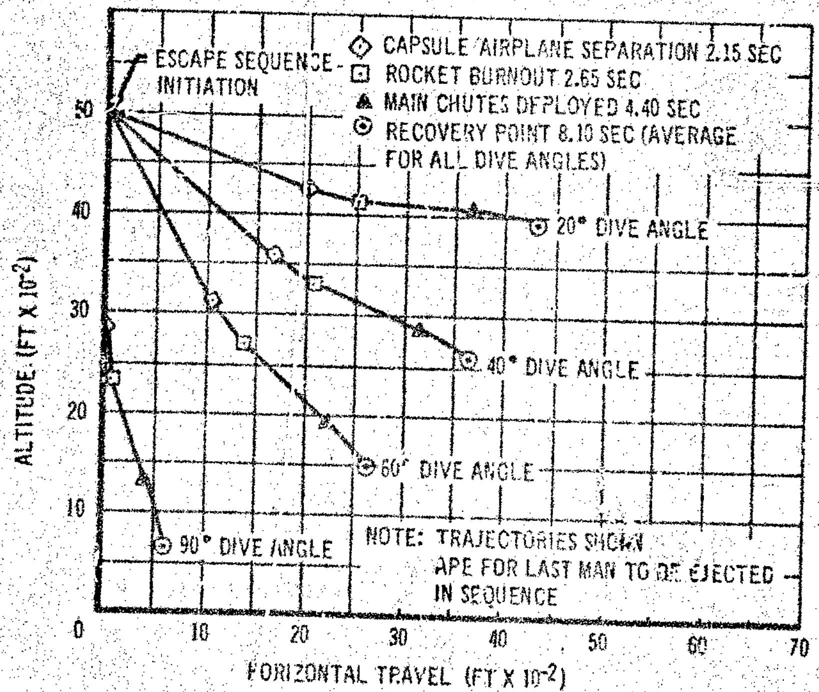
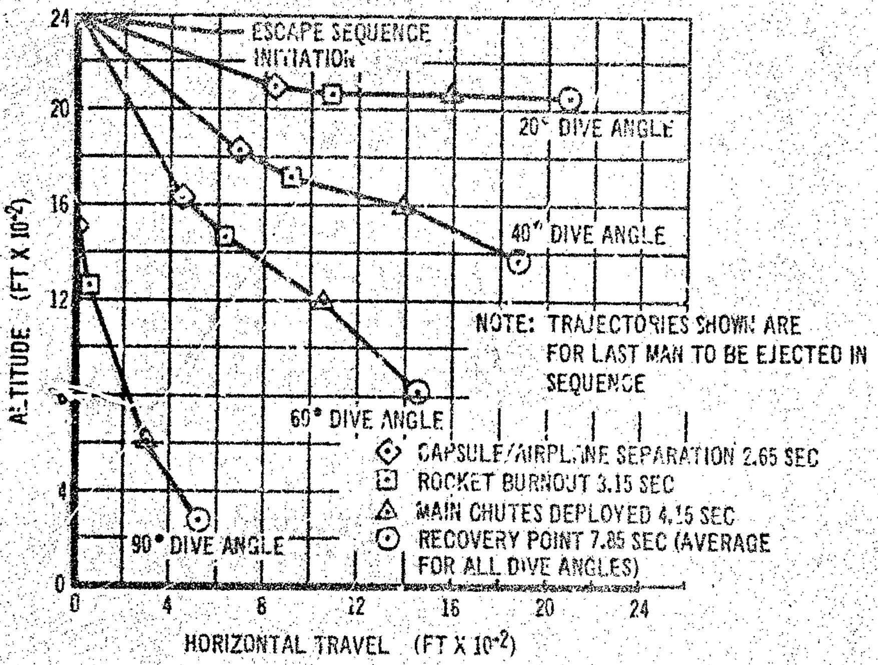
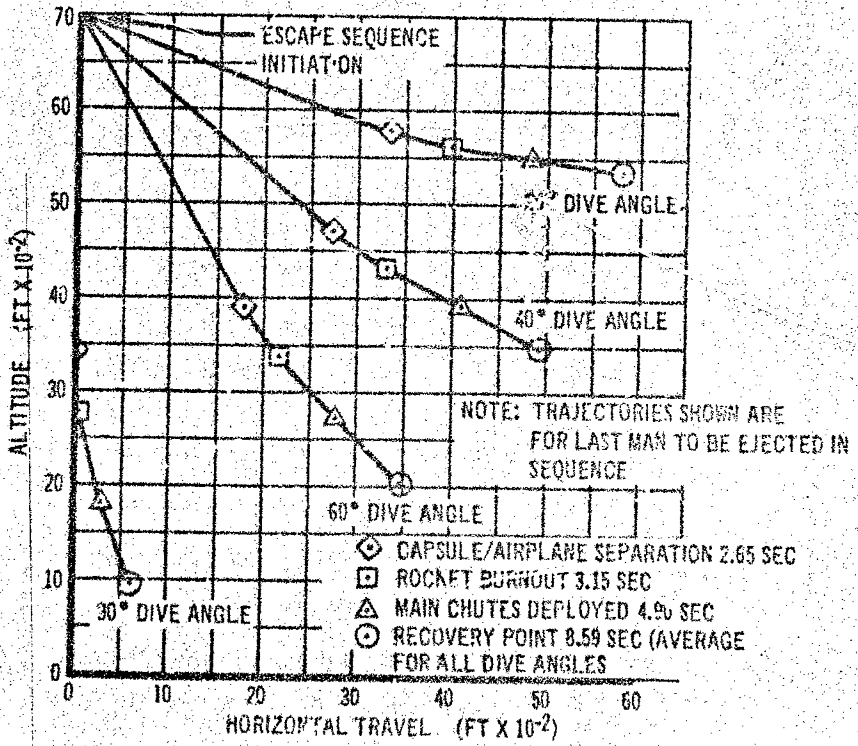


Figure 40. Two-Man Vehicle Encapsulated Ejection Seat Dive Trajectories, 600 Knots



NOTE: TRAJECTORIES SHOWN ARE FOR LAST MAN TO BE EJECTED IN SEQUENCE

Figure 41. Three-Man Vehicle Encapsulated Ejection Seat Dive Trajectories, 200 Knots



NOTE: TRAJECTORIES SHOWN ARE FOR LAST MAN TO BE EJECTED IN SEQUENCE

Figure 42. Three-Man Vehicle Encapsulated Ejection Seat Dive Trajectories, 800 Knots

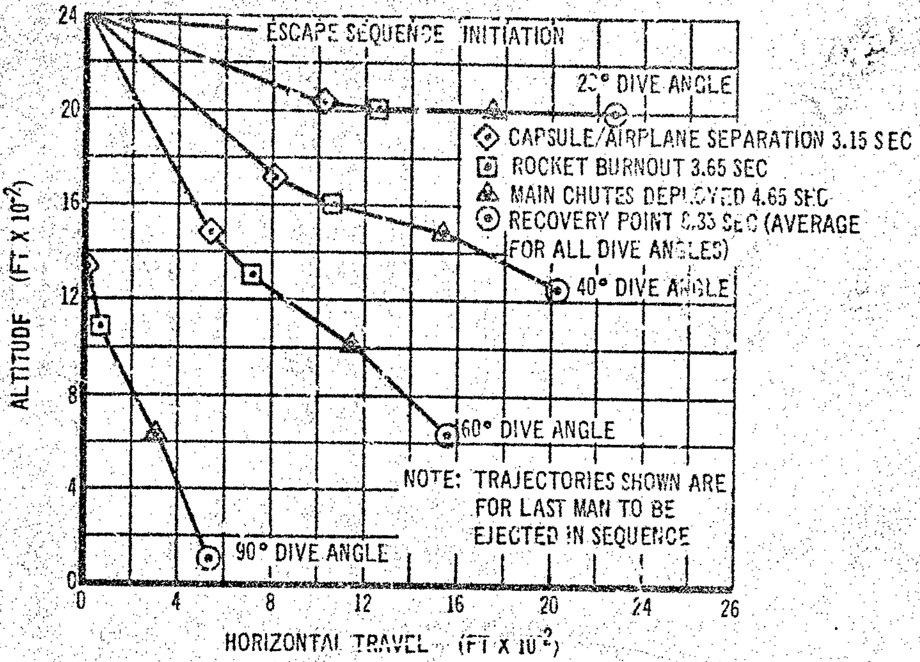


Figure 43. Four-Man Vehicle Encapsulated Ejection Seat Dive Trajectories, 200 Knots

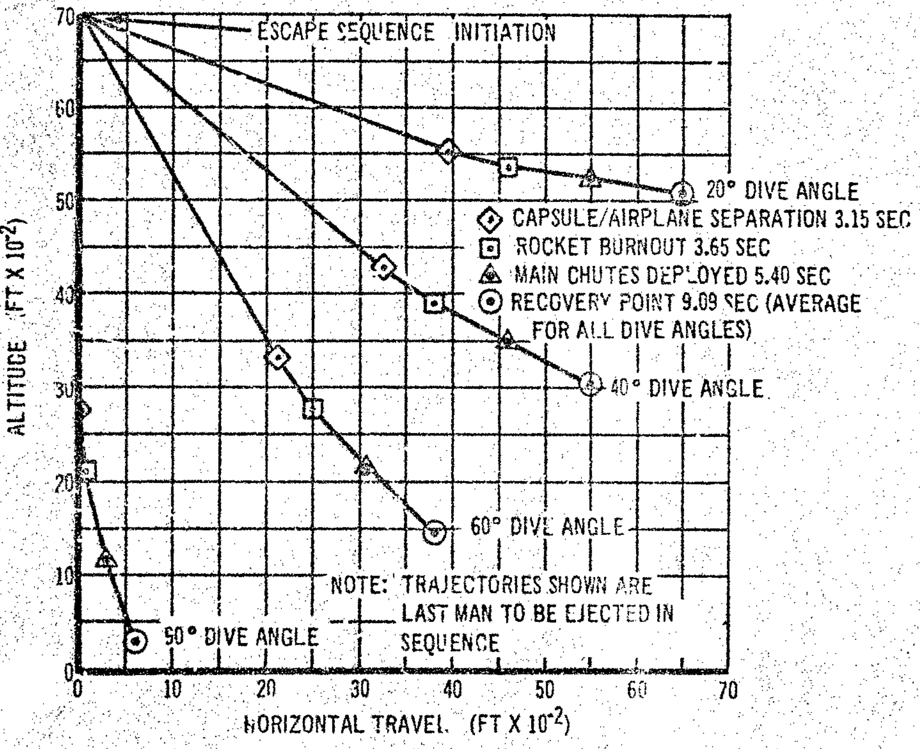
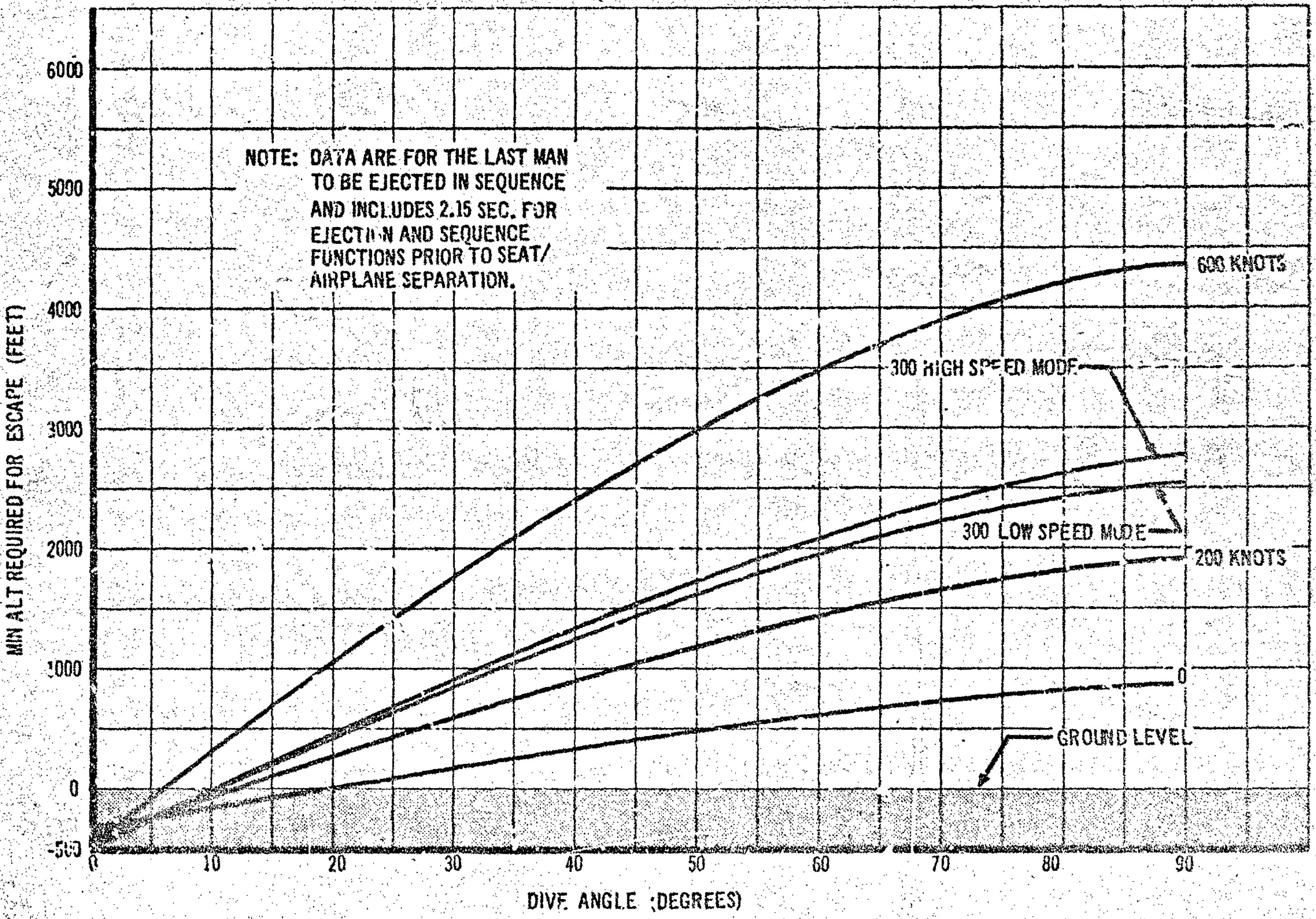


Figure 44. Four-Man Vehicle Encapsulated Ejection Seat Dive Trajectories, 800 Knots



NOTE: DATA ARE FOR THE LAST MAN TO BE EJECTED IN SEQUENCE AND INCLUDES 2.15 SEC. FOR EJECTION AND SEQUENCE FUNCTIONS PRIOR TO SEAT/ AIRPLANE SEPARATION.

Figure 45. Two-Man Vehicle Encapsulated Ejection Seat Escape Altitude Required

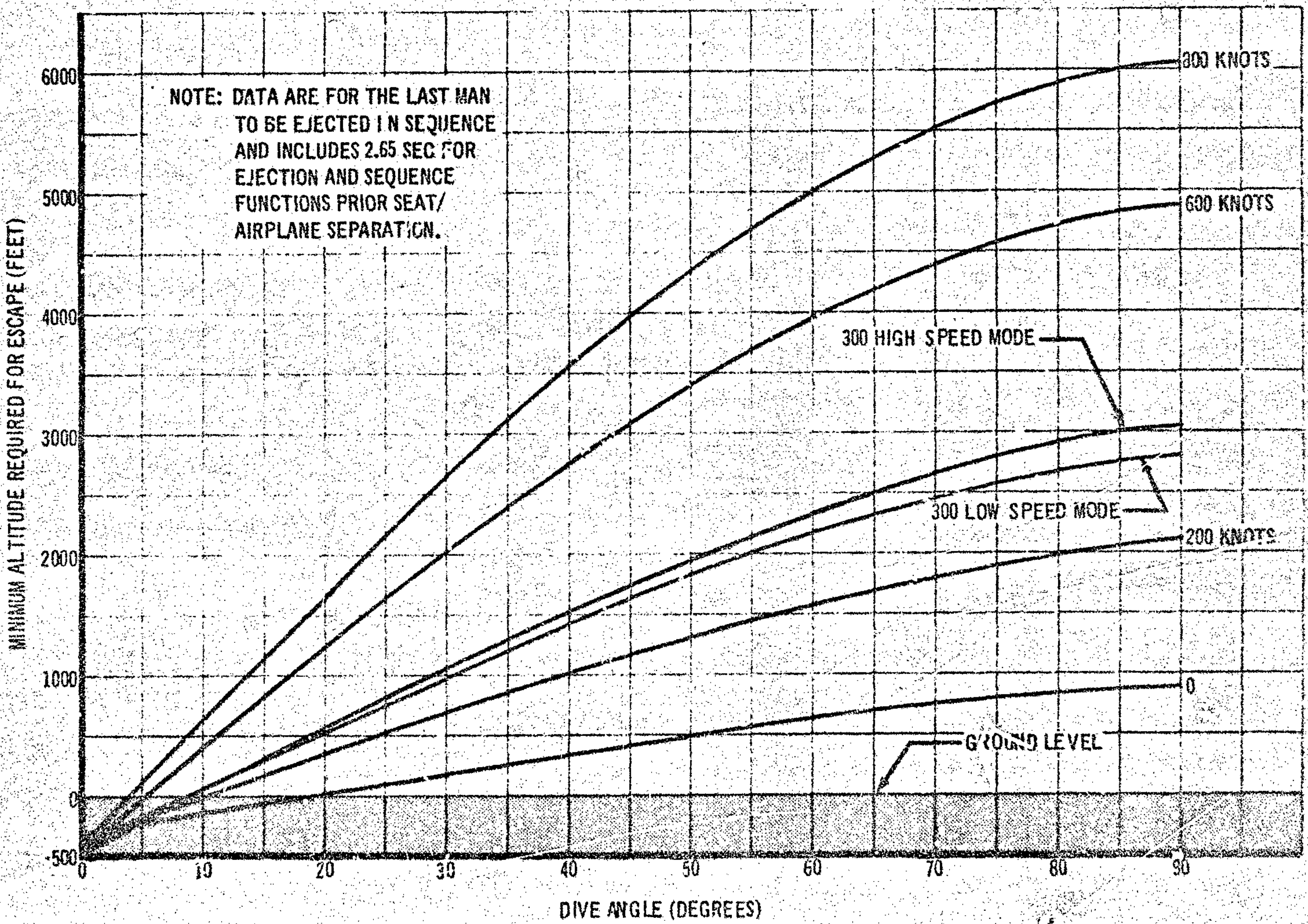
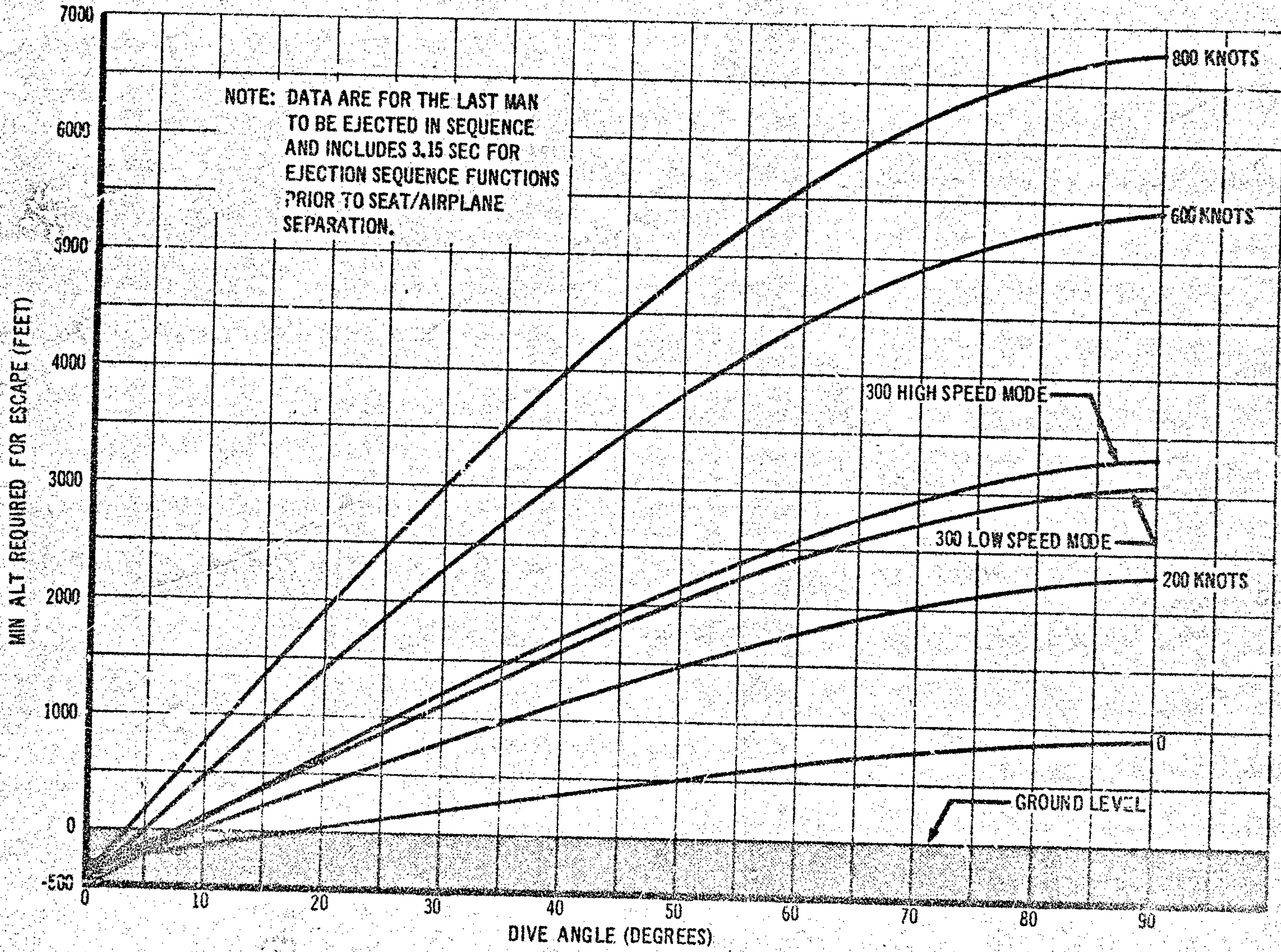


Figure 46. Three-Man Vehicle Encapsulated Ejection Seat Escape Altitude Required



NOTE: DATA ARE FOR THE LAST MAN TO BE EJECTED IN SEQUENCE AND INCLUDES 3.15 SEC FOR EJECTION SEQUENCE FUNCTIONS PRIOR TO SEAT/AIRPLANE SEPARATION.

Figure 47. Four-Man Vehicle Encapsulated Ejection Seat Escape Altitude Required

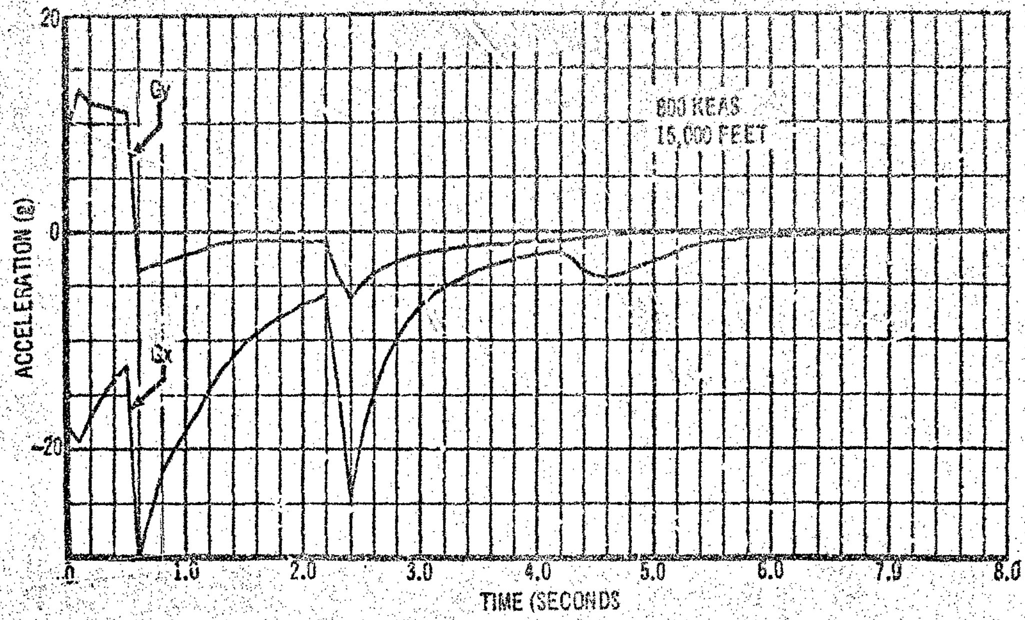


Figure 48. Encapsulated Seat – Computer Plot of Acceleration

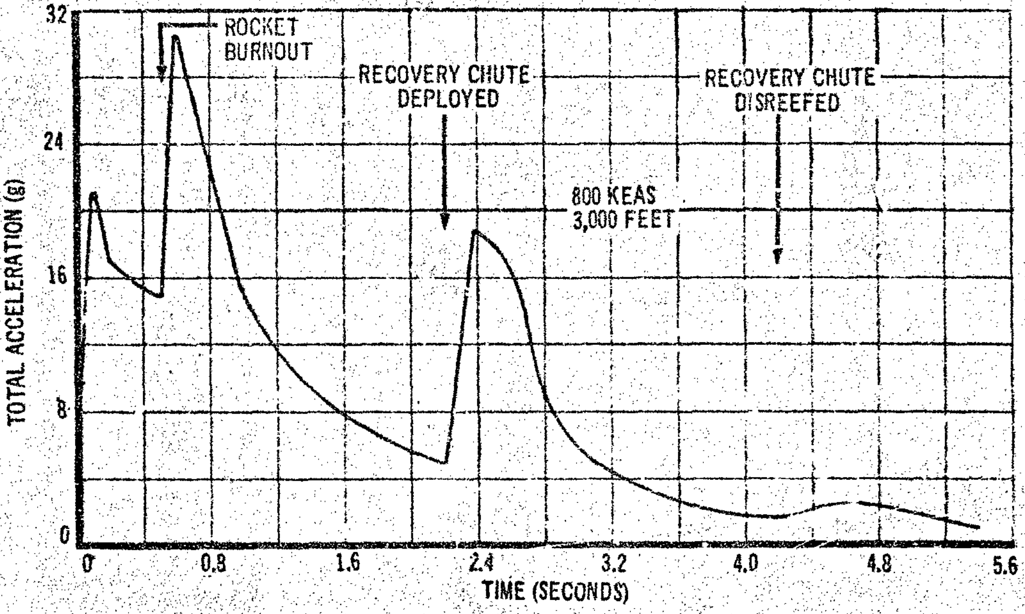


Figure 49. Encapsulated Ejection Seat -- Acceleration

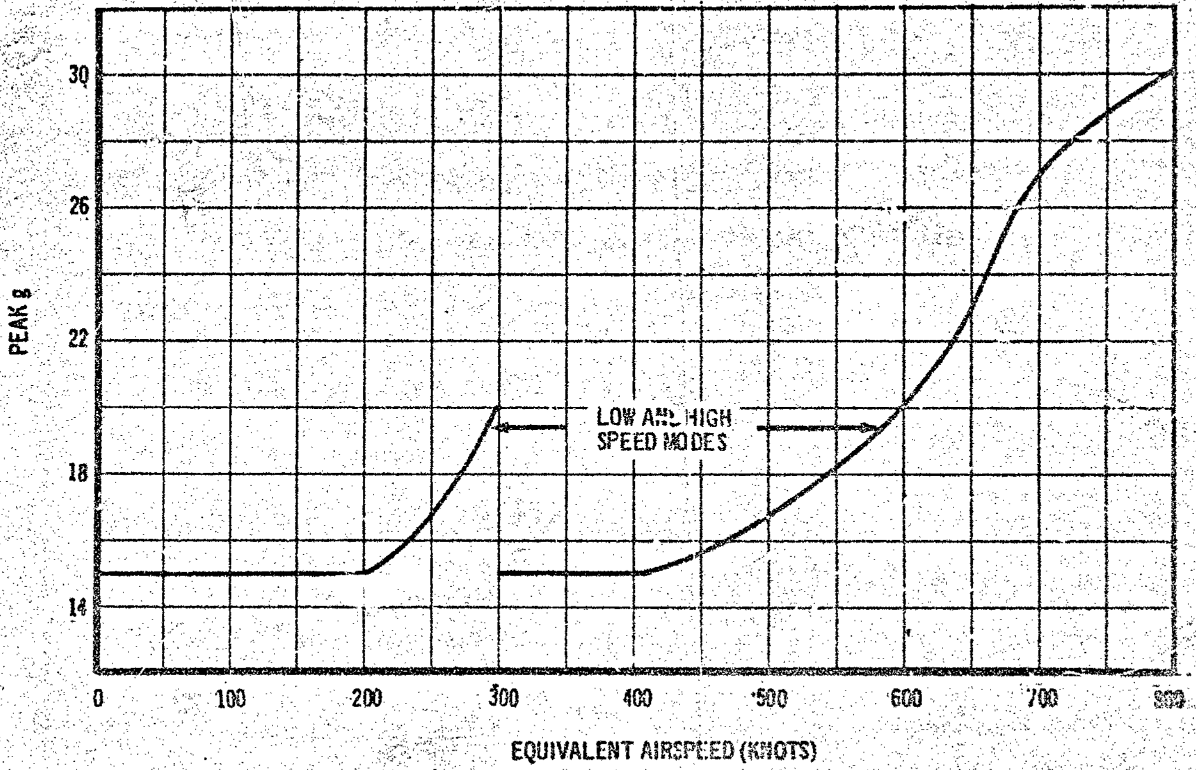


Figure 50. Encapsulated Ejection Seat – Peak g

3. COCKPIT POD CAPSULE CONFIGURATIONS

a. Configurations

This section describes preliminary design configurations of cockpit pod capsule escape systems for the two-man subsonic VTOL vehicle, four-man supersonic dash vehicle, and the three-man combined capability vehicle. The escape systems were designed to provide safe escape at zero-speed, zero-altitude and throughout the performance envelopes.

The cockpit pod capsule (CPC) concepts for the two-, three-, and four-man configurations are shown in Figs. 51, 52 and 53. The heavy solid lines in both the plan and side views trace the outline of the CPC after separation. The drawings also show the location and approximate sizes of the subsystems required for escape.

Upon escape initiation, the crew compartment is separated from the rest of the airplane by linear shaped charges. Two stabilization parachute booms are extended and a stabilization parachute is deployed from each. The escape boost rocket then propels the capsule up and away from the rest of the airplane.

As soon as the capsule has decelerated to a dynamic pressure corresponding to safe structural loads of the parachutes, they are deployed. The time required for capsule deceleration is a function of the dynamic pressure at the time of escape initiation. To provide optimum escape performance at low and high speeds, a two-mode timing sequence is employed. At speeds above 350 KEAS, the high-speed mode is used; below 350 KEAS the low-speed mode is used. The escape timing sequences for both modes are shown in Figs. 54, 55 and 56.

Table III lists capsule design data with escape subsystem sizes and weights. Subsystems related to escape activity are described in more detail in Section III.5.

b. Performance

Capsule recovery altitude — that is, the aircraft altitude required for the main parachute to fully open — is a function of timing sequence, stabilization of capsule in a positive lift attitude, rocket thrust, burntime, rocket nozzle angle, and location of thrust line below the capsule center of gravity.

During level flight at ground level, all three cockpit pod capsules were computed to fully recover at any velocity within their speed range. This is shown in Figs. 57, 58 and 59. Figures 60 through 65 show capsule escape trajectories at both 200 KEAS and maximum airplane speeds during diving flight. Overall capsule performance with respect to the minimum altitude required for successful escape for various velocities and dive angles is shown in Figs. 66, 67 and 68. These plots include a time delay of 0.2 second from escape initiation to capsule separation. The notations of the high-speed and low-speed modes refer to the two-mode timing sequence shown in Figs. 54, 55 and 56. Figures 69, 70 and 71 show the maximum peak capsule accelerations experienced during escape versus equivalent airspeed at the time of escape initiation. Accelerations versus time for the maximum speed conditions at 15,000 feet in the X and Y directions are shown on computer plots in Figs. 72, 73 and 74. Figures 75, 76 and 77 show the resultant g for the same conditions.

All data shown include a 0.2-second time delay from escape initiation to capsule separation. No time is included for detection, decision making, or control actuation required by the crew.

Table III. Cockpit Pod Capsule Design Data

		Vehicle		
		Two Man	Three Man	Four Man
Capsule				
Weight (total ejectable)	Lb	3,600.0	6,500.0	9,000.0
Length, overall	Ft	14.0	16.0	21.6
Ref. area	Ft^2	22.0	40.0	63.0
Pitch inertia	$Lb\text{-}Sec^2\text{-}Ft$	2,000.0	4,000.0	6,120.0
Separation System				
Weight of FLSC (flexible linear shaped charge)	Lb	26.0	26.0	26.0
Weight of initiating system plus Function Fittings	Lb	12.6	12.6	12.6
Boost Rocket				
Thrust	Lb	43,700.0	110,000.0	171,000.0
Burntime	Sec	0.6	0.6	0.6
Volume	In^3	4,300.0	12,200.0	19,500.0
Nozzle angle	Deg	34.2	23.6	20.9
Weight	Lb	180.0	460.0	720.0
Thrust/CG Misalignment	Ft	0.5	1.0	1.0
Stabilization Booms (2 per vehicle)				
No. of tubes		3.0	3.0	3.0
Boom length stored	Ft	3.8	4.5	5.0
Boom length extended	Ft	10.2	12.0	13.0
Storage tube OD	In	14.9	17.4	19.7
Weight (total) (not including weight of bridle and parachute)	Lb	1,000.0	1,500.0	1,800.0
Stabilization Parachutes (2 per vehicle)				
Reefed diameter	Ft	3.5	5.4	6.8
Flat diameter	Ft	10.0	11.0	12.0
Stowed vol (total)	In^3	1,000.0	3,000.0	6,000.0
Weight (total)	Lb	40.0	70.0	110.0

Table III. (Continued)

		Vehicle		
		Two Man	Three Man	Four Man
Recovery Parachutes				
No. of parachutes		1.0	2.0	3.0
Reefed diameter	Ft	12.9	13.3	11.9
Flat diameter	Ft	71.0	69.6	69.0
Stowed vol (total)	In^3	8,000.0	15,000.0	22,500.0
Weight (total)	Lb	110.0	210.0	290.0
Impact Attenuation System				
Bag weight	Lb	32.0	45.0	57.0
Inflated vol	Ft^3	66.0	123.0	167.0
Stowed vol	In^3	2,700.0	3,700.0	4,600.0
Pressure bottle vol	In^3	650.0	1,150.0	1,600.0
Inflation assy weight	Lb	26.0	39.0	51.0
Flotation System				
Bag dia spherical, (4 ea)	Ft	3.0	3.7	4.1
Bag wt (total)	Lb	17.0	34.0	46.0
Inflation bottle vol	In^3	650.0	1,430.0	1,880.0
Bottle, gas & valve wt	Lb	22.2	41.0	51.5
Self righting bag (1 ea) (Same dia as flot bag)				
Bag wt	Lb	4.3	8.5	11.5
Inflation bottle vol	In^3	190.0	360.0	470.0
Bottle, gas and valve wt	Lb	7.2	12.5	15.5
Weight Summary (Lbs)				
Separation system		38.6	38.6	38.6
Nose radome thrusters		0.0	0.0	13.0
Boost rocket		180.0	460.0	720.0
Stabilization booms		1,000.0	1,500.0	1,800.0
Stabilization parachutes		40.0	70.0	110.0
Recovery parachutes		110.0	210.0	290.0
Impact attenuation system		58.0	84.0	108.0
Flotation system		50.7	96.0	124.5
Rocket support structure		30.0	78.0	120.0
Stabilization boom attachment		61.0	92.0	110.0
Recovery parachute attachment		20.0	30.0	40.0
Survival equipment		100.0	150.0	200.0
TOTAL (Penalty)		1,589.3	2,808.6	3,674.1

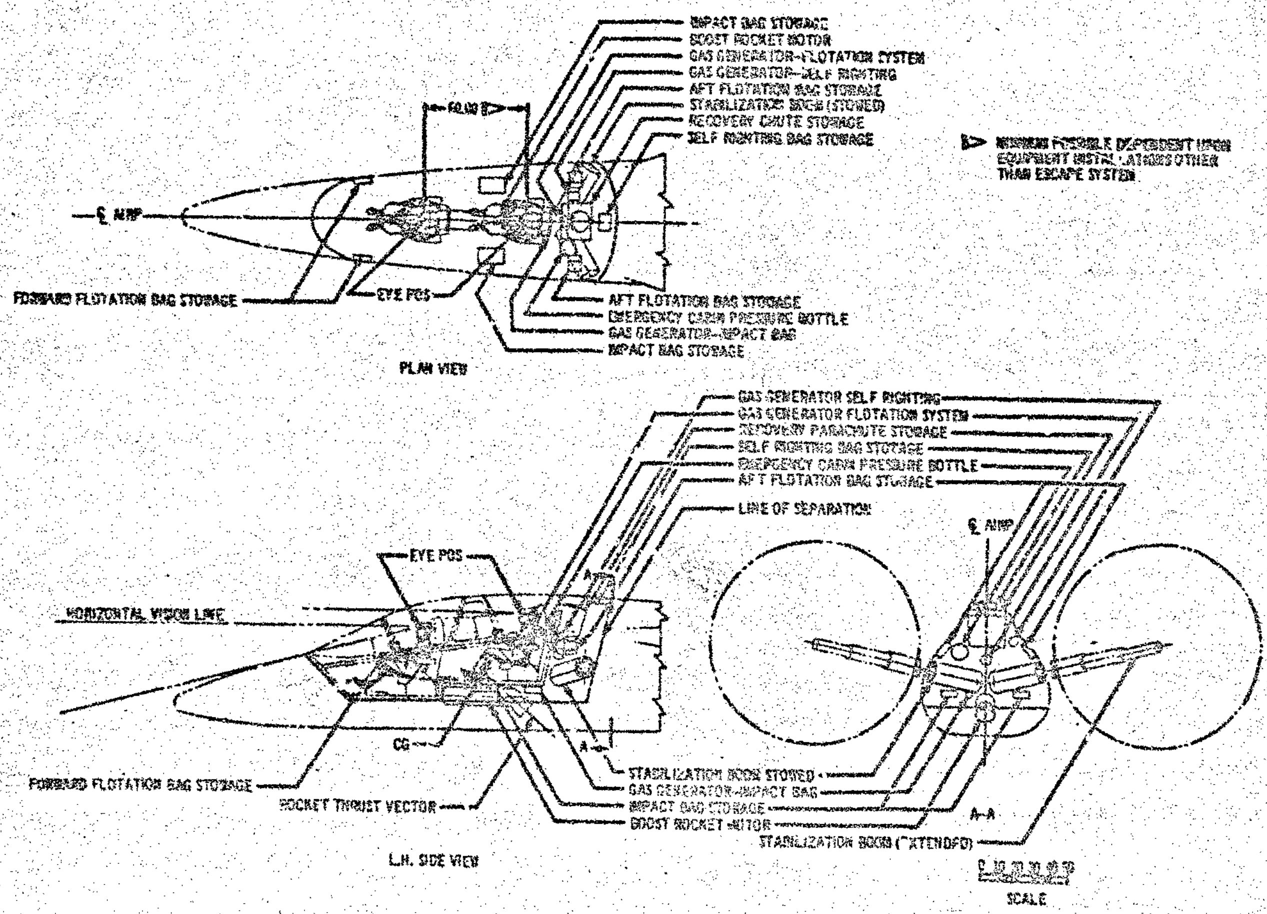


Figure 51. Two–Man Subsonic VTOL Vehicle Cockpit Pod Capsule Configuration

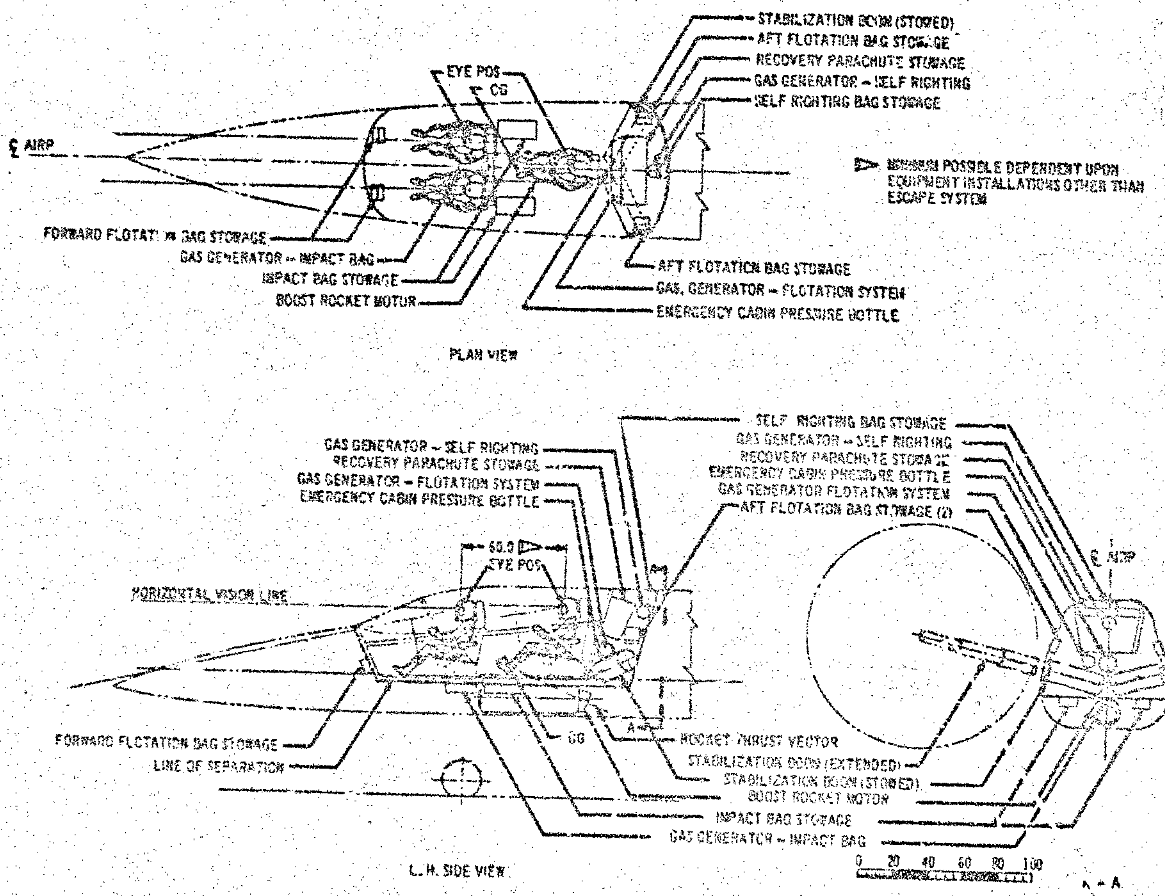


Figure 52. Three–Man Combined Capability Vehicle Cockpit Pod Capsule Configuration

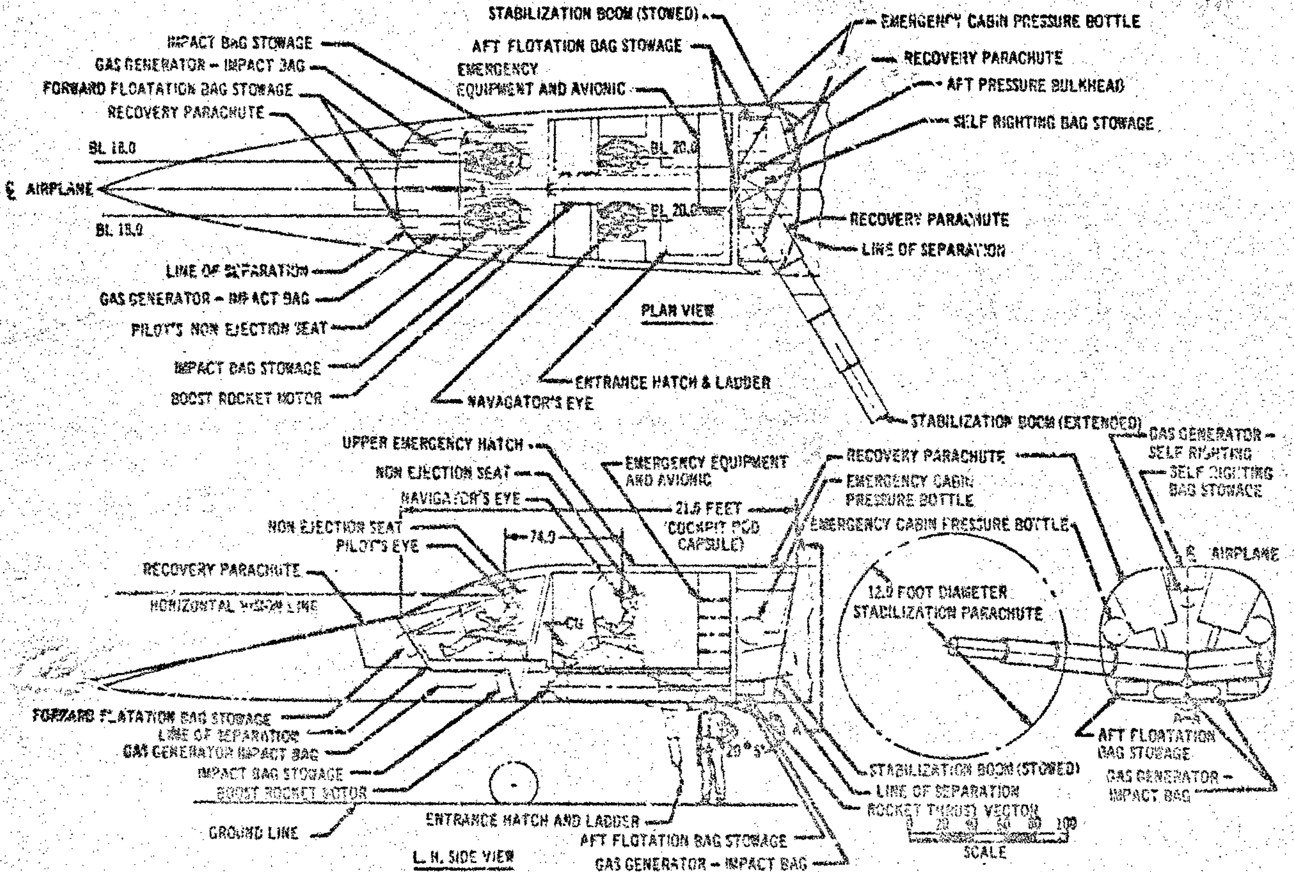
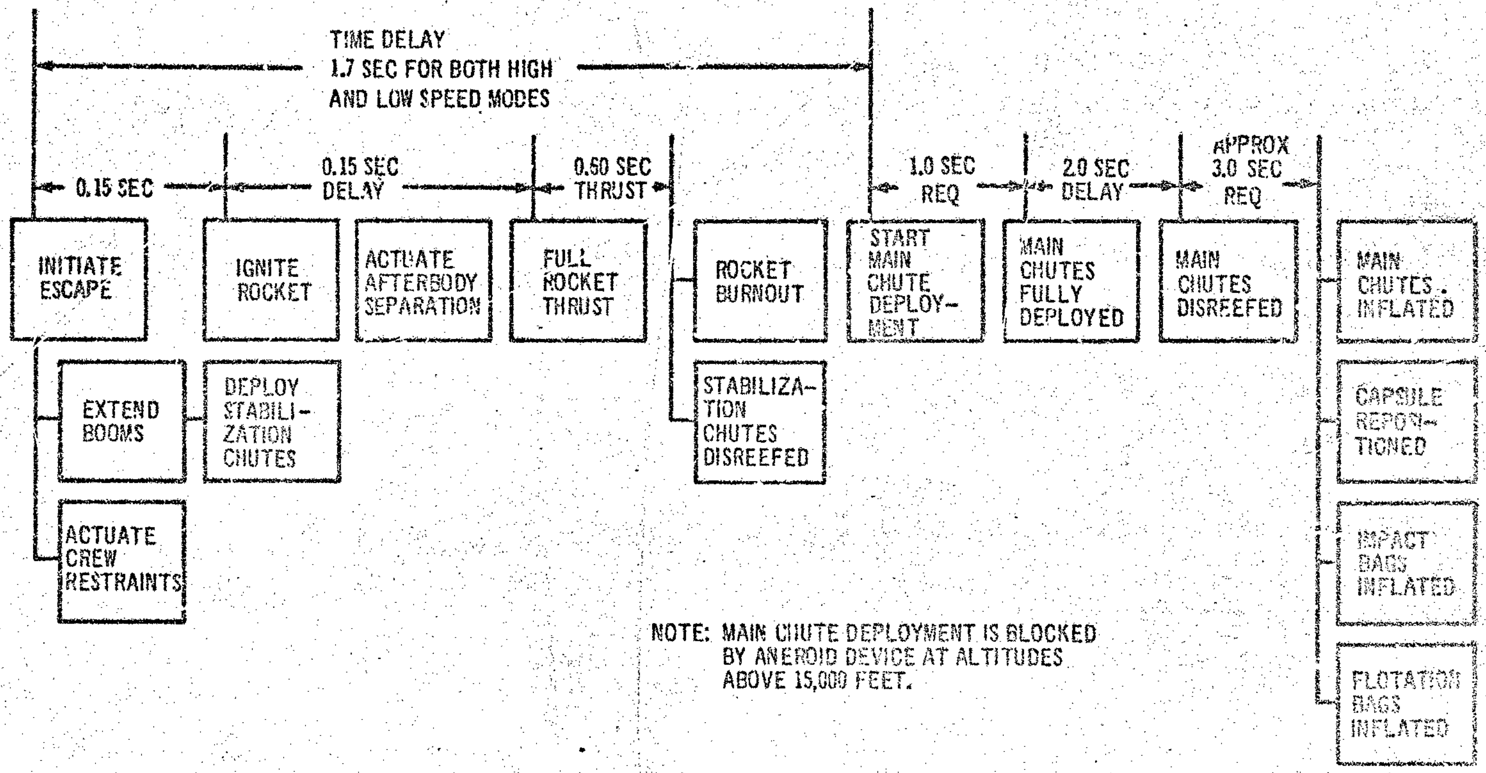
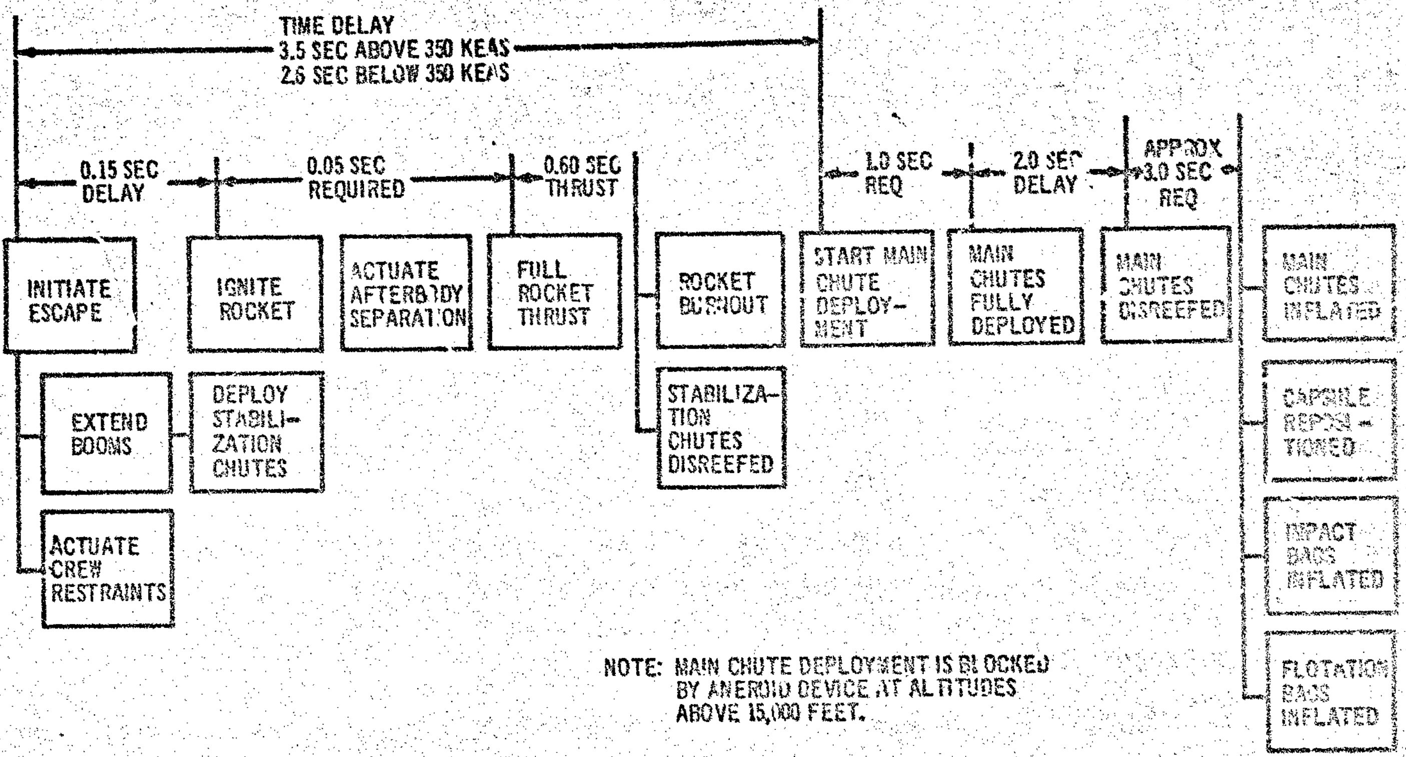


Figure 53. Four-Man Supersonic Dash Vehicle Cockpit Pod Capsule Configuration



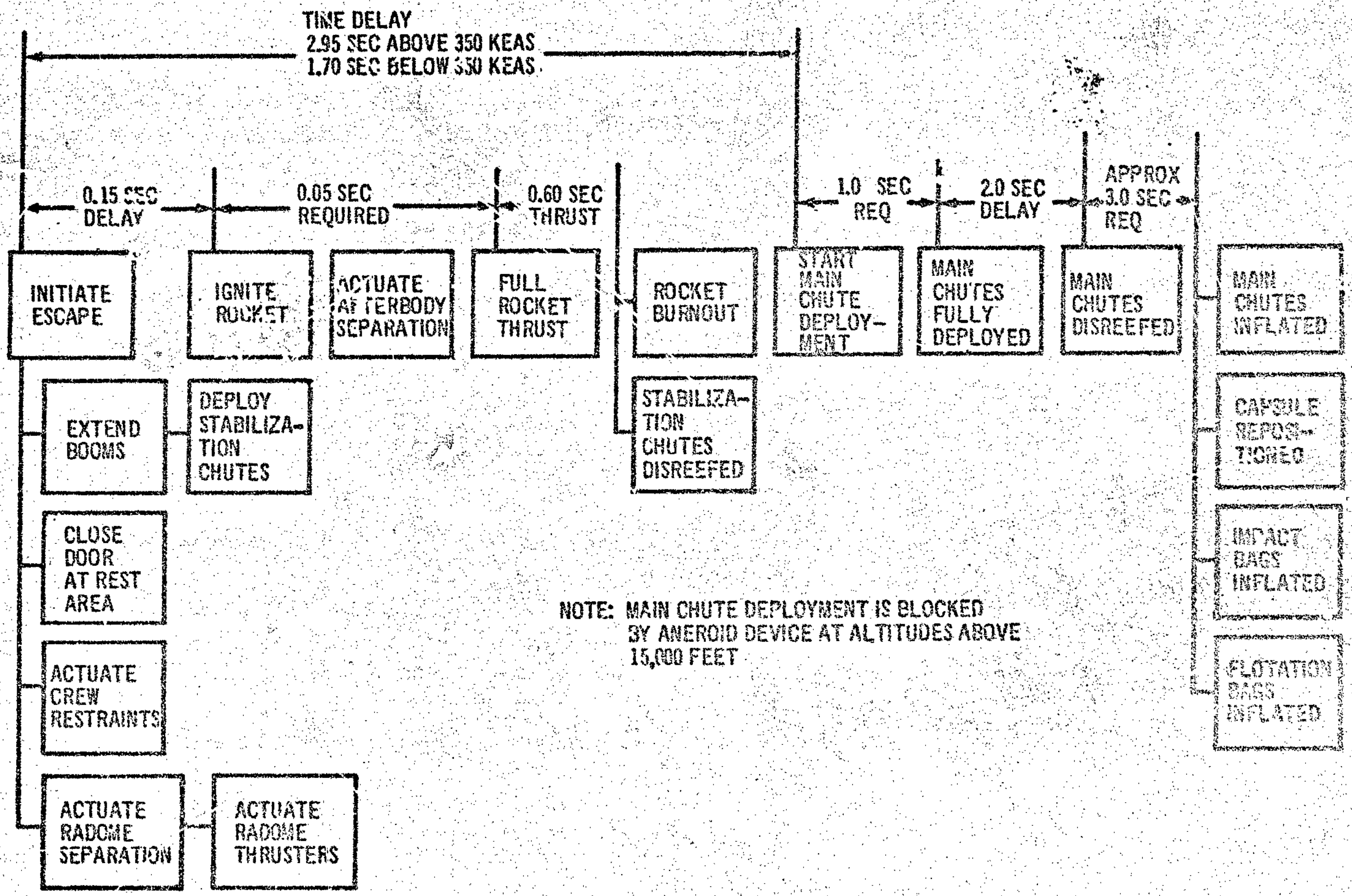
NOTE: MAIN CHUTE DEPLOYMENT IS BLOCKED BY ANEROID DEVICE AT ALTITUDES ABOVE 15,000 FEET.

Figure 54. Block Diagram – Escape Events Two-Man Cockpit Pod Capsule



NOTE: MAIN CHUTE DEPLOYMENT IS BLOCKED BY ANEROID DEVICE AT ALTITUDES ABOVE 15,000 FEET.

Figure 55. Block Diagram – Escape Events Three-Man Cockpit Pod Capsule



NOTE: MAIN CHUTE DEPLOYMENT IS BLOCKED BY ANEROID DEVICE AT ALTITUDES ABOVE 15,000 FEET

Figure 56. Block Diagram – Escape Events Four–Man Cockpit Pod Capsule

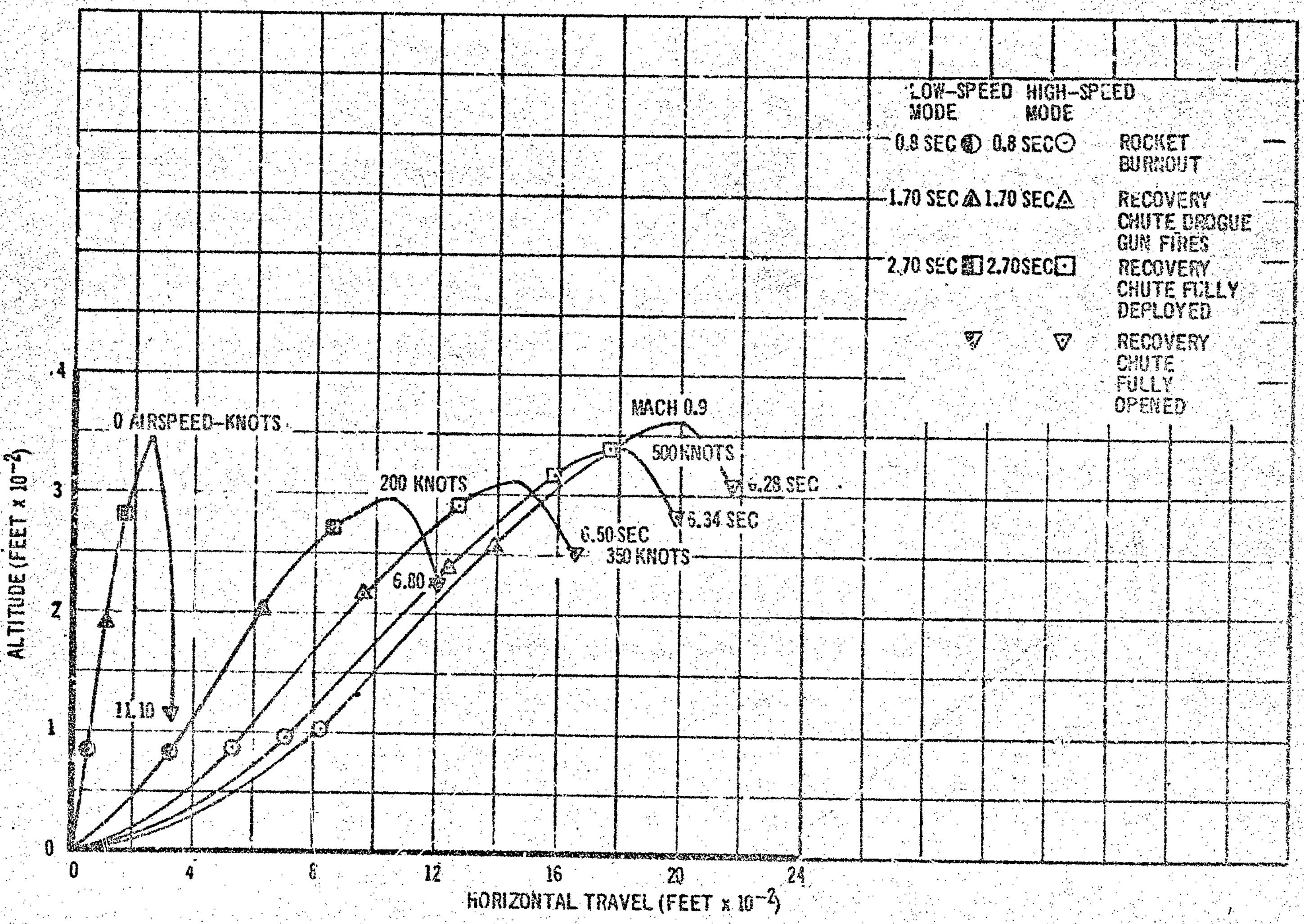


Figure 57. Two-Man Cockpit Pod Capsule Level Flight Trajectories

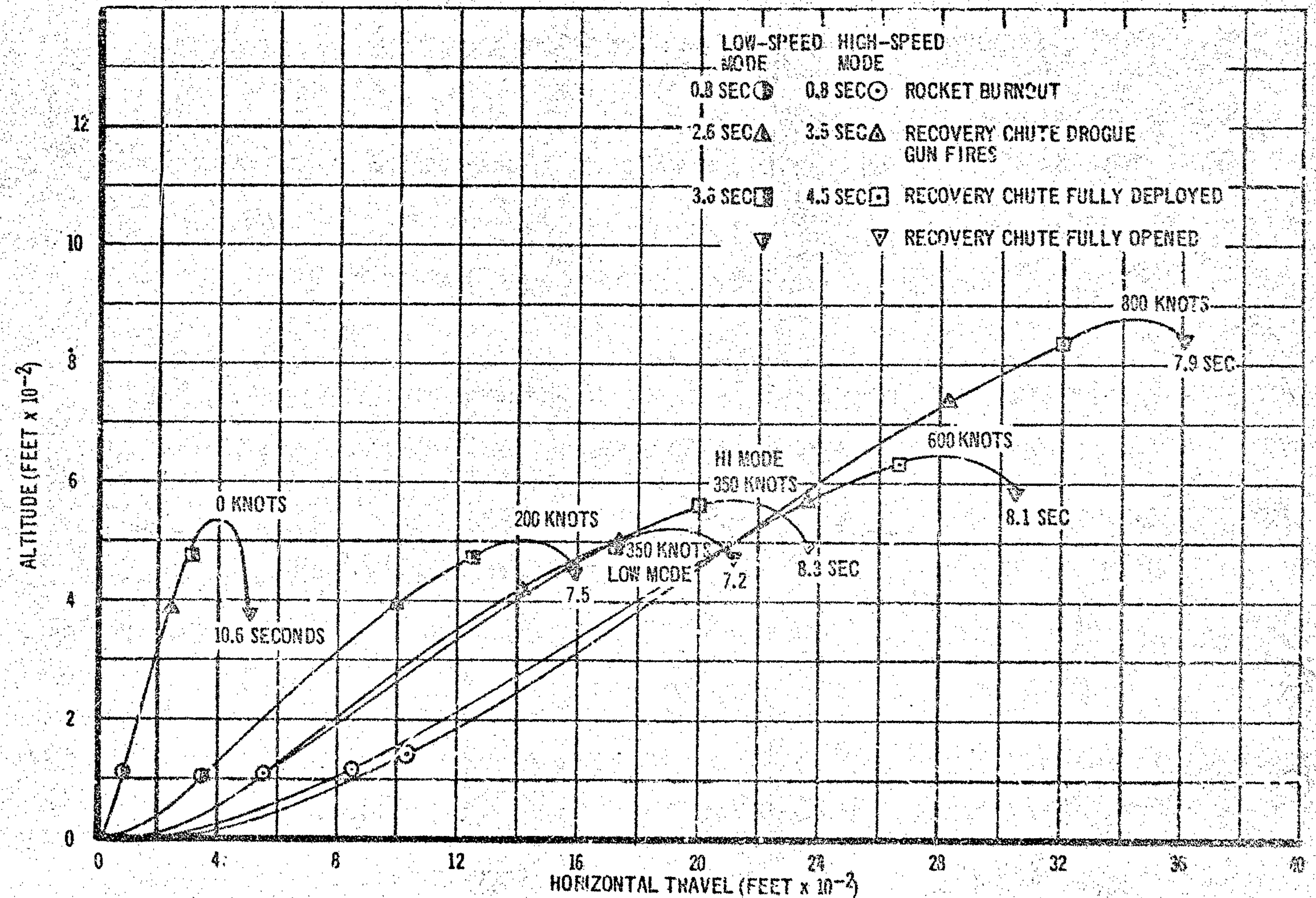


Figure 58. Three-Man Cockpit Pod Capsule Level Flight Trajectories

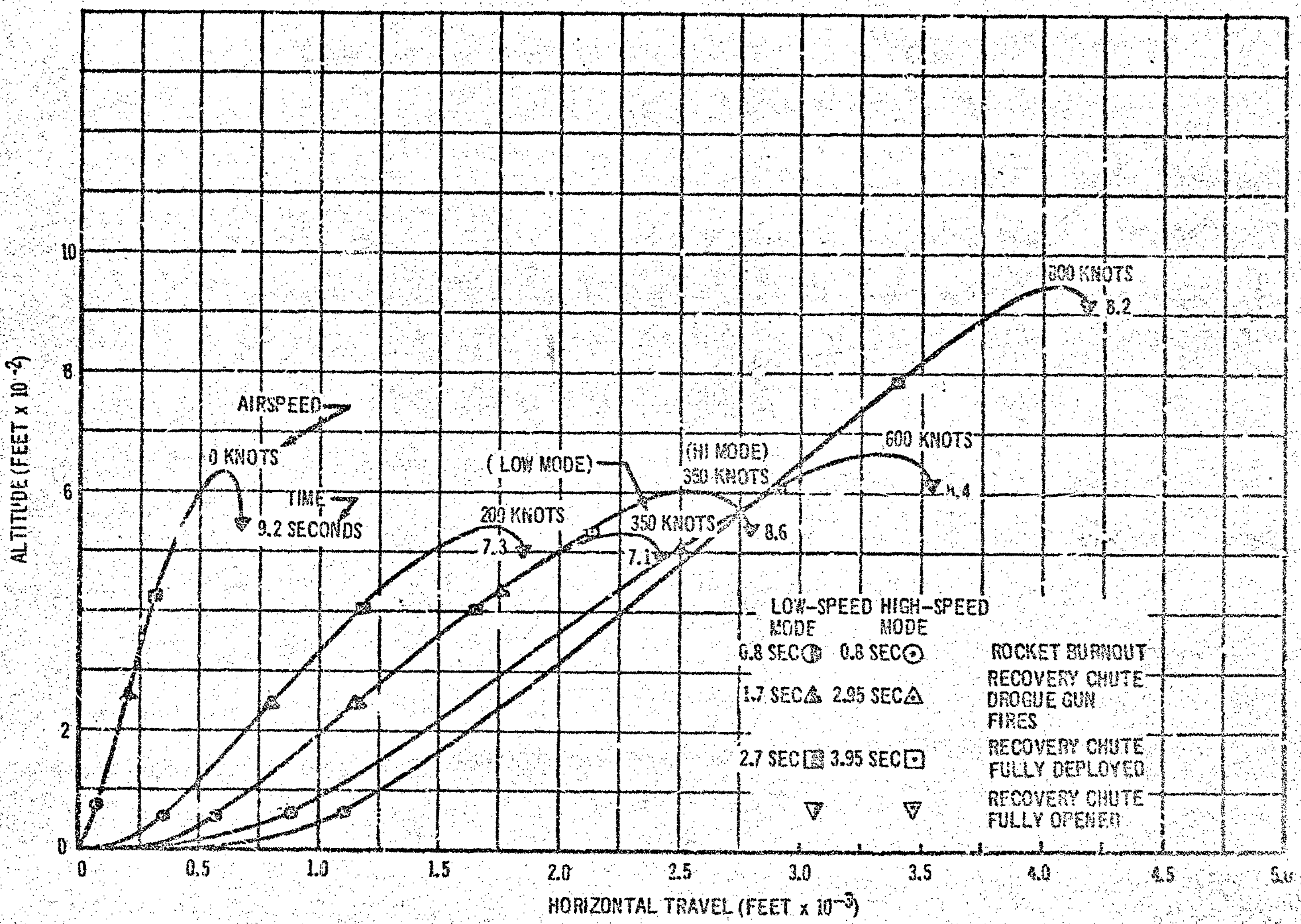


Figure 59. Four-Man Cockpit Pod Capsule Level Flight Trajectories

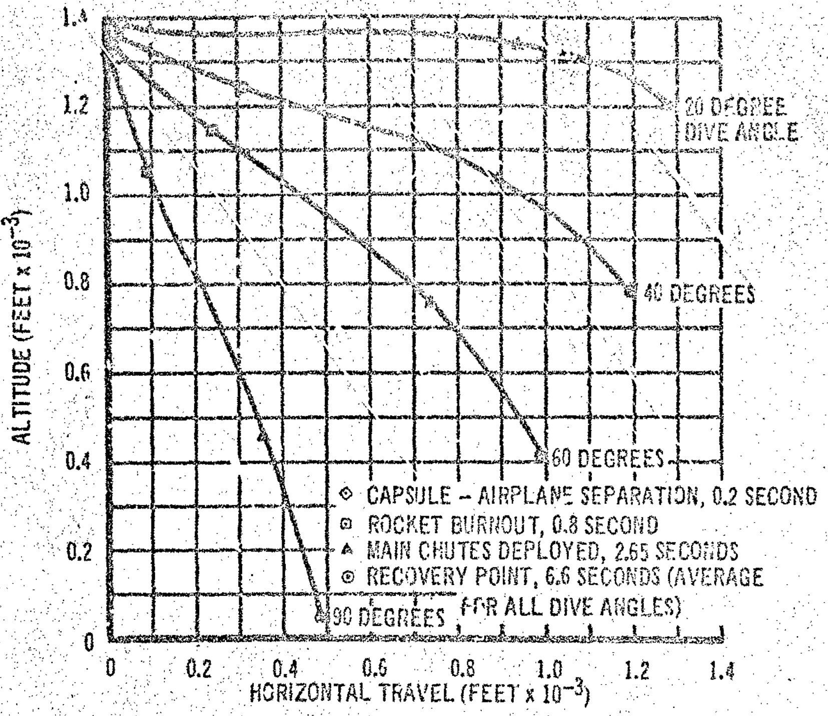


Figure 60. Two-Man Cockpit Pod Capsule Dive Trajectories, 200 Knots

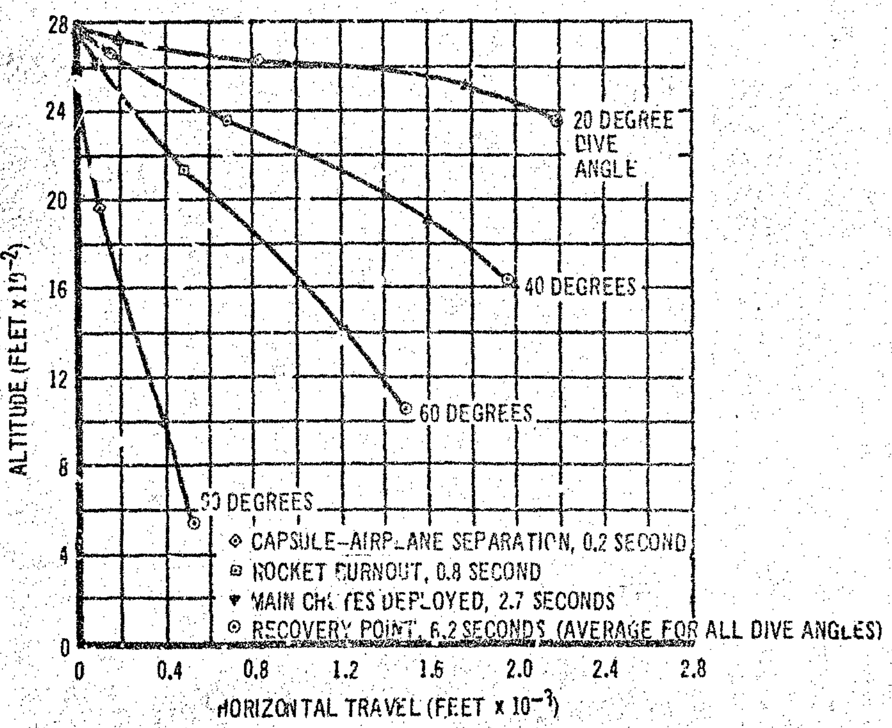


Figure 61. Two-Man Pod Capsule Dive Trajectories, M 0.9

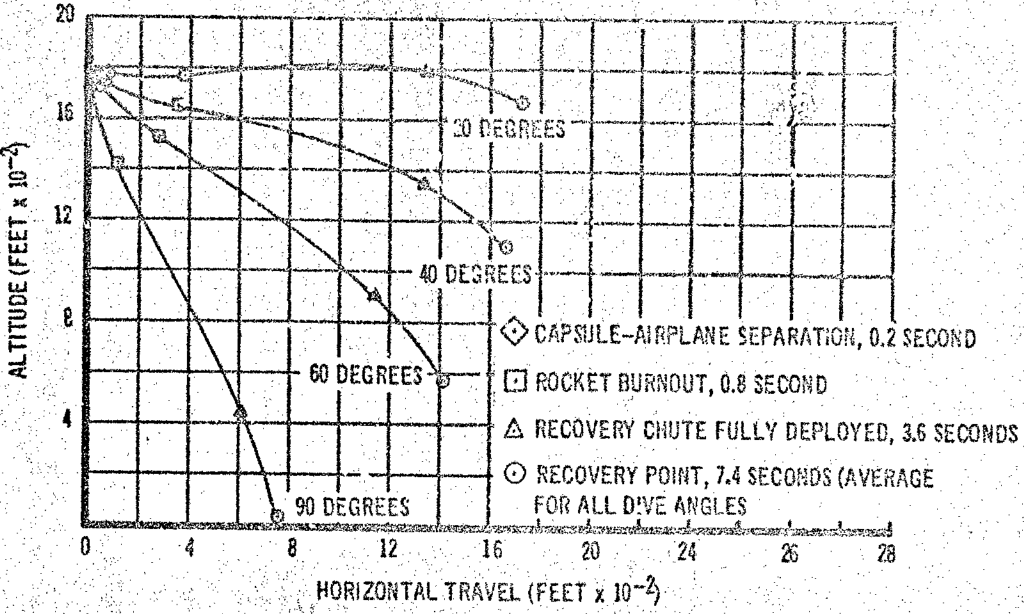


Figure 62. Three-Man Cockpit Pod Capsule Dive Trajectories, 200 Knots

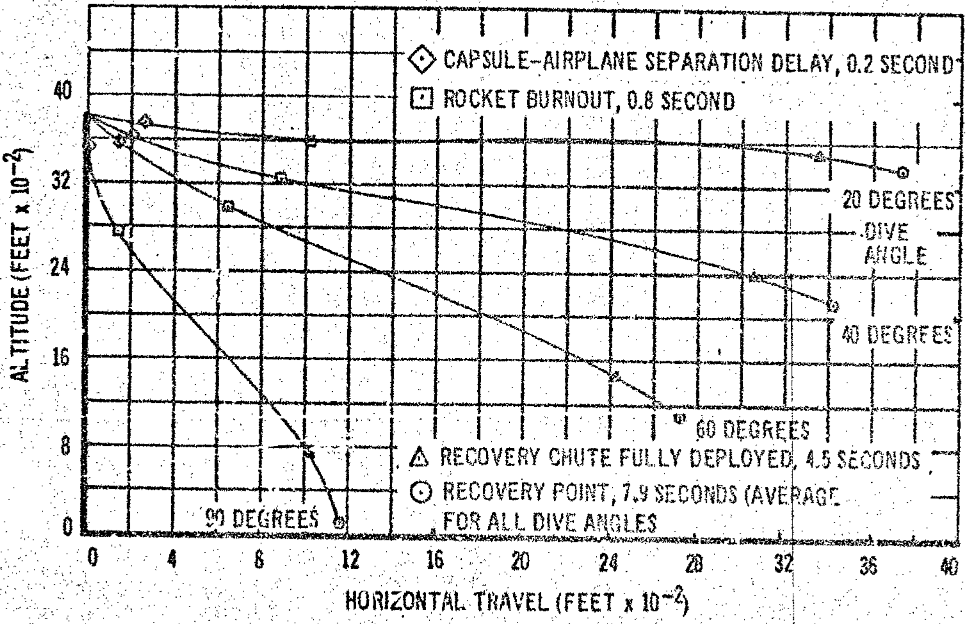


Figure 63. Three-Man Cockpit Pod Capsule Dive Trajectories, 600 Knots

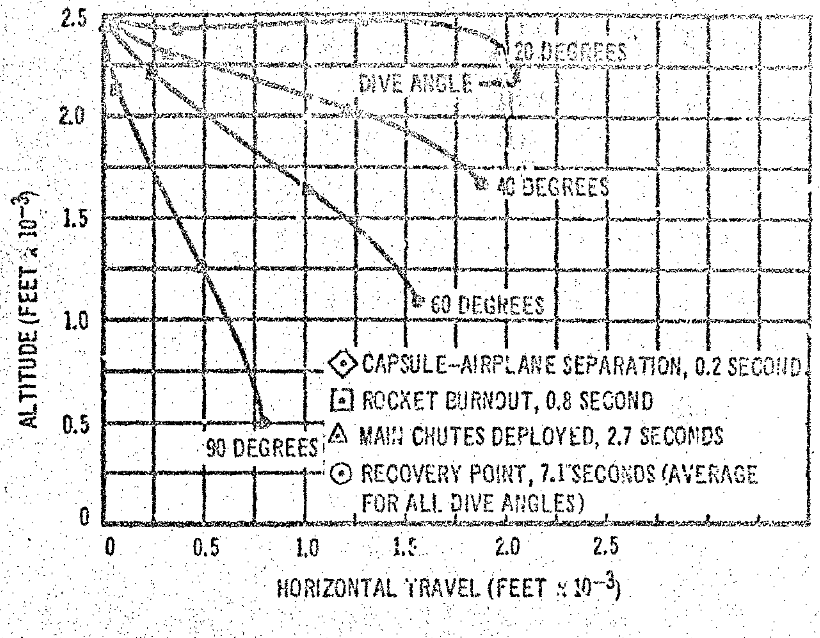


Figure 64. Four-Man Cockpit Pod Capsule Dive Trajectories, 200 Knots

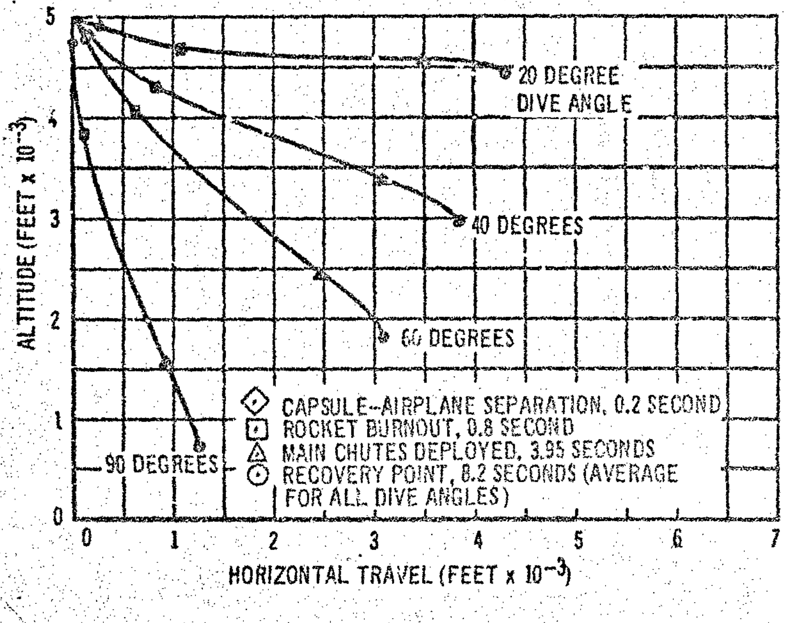


Figure 65. Four-Man Cockpit Pod Capsule Dive Trajectories, 800 Knots

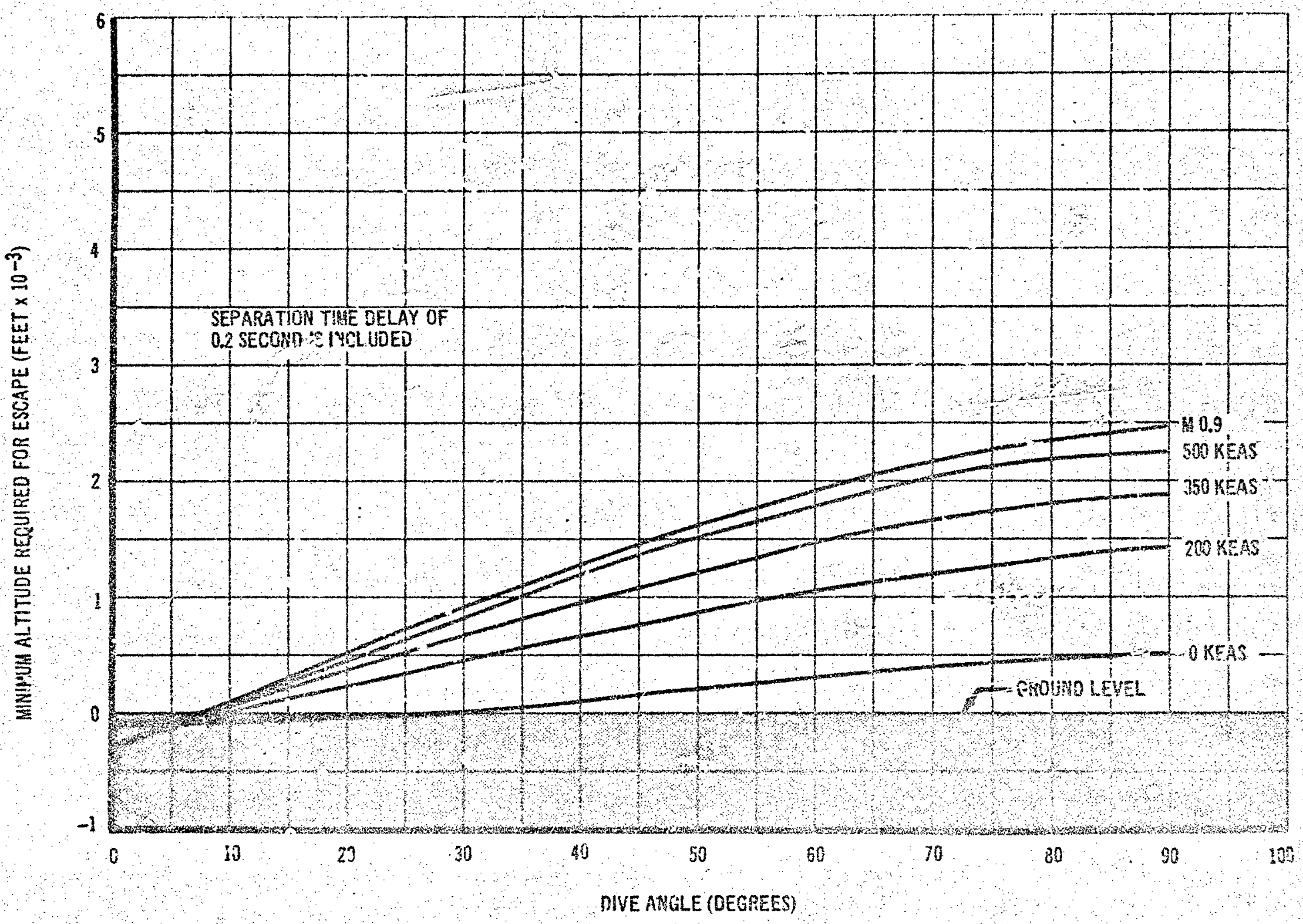


Figure 66. Two-Man Cockpit Pod Capsule Escape Altitude Required

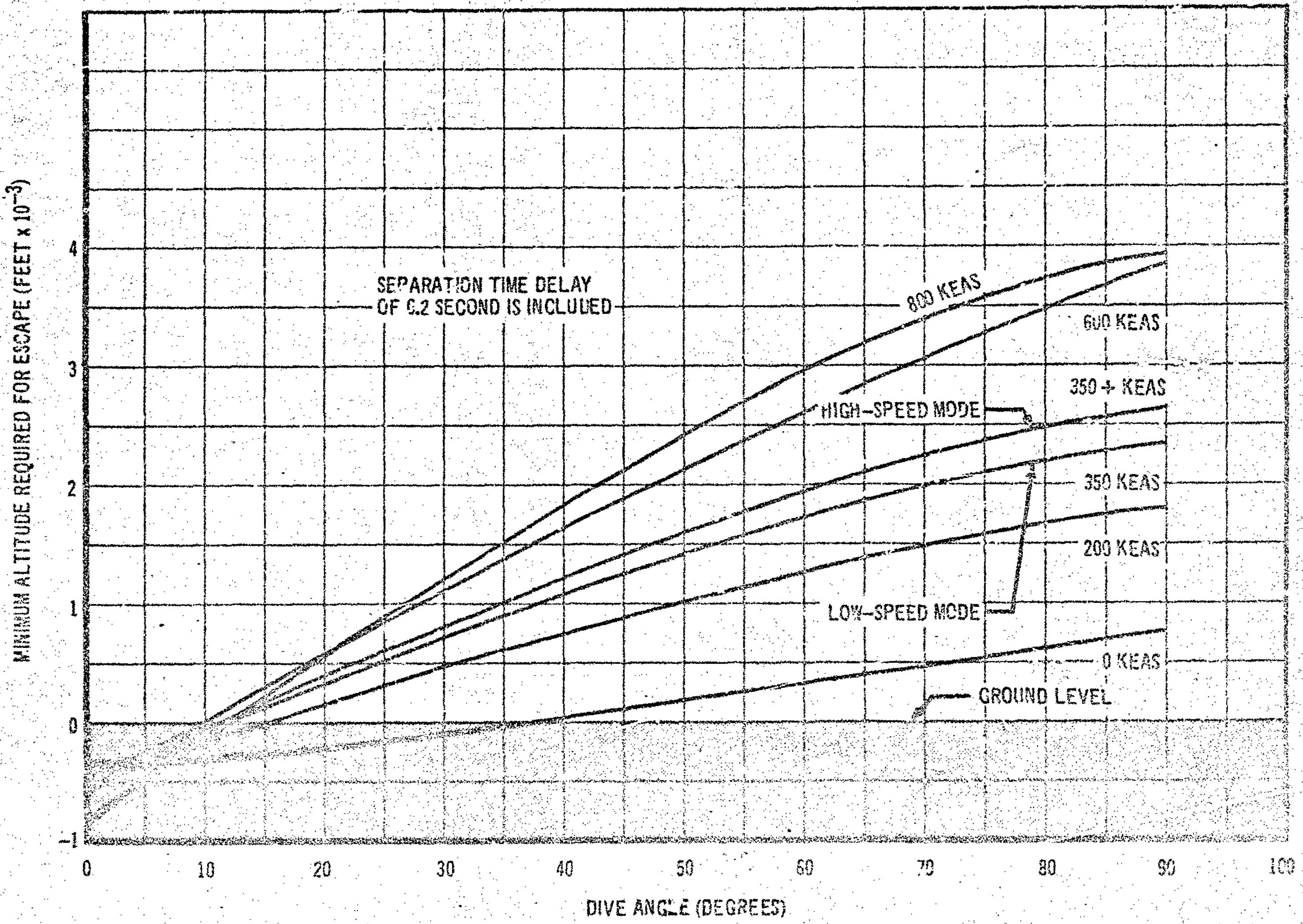


Figure 67. Three-Man Cockpit Pod Capsule Escape Altitude Required

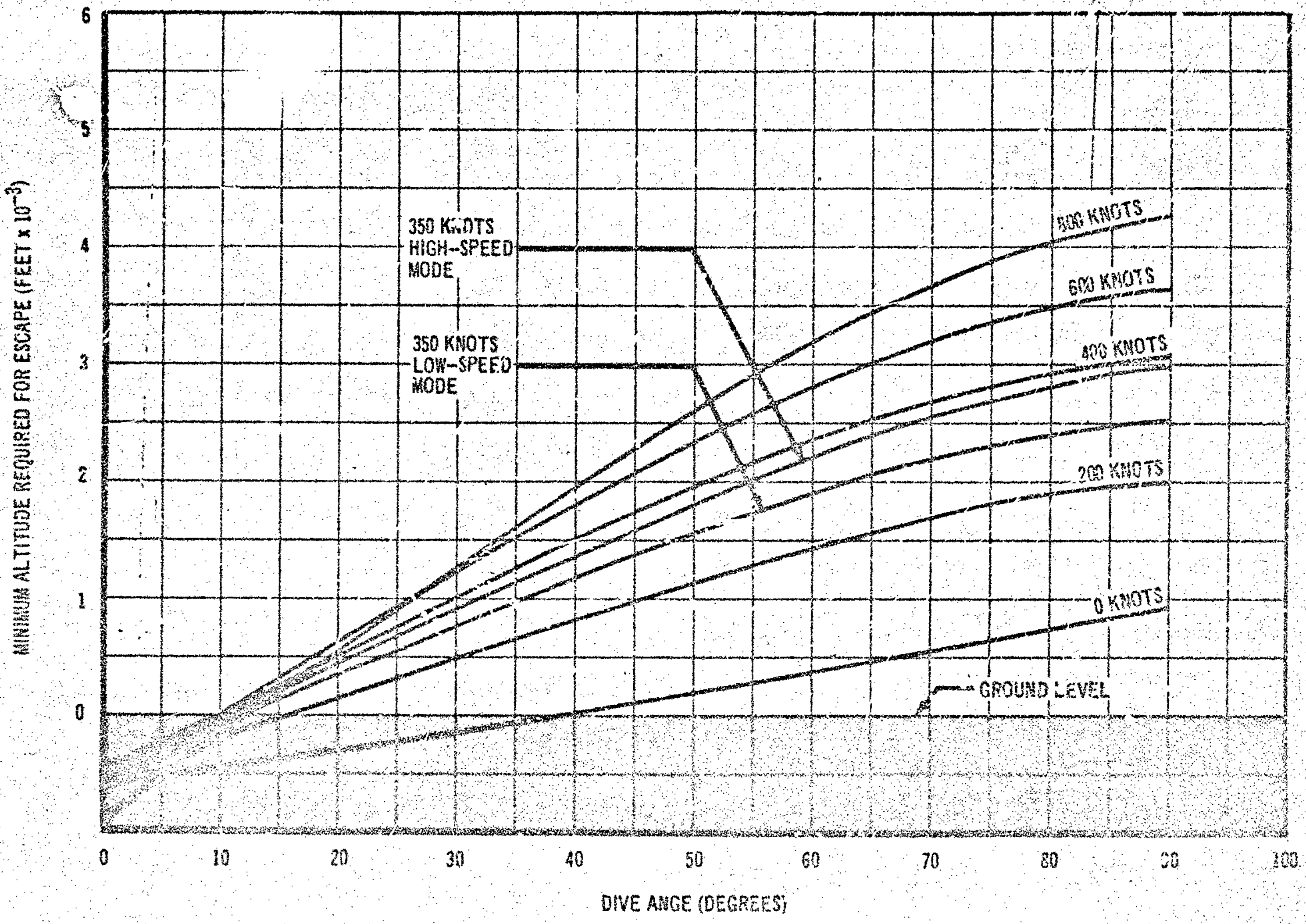


Figure 68. Four-Man Cockpit Pod Capsule Escape Altitude Required

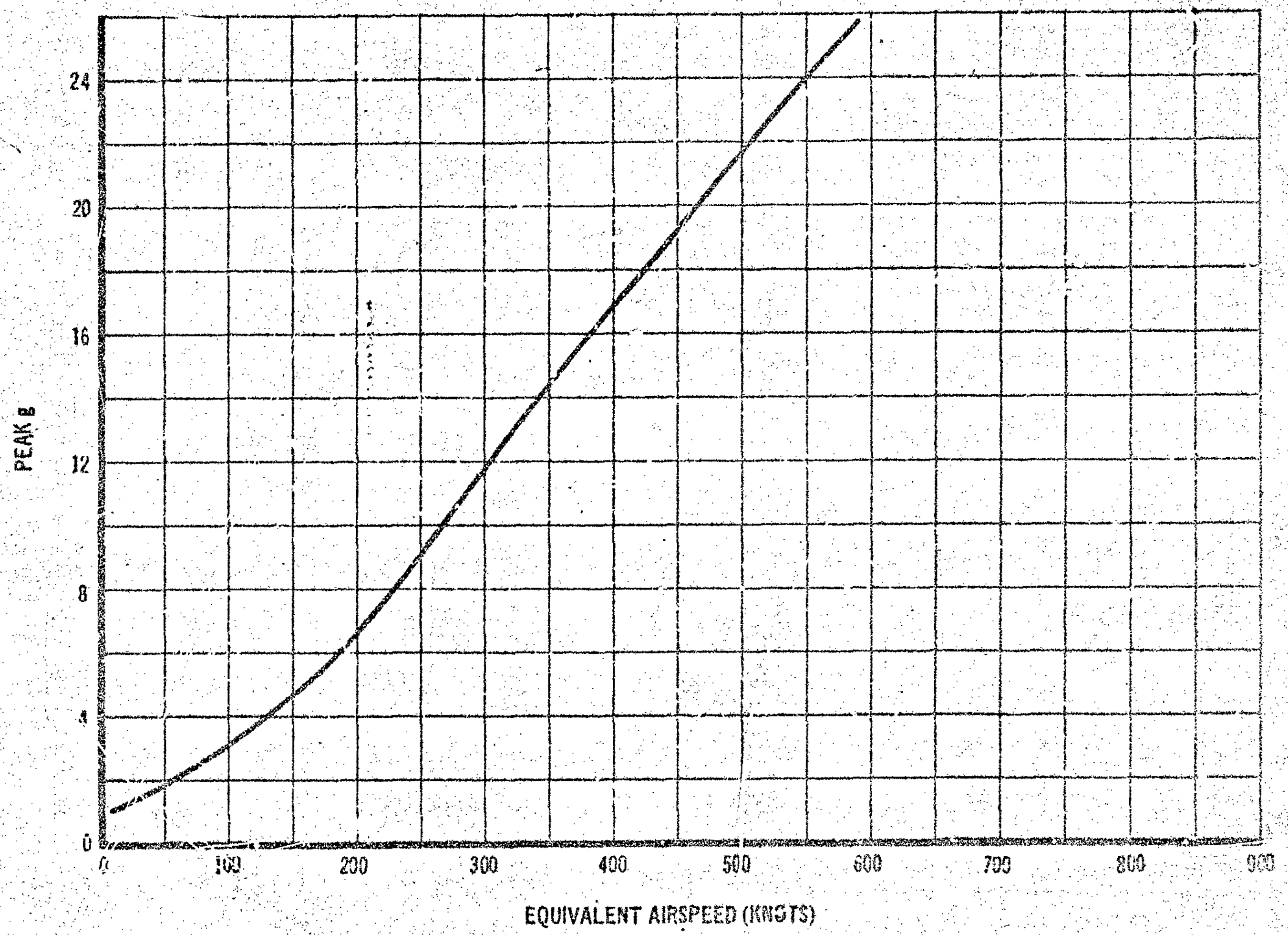


Figure 69. Peak g Two-Man Cockpit Pod Capsule

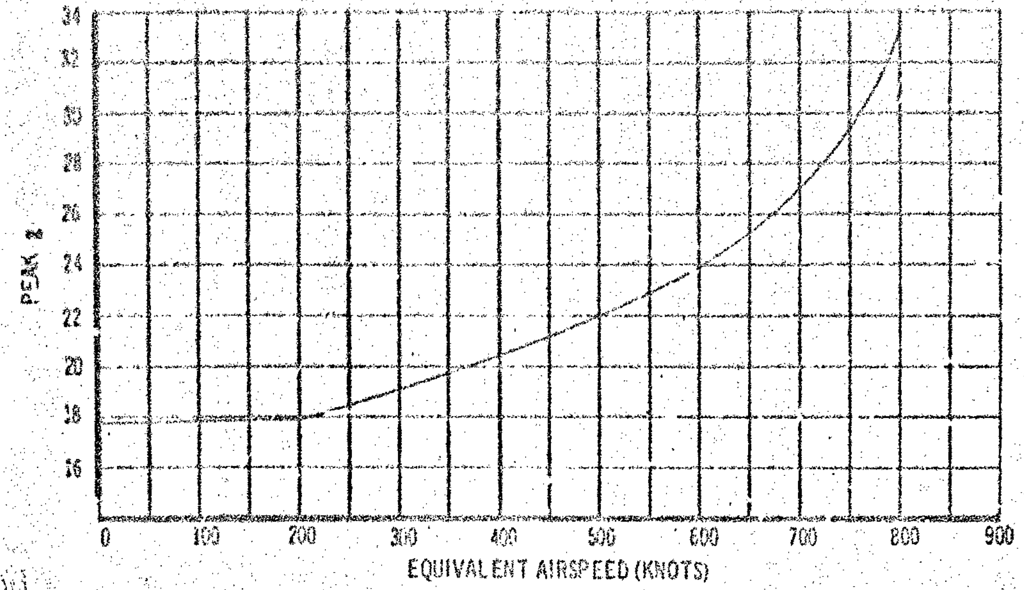


Figure 70. Peak g Three-Man Cockpit Pod Capsule

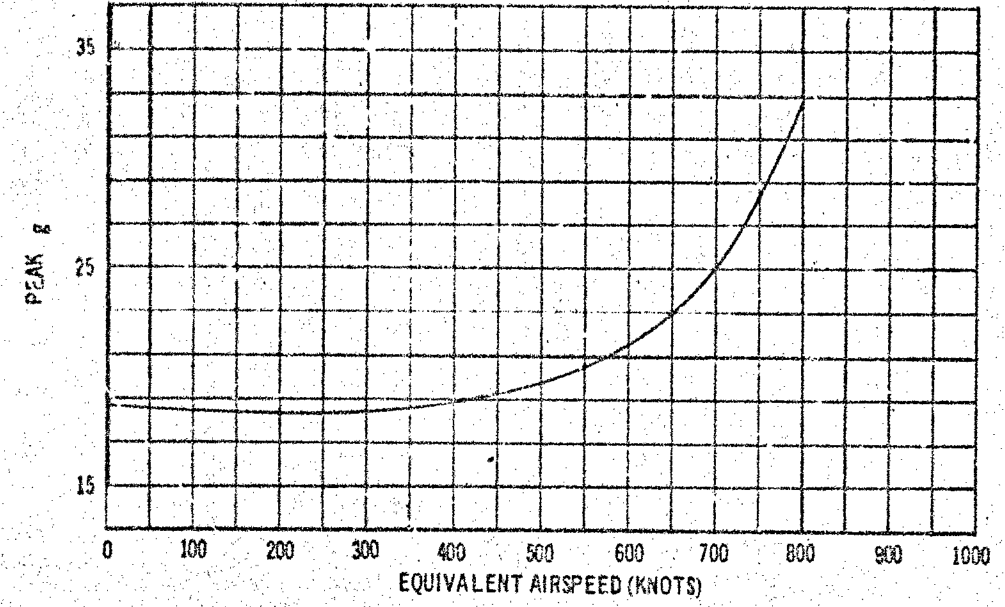


Figure 71. Peak g Four-Man Cockit Pod Capsule

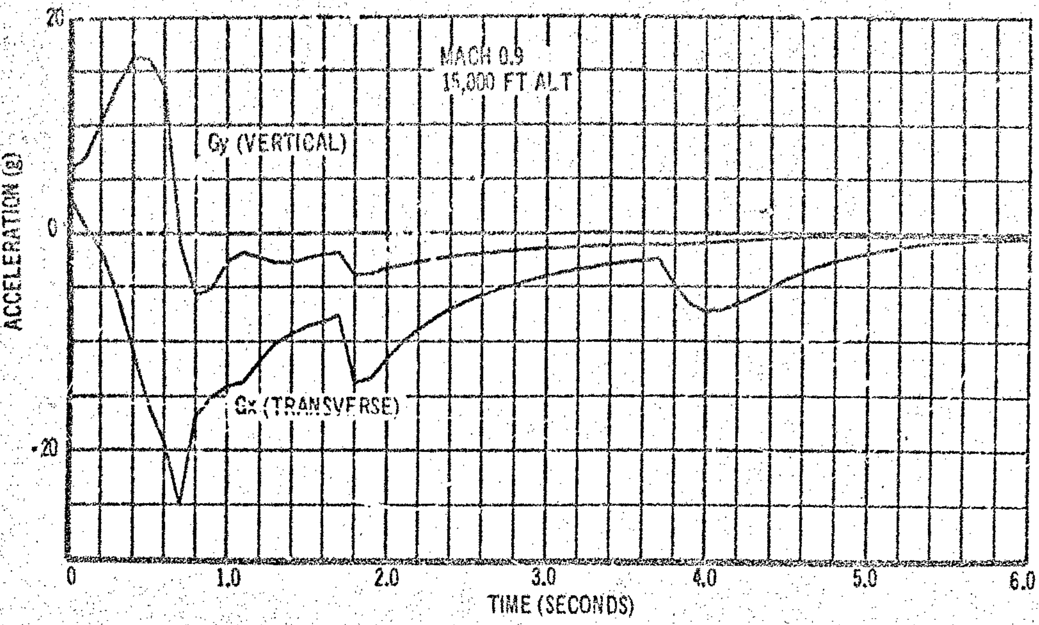


Figure 72. Two-Man Cockpit Pod Capsule Computer Plot of Maximum Acceleration

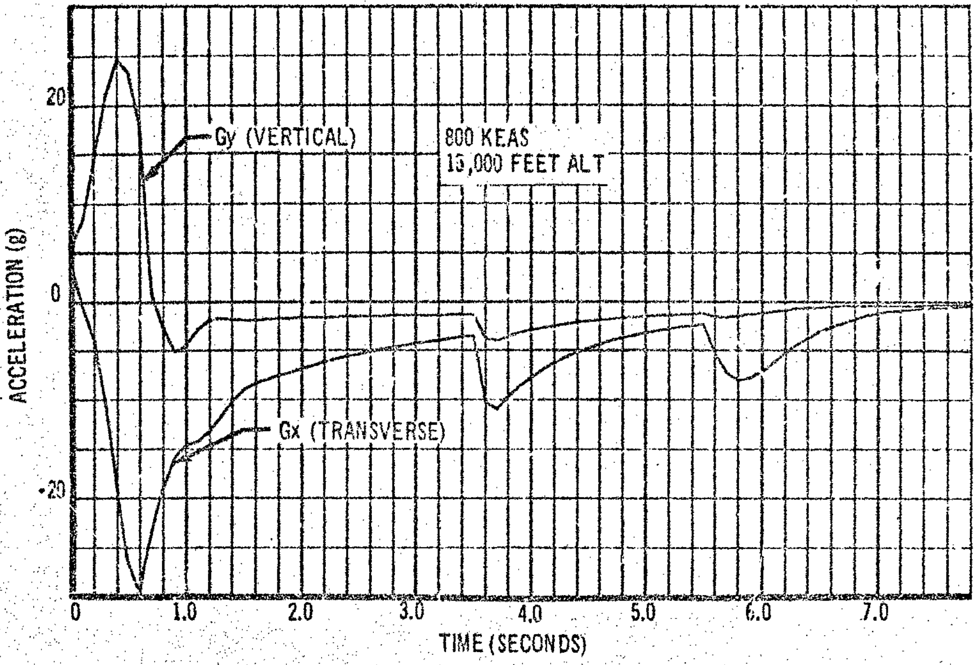


Figure 73. Three-Man Cockpit Pod Capsule Computer Plot of Maximum Acceleration

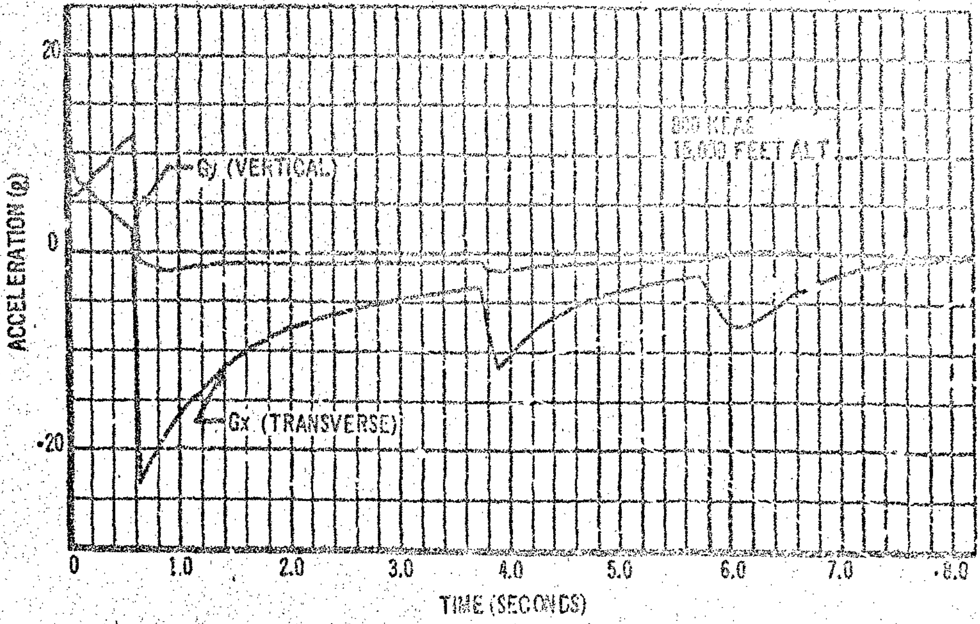


Figure 74. Four-Man Cockpit Pod Capsule Computer Plot of Maximum Acceleration

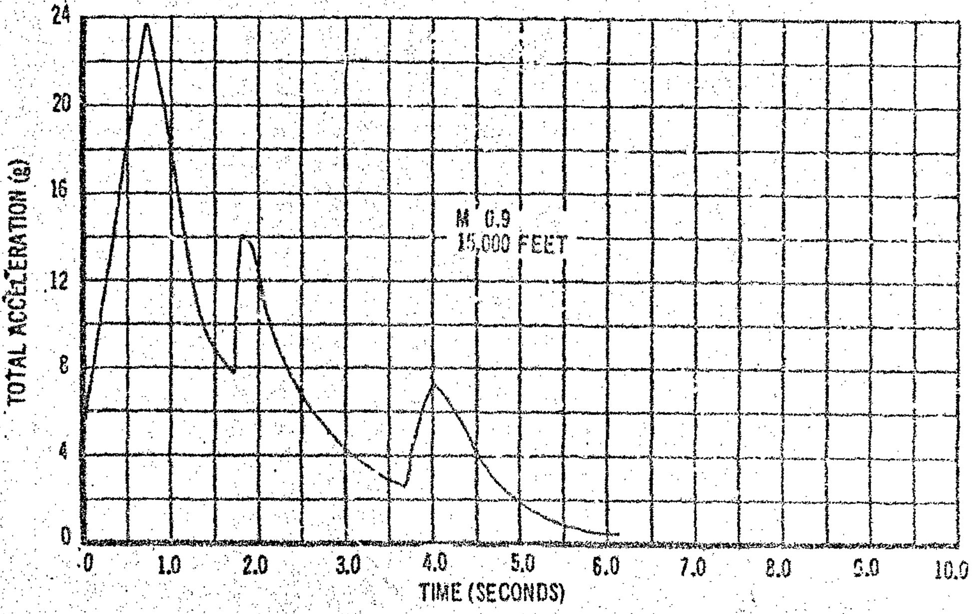


Figure 75. Two-Man Cockpit Pod Capsule – Acceleration Versus Time

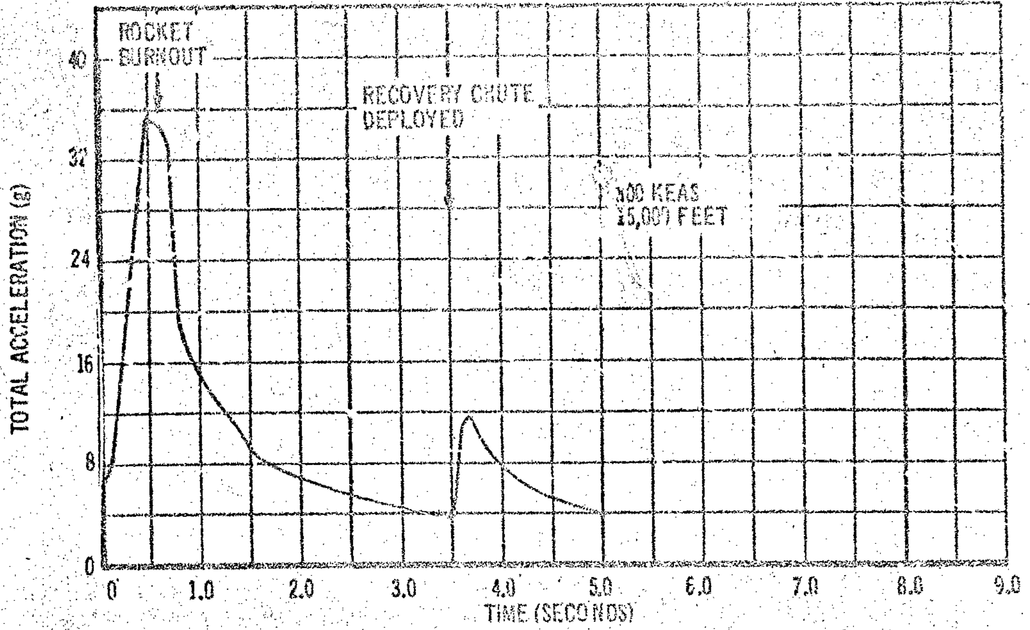


Figure 76. Three-Man Cockpit Pod Capsule – Acceleration Versus Time

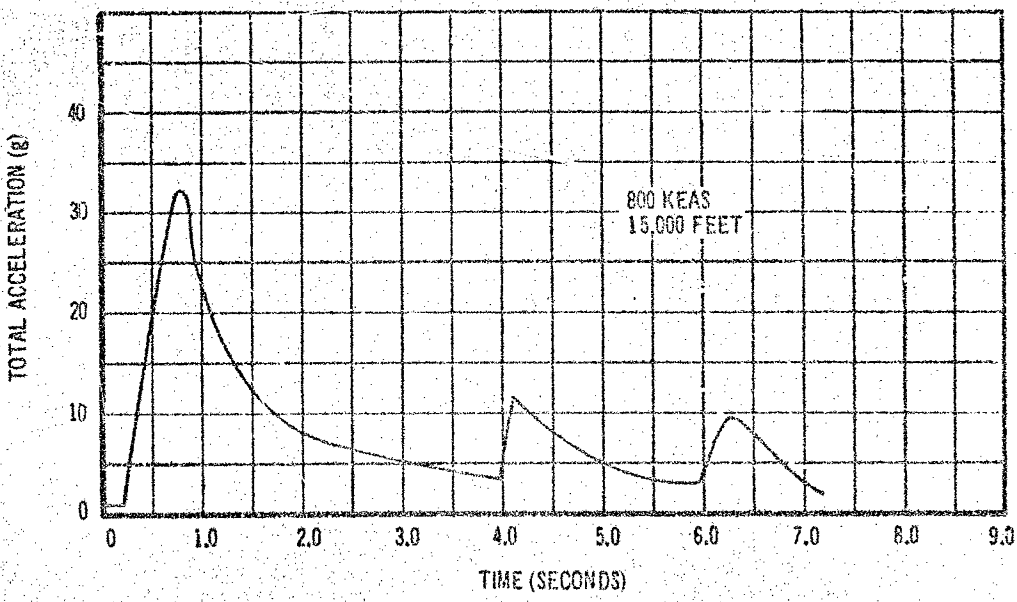


Figure 77. Four-Man Cockpit Pod Capsule – Acceleration Versus Time

4. SEPARABLE NOSE CAPSULE CONFIGURATIONS

a. Configuration

The separable nose capsule (SNC) concepts for two-, three-, and four-man configurations are shown in Figs. 78, 79 and 80.

Escape sequence for the SNC is similar to the sequence described for the cockpit pod capsule. The performance envelopes for the two-, three-, and four-man separable nose capsules are the same as the two-, three-, and four-man cockpit pod capsules. Escape event timing sequences are shown in Figs. 81, 82 and 83.

Table IV lists capsule design data and subsystem sizes and weights. Escape subsystems are described in Section II.5.

b. Performance

The dynamic characteristics of the separable nose capsules are the same as the cockpit pod capsules.

As for the cockpit pod capsules, the separable nose capsules were computed to fully recover during level flight at ground level from zero velocity to the maximum speed capability of the vehicles. Level flight trajectories are shown in Figs. 84, 85 and 86. Figures 87 through 92 show escape trajectories during diving flight at 200 KEAS and at maximum speed. Minimum escape altitude curves are shown on Figs. 93, 94 and 95. Maximum peak accelerations experienced during escape versus equivalent airspeed are shown in Figs. 96, 97 and 98. Computer plots (Figs. 99, 100 and 101) show vertical and transverse acceleration components during escape at the critical conditions of maximum speed at 15,000 feet. Resultant g for the same conditions are shown in Figs. 102, 103 and 104.

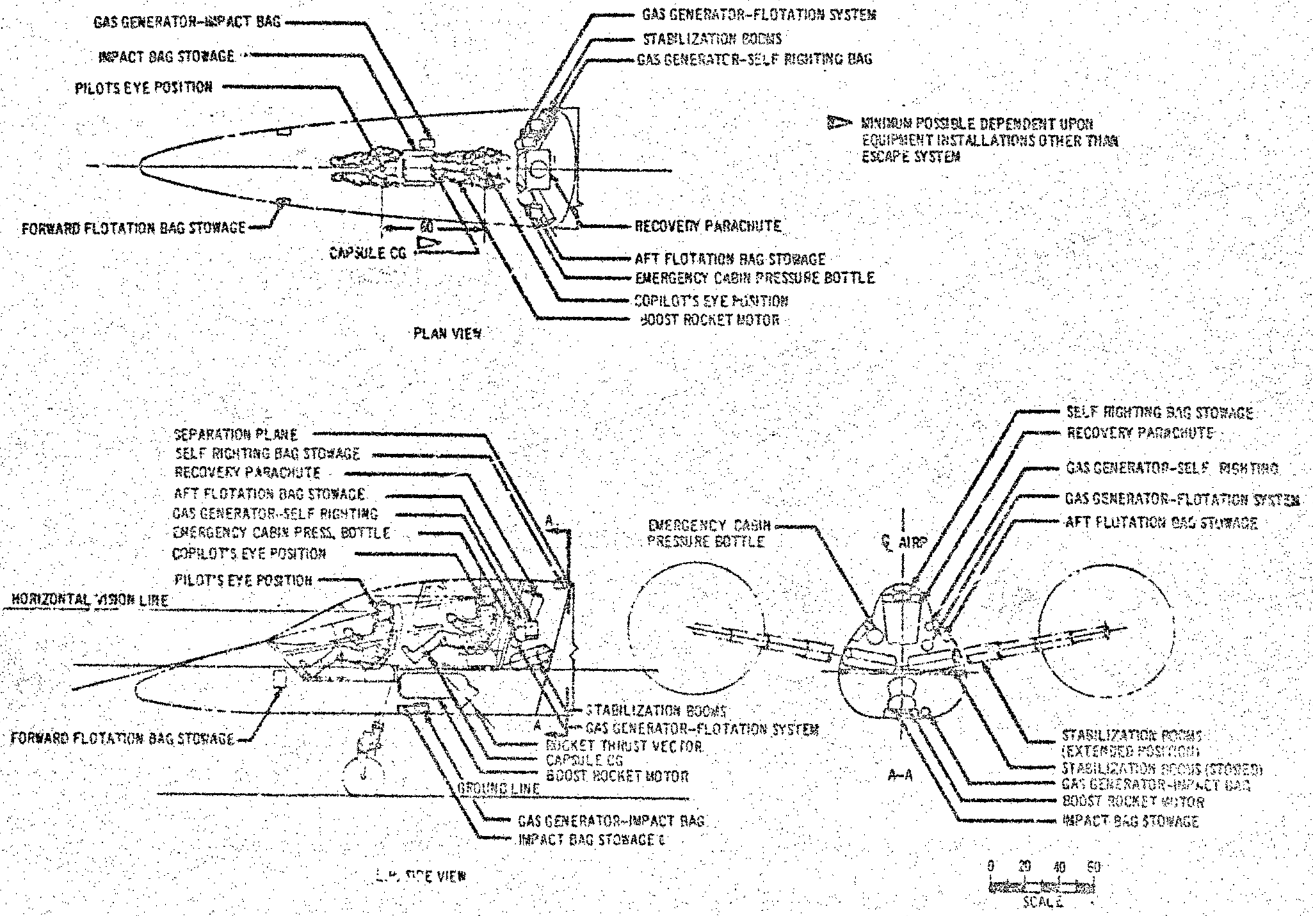


Figure 78. Two-Man Subsonic VTOL Vehicle Separable Nose Capsule Configuration

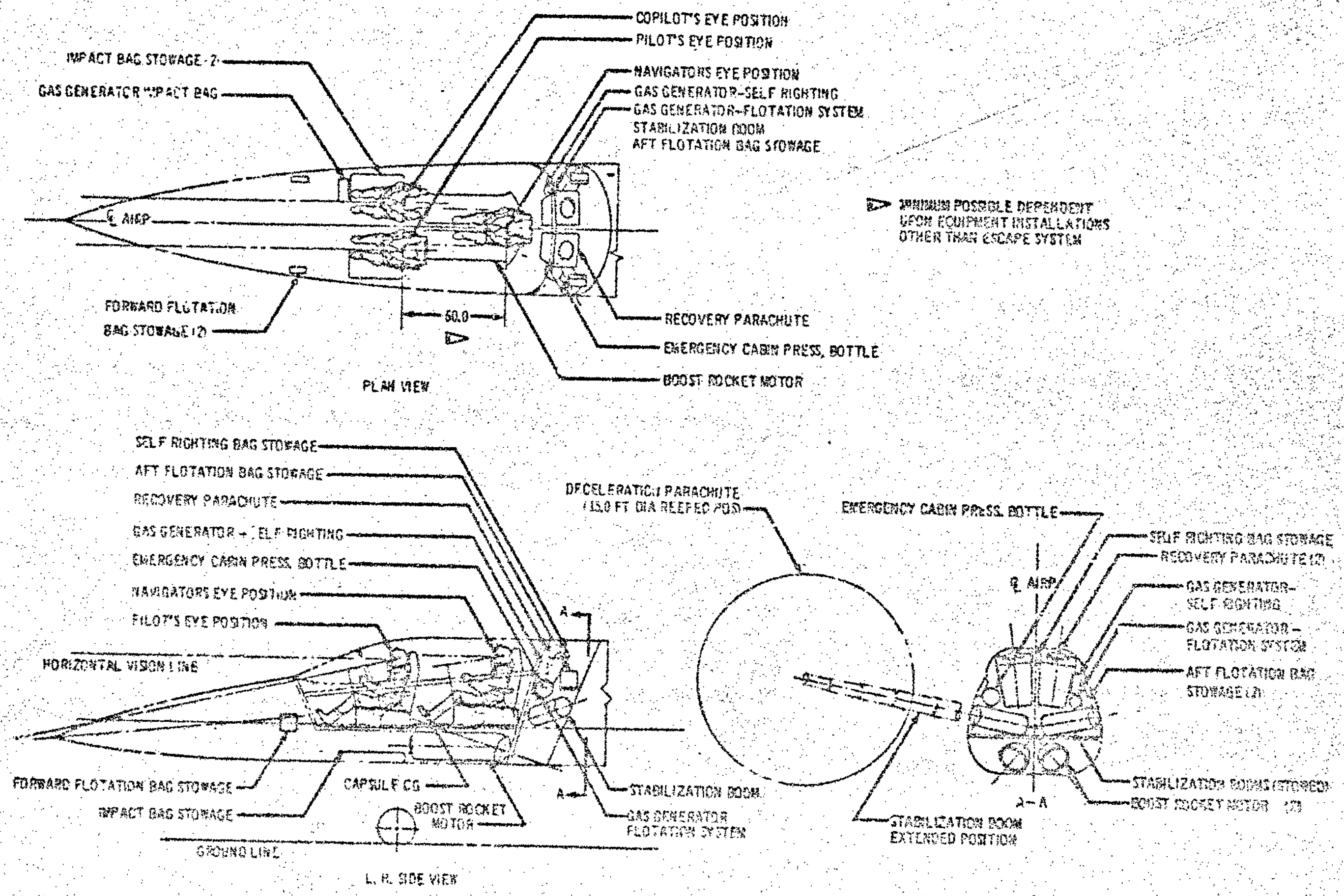


Figure 79. Three-Man Combined Capability Vehicle Separable Nose Capsule Configuration

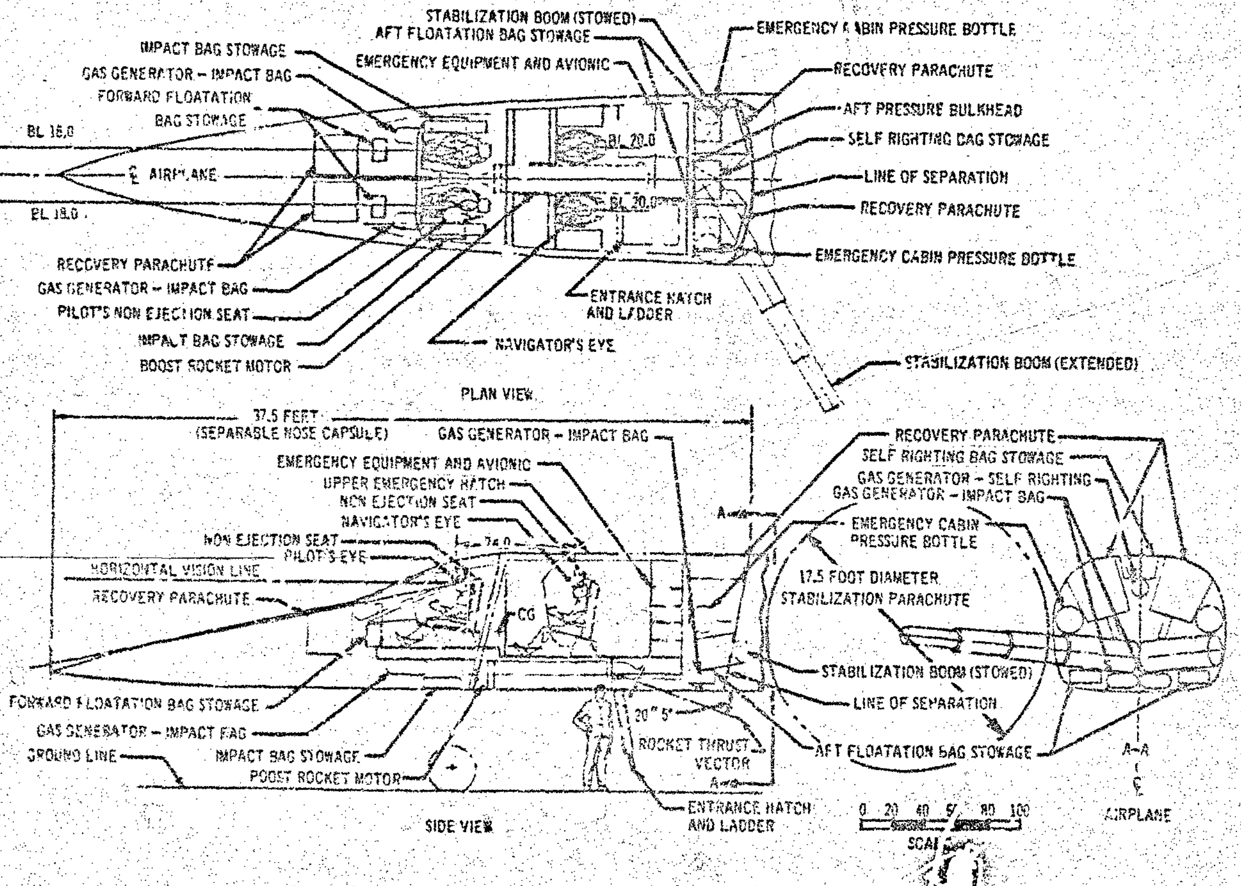
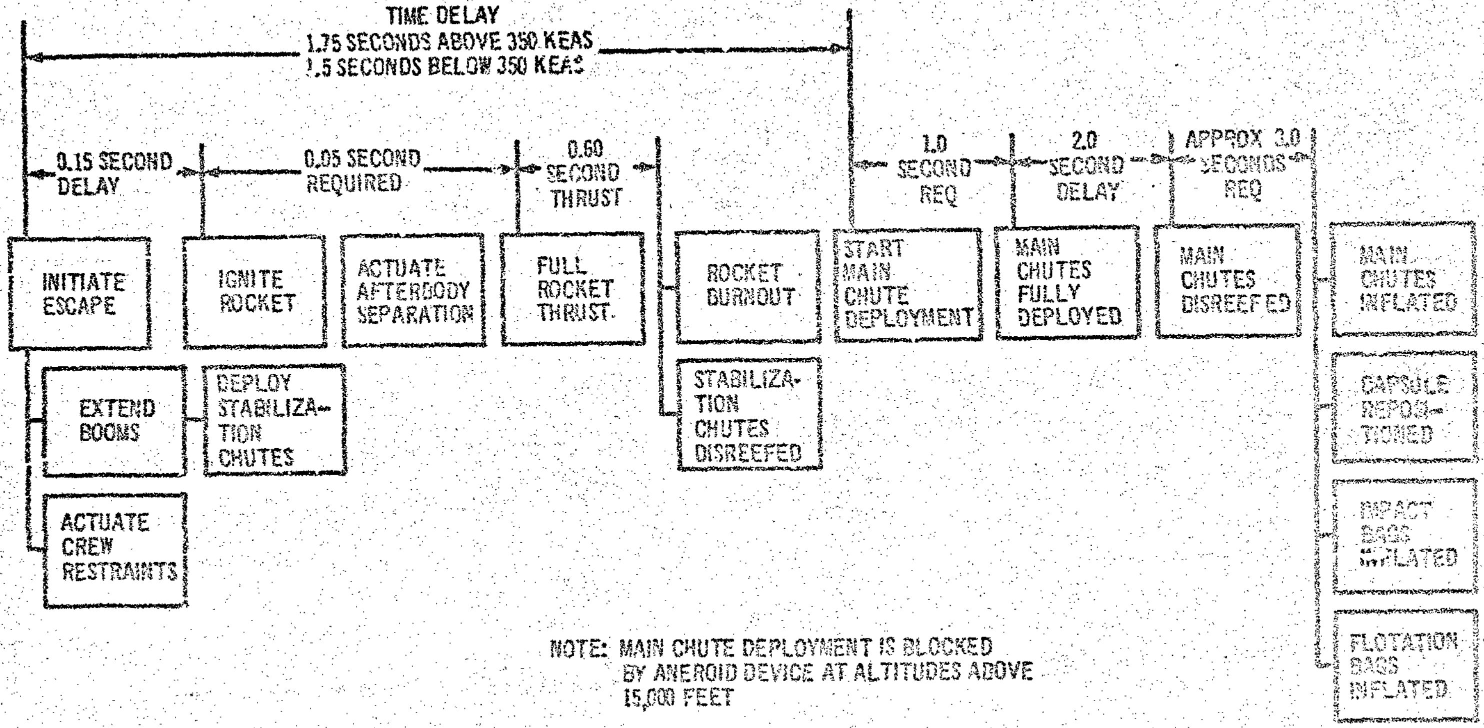
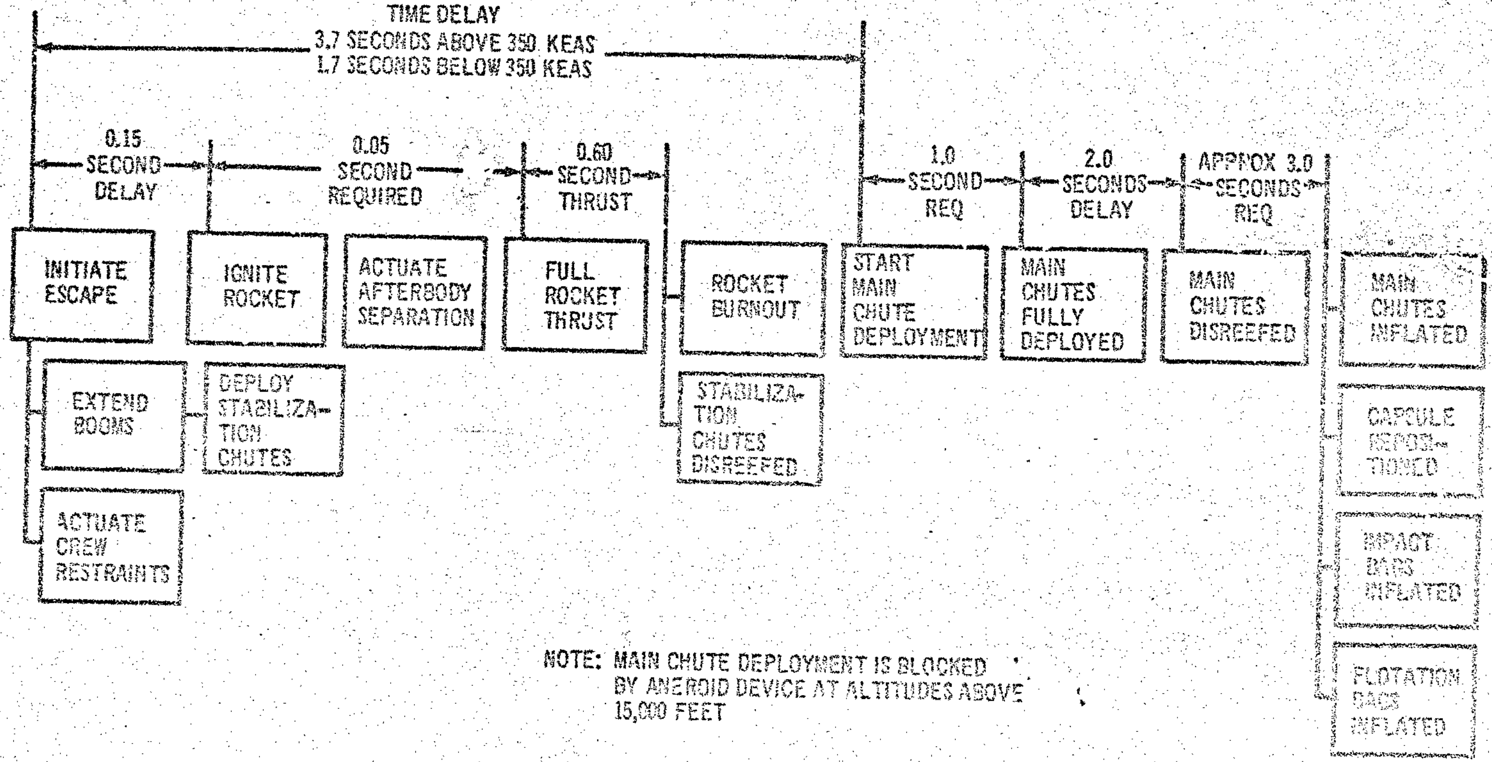


Figure 80. Four-Man Supersonic Dash Vehicle Separable Nose Capsule Configuration



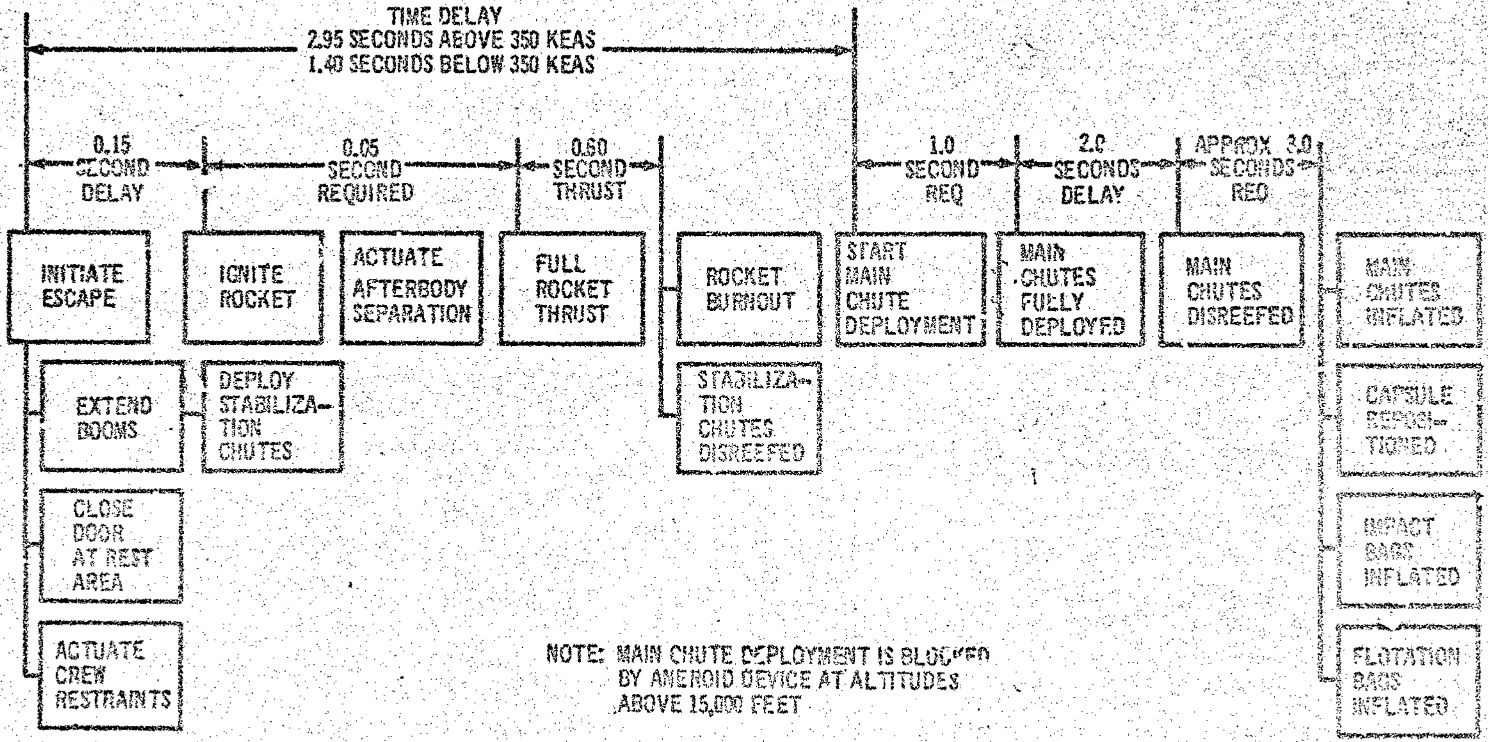
NOTE: MAIN CHUTE DEPLOYMENT IS BLOCKED BY ANEROID DEVICE AT ALTITUDES ABOVE 15,000 FEET

Figure 81. Block Diagram – Escape Events Two-Man Separable Nose Capsule



NOTE: MAIN CHUTE DEPLOYMENT IS BLOCKED BY ANEROID DEVICE AT ALTITUDES ABOVE 15,000 FEET

Figure 82. Block Diagram – Escape Events Three–Man Separable Nose Capsule



NOTE: MAIN CHUTE DEPLOYMENT IS BLOCKED BY ANEROID DEVICE AT ALTITUDES ABOVE 15,000 FEET

Figure 83. Block Diagram – Escape Events Four-Man Separable Nose Capsule

Table IV. Separable Nose Capsule Design Data

		Vehicle		
		Two Man	Three Man	Four Man
Capsule				
Weight (total ejectable)	Lb	4,800.0	9,000.0	12,660.0
Length overall	Ft	24.0	30.0	37.5
Ref. area	Ft^2	24.0	40.0	63.0
Pitch inertia	Lb-Sec^2-Ft	2,700.0	12,000.0	24,700.0
Separation System				
Weight of FLSC	Lb	12.0	12.0	12.0
Weight of initiating system plus junction fittings	Lb	5.5	5.5	5.5
Boost Rocket				
Thrust	Lb	58,600.0	184,000.0	245,000.0
Burntime	Sec	0.6	0.6	0.6
Volume	In^3	6,000.0	21,300.0	30,600.0
Nozzle angle	Deg	46.5	19.3	20.5
Weight	Lb	250.0	760.0	1,020.0
Thrust/CG Misalignment	Ft	0.5	0.5	0.5
Stabilization Booms (2 per vehicle)				
No. of tubes		3.0	3.0	3.0
Boom length, stored	Ft	4.0	5.0	5.4
Boom length, extended	Ft	11.0	13.0	16.2
Storage tube OD	In	16.0	19.7	26.9
Weight (total) (not including bridle and parachute weight)	Lb	1,200.0	1,800.0	3,900.0
Stabilization Parachutes (2 per vehicle)				
Reefed diameter	Ft	6.5	10.5	12.0
Flat diameter	Ft	13.0	15.0	17.5
Stowed vol (total)	In^3	3,000.0	6,000.0	11,000.0
Weight (total)	Lb	50.0	110.0	200.0

Table IV. (Continued)

		Vehicle		
		Two Man	Three Man	Four Man
Recovery Parachutes				
No. of parachutes		2.0	3.0	4.0
Reefed diameter	Ft	11.9	13.7	13.5
Flat diameter	Ft	59.8	69.0	73.4
Stowed vol (total)	In^3	11,500.0	22,500.0	30,000.0
Weight (total)	Lb	150.0	200.0	395.0
Impact Attenuation System				
Bag weight	Lb	38.0	57.0	74.0
Inflated vol	Ft^3	89.0	167.0	235.0
Stowed vol	In^3	3,100.0	4,600.0	5,900.0
Pressure bottle Vol	In^3	860.0	1,600.0	2,200.0
Inflation assy weight	Lb	31.0	51.0	68.0
Flotation System				
Bag dia spherical, (4 each)	Ft	3.3	4.0	4.5
Bag weight (total)	Lb	25.0	46.0	54.0
Inflation bottle vol	In^3	910.0	1,880.0	2,470.0
Bottle, gas and valve wt	Lb	29.7	51.5	68.2
Self righting, bag, (1 each) (Same dia as flot bag)				
Bag, weight	Lb	6.3	11.5	13.5
Inflation bottle vol	In^3	240.0	470.0	620.0
Bottle, gas and valve wt	Lb	11.1	15.5	18.9
Weight Summary (Lb)				
Separation system		17.5	17.5	17.5
Boost rocket		250.0	760.0	1,020.0
Stabilization booms		1,200.0	1,800.0	3,900.0
Stabilization parachutes		50.0	110.0	200.0
Recovery parachutes		150.0	290.0	395.0
Impact attenuation system		69.0	108.0	142.0
Flotation system		71.2	124.5	156.4
Rocket support structure		40.0	124.0	165.0
Stabilization boom attachment		73.0	110.0	238.0
Recovery parachute attachment		21.0	40.0	36.0
Survival equipment		100.0	150.0	200.0
TOTAL (Penalty)		2,041.7	3,634.0	6,483.1

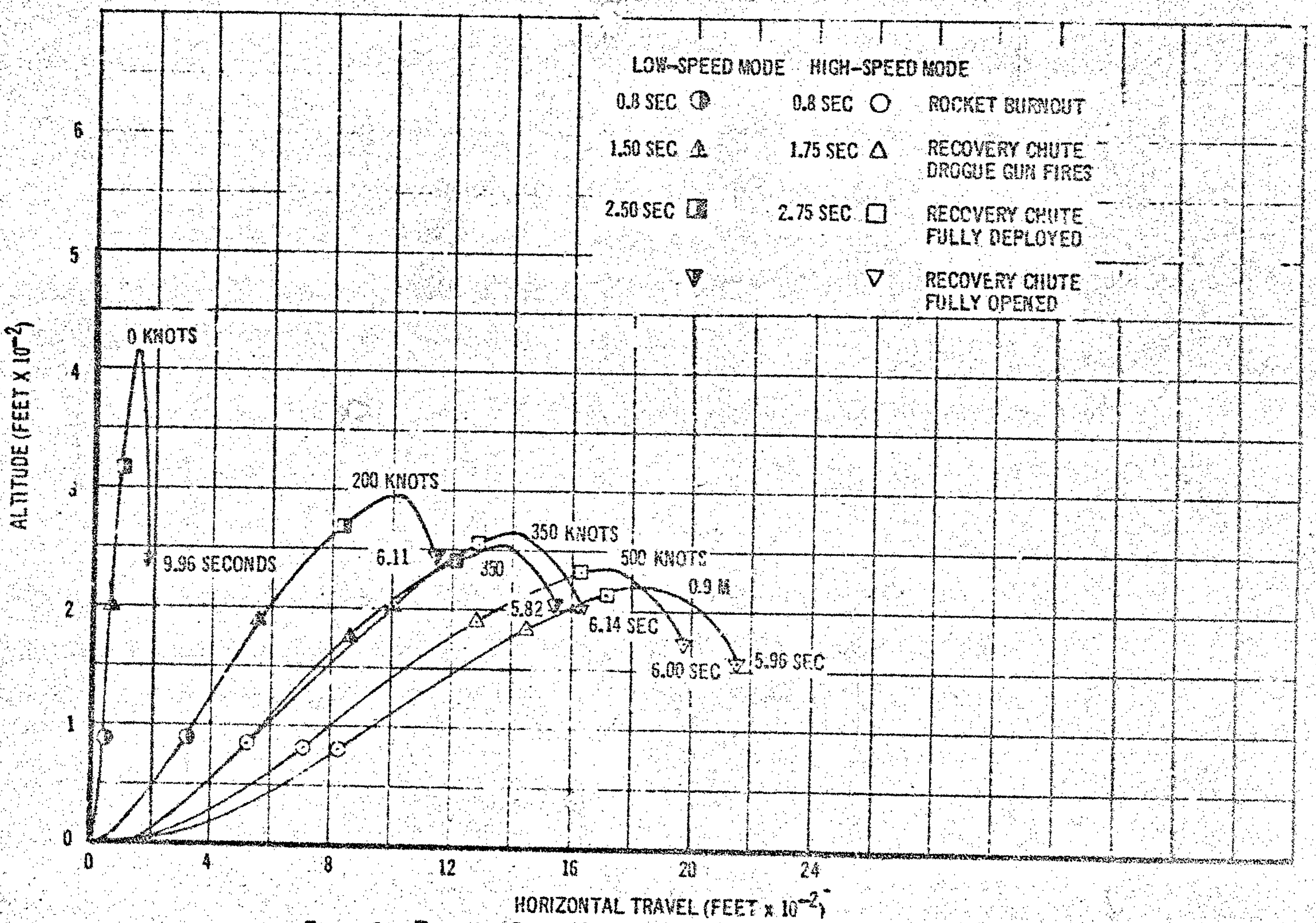


Figure 84. Two-Man Separable Nose Capsule Level Flight Trajectories

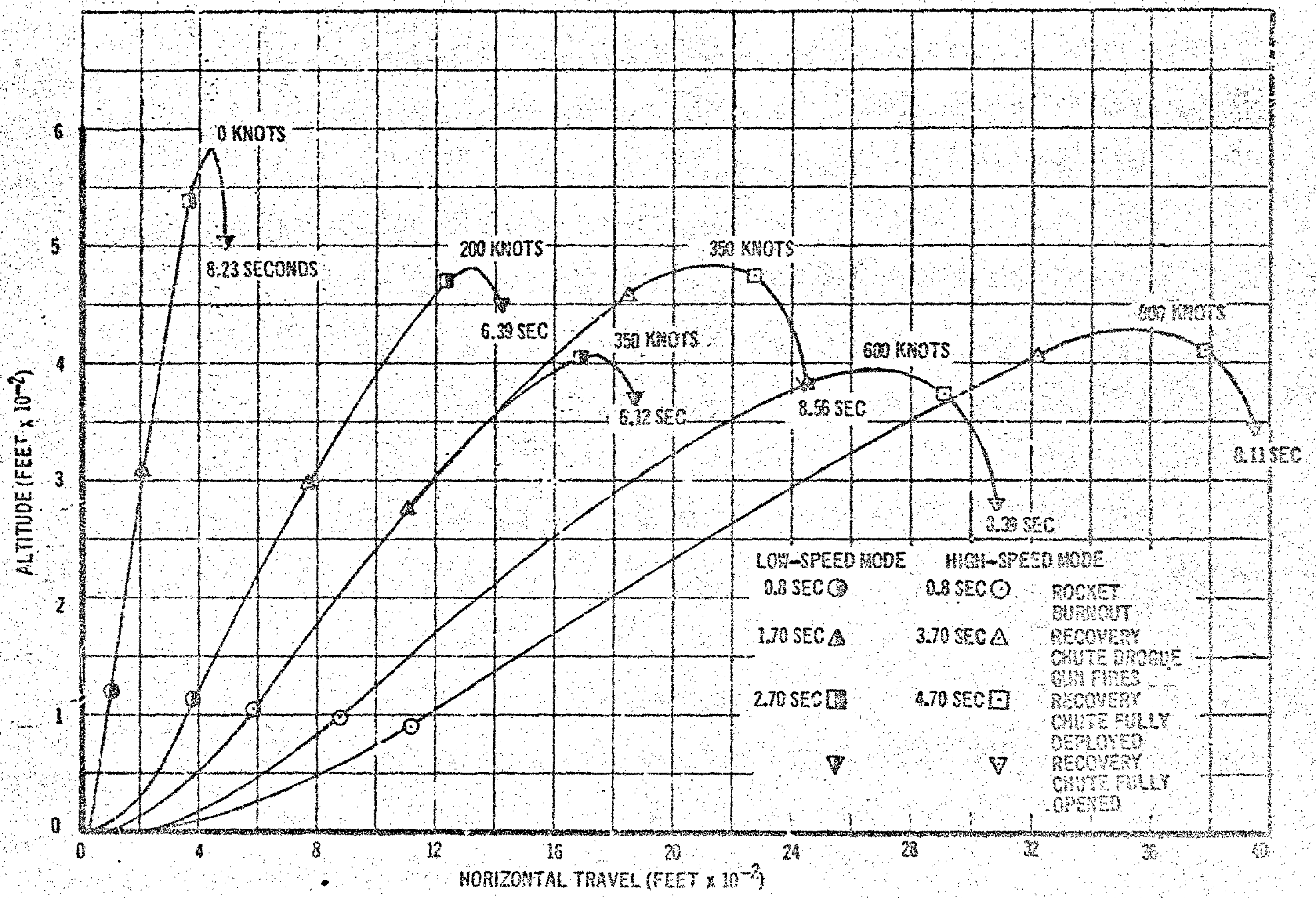


Figure 85. Three-Man Separable Nose Capsule Level Flight Trajectories

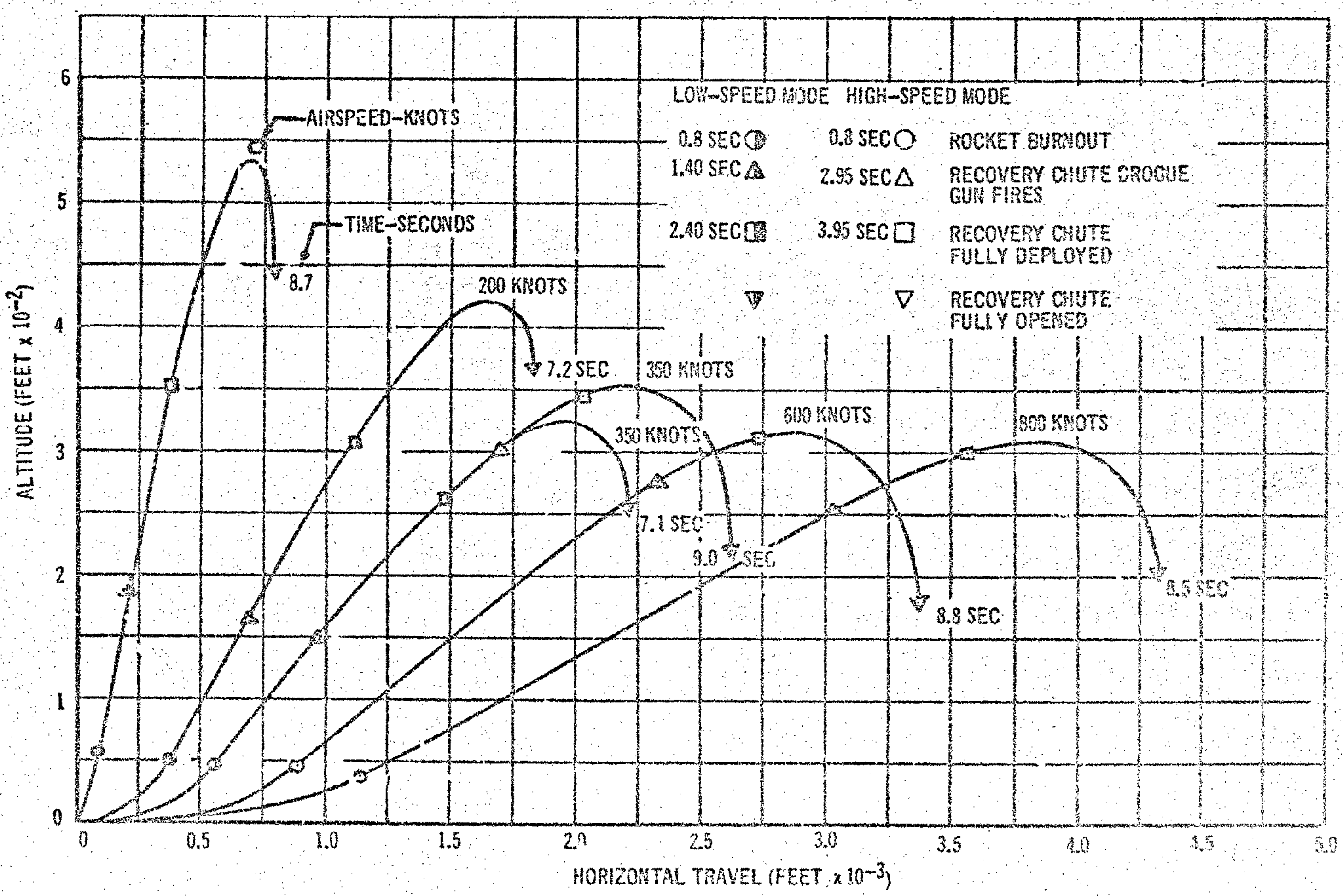


Figure 86. Four–Man Separable Nose Capsule Level Flight Trajectories

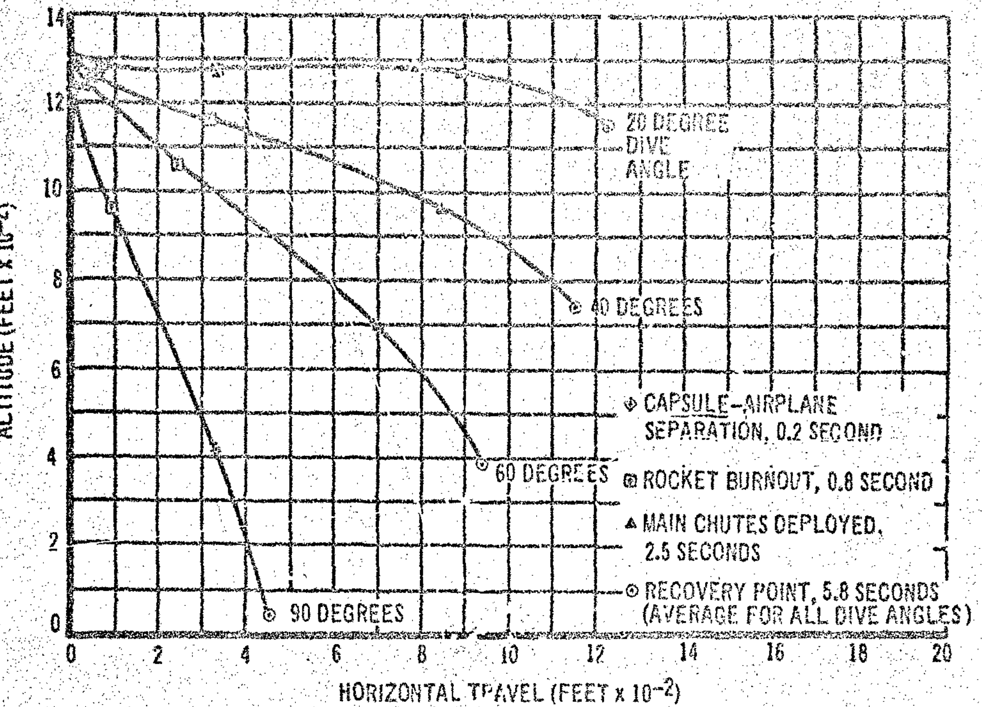


Figure 87. Two–Man Separable Nose Capsule Dive Trajectories, 200 Knots

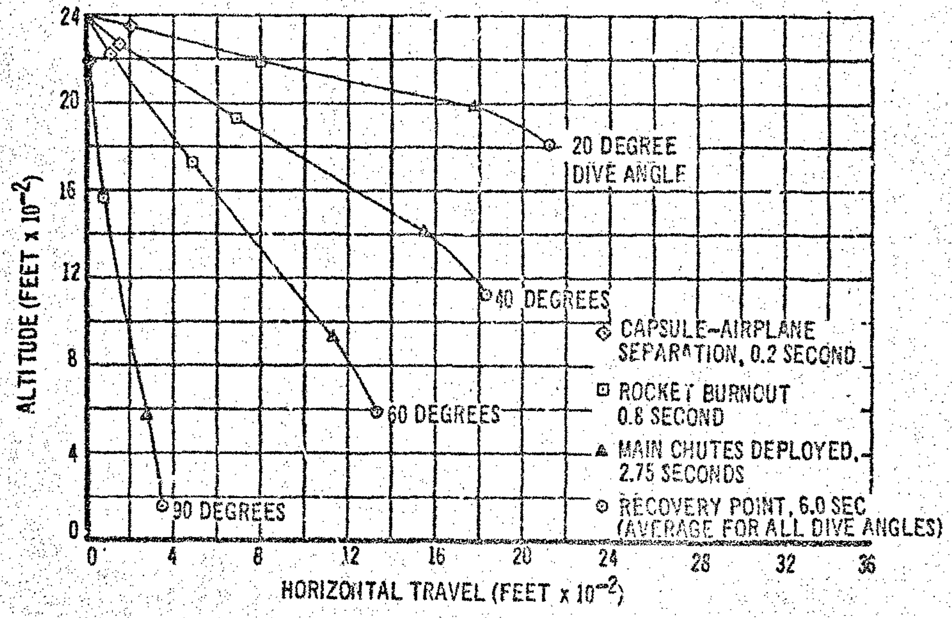


Figure 88. Two–Man Separable Nose Capsule Dive Trajectories, M 0.9

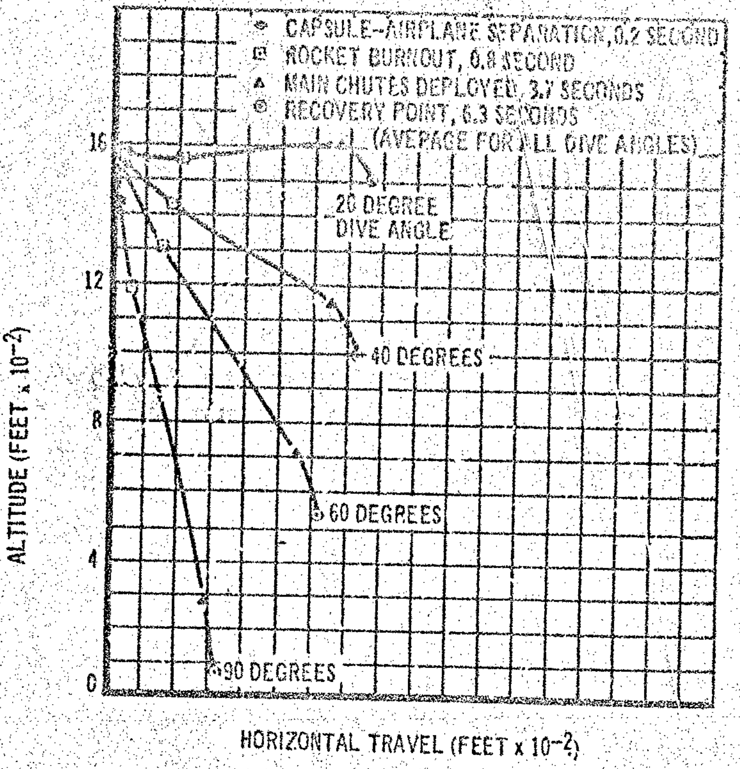


Figure 89. Three–Man Separable Nose Capsule Dive Trajectories, 200 Knots

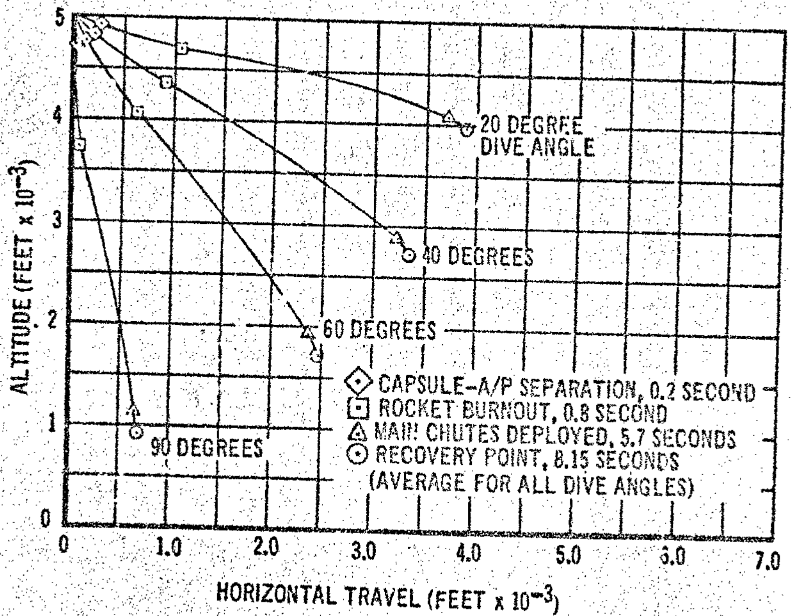


Figure 90. Three–Man Separable Nose Capsule Dive Trajectories, 600 Knots

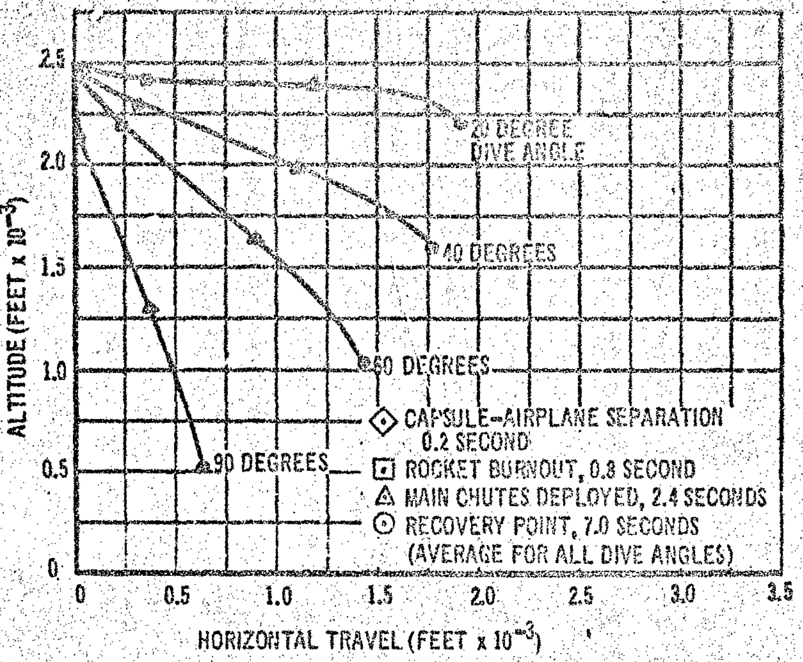


Figure 91. Four-Man Separable Nose Capsule Dive Trajectories, 200 Knots

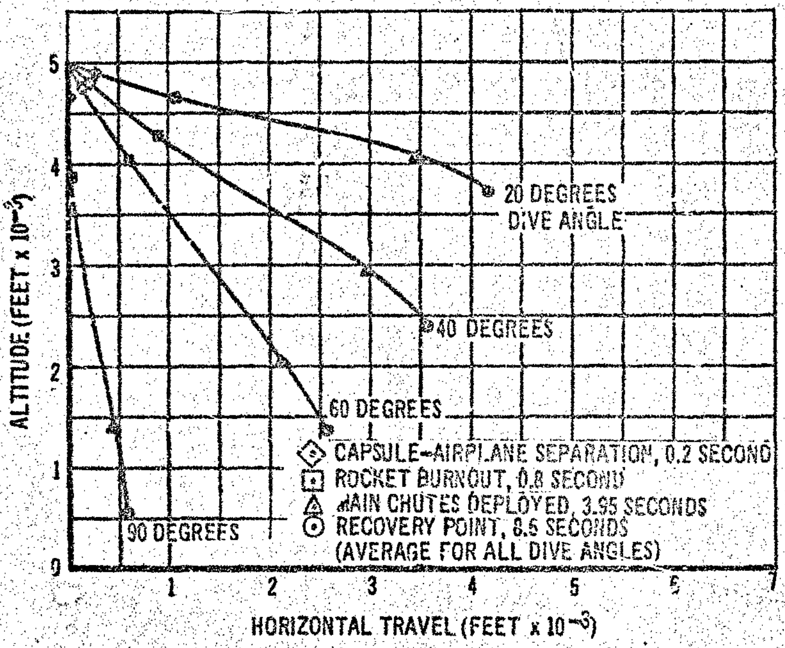


Figure 92. Four-Man Separable Nose Capsule Dive Trajectories, 800 Knots

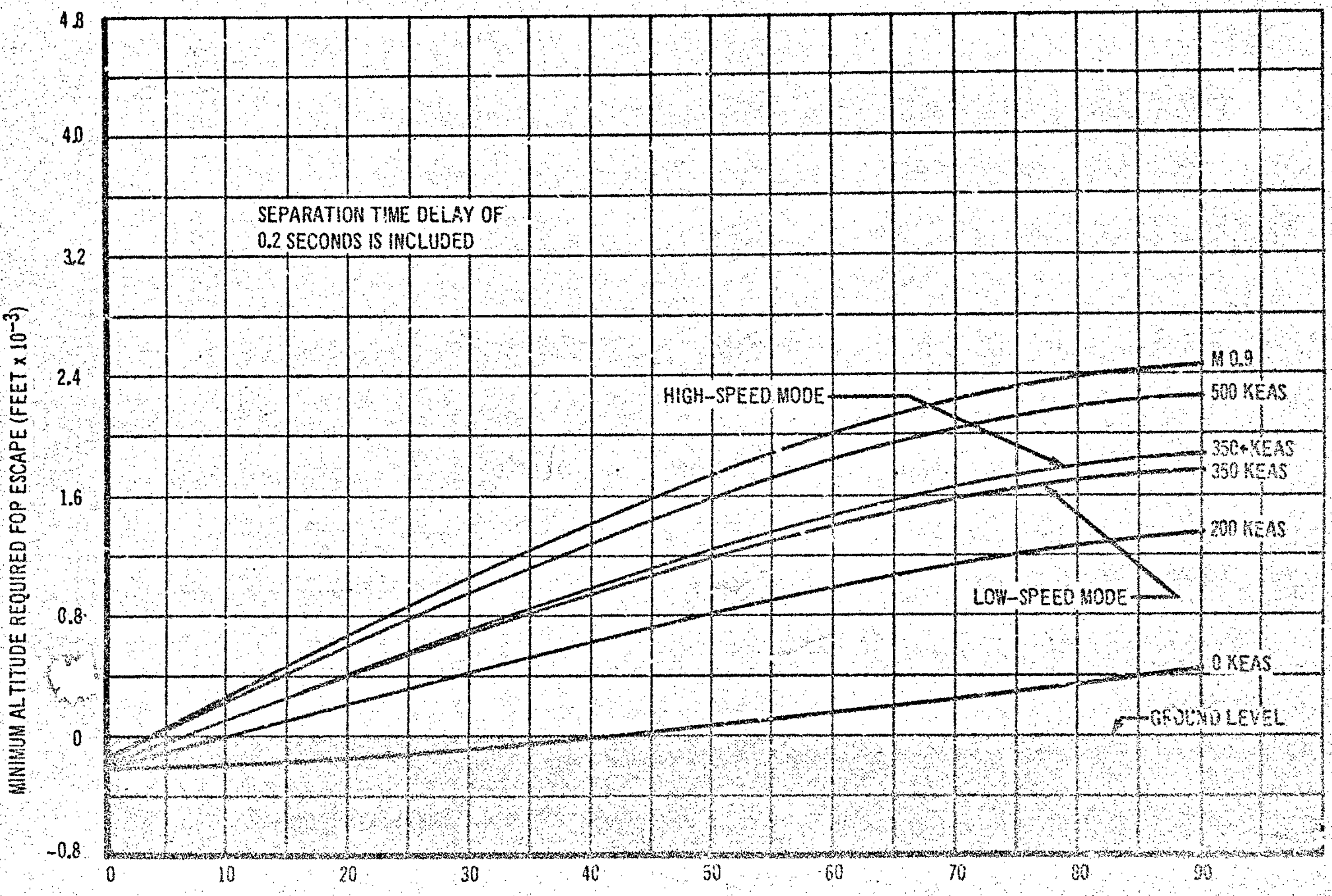


Figure 93. Two-Man Separable Nose Capsule – Minimum Escape Altitudes

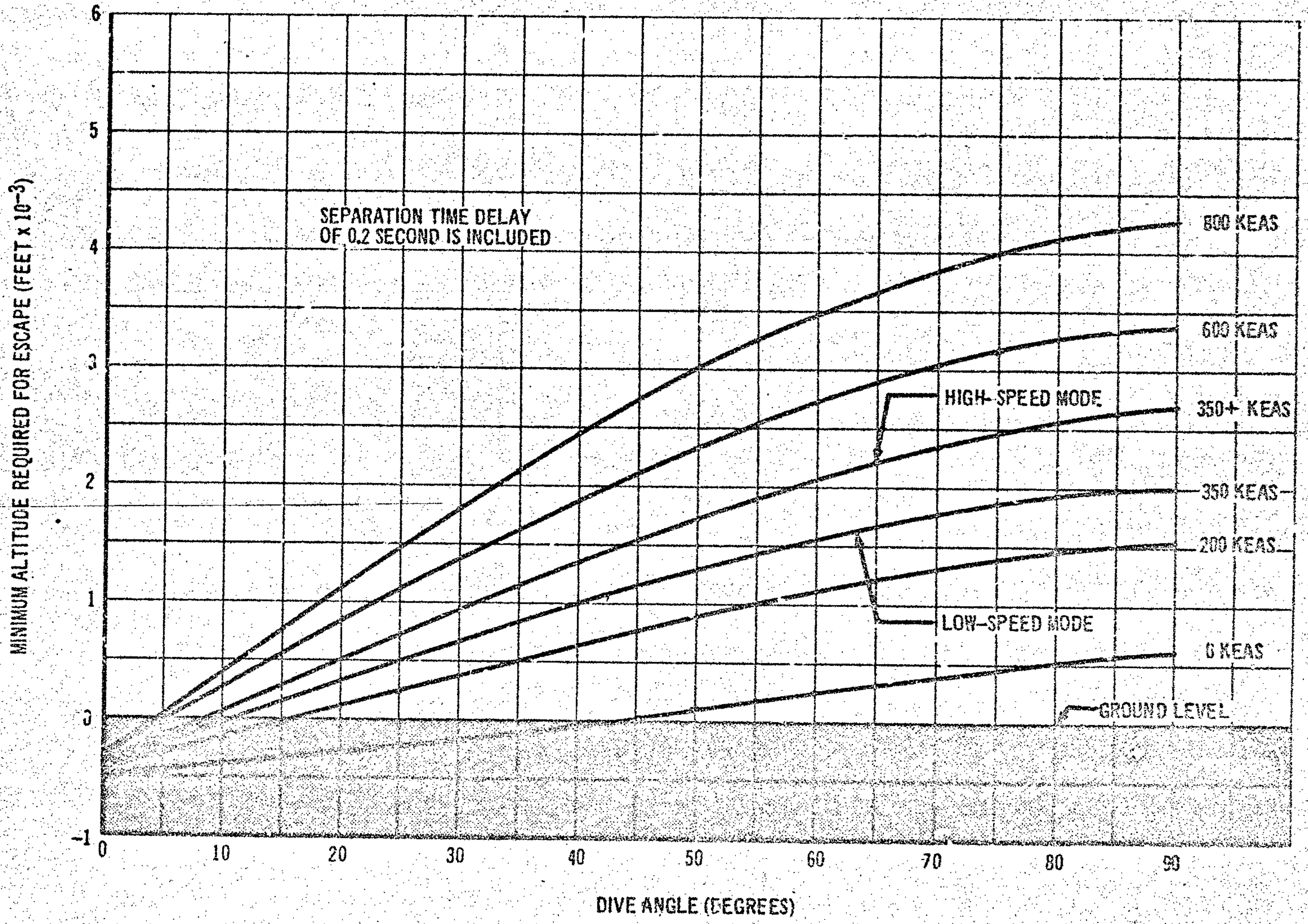


Figure 94. Three-Man Separable Nose Capsule – Minimum Escape Altitudes

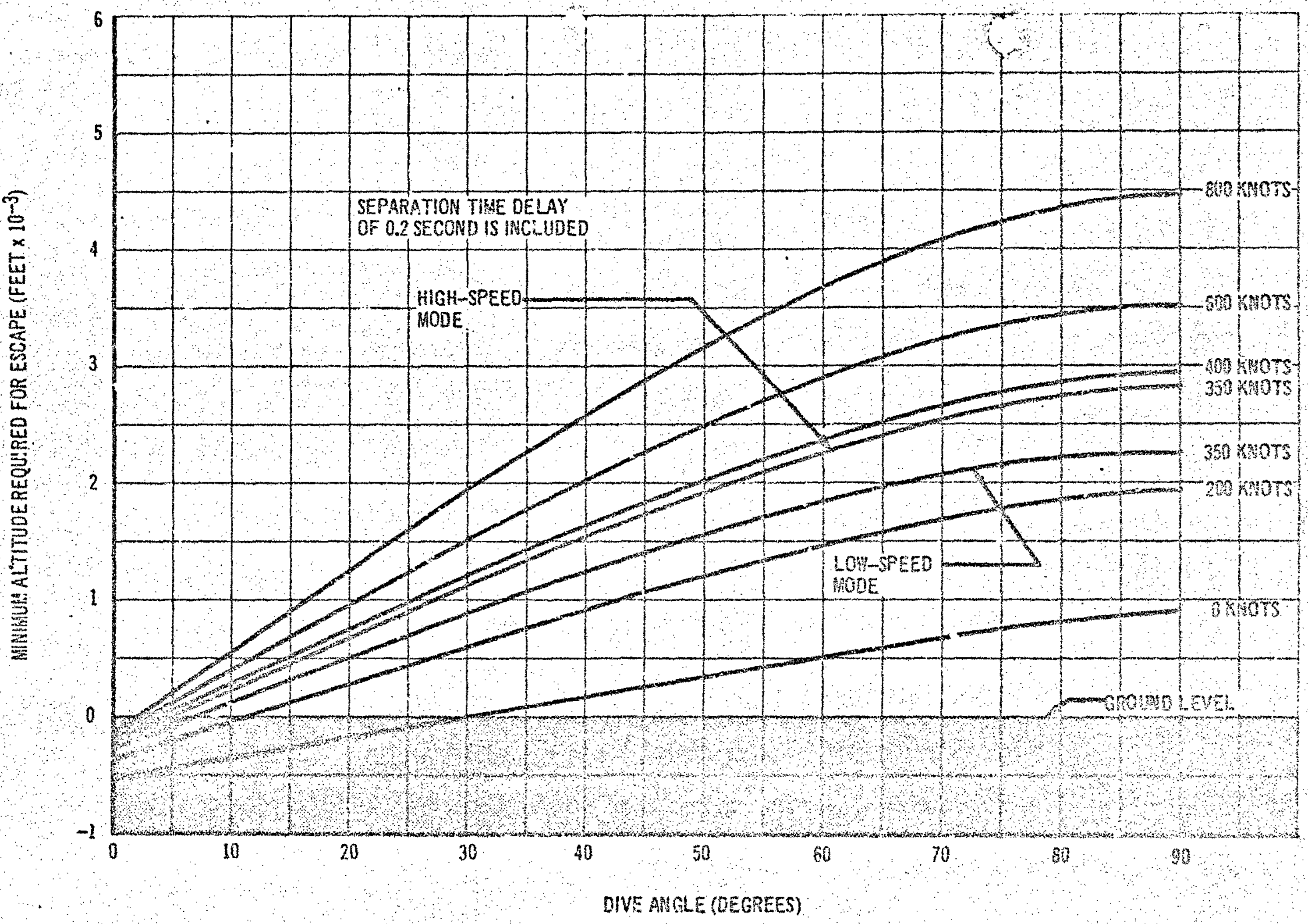


Figure 95. Four-Man Separable Nose Capsule – Minimum Escape Altitudes

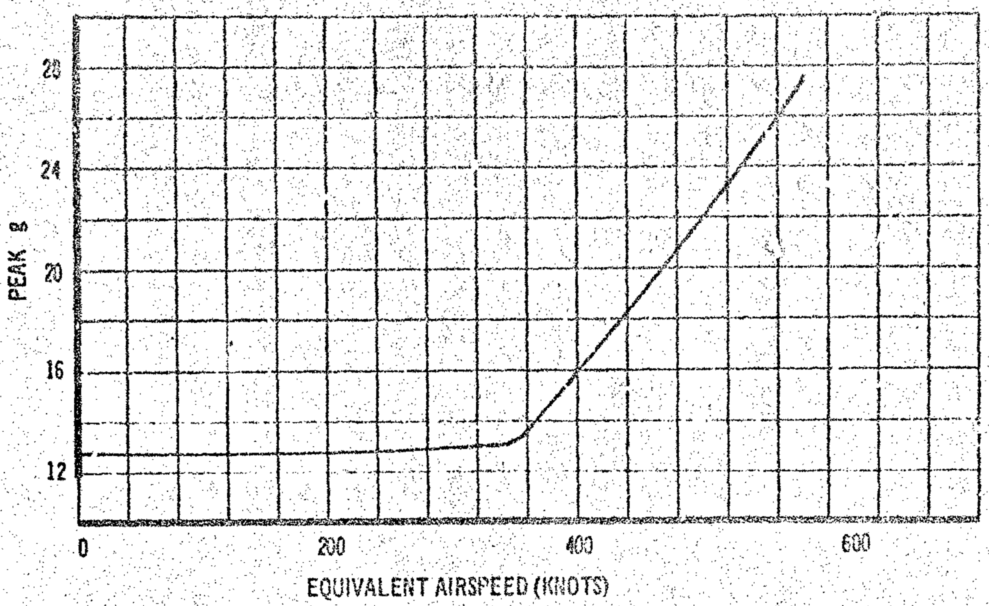


Figure 96. Peak g, Two-Man Separable Nose Capsule

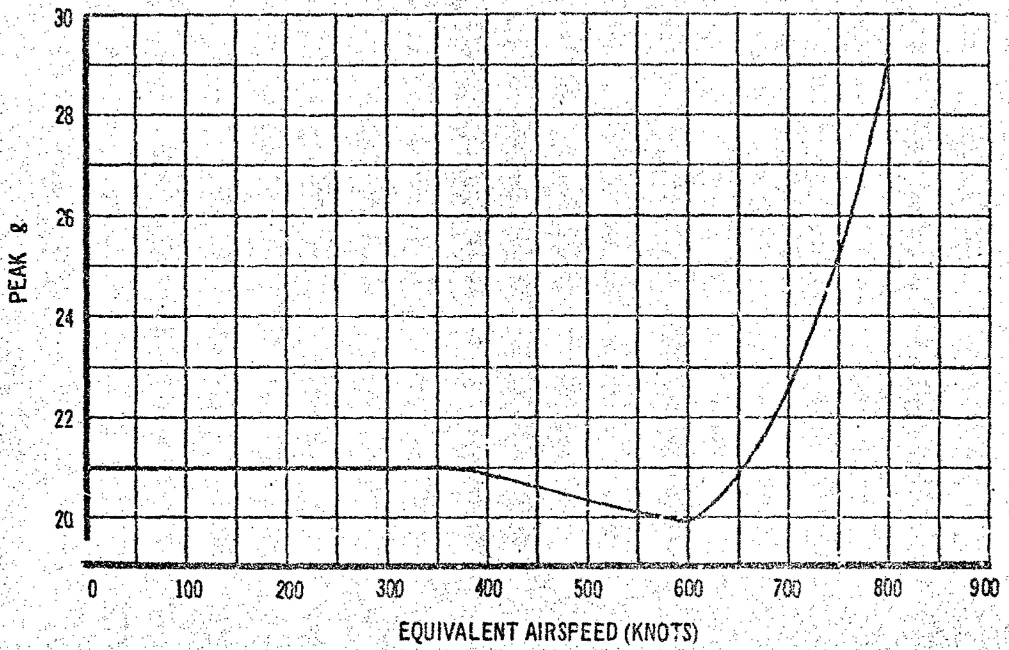


Figure 97. Peak g, Three-Man Separable Nose Capsule

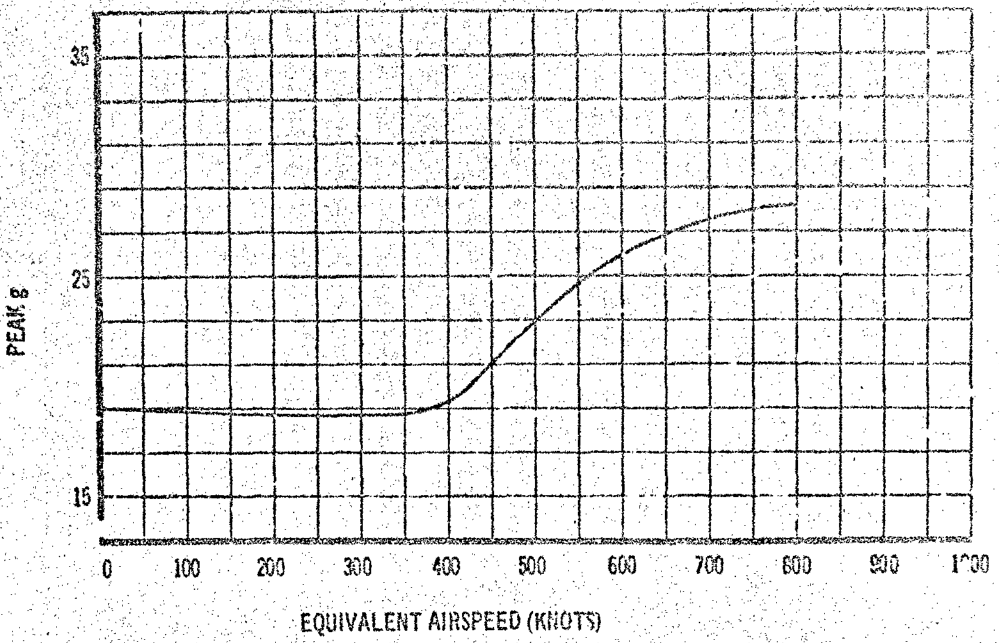


Figure 98. Peak g, Four-Man Separable Nose Capsule

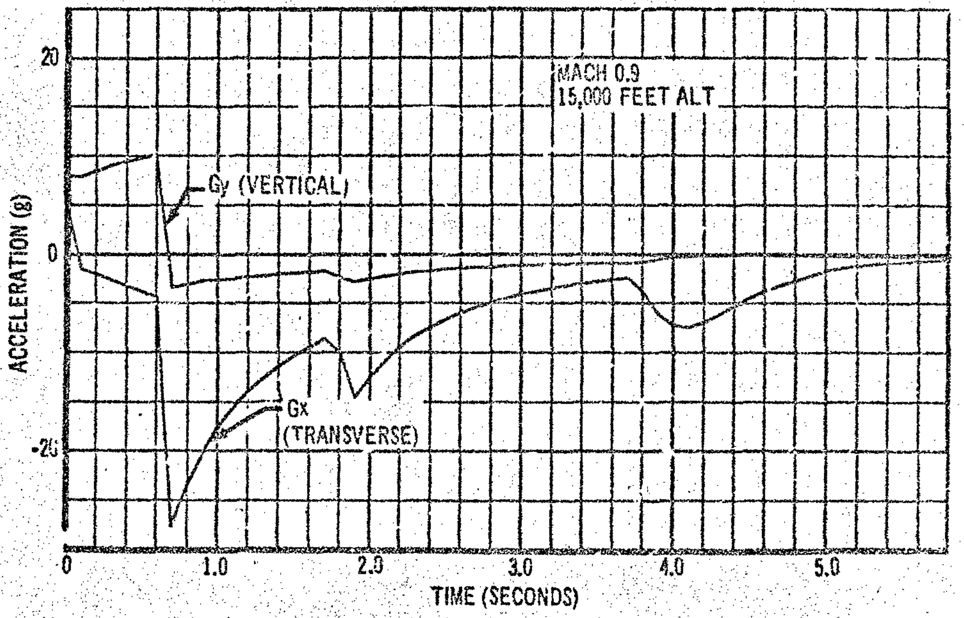


Figure 99. Two-Man Separable Nose Capsule Computer Plot of Maximum Acceleration

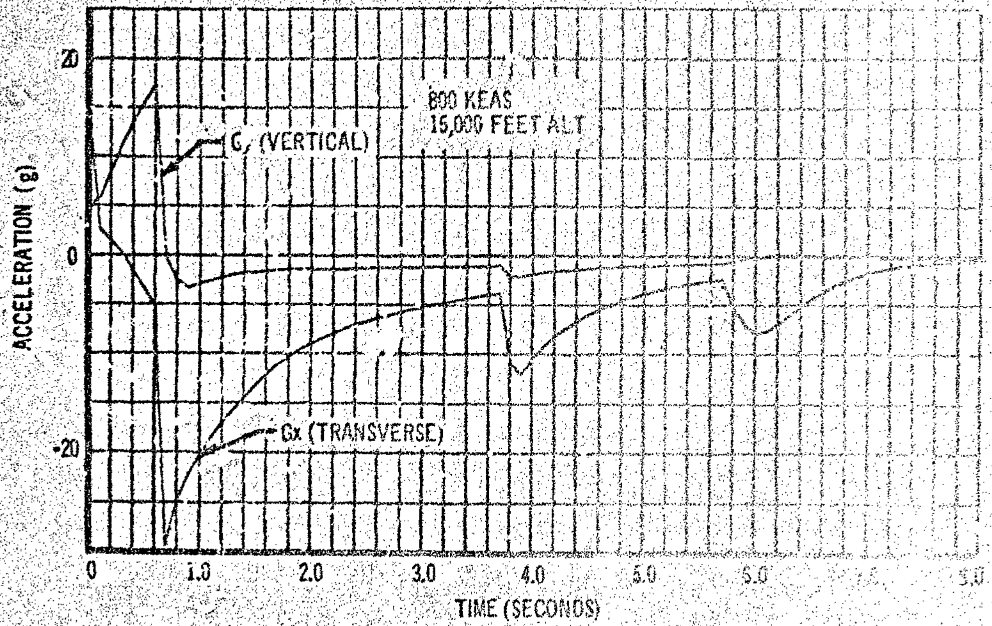


Figure 100. Three–Man Separable Nose Capsule Computer Plot of Maximum Acceleration

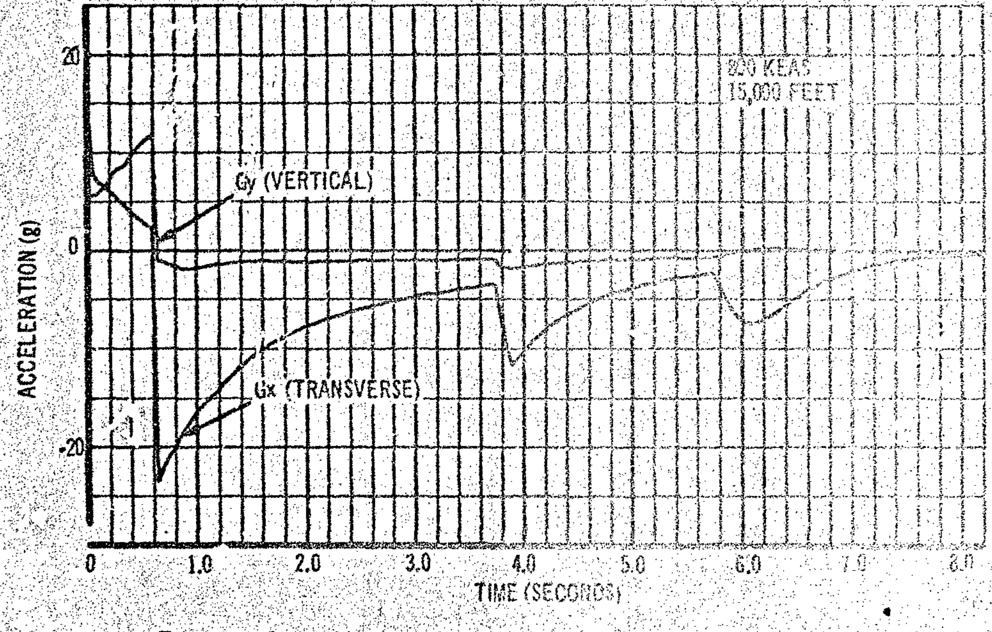


Figure 101. Four–Man Separable Nose Capsule Computer Plot of Maximum Acceleration

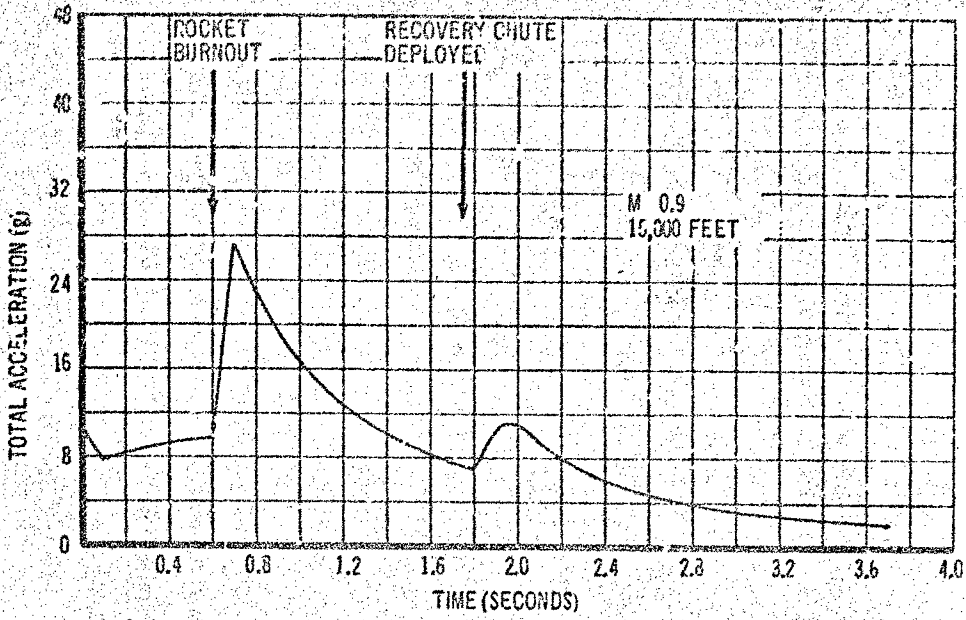


Figure 102. Two–Man Separable Nose Capsule – Acceleration Versus Time

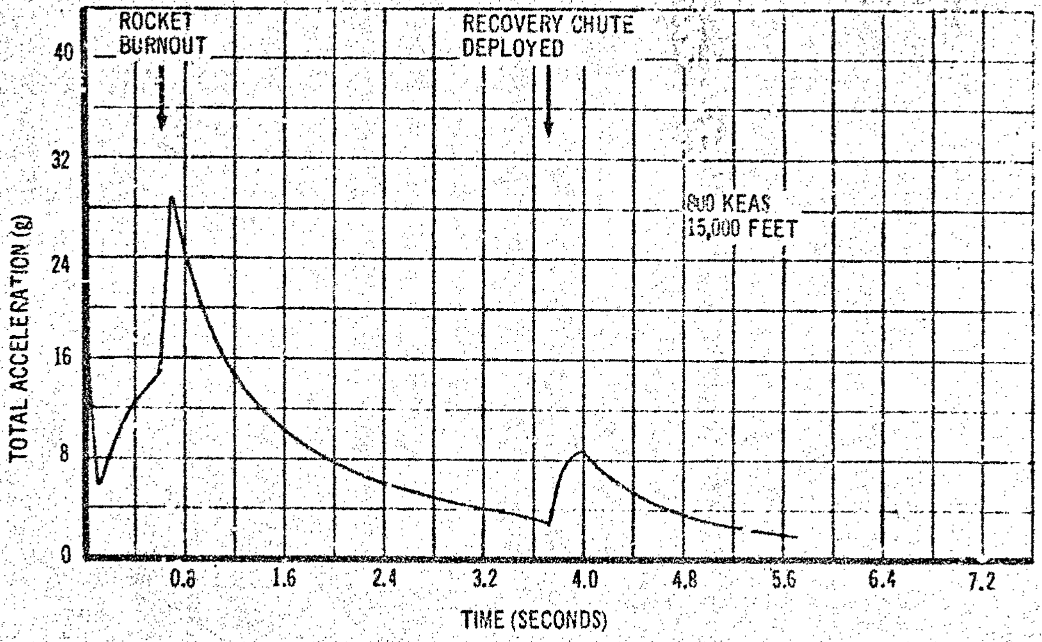


Figure 103. Three–Man Separable Nose Capsule – Acceleration Versus Time

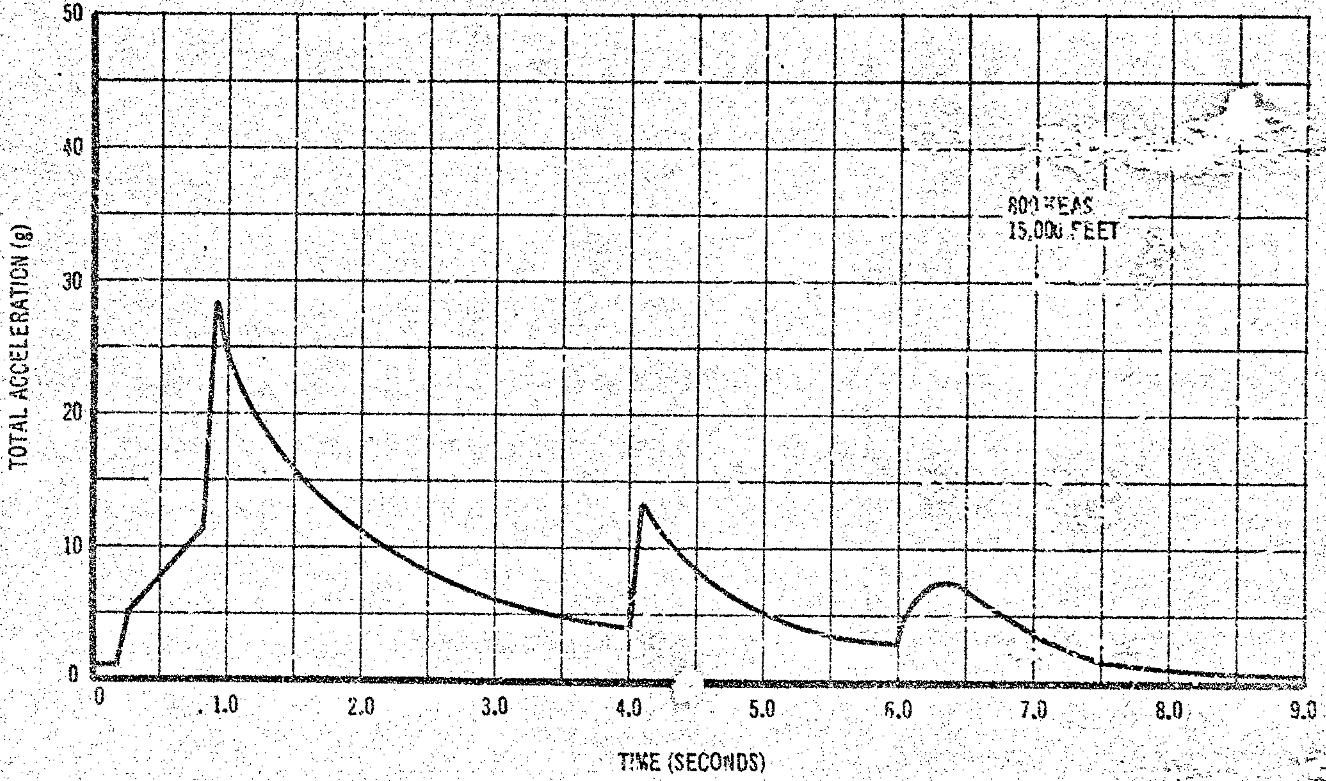


Figure 104. Four-Man Separable Nose Capsule – Acceleration Versus Time

5. CAPSULE SUBSYSTEMS

Subsystem descriptions contained in this section are generally applicable to each of the representative CPC and SNC escape concepts for the two-, three-, and four-man vehicles. This information, together with the design data of the preceding sections, completes the definitions of the capsule subsystems.

a. Separation System

Separation is accomplished with flexible linear shaped charges (FLSC) installed at the separation plane on skin, structure, and around tubing and wires. The respective separation planes are shown on each capsule drawing. The FLSC weight shown includes weight allowance for charge holder, but no weight is added for cover plates that might be required in some areas. Initiation occurs simultaneously with boost rocket firing. Two separate explosive initiators mounted at the boost rocket initiator accomplish this. The explosive stimulus is transferred through a metal clad mild detonating fuse (MDF). Explosive junction or transfer fittings, machined from aluminum are installed at the junction of the MDF and FLSC. System reliability is improved by providing explosive connections at both ends of each segment of the FLSC. The whole system is sealed in order to function under water.

b. Boost Rocket

The capsule boost rocket is a solid propellant rocket with a fixed nozzle angle. The rocket case consists of welded steel with a wound fiberglass outer wrap. Threaded attachments will be used for the end cap and the nozzle assemblies. The rocket is mounted on the capsule structure so that the thrust line passes slightly underneath the capsule center of gravity. This thrust eccentricity is calculated to provide the capsule with a positive lift attitude. Estimated rocket burntime is 0.6 second for all capsules.

c. Stabilization Booms

The ballistically deployed telescoping booms consist of three aluminum tubes each. Fist ribbon stabilization/deceleration parachutes are stored in and released from the booms. The booms and the stabilization chutes are deployed at separation of the capsule from the aircraft.

Aircraft separable nose and cockpit pod escape capsules are basically aerodynamically unstable bodies. To stabilize the capsules, large parachute forces are required. These forces directly affect stabilization parachute size and boom size.

Alternate stabilization systems such as canard, or even a reaction control system, might afford some weight savings. This depends on capsule configuration and the stabilizing forces required. However, any stabilization system imposes a respectable weight penalty for large capsules.

d. Parachutes

The stabilization/deceleration parachutes are drogue gun deployed in a reefed condition at the time of escape rocket initiation. At the time of rocket burnout, the parachutes are disreefed to provide the capsule with a maximum of 30g deceleration. Conical ribbon type parachutes are used for this purpose.

When capsule velocity decreases to a point where the dynamic pressure is 300 psf, the deceleration chutes are jettisoned and the main recovery parachutes are gun-deployed and opened to a reefed condition. The type of parachute chosen for this purpose is the Ring Sail canopy. This parachute is sized to provide the capsule with a descent velocity of 30 fps.

e. Impact Attenuation System

The impact attenuation system is activated at the time the recovery parachute is filled. It consists of an inflating system and impact bags. The elements making up the inflating system are a 3000 psi bottle of nitrogen, a squib valve, pressure gauge, regulator, and distribution lines. Gas quantity available is sufficient to inflate the bag to a pressure of 2 to 3 psi.

The bag has a short cylindrical shape and is made of neoprene coated nylon. It is provided with blowout plugs and orifices. The plugs blow out when the compression of the bag reaches an equivalent of 10g deceleration. Orifices then limit the maximum deceleration to approximately 25g. The impact bag is either compartmentized or rigidized internally to permit impact angles up to 15 degrees. Deceleration stroke of the bag is kept to the lowest distance practicable.

f. Flotation System

The flotation system for either the CPC or the SNC consists of four flotation bags and one self-righting bag. All bags are approximately spherical in shape and are made of rubber covered nylon or dacron. Two separate inflation systems, one supplying the flotation bags and the other the self-righting bag, are installed. The flotation bag inflation system consists of one 3000 psi bottle of nitrogen provided with redundant squib valves and a regulator. Four check and pressure relief valves and metering orifices, one at each flotation bag, are also included. A separate system consisting of a pressure bottle and a regulator valve inflates the self-righting bag. Actuation of the flotation system is sequenced so that the self-righting bag is inflated first.

g. Nose Thruster (Four-Man Cockpit Pod Capsule)

In the cockpit pod concept for the two-and three-man vehicles, the pod containing the crew is lifted out of the fuselage. In the four-man vehicle, however, the cockpit pod is severed the same way as the separable nose capsule, with a rear parting plane completely through the fuselage. The cockpit pod capsule is then made by dropping the nose radome from the rest of the capsule.

The nose thrusters push the airplane radome down and away from the rest of the capsule immediately after it has been separated from the capsule. The system consists of two ballistically actuated thrusters weighting about 6.5 pounds each.

6. CAPSULE AERODYNAMIC CHARACTERISTICS

Capsule performance calculations were based on basic cockpit pod and separable nose capsule wind tunnel data from tests conducted in the Cornell 8-foot transonic wind tunnel and the Boeing supersonic wind tunnel. These data were obtained over a Mach number range of 0.5 to 3.0 for pitch angles to ±60 degrees and yaw angles to 40 degrees. Figures 105 through 108 show the capsule aerodynamic characteristics.

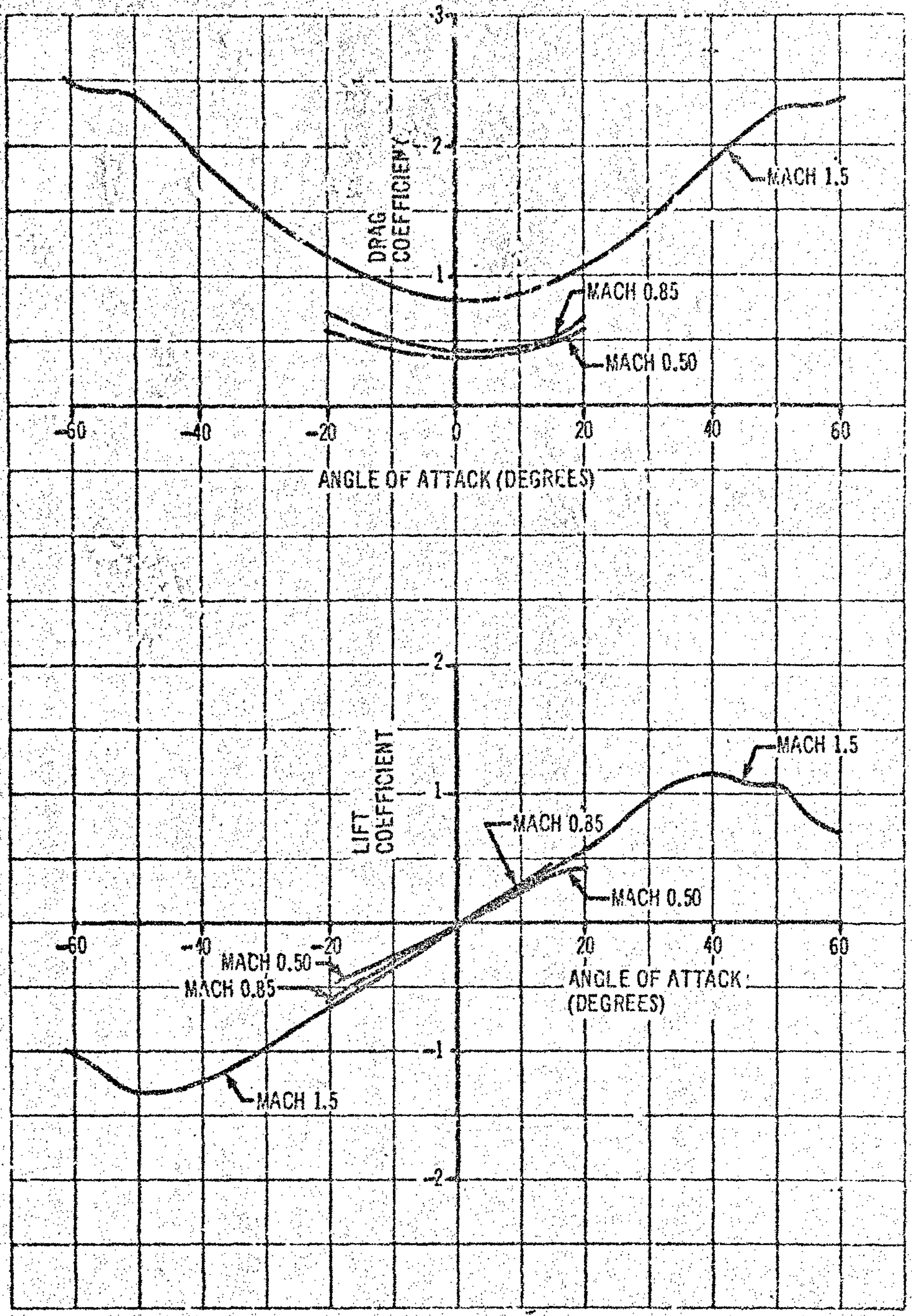


Figure 105. Cockpit Pod Capsule Drag and Lift Coefficients

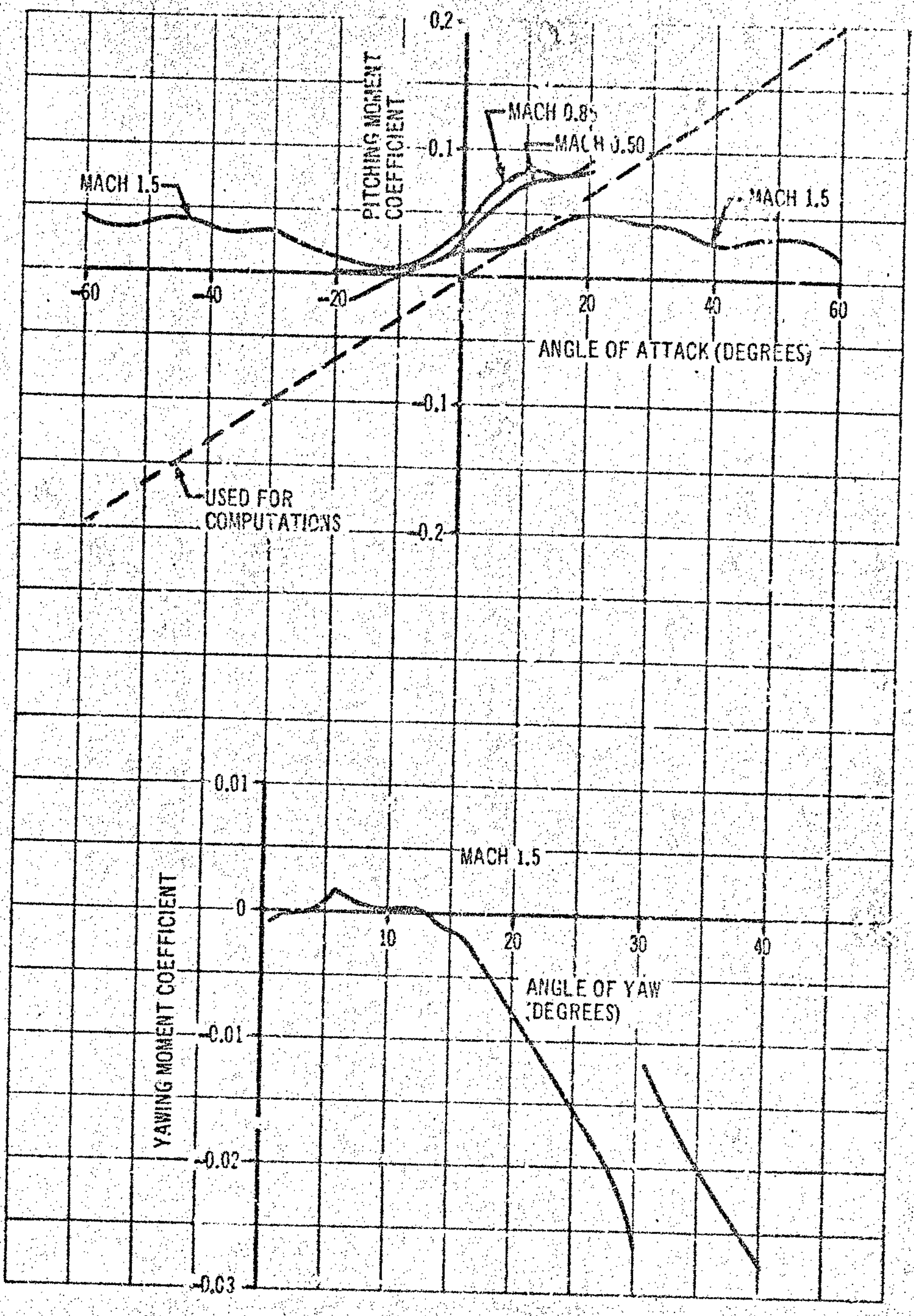


Figure 106. Cockpit Pod Capsule Pitch and Yaw Coefficients

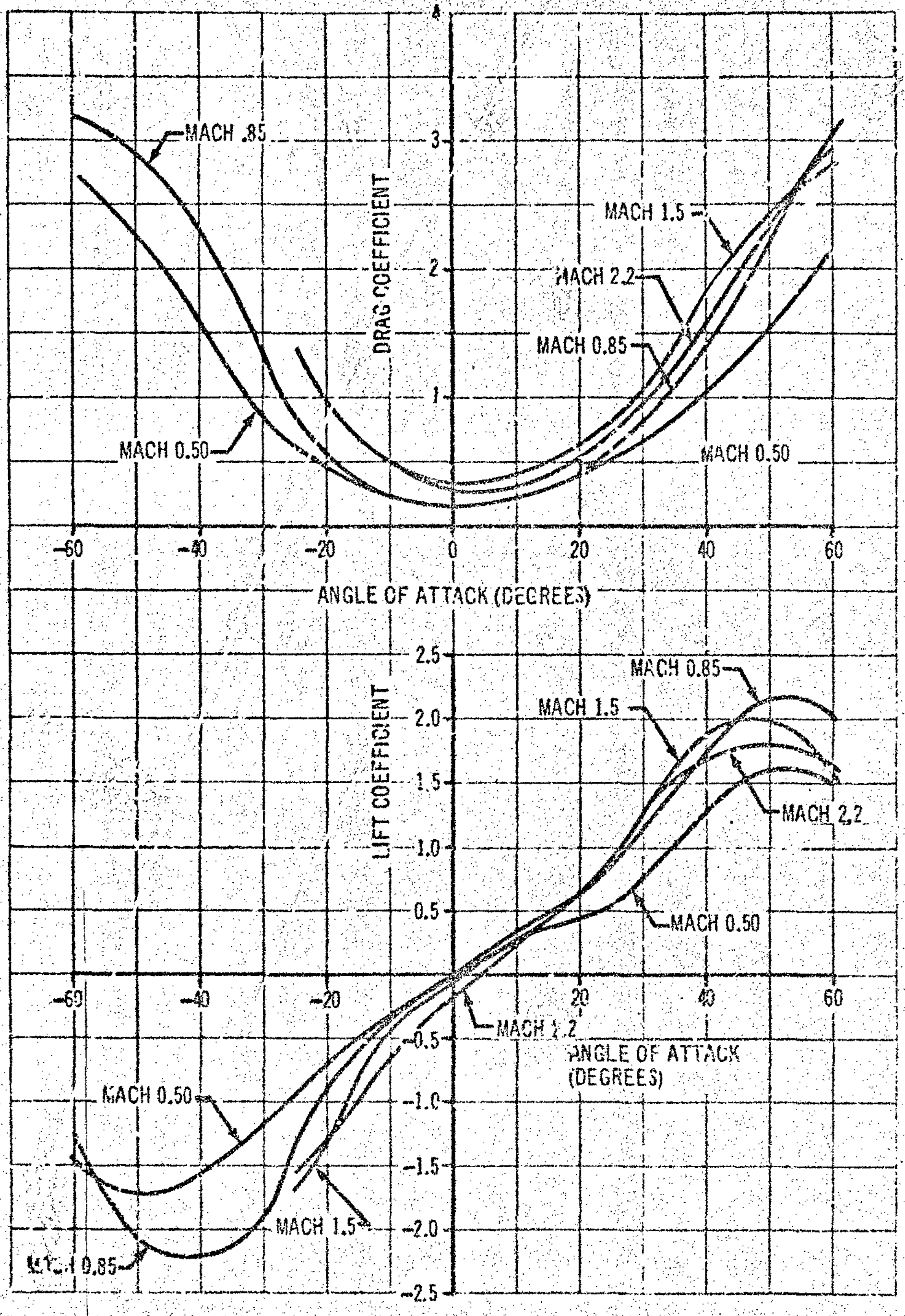


Figure 107. Separable Nose Capsule Drag and Lift Coefficients

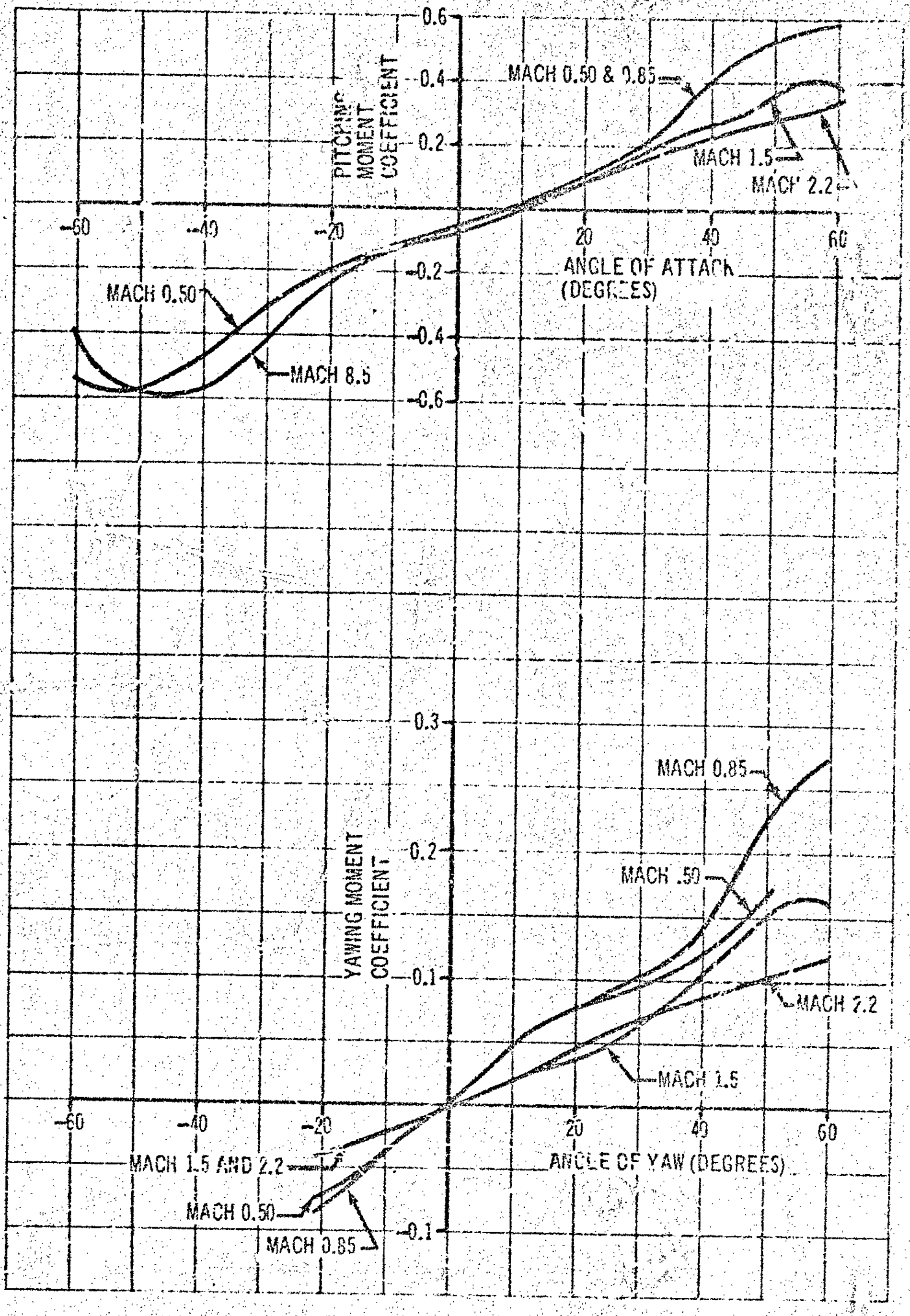


Figure 108. Separable Nose Capsule Pitch and Yaw Coefficients

SECTION IV

TEST REQUIREMENTS

This section describes tests required to verify escape system performance for the twelve representative escape concept/vehicles configurations. The test programs described include wind tunnel model tests, subsystem tests, and integrated system development and qualification tests that normally would be accomplished by the airframe prime contractor. In addition, estimated test program scheduling requirements and budgetary cost data are presented for basic subsystems development that normally would be accomplished by companies specializing in the specific subsystem technologies.

1. DEVELOPMENT AND QUALIFICATION TESTS

Estimated test schedule requirements for developmental and qualification programs for open ejection seats, encapsulated ejection seats, and cockpit and nose capsule systems are shown in Figs. 109, 110, and 111 respectively. The test item numbers refer to test requirements described in Tables V and VI. The open and encapsulated ejection seats were considered to be supplier-developed items and the detail test requirements described herein include only those tests required to verify system performance, prove seat/vehicle compatibility, and qualify the integrated system. However, the scheduling requirements for seat development are included in the phasing chart.

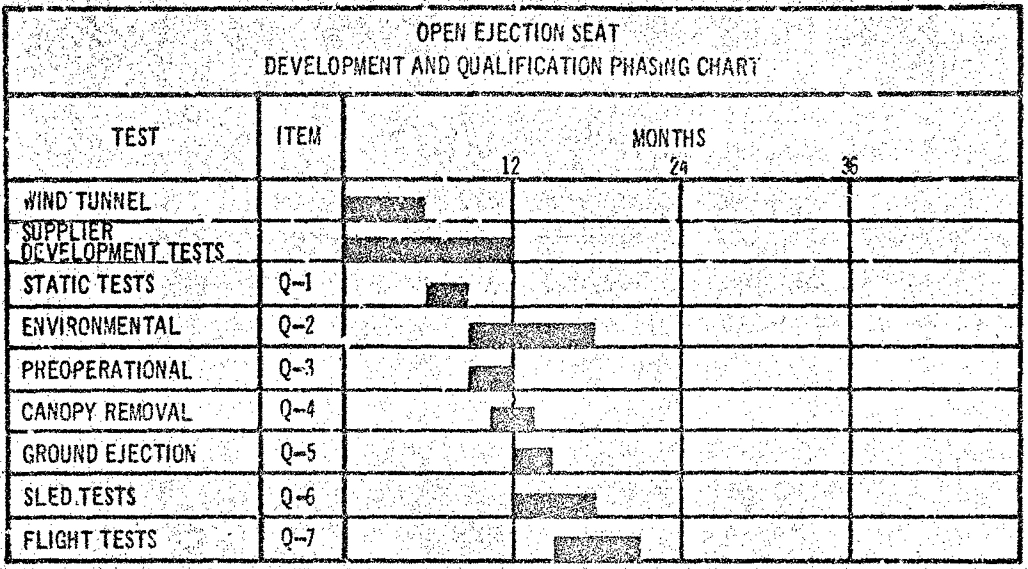
2. WIND TUNNEL PROGRAMS

Wind tunnel test programs were developed for the twelve escape concept/vehicle combinations to determine the overall RDT&E requirements and costs for each combination, and to support the design, test, and qualification of these systems. However, due to the similarity in the test requirements for some configurations the programs were grouped as shown in the following test plans.

a. Two-Man Subsonic VTOL Vehicle Open Ejection Seats and Encapsulated Ejection Seats

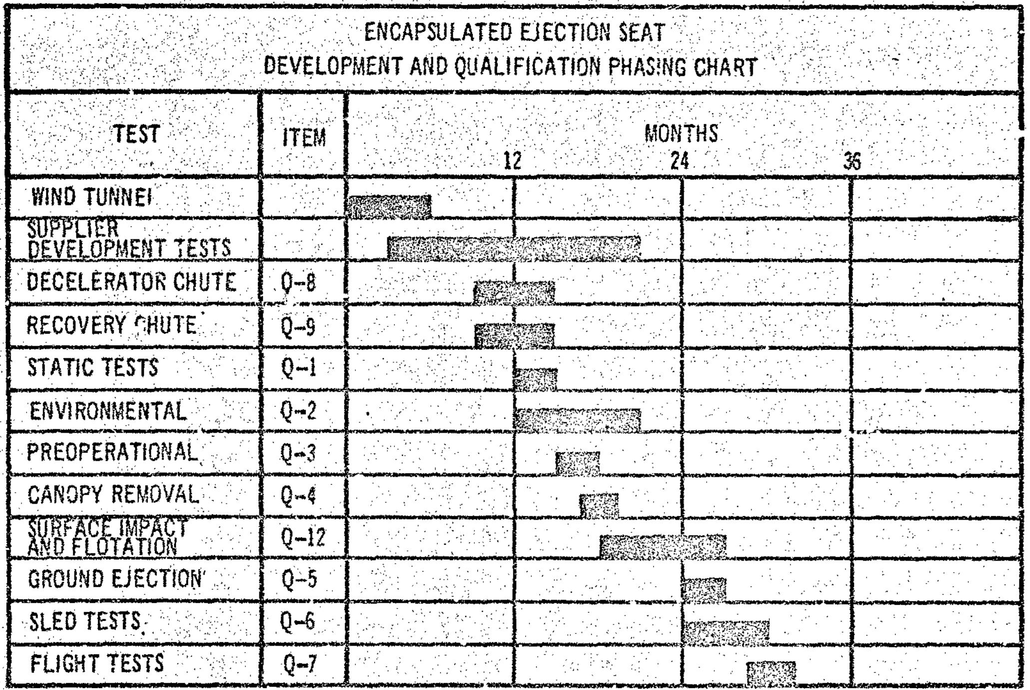
Equipment

- Transonic wind tunnel.
- One partial aircraft model (nose to trailing edge of the wings, wings included). Model will have two operable hatches and capability to eject seats from either or both crew stations.
- One force model of ejection seat/encapsulated seat.
- Fifteen ejectable seat models and hatches.
- Three configurations of seat stabilizing devices attachable to both force and ejection models. Eighteen sets of stabilizing devices



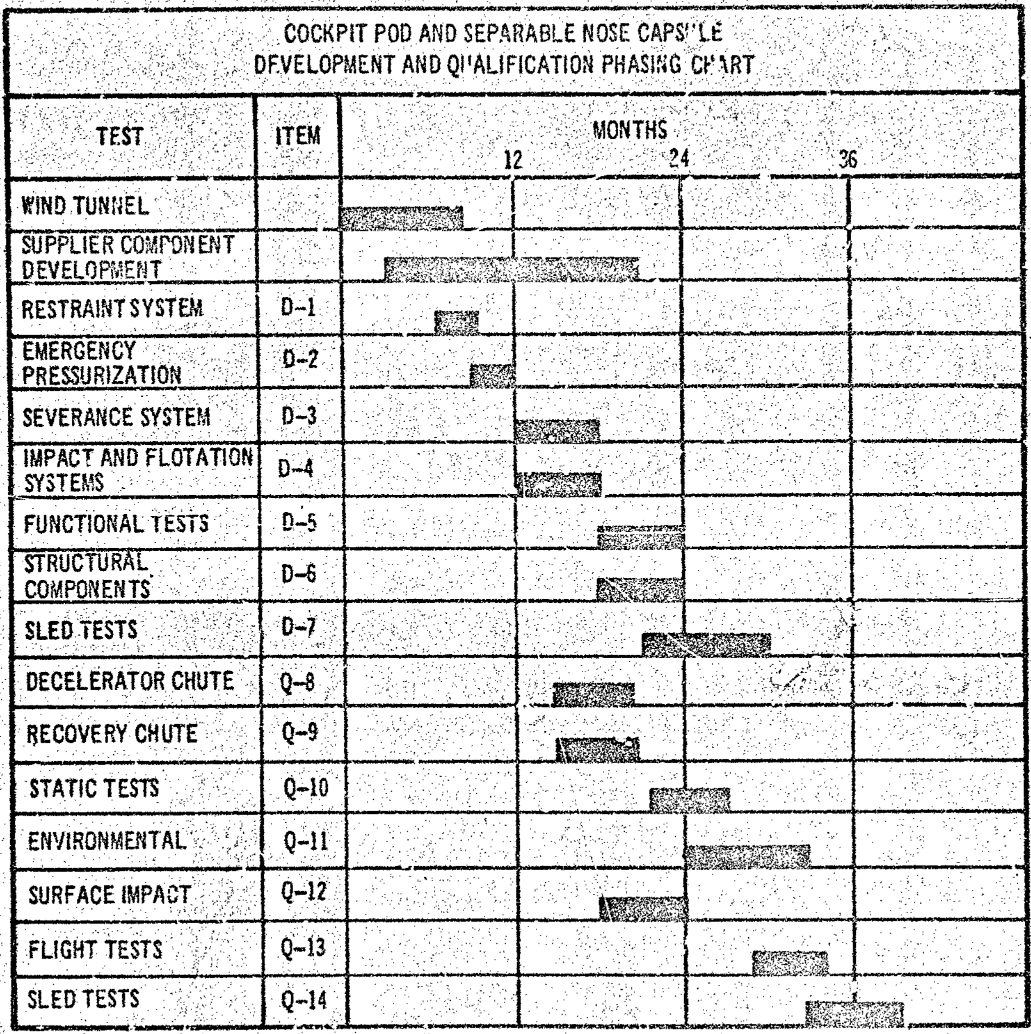
Q REFERS TO QUALIFICATION TESTS TABLE VI

Figure 109. Open Ejection Seat Test Requirements



Q REFERS TO QUALIFICATION TESTS TABLE VI

Figure 110. Encapsulated Ejection Seat Test Requirements



COCKPIT POD AND SEPARABLE NOSE CAPSULE
DEVELOPMENT AND QUALIFICATION PHASING CHART

TEST	ITEM
WIND TUNNEL	
SUPPLIER COMPONENT DEVELOPMENT	
RESTRAINT SYSTEM	D-1
EMERGENCY PRESSURIZATION	D-2
SEVERANCE SYSTEM	D-3
IMPACT AND FLOTATION SYSTEMS	D-4
FUNCTIONAL TESTS	D-5
STRUCTURAL COMPONENTS	D-6
SLED TESTS	D-7
DECELERATOR CHUTE	Q-8
RECOVERY CHUTE	Q-9
STATIC TESTS	Q-10
ENVIRONMENTAL	Q-11
SURFACE IMPACT	Q-12
FLIGHT TESTS	Q-13
SLED TESTS	Q-14

D REFERS TO DEVELOPMENT TESTS TABLE V
Q REFERS TO QUALIFICATION TESTS TABLE VI

Figure 111. Cockpit Pod and Separable Nose Capsule Test Requirements

ITEM	TEST TYPE	MAJOR EQUIPMENT	TEST COND
D-1	**Restraint Systems**	Mechanical lab space. Cockpit floor, operable seats, and seat attachment structure.	Apply loads to crew system.
D-2	**Emergency Pressurization System**	Mechanical lab space. Nose section mockup incorporating cockpit capsule/separable nose areas. Functioning seals associated with severance operation.	Pressurize 20 time severance simulate
D-3	**Severance System**	Mechanical lab space. Mockup of capsule with actual aircraft structure contiguous to the separation plane. 100 test items for severance tests, structural samples, cable runs, ducts, and wire bundles. Spare parts to support full-scale separation firings.	(1) 100 severance small test item (2) 10 severance fi the complete se plane.
D-4	**Impact & Flotation Systems**	Mechanical lab space. Boilerplate capsule with actual impact system, crushable structure, energy absorbers, or impact bags. Flotation equipment. Weight of drop bodies to be controlled. Water drop facility.	Conduct 12 drop tes sule/separable nose land surface, and 6 Impacts will occur capsule orientations the flight path and i conditions of crossw
D-5	**Functional Tests**	Mechanical lab space. Breadboard set-up of escape system ballistic train. Includes all operating components up to severance system initiation manifold and rocket. System will include electrical, gas operated, and manually operated devices.	Conduct 20 tests of operation.
D-6	**Structural Component**	Mechanical lab space. Structural test items: Rocket attachment fittings; Parachute attachment fittings; Seat mountings; Stabilizing booms and attachments; Stabilizing boom actuators and attachments.	Ten load tests on ea
D-7	**Sled Tests**	Dummy (Boilerplate) capsules with prototype rocketmotors, stabilization booms, stabilization parachutes, recovery parachutes, and impact subsystems.	Conduct eight sled te the system at incren speed from zero to t capability of the veh

Table V. Subsystem Developmental Testing
– Cockpit Pod Capsule/Separable Nose Capsule

TEST CONDITIONS	SITE	OBJECTIVE	INSTRUMENTATION
loads to crew restraint m.	Contractor	Develop restraint system.	Loads
urize 20 times. Capsule ance simulated.	Contractor	(1) Develop emergency pressurization system sensing and control system. (2) Develop pressure seals for severance plans. (3) Develop capability to pressurize capsule.	Pressure Time
00 severance firings of mall test items. 0 severance firings of e complete separation ane.	Contractor	(1) Develop design details for separation plane. (2) Develop complete severance system.	Pressure Time Movies
ct 12 drop tests of cap- separable nose; 6 onto surface, and 6 into water. ts will occur with various le orientations relative to ght path and in several tions of crosswind.	Contractor	Develop impact attenuation system.	Accelerations Time Movies
ct 20 tests of system tion.	Contractor	(1) Integration of system components. (2) Development of desired operating characteristics.	Pressure Time Movies
oad tests on each item.	Contractor	Develop structural components.	Pressure Time Movies
ct eight sled tests of ystem at increments of from zero to the maximum ility of the vehicle.	Track	Integrated system development and subsystem refinement or modification.	Acceleration Loads Time Movies

2

ITEM	TEST TYPE	MAJOR EQUIPMENT	TEST CONDITIO
Q-1	Static Structural Tests	Seat and attach structure. Fixture for application of loads.	Apply loads.
Q-2	Environmental Tests	Structurally complete seat and support structure assembly. Support fixture.	One functional firing at th end of the environmental testing. Tests: high tem ature, low temperature, humidity, salt spray, san vibration.
Q-3	Preoperational	Cockpit mockup including seat system less only catapult and hatch thrusters. Support fixture.	Actuate system once for crew position.
Q-4	Canopy/Hatch Removal	Cockpit mockup with canopy removal system and required portions of ejection system.	Actuate each hatch remov tem once. Hatch is close locked for the test. Utili seat trigger mechanism f tion of the sequence. Tw three, and four jettison te respectively, two, three, four-place airplanes.
Q-5	Ground Ejection Test	Cockpit mockup including complete seat system. Support fixture.	Eject seat twice from eac position. Once with norm hatch removal as a conse of the ejection sequence a once through the canopy. six, and eight ejections fo respectively, two, three, four-place airplanes.
Q-6	Sled Tests	Complete aircraft nose mockup, with operable ejection seat system. Fixture; nose section to sled attachment. Test seats are recovered undamaged 50% of the time. Remainder lost.	Required Test Ejectio Speeds/ Stations: Pilot 2nd Crew Minimum IAS 1 1 Intermediate IAS 1 0 Maximum IAS 1 1 Five, seven, and nine eje spectively, two, three, or airplanes.
REFERENCE: MIL-E-9426A MIL-C-25969A MIL-C-26218			

Table VI. Qualification Test Summary

ONDITIONS	SITE	OBJECTIVE	INSTRUMENTATION
	Contractor	Structural integrity demonstration.	Loads
ring at the onmental high temper- erature, altitude, pray, sand and r.	Contractor	(1) Functional demonstration. (2) Demonstrate design resistance to environmental effects on performance.	Temperature Time Pressure Movies
once for each	Contractor	(1) Obtain pressure and force time histories from system operation. (2) Verify proper sequencing of serial operations.	Pressure Time Loads Movies
ch removal sys- h is closed and est. Utilize the chanism for initia- ence. Two, jettison tests for, o, three, or anes.	Contractor	(1) Functional demonstration.	Pressure Time Loads Movies
from each crew with normal s a consequence equence and canopy. Four, jections for, o, three, or lanes.	Contractor	(1) Static demonstration of escape system.	Pressure Time Loads Movies Accelerations
st Ejections ot 2nd Crew 3rd Crew 4th Crew 1 1 1 0 0 0 1 1 1 d nine ejections for, re- three, or four-place	Test Track	Demonstrate sea level operation of system over speed range of aircraft.	Pressure Load Time Acceleration Movies

ITEM	TEST TYPE	MAJOR EQUIPMENT	TEST CONDITION
Q-7	Flight Tests	Test Aircraft; operable ejection seat system at selected crew station. Test seats are recovered undamaged 50% of the time. Remainder lost.	Required Test Eject Speeds/ Stations: Pilot 2nd Crew Min. Mach. no. 0 1 Intermediate Mach. no. 0 1 Max. Mach. no. 0 2 Four, six, and eight ejectio tively, from two, three or f airplanes.
Q-8	First Stage Decelerator	(1) Test article shape and fixture for attachment to sled.	(1) Deploy first stage decele tests. Conduct two tests at equally-spaced speeds from maximum. Test article is n from sled.
		(2) Seven expendable test article shapes. Carrier airplane.	(2) Conduct seven tests. De deployment altitude approxim 1,000 feet. Test article rele titude tailored to give deploy ocities over desired speed ra
		(3) Seven expendable test article shapes. Carrier airplane.	(3) Conduct seven tests. T release is from maximum a carrier aircraft. Deployme from minimum to maximum Mach Number.
Q-9	Main Recovery Parachute	Test article shape. Carrier airplane modified for air drop of test article.	Conduct ten drops from safe drops minimum carrier spe drops in equal increments to speed of carrier.
Q-10	Static Structural Tests	Structurally complete test article.	Apply loads.
Q-11	Environmental Tests	Structurally complete test article with operational escape subsystems (1) Seat, including restraint & positioning system. (2) Structural mockup with actual separation plane, separation system and rocket ignition system. (3) Parachute subsystems.	Environmental tests on esca subsystems. System functio test at the conclusion of envi mental test. Tests: high te erature, low temperature, a humidity, salt spray, sand, vibration.

Table VI. (Continued)

NDITIONS	SITE	OBJECTIVE	INSTRUMENTATION
ect Ejections 2nd Crew / 3rd Crew / 4th Crew 1 0 0 1 0 0 2 2 2 t ejections, respec- three or four-place	Drop Range	Demonstrate altitude operation of the system.	Pressure Load Time Acceleration Movies
age decelerator in ten tests at each of five eds from minimum to rticle is not launched	Track	(1) Demonstrate satisfactory deployment characteristics and chute stability in the wake of the test article.	Load Accelerations Pressure Movies
tests. Decelerator approximately rticle release al- ive deployment vel- d speed range.	Drop Range	Verify predicted deceleration loads. (2) Demonstrate satisfactory operation in free-stream conditions.	
tests. Test article aximum altitude of Deployments are maximum available.	Drop Range	(3) Demonstrate satisfactory operation at high Mach numbers.	
from safe altitude, five rrier speed and five rements to maximum	Drop Range	Demonstrate deployment characteristics, chute stability, and design sink rates.	Load Acceleration Movies
	Contractor	(1) Functional demonstration. (2) Data to prove demonstration.	Load
ts on escape em functional ion of environ- s: high temp- erature, altitude, ay, sand, and	Contractor	Demonstrate design resistance to environmental effects on performance.	Temperature Pressure Time Movies

2

ITEM	TEST TYPE	MAJOR EQUIPMENT	TEST CONDITIO
Q-12	Surface Impact	Structurally complete test article with operational escape subsystems. Drop facility for land and water drops. Spare parts for repair after land drop.	Drop tests require impa combining maximum des rate with maximum desi components. Test artic positioned in most critic tation with respect to su at instant of impact. (1) Conduct one drop ont crete surface. Repair te ticle as required. (2) Conduct one drop ont water surface. No resto of test article after water and before sea worthines allowed. (3) Conduct sea worthi stration in Beaufort scal Seventy-two hour flotatio stability demonstration r
Q-13	Flight Tests	Structurally complete test article with operational escape subsystems except: no rocket. Nine repair kits for restoration of impact system.	Conduct a total of ten dro a carrier airplane. (1) Five drops at even in of speed from minimum t mum of carrier. Drop a 2000 feet. (2) Five drops at even in of speed from minimum t mum of carrier. Drop a maximum of carrier.
Q-14	Sled Tests	Structurally complete test article with operational escape subsystems. Fixture for attachment to sled that permits small adjustment of angle of attack and yaw angle. Seven repair kits for restoration of impact system. For capsule and separable nose type tests: Seven kits for replacement of structure at separation plane.	Conduct eight test opera the escape system from Two tests at zero airspe remaining tests at even of airspeed from minim maximum. One addition at maximum IAS. Eight utively successful demon required.

Table VI. (Continued)

DITIONS	SITE	OBJECTIVE	INSTRUMENTATION
impact velocity n design sirk design drift article shall be critical orien- to surface track . op onto a con- pair test ar- op onto calm restoration water drop thiness test orthiness demon- t scale 5 seas. flotation and ation required.	Contractor	(1) Functional demonstration of impact attenuation system. (2) Data to prove demonstration.	Acceleration Time Movies
ten drops from . even increments imum to maxi- Drop altitude even increments imum to maxi- Drop altitude er.	Drop Range	(1) Recovery system operational demonstration. (2) System data.	Acceleration Time Movies
operations of from sled. airspeed; five even increments minimum to dditional test Eight consec- demonstrations	Track	(1) Operational demonstration. (2) System data.	Acceleration Time Movies

will be required. Fifteen are presumed to be consumed during the ejection tests; three used in development test.

- Two high-speed motion picture cameras mounted on the tunnel ceiling and wall for plan and elevation pictures.

- Two multiple-exposure still cameras; plan and evaluation.

Test Conditions

- Obtain forces and moments on seat model in free-stream conditions. Proximity to airplane not required. Develop required stabilizer configuration.

- Eject model seat ten times from one crew position and five times from the other. Ten ejections will cover a range of speeds and airplane attitudes from the primary test station. Five ejections from the second crew station under the most critical combinations of speed and attitude.

Test Variables

$0.3 \leq M \leq 1.1$ (M may be scaled for ejection tests)

h = sea level, and scaled 25,000 feet

Airplane attitude (ejection tests):

$-5^\circ \leq \alpha_A \leq 10^\circ \qquad \Delta\alpha_A = 5^\circ$

$\beta_A = 0^\circ$ and 5°

Seat attitudes (Force tests):

$-60^\circ \leq {}_s \leq 60^\circ \qquad \Delta\alpha_s = 10^\circ$

$-60^\circ \leq \beta_s \leq 60^\circ \qquad \Delta\beta_s = 10^\circ$

Data

- Three force coefficients $f(M, \alpha, \beta, \phi)$
- Three moment coefficients $f(M, \alpha, \beta, \phi)$
- Ten pressures (Hatch jettison $f(M, \alpha, \beta, \phi)$ characteristics. For comparison with full-scale sled data. Sea level condition only.)
- Ejection trajectory movies
- Multiple-exposure still photographs.

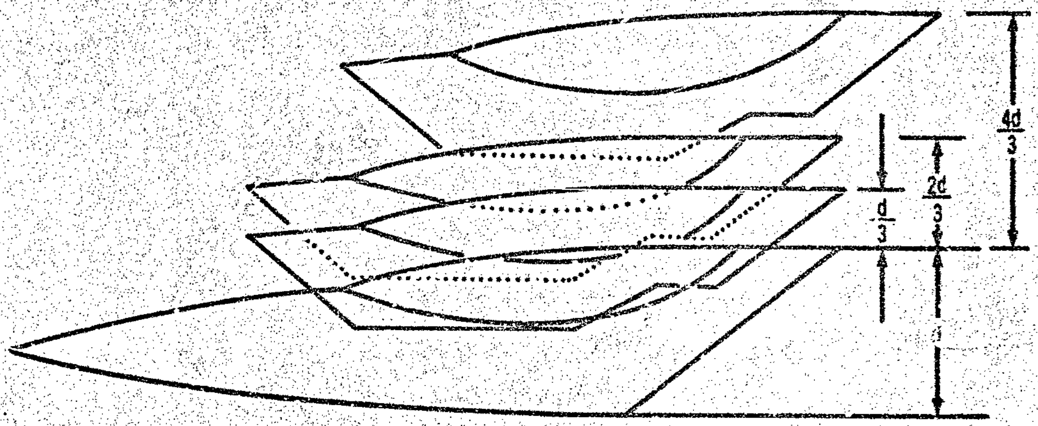
Results

- Establish seat/stabilizing-device stability characteristics.
- Establish desired hatch jettisoning characteristics.
- Establish safe escape trajectories.

b. Two-Man Subsonic VTOL Vehicle Cockpit Pod and Separable Nose Capsules

Equipment

- Transonic wind tunnel
- One partial airplane model (nose to trailing edge of the wings; wings included). The model is built in two parts: (1) the ejectable escape portion — cockpit pod/separable nose (this section will be a force model); and (2) the remaining portion of the partial model. Modeling must have the capability to adjust the capsule in three positions relative to the airplane to determine the forces on the separable portion while it is in the near-airplane portion of the escape trajectory as shown below. Capability to simulate booster wake (cold flow) must be included.



- One full model of carrier aircraft for capsule carrier aircraft separation tests.
- Ten ejectable cockpit pod/separable nose capsules.
- Three configurations of stabilizing devices attachable to both force and ejection models. They will require deployment capability on ejection models but may be fixed during force tests. Thirteen sets of stabilizing devices required. Ten sets will be consumed during ejection tests.
- Two high-speed motion picture cameras. Tunnel-ceiling and tunnel-wall mounted for plan and elevation pictures.
- Two multiple-exposure still cameras for plan and elevation.

Test Conditions

- Obtain forces and moments on capsule in free-stream conditions.
- Obtain forces and moments on capsule in three positions in the near-airplane portion of the escape trajectory. Rocket wake simulation required.
- Eject capsule ten times. The ten ejections will cover a range of speeds and attitudes.
- Obtain carrier aircraft — capsule separation characteristics to support follow-on flight test drops of full scale capsule. Drops for separation are at $\beta_A = 0$ and α_A appropriate to minimum, intermediate, and maximum carrier speeds.

Test Variables:

$0.3 \geq M \leq 1.1$

h = sea level, and scaled 25,000 feet

Capsule attitudes: (free-stream force tests)

$-60° \leq \alpha_c \leq 60°$
$-60° \leq \beta_c \leq 60°$

Airplane attitudes (airplane-capsule force tests and ejection tests)

$-5° \leq \alpha_A \leq 10°$ $\Delta \alpha_A = 5°$
$\beta = 0°$ and $5°$

Data

- Three force coefficients $f(M, \alpha, \beta, \phi)$

  Capsule alone
  Airplane-capsule combination

- Three moment coefficients $f(M, \alpha, \beta, \phi)$

  Capsule alone
  Airplane-capsule combination

- Thirty pressures (to compare tunnel results with similar full-scale sled test data to be acquired during track testing).
- Verification of rocket wake simulation. Weight flow measurement.
- Ejection trajectory movies.
- Multiple-exposure still photographs.
- Carrier airplane-capsule drop movies and still photographs.
- Carrier airplane-capsule forces and moments.

Results

- Establish capsule/stabilizing device stability characteristics.
- Establish safe escape trajectories.
- Use combination of wind tunnel-test sled data to establish highest possible confidence level in system capabilities in conditions impossible to flight test.

c. Three-Man Combined Capability Vehicle Open Ejection Seats and Encapsulated Ejection Seats

Equipment

- Transonic wind tunnel.
- Supersonic wind tunnel.
- One partial airplane model (nose to aft of cockpit area). Model will have three operable hatches and capability to eject seats from all crew stations.
- One force model of ejection open/seat encapsulated seat.
- Twenty ejectable seat models (two scales: sea level and altitude).

- Five configurations of seat stabilizing devices attachable to both force and ejection models. Twenty-five sets of stabilizing devices will be required. Twenty sets to be consumed in ejection tests. Five sets used in development tests.
- Two high-speed motion picture cameras. Tunnel-ceiling and tunnel-wall mounted for plan and elevation pictures.
- Two multiple-exposure still cameras for plan and elevation.

Test Conditions

- Obtain forces and moments on seat model in free-stream conditions. Proximity to airplane not required. Develop required stabilizer configuration.
- Eject model seat ten times from critical crew position, and five times from each of the other stations. Ten ejections will cover a range of speeds, attitudes, and two altitudes. Five ejections each from other crew stations at most critical combinations of speed, attitude, and altitude.

Test Variables

- Mach No. (M may be scaled for ejection tests.)

  Transonic $0.3 \leq M \leq 1.1$
  Supersonic $1.9 \leq M \leq 3.0$

  Conduct supersonic tests at altitude only. It is assumed that a crew member would not survive above $V_C = 600$ knots in an open seat or above $V_C = 800$ knots in an encapsulated seat.

- Altitudes

  Sea level
  Scaled 55,000 feet

- Airplane attitudes (ejection tests)

  Transonic $-5^\circ \leq \alpha_A \leq 10^\circ$ $\Delta \alpha_A = 5^\circ$
  $\beta_A = 0$ and 5
  Supersonic $\alpha_A = 0^\circ$
  $\beta_A = 0$ and 5

- Seat attitudes (force tests)

  $-60^\circ \leq \alpha_s \leq 60^\circ$ $\Delta \beta_s = 10^\circ$
  $-60^\circ \leq \beta_s \leq 60^\circ$ $\Delta \beta_s = 10^\circ$

Data

- Three force coefficients $f(M, \alpha, \beta, \phi)$.
- Three moment coefficients $f(M, \alpha, \beta, \phi)$
- Thirty pressures (hatch $f(M, \alpha, \beta, \phi)$ jettison characteristics. For comparison with full-scale sled data. Sea level conditions only).
- Ejection trajectory movies.
- Multiple-exposure still photographs.

Results

- Establish seat/stabilizing device stability characteristics.
- Establish desired hatch jettisoning characteristics.
- Establish safe escape trajectories.

d. Three-Man Combined Capability Vehicle Cockpit Pod and Separable Nose Capsules

Equipment

- Transonic wind tunnel.
- Supersonic wind tunnel.
- One partial airplane model (nose to aft of cockpit capsule/nose separation plane). The model is built in two parts: the ejectable escape portion; cockpit pod/separable nose (this section will be a force model); remaining portion of the partial model. Modeling must have the capability to adjust to capsule in three positions relative to the airplane to determine the forces on the separable portion while it is in the near-airplane portion of the escape trajectory. Capability to simulate booster wake influence (cold flow) must be included.
- Fifteen ejectable capsule models and ten drop models for carrier/capsule separation tests.
- Five configurations of stabilizing devices attachable to both force and ejection models. They will require deployment capability on ejection models but may be fixed during force tests. Fifteen sets of the final configuration of stabilizing devices will be consumed during the ejection tests.
- One full model of carrier aircraft for capsule/carrier aircraft separation tests.

- Two high-speed motion pictures. Tunnel-ceiling and tunnel-wall mounted for plan and elevation pictures.
- Two multiple-exposure still cameras for plan and elevation.

Test Conditions

- Obtain forces and moments on capsule in free-stream conditions.
- Obtain forces and moments on capsule in three positions in the near-airplane portion of the escape trajectory. Rocket wake simulation required.
- Obtain carrier aircraft/capsule separation characteristics to support follow-on flight test drops of full-scale capsule.
- Eject capsule 15 times. Ejections will cover a range of speeds and attitudes at two altitudes.

Test Variables

- Mach No. (M may be scaled for ejection tests.)

  Transonic $0.3 \leq M \leq 1.1$
  Supersonic $1.4 \leq M \leq 3.0$

- Altitudes

  Sea level
  Scaled 55,000 feet

- Airplane attitudes (ejection and capsule-airplane force tests)

  Transonic $-5° \leq \alpha_A \leq 10°$ $\Delta\alpha_A = 5°$
  $\beta_a = 0°$ and $5°$
  Supersonic $\alpha = 0°$
  $\beta_a = 0°$ and $5°$

- Capsule attitudes (free-stream force tests)

  $-60° \leq \alpha_s \leq 60°$ $\Delta\alpha_s = 10°$
  $-60° \leq \beta_s \leq 60°$ $\Delta\beta_s = 10°$

Data

- Three force coefficients $f(M, \alpha, \beta, \phi)$
- Three moment coefficients $f(M, \alpha, \beta, \phi)$
- Carrier airplane-capsule forces and moments.

- Carrier airplane-capsule drop movies and still photographs.
- Ejection trajectory movies.
- Multiple-exposure still photos of ejections.
- Verification of rocket wake simulation. Weight flow measurement.

Results

- Establish capsule stabilizing device stability characteristics.
- Establish safe escape trajectories.
- Establish feasibility of dropping capsule from a carrier airplane.
- Use combination of wind tunnel-test sled data to establish highest possible confidence level in escape system capabilities in conditions impossible to flight test.

e. Four-Man Supersonic Dash Vehicle Open Ejection Seats, Encapsulated Ejection Seats, Cockpit Pod Capsules, and Separable Nose Capsules

Same test programs as for three-man vehicle.

3. DEVELOPMENT AND QUALIFICATION COST SUMMARY

Program costs developed for the twelve escape system concept/vehicle combinations are shown in Table VII. The costs shown as item 1 are the costs for each program as defined by the test outlines (Sec. IV.1). The item 2 costs reflect supplier development costs for the open ejection seat system, the encapsulated seat system, and the cockpit pod and separable nose capsule subsystems.

The test program costs are classified as budgetary and were developed to be used as a trade factor to aid in the selection of suitable escape systems for specific airplane configurations. To have a basis of establishing some of the item costs, it was necessary to make the following assumptions:

- Each test program was assumed to be a part of an airplane production program.
- The costs are in terms of 1966 dollars.
- The time from program approval to roll-out of the first flight article was assumed to be 30 months.
- No new capital equipment will be required for these programs to record test data.
- Major test parts (viz., cockpit pod capsules, separable nose capsules, airplane nose sections, or airplane structure contiguous to separation planes) will be provided from production parts; not built in experimental shops.

Table VII. Development Cost Summary

Crew Size	Two-Man Subsonic VTOL	Three-Man Supersonic VTOL	Four-Man Supersonic Dash
Open Ejection Seat			
Item 1	$ 1,569,156	$ 2,039,498	$ 3,033,589
Item 2	575,840	575,840	575,840
TOTAL	$ 2,144,996	$ 2,615,338	$ 3,609,429
Encapsulated Seat			
Item 1	$ 2,651,258	$ 3,140,801	$ 4,178,412
Item 2	7,500,000	7,500,000	7,500,000
TOTAL	$10,151,258	$10,640,801	$11,678,412
Cockpit Pod Capsule			
Item 1	$ 6,481,994	$ 8,108,703	$13,760,426
Item 2	9,518,975	10,437,750	11,260,137
TOTAL	$16,000,969	$18,546,453	$25,020,563
Separable Nose Capsule			
Item 1	$ 7,425,528	$ 8,897,993	$15,797,007
Item 2	9,632,750	11,177,750	12,124,127
TOTAL	$17,058,278	$20,075,743	$27,921,134

Item 1	Contractor development and qualification tests
Item 2	Supplier incurred RDT & E — nonrecurring cost

SECTION V

ESCAPE CONCEPT PERFORMANCE EVALUATION

Section III presents basic escape system performance capabilities with respect to airplane altitude, velocity, and descent angle at the time of escape initiation for twelve representative escape concept/vehicle combinations. This section covers the results of an analysis of the effectiveness of the escape concepts to provide safe escape during certain critical phases of flight. The need for automatic or semiautomatic detection and escape initiation also is analyzed.

The phases of flight considered are VTOL hover and transition, conventional takeoff and landing, low altitude dash, and high speed and altitude. To accomplish the analysis, "check point" emergency escape situations representative of the escape conditions that might occur during each phase of flight were defined. Each escape concept was then compared with the escape conditions to determine the relative effectiveness of each concept. The need for, or benefits of, automatic detection and initiation were evaluated by: 1) considering the time required for a crewman to detect the emergency and to manually initiate escape; and 2) determining the probability of escape initiation in time for successful recovery during the emergency situations or conditions defined for each phase of flight.

1. VTOL HOVER AND TRANSITION

To evaluate the effectiveness of various escape concepts for the VTOL hover and transition flight regime, certain emergency flight conditions representing the type of escape situations that might exist were defined. To provide a basis for establishing the representative emergency flight conditions, a survey of available information pertaining to advanced VTOL technology was made. The following paragraphs summarize information concerning types of VTOL vehicles, propulsion arrangements, control power requirements, methods of control moment generation, stability augmentation requirements, reliability and control redundancy requirements, thrust to weight requirements, and vertical takeoff and transition techniques.

Types of VTOL Vehicles

VTOL jet aircraft, relative to lift engine grouping, generally fall into one of three categories:

- A single cluster of lift engines centered around the vehicle center-of-gravity. This arrangement results in minimum engine failure control problems, but engine thrust modulation does not provide an effective means of attitude control.
- Two clusters of lifting engines, fore and aft in the body. This leaves the body in the center of gravity area free for loading fuel or stores. The engine failure pitch moments are high, but the engines may be used for pitch control. In this arrangement the thrust vector of the aft engines may be rotated to the longitudinal direction, thus becoming combination lift and cruise engines.

- Three clusters of lifting engines in a triangular arrangement. This arrangement allows the basic vehicle to use thrust modulation control for all axes, but engine failure moments are high in pitch, roll, and yaw. The VJ-101C is this type of vehicle.

Control Power Requirements

The generally accepted and recommended levels of control power required for VTOL hover flight are:

$$\text{Pitch } (\ddot{\theta}) = 0.6 \text{ rad/sec}^2$$

$$\text{Roll } (\ddot{\phi}) = 1.2 \text{ rad/sec}^2$$

$$\text{Yaw } (\ddot{\psi}) = 0.4 \text{ rad/sec}^2$$

Control Moment Generation

Methods of control moment generation for VTOL hover and transition include the following:

Engine Thrust Modulation

On vehicles having the lifting engines located at some distance from the center of gravity, thrust modulation provides an effective means of attitude control, provides large control power, and is efficient in the use of engine thrust. The differential-thrust increments of opposing lifting engine clusters are generally scheduled to be of equal magnitude and include both increasing and decreasing thrust changes. When the engines are at full rating, the control increment will be down only. A vertical acceleration coupling exists whenever the increasing thrust modulation increment is not the same magnitude as the decreasing increment on the opposing engine. Pitch control by use of thrust modulation requires no additional equipment or weight to the vehicle other than provisions for combining pitch differential thrust signals with the collective thrust signals. For effective roll control by thrust modulation, the lifting engines should be located at the wing tips or at some distance out from the body. Success of thrust modulation for control depends on the response and resolution characteristics of the engine to control inputs. Lift engines, because of their low weight and inertia, have rapid response times. The heavier cruise engines have substantially longer response times.

Engine Bleed Reaction Controls

Reaction control systems utilize engine bleed ducted to reaction control nozzles located at the wing tips for roll control, or located in the tail and nose for pitch control. Reaction control systems are superior to thrust modulation systems in response and resolution of control moments. Efficient use of engine thrust is achieved for roll control systems because larger moment arms are possible. Reaction systems require large volume and weight for ducting. Since reaction systems extract energy from the lift engine, an effective loss of thrust results when control power is applied. The thrust loss associated with average control usage is dependent on whether the system is designed as a demand or continuous bleed system.

Differential Engine Vectoring

This means of control is used in the VJ-101C in conjunction with thrust modulation for pitch and roll control. Lateral rotation of cruise engines for yaw control is considered satisfactory for some installations.

Engine Bleed and Burn Reaction Control

Bleed air thrust may be augmented by the introduction and burning of fuel. However, the use of burners increases the complexity of the system and adds weight at aircraft extremities. This increases rotational inertias and therefore control force requirements.

Fans

The use of fans for augmenting bleed thrust offers a considerable reduction in bleed air requirements and minimizes engine thrust losses. These systems, however, pose a weight, volume, and installation problem.

Separate Gas Generators and Propellant Fueled Rockets

These methods of providing control introduce complexity and logistic problems and are not considered appropriate for use in VTOL vehicles.

Stability Augmentation

VTOL vehicles without stability augmentation respond to external moments with a constant angular acceleration. Flying an airplane with these characteristics is extremely difficult and under operational conditions probably impossible. The simplest stability augmentation system is a rate-damped system that modifies the airplane response to produce angular rate proportional to control or disturbance input. Although experienced pilots accept rate-control systems and are able to control hovering airplanes having rate damping only, flight conditions must be nearly ideal. Flying a rate-control system requires continuous pilot attention and leaves him little time for other tasks during the VTOL phase of flight. For flying under operational conditions, including all-weather and gusty air conditions, rate-control systems are not satisfactory in pitch and roll. An attitude stability augmentation system, that maintains vehicle attitude proportional to stick deflection, has a number of advantages over a rate system because it reduces pilot control effort significantly and improves hover accuracy. Simulator tests have indicated that an attitude system will provide satisfactory pitch and roll control with the recommended available control power levels listed in the preceeding paragraphs. A rate control system is satisfactory for yaw axis control.

Thrust to Weight Requirements

VTOL control systems extract energy from the installed thrust capability, and any demand on the reaction control system represents an effective decrease in the thrust available for lift. Estimates of control demands for vertical control, continuous control requirements, center-of-gravity trim, steady wind, and static suckdown indicate that a total installed thrust-to-weight value of about 1.18 probably will be required for future VTOL aircraft. Further, large discrete maneuvers, involving abrupt maximum amplitude control inputs to thrust modulation control systems, will normally result in a momentary loss of effective thrust-to-weight to a value significantly less than 1.0.

Control System Redundancy

VTOL vehicles require stability and control augmentation for mission success and flight safety. This leads to the need of an extremely reliable flight control system, requiring redundant or fail-operational systems. This has been proved by crashes of all previous VTOL aircraft. Advanced VTOL aircraft will probably require triple redundancy for all flight safety critical control system elements, being fail-operational for all possible first failures and fail-safe for most probable dual failures.

Vertical Takeoff and Transition Techniques

Vertical takeoff and transition techniques and procedures will vary depending on particular vehicle geometric configurations, handling qualities, fuel consumption, and elapsed time considerations. However, the general procedure is to bring all engines to full power with thrust pointing vertically. After the vehicle has reached the desired altitude, transition is started and the flight path is controlled by a smooth forward rotation of the thrust vector angle. Vehicle attitude is controlled during hover by thrust modulation, engine bleed reaction systems, differential engine vectoring, or combinations thereof. During transition, control is provided by engine control and aerodynamic control surfaces. Retransition for landing is accomplished by reducing engine thrust to idle, during wing borne flight, with the thrust vector angle at zero. Thrust rotation is initiated and gradually increased to the maximum deflection angle (vertical). Engine thrust is increased to maintain the desired flight path until the longitudinal velocity becomes zero. The vertical landing is then completed.

a. Escape Conditions

Due to the large number of possible variations in future VTOL vehicle configurations and designs as discussed in the preceding paragraphs, as well as unforseen changes in the rapidly advancing VTOL technology, it is not possible to define precise and complete escape requirements that would be appropriate for all future VTOL vehicles. However, if certain standards relative to flight safety critical areas are adhered to in future VTOL designs, it is possible to define some specific limiting escape conditions that will provide a suitable basis for escape concept evaluations and comparisons.

Experience with past VTOL experimental vehicles has resulted in certain design philosophies with respect to flight safety critical areas involving vehicle geometry and control requirements. This involves engine placement and grouping to eliminate excessive uncontrollable pitch or roll resulting from engine failure, stability augmentation, and highly reliable redundant control systems.

Emergency escape situations resulting from propulsion system failures were selected as representative of escape conditions that might be expected during hover or transition flight. A detailed analysis was made of escape conditions for engine failures throughout hover and transition flight. The basis and results of the analysis are presented in the following pages of this section.

The most critical possible control system failure would be one in which the maximum available control power is continually applied toward hard-over pitch or roll. This would result in a tumbling condition that would not allow the successful use of any realistically designed escape system. However, the probability of this critical control system failure occurring would be extremely rare in view of stability augmentation and control system reliability requirements for VTOL vehicles. A more probable control system failure would be a fail-safe or passive situation in which positive control may be lost, but adverse control or external moments would be transient only. A detailed analysis of possible control system failures and resulting escape conditions was not accomplished. For this study, it is presumed that future VTOL vehicle designs will be such that the most probable control system failures will not result in escape situations significantly more severe than those defined by the engine failure analysis.

Prevailing philosophy concerning flight safety for future operational VTOL jet aircraft calls for favorable engine placement relative to the center-of-gravity, multiple engines per cluster, and stability and control augmentation that will automatically compensate for an engine failure by modulating thrust of opposing engines. Thus, minimizing adverse pitch and roll and maintaining safe escape attitudes in the event of an engine failure. The ideally designed vehicle would crash in a controlled level attitude following an engine failure during hover or transition. Figure 112 shows the escape conditions that will exist for the maximum stability case engine failure at altitudes from zero to 500 feet during hover flight. For this case it was assumed that a minimum thrust-to-weight ratio of 0.5 for the trimmed condition following engine failure.

VTOL vehicle behavior following an engine failure is dependent upon the vehicle mass and moments of inertia; geometric arrangement of the lifting engines; distance of engines from vehicle cg; number of engines in each cluster; type of control and stability augmentation systems; engine response; reaction control system response; vehicle aerodynamic lift and control characteristics; installed thrust-to-weight ratio; takeoff, landing and transition techniques; pilot emergency procedures; and vehicle flight conditions, power settings and thrust deflection angle at the time of engine failure.

To establish boundary escape conditions for engine failure situations in VTOL vehicles in general, certain minimum vehicle design considerations relative to flight safety critical areas were prescribed. These design considerations were based on current and projected VTOL technology and design philosophies, and are believed to realistically represent the critical escape conditions that are most likely to occur.

Following is a listing of the minimum VTOL vehicle design considerations that collectively describe a hypothetical VTOL vehicle able to show the boundary escape conditions for hover and transition flight. Figure 113 shows the propulsion and control arrangement representing the minimum requirements vehicle which is controlled during hover by engine thrust modulation in pitch, and by engine bleed reaction control in roll.

Number of Lifting Engines

A minimum of two lifting engines in each cluster is required to assure pitch control and to maintain acceptable escape attitudes in the event of an engine failure. The minimum engine requirements are shown in Figure 113 and consist of two forward lift engines and two aft cruise engines of which the thrust is deflected vertically to provide lift for takeoff and landing.

Distance of Lifting Engines from Vehicle Center-of-Gravity and Mass Moment-of-Inertia Considerations

The relationship between engine thrust, location relative to the cg, and rolling and pitching moments of inertia shall be such that the vehicle response to a single engine failure will not exceed ±0.8 rad/sec^2 in pitch or ±1.2 rad/sec^2 in roll.

Engine Response Time

A ramp thrust decay or buildup of 3.0 seconds for a thrust change of 80 percent of maximum for both lift and cruise engines was assumed for engine modulation pitch control.

Reaction Control Response Time

A 0.3 second response time for application of full roll control power was used for the minimum requirements vehicle engine bleed reaction control system.

Thrust-to-Weight

The total installed thrust-to-weight, exclusive of demands of the engine bleed reaction control system, shall not be less than 1.0 at maximum power for steady state trim conditions.

Stability Augmentation

The minimum requirements vehicle shall be provided with a stability augmentation system which, through the thrust modulation pitch control system and the engine bleed reaction control system, will automatically act toward achieving a stable level attitude in the event of engine failure or the application of other external moments.

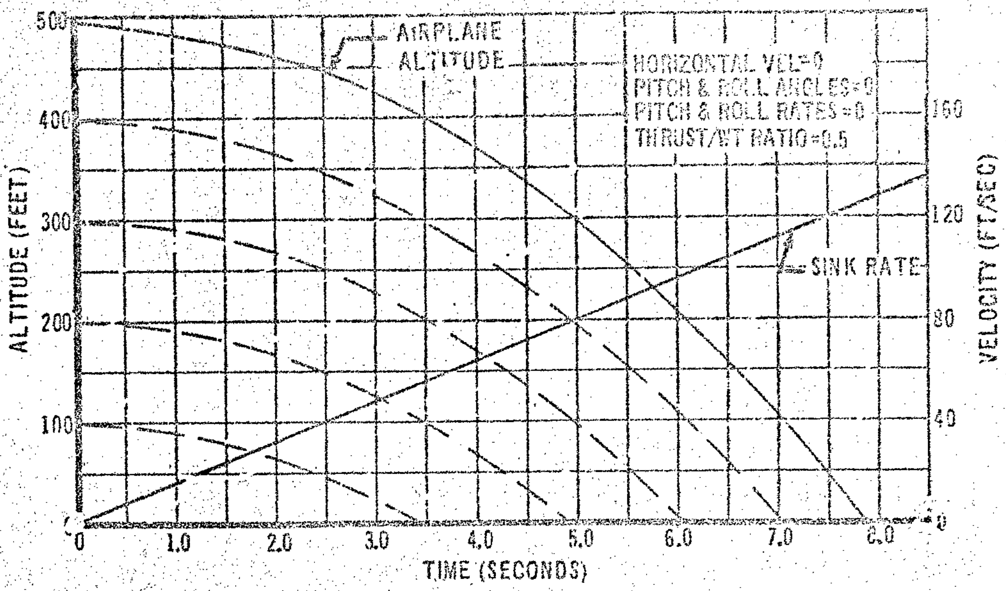


Figure 112. Escape Conditions for Engine Failure During VTOL Hover Flight – Flat Attitude, Maximum Stability Case

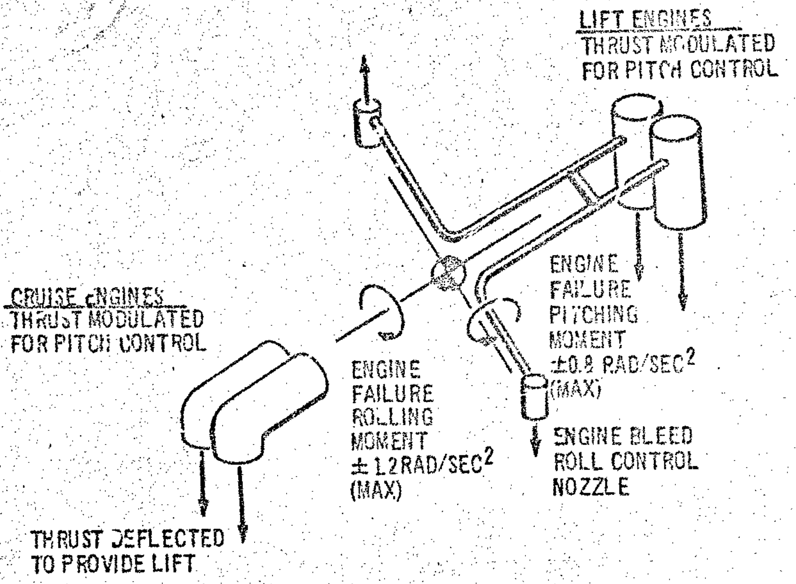


Figure 113. VTOL Vehicle Propulsion and Control Arrangement

Hover Control Power

The maximum control power available for roll control during hover is 1.2 rad/sec^2. This is the recommended stick control authority needed for hover flight and is equal to the maximum engine failure response. The recommended stick authority for pitch control is 0.6 rad/sec^2. However, the maximum pitch control power available by 80 percent thrust modulation for the minimum requirements vehicle is 1.28 rad/sec^2.

Aerodynamic Control

Figure 114 is a plot of aerodynamic pitch and roll control power available throughout the transition. These values were based on a normal aerodynamic control availability of 0.4 rad/sec^2 in pitch and 1.35 rad/sec^2 in roll at the transition completion velocity (wingborne flight) of 240 feet per second EAS.

Aerodynamic Lift

Aerodynamic lift-to-weight ratio as a function of transition velocity and angle of attack is shown in Figure 115. This is based on a lift-to-weight ratio of 1.0 at the minimum wingborne velocity of 240 feet per second EAS.

Transition Technique

The transition technique used for defining the vehicle flight conditions for engine failure analyses is to rise vertically to the desired transition altitude. Transition may be started at any altitude from ground level to 500 feet and may be accomplished in level or ascending flight. Cruise engine thrust is pointed vertically at the start of transition and is gradually rotated to the horizontal direction at the completion of transition. The total thrust-to-weight ratio is initially 1.0 (0.5 for cruise engines plus 0.5 for lift engines at the start of transition). Cruise engine T/W is maintained constant through the transition, and lift engine T/W is decreased as required to maintain trim and the desired equilibrium flight conditions. The VTOL transition schedule for a level flight transition is shown in Figure 116.

Based on the previously described minimum requirements VTOL vehicle characteristics, boundary escape conditions were calculated for cruise and lift engine failures at various check points throughout the transition envelope. The escape condition check points are shown in Figure 117 and are as follows:

Velocity		Percent of "q" Required For Wingborne Flight
Ft/Sec	Knots	
0	0	0.0
85	50	12.5
120	71	25.0
170	100	50.0
240	142	100.0

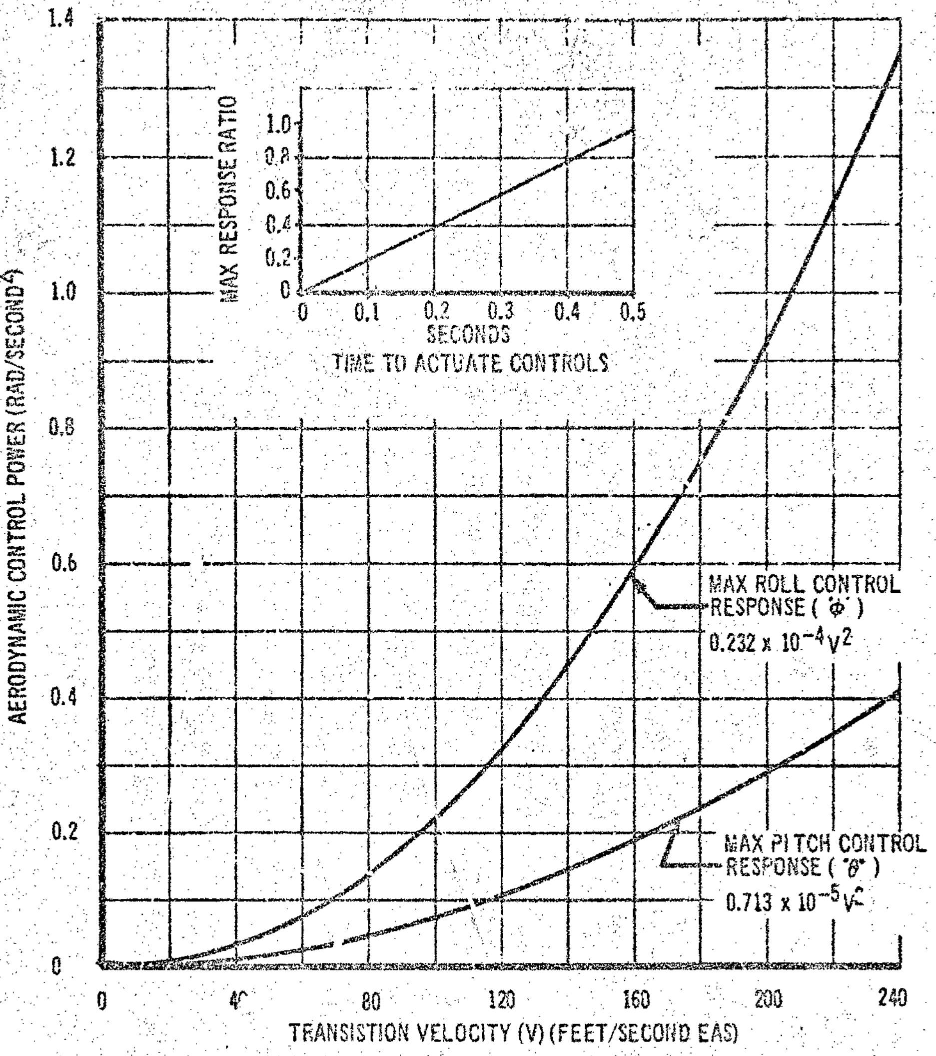


Figure 114. Aerodynamic Control Available During VTOL Transition

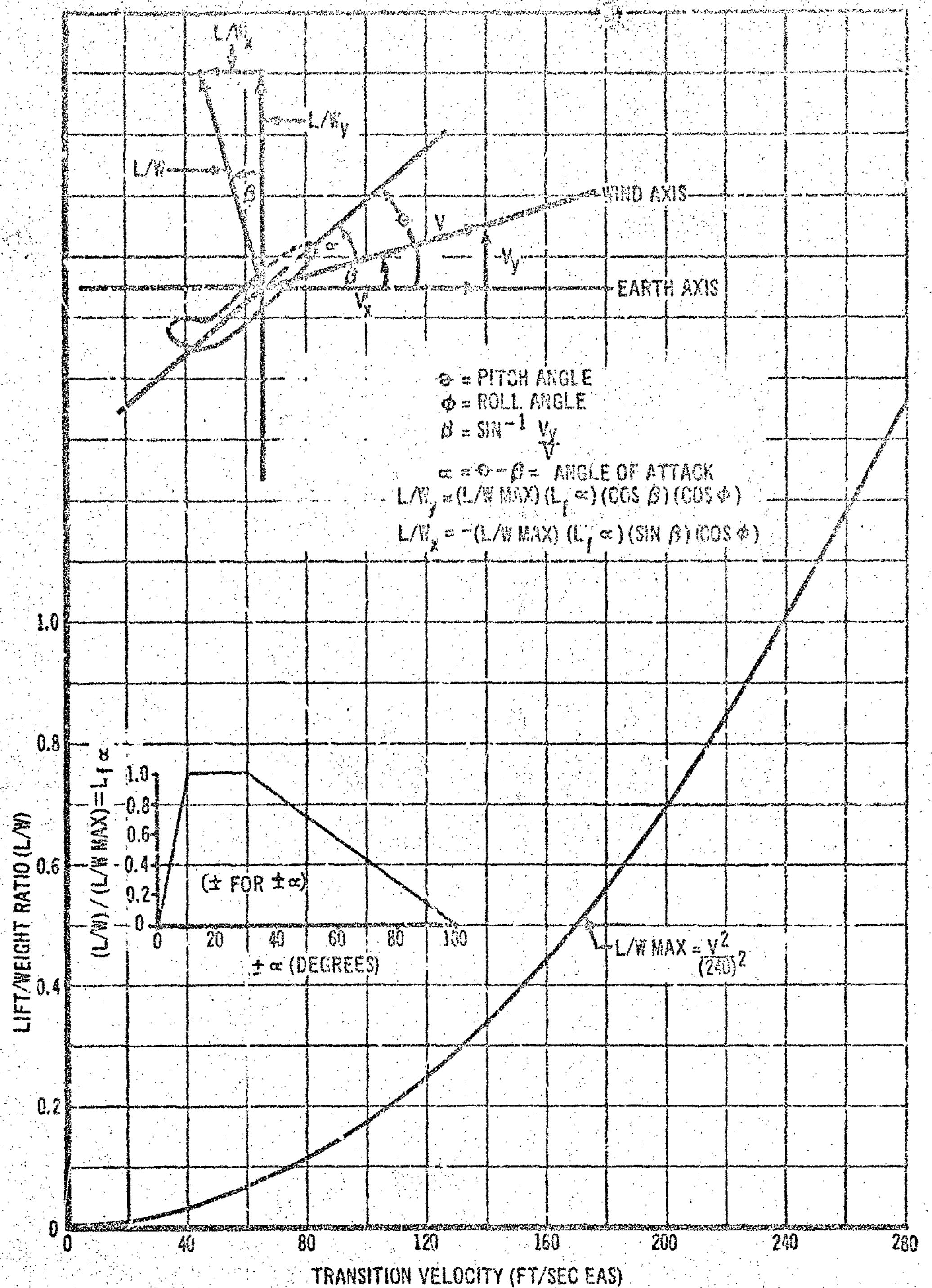


Figure 115. Aerodynamic Lift Available During VTOL Transition

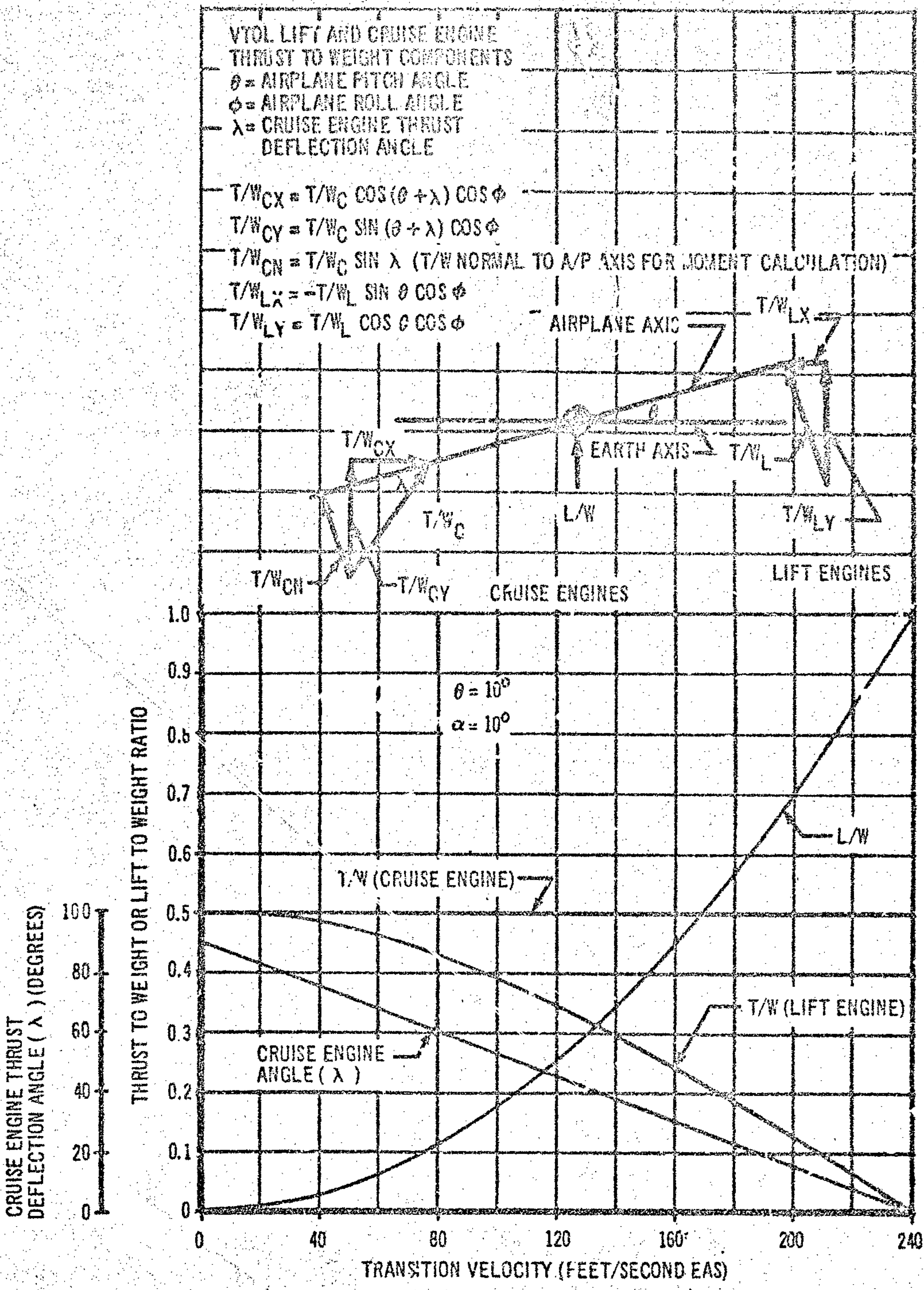


Figure 116. VTOL Vehicle Transition Schedule

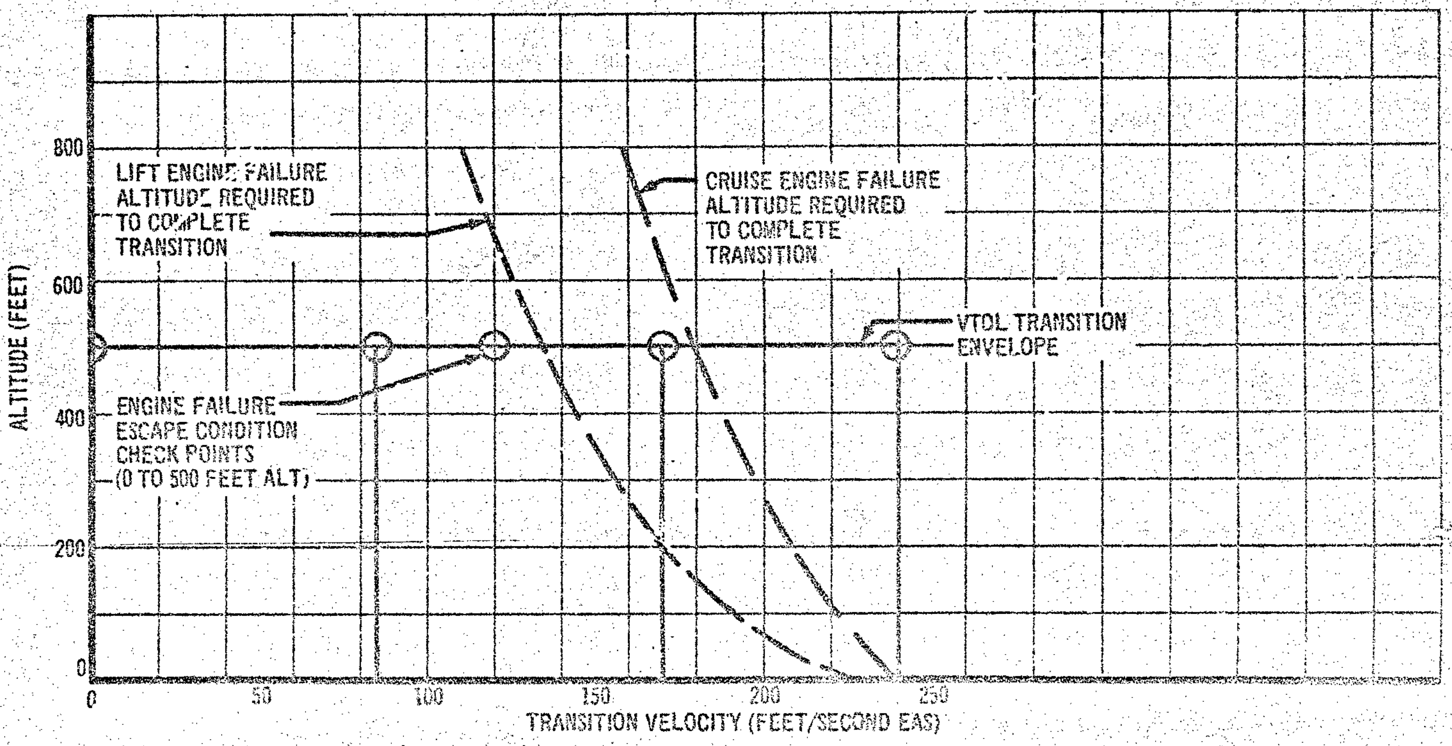


Figure 117. VTOL Engine Failure Escape Condition Check Points

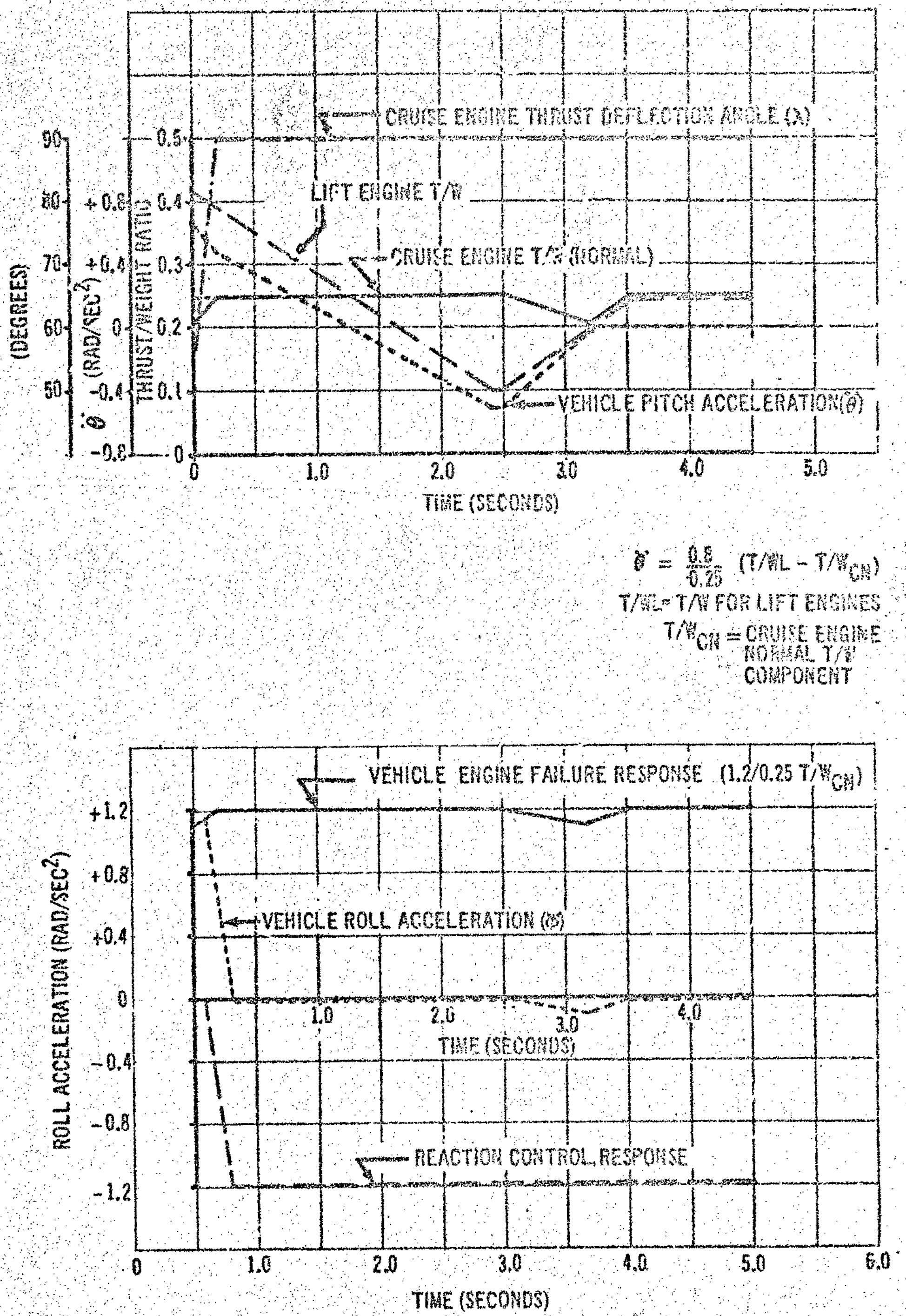
For the 85 ft/sec check point, the escape conditions were calculated with cruise engine thrust vector being returned to vertical, following engine failure, to maintain the maximum vertical T/W ratio. For the 120 ft/sec and higher velocity check points, it was assumed that an attempt to complete transition and continue to fly would be made. For these conditions the cruise engine thrust vector was rotated to the horizontal direction (vehicle-body axis) to provide maximum acceleration and chance of vehicle recovery. Figures 118 and 119 show the pitch control engine thrust modulation, cruise engine thrust vector angle, and engine bleed roll control moments versus time following cruise and lift engine failures at 85 ft/sec during transition. These curves are typical of the data developed for calculation of the escape conditions for each check point.

Figures 120 through 126 present the boundary escape conditions in terms of vehicle altitudes, pitch angles, roll angles, horizontal velocities and sink rates for engine failures at points in the transition envelope from zero to 500 feet altitude and zero to 240 ft/sec velocity.

b. Escape Concept Effectiveness

To evaluate the effectiveness of the various escape concepts for the VTOL hover and transition flight regime, an escape concept effectiveness index was established. The method devised for determining the relative effectiveness of the escape concepts for each of the emergency situations defined in the preceding section, is illustrated in Figure 127. The "airplane altitude" lines on the figure represent the loss of altitude versus time for similar emergency situations originating at different altitudes (100 foot increments) from zero to 500 feet. The altitude versus time limit for seat or capsule separation, required for successful recovery, was established from special computations based on the escape concept configurations defined in Section III. These limits were determined by computing the altitude required for recovery for the specific horizontal velocity, sink rate, pitch and roll angle conditions existing at various times following the start of an emergency. The "escape initiation required" line defines the points on the airplane versus time curves where escape must be initiated for successful recovery of the entire crew. The time lag between initiation and separation takes into account pre-ejection (or pre-separation) functions and ejection sequencing requirements for open and encapsulated ejection seats. The time allowance for preseparation functions for the capsule systems is 0.2 second. For the open ejection seat concept, the time required from initiation until the last seat clears the vehicle is 1.06 seconds for the two-man vehicle and 1.56 seconds for the three-man vehicle. For the encapsulated ejection seat concept, 2.15 seconds are required for the two-man vehicle and 2.65 seconds for the three-man vehicle.

For the escape concept effectiveness index determinations it was assumed that the VTOL emergency situations (engine failures) might occur at any altitude from zero to 500 feet, and that escape may be initiated at any time from the start of the emergency to ground impact. Therefore, the area to the left of the escape initiation line (Figure 127) represents the altitude-time spectrum where initiation would result in successful escape. The area to the right represents the unsuccessful escape initiation area. The ratio of the successful escape initiation area to the total area provides an index or measure of the relative effectiveness of the escape concepts.



$\ddot{\theta} = \frac{0.8}{0.25}$ (T/WL - T/W$_{CN}$)

T/WL = T/W FOR LIFT ENGINES

T/W$_{CN}$ = CRUISE ENGINE NORMAL T/W COMPONENT

Figure 118. VTOL Vehicle Thrust, Thrust Deflection Angle, Pitching Moments and Rolling Moments Following Cruise Engine Failure at 85 Ft/Sec EAS

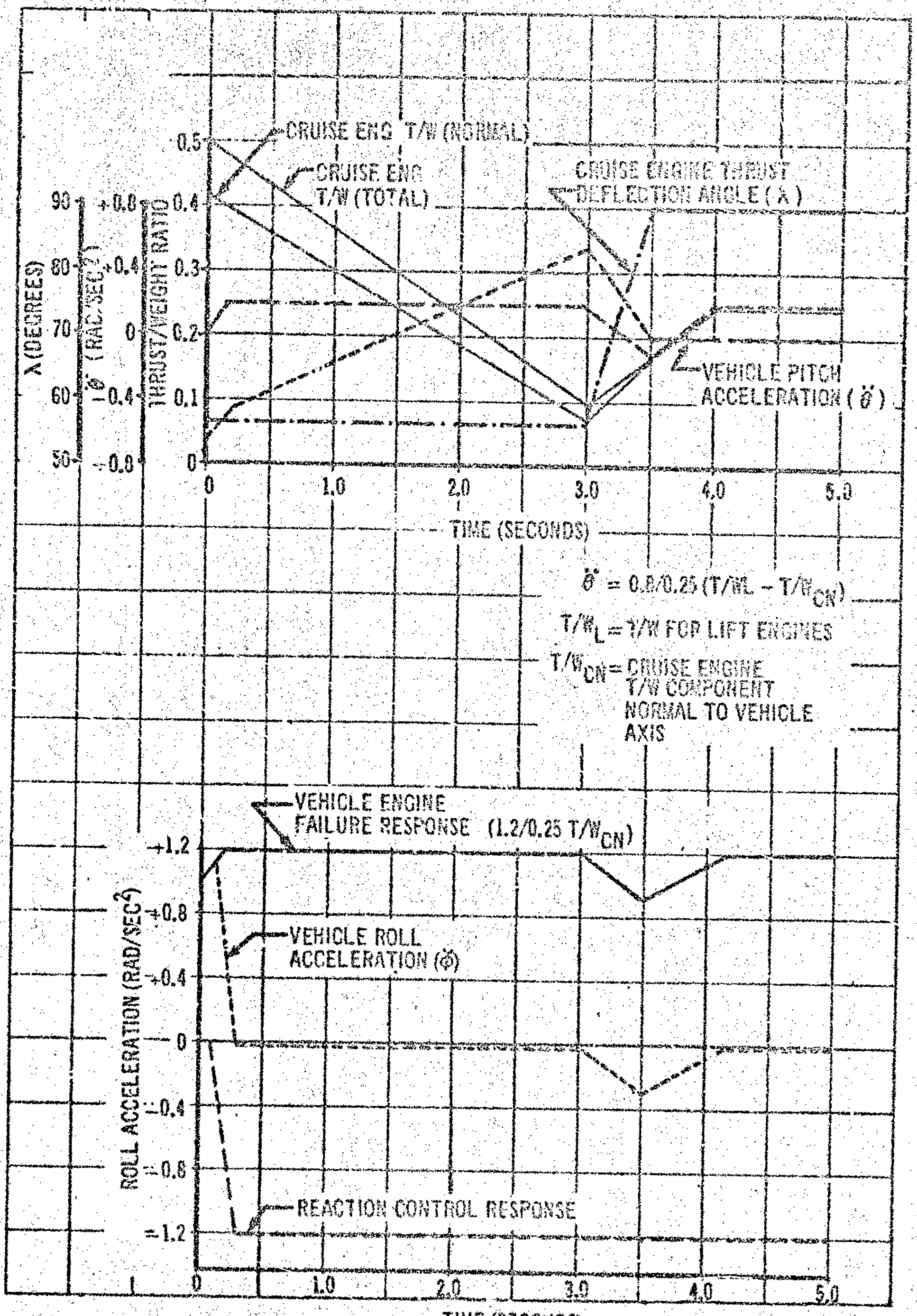


Figure 119. VTOL Vehicle Thrust, Thrust Deflection Angle, Pitching and Rolling Moments Following Lift Engine Failure at 85 Ft/Sec EAS

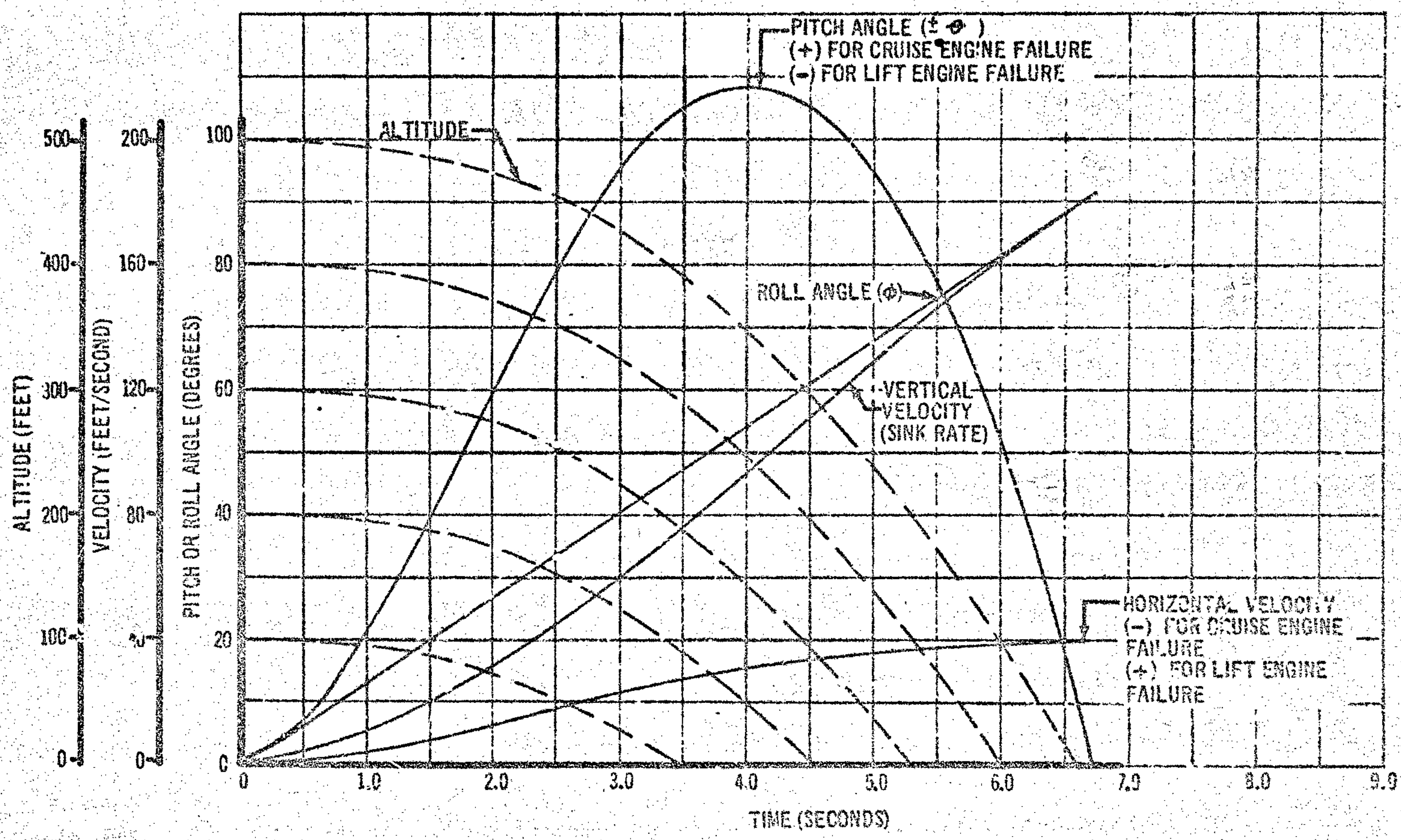


Figure 120. Escape Conditions for Engine Failure During VTOL Hover Flight

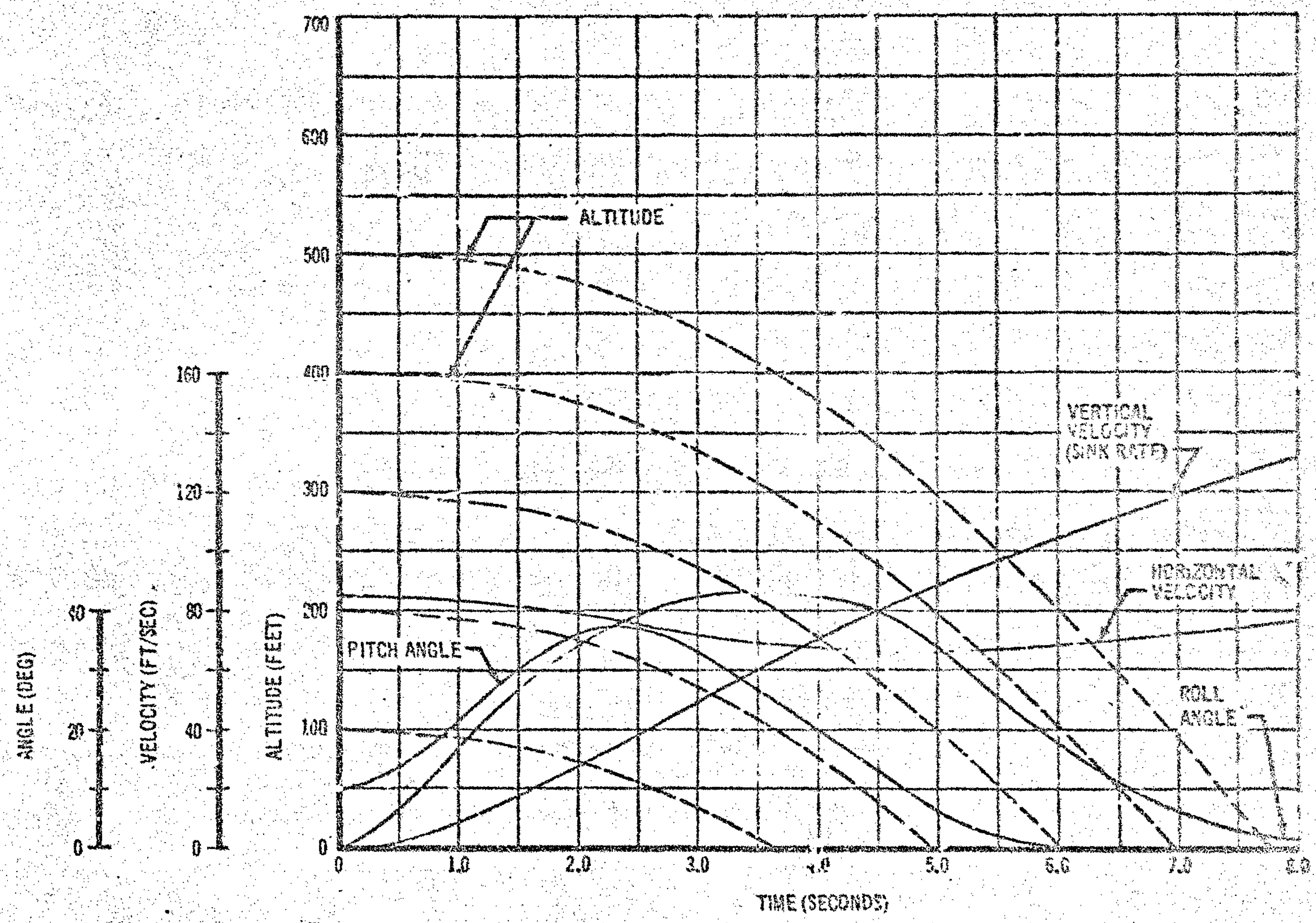


Figure 121. Escape Conditions for VTOL Cruise Engine Failure During Transition at 85 Ft/Sec EAS

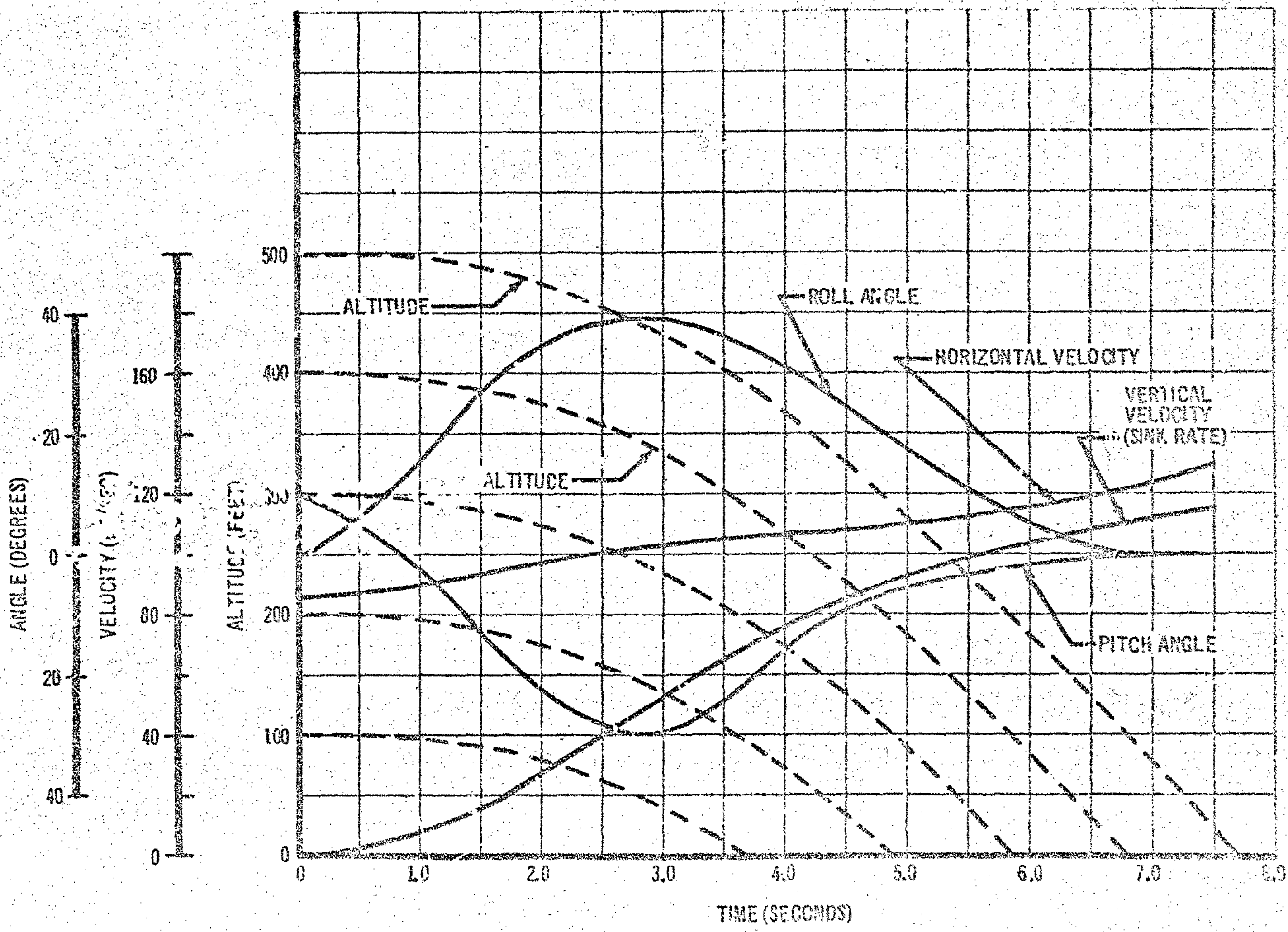


Figure 122. Escape Conditions for VTOL Lift Engine Failure During Transition at 85 Ft/Sec EAS

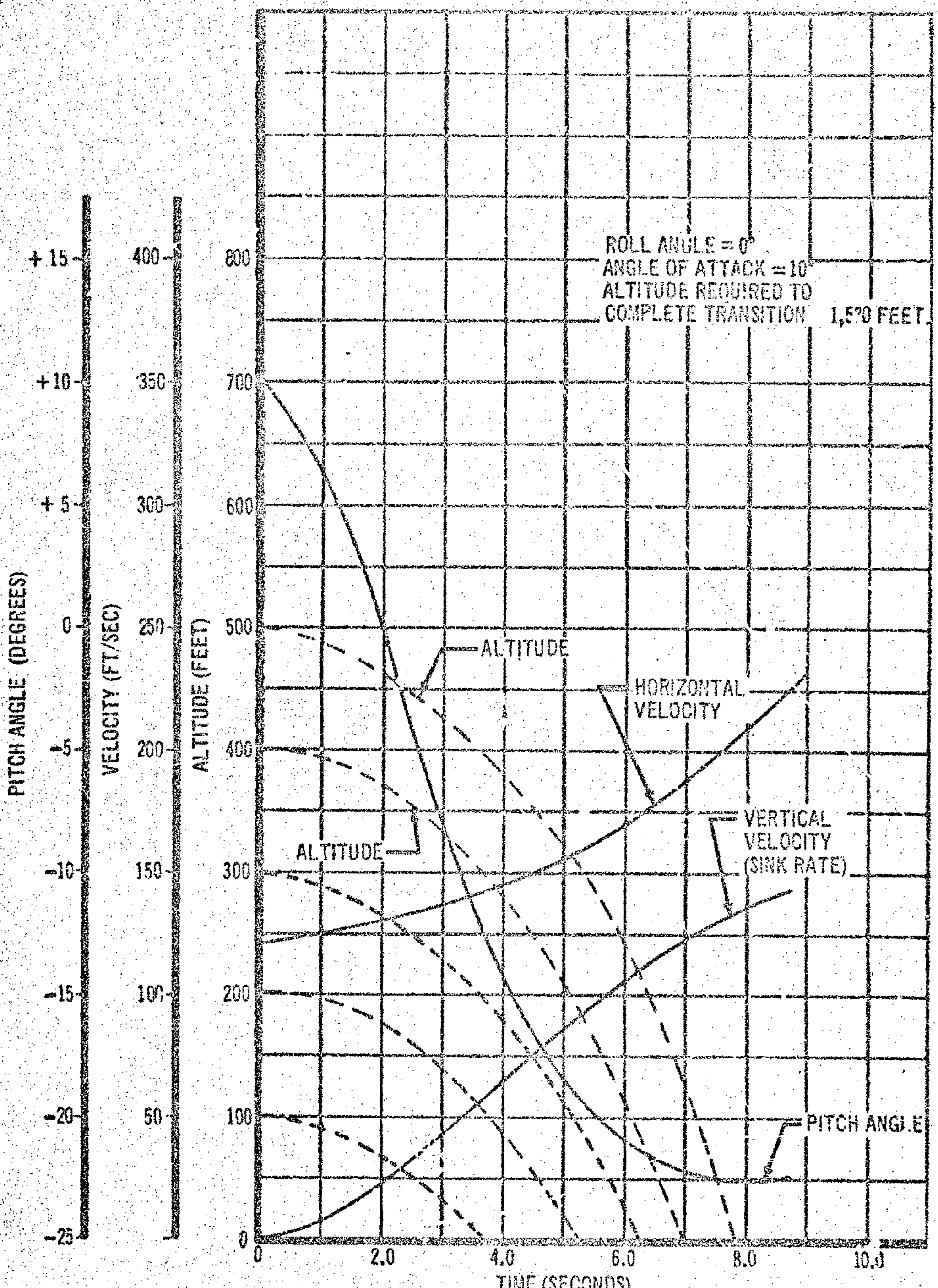


Figure 123. Escape Conditions for VTOL Cruise Engine Failure During Transition at 120 Ft/Sec EAS

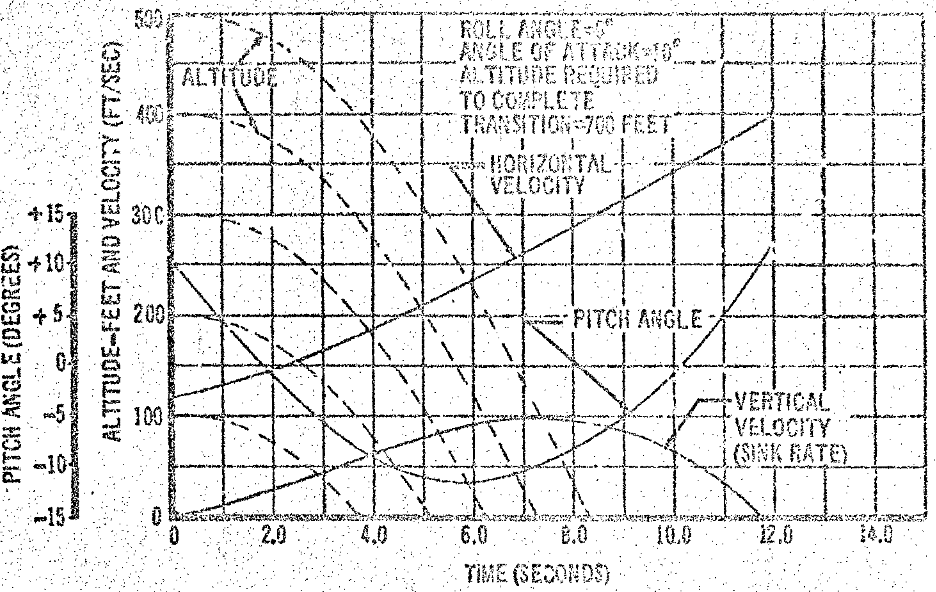


Figure 124. Escape Conditions for VTOL Lift Engine Failure During Transition at 120 Ft/Sec EAS

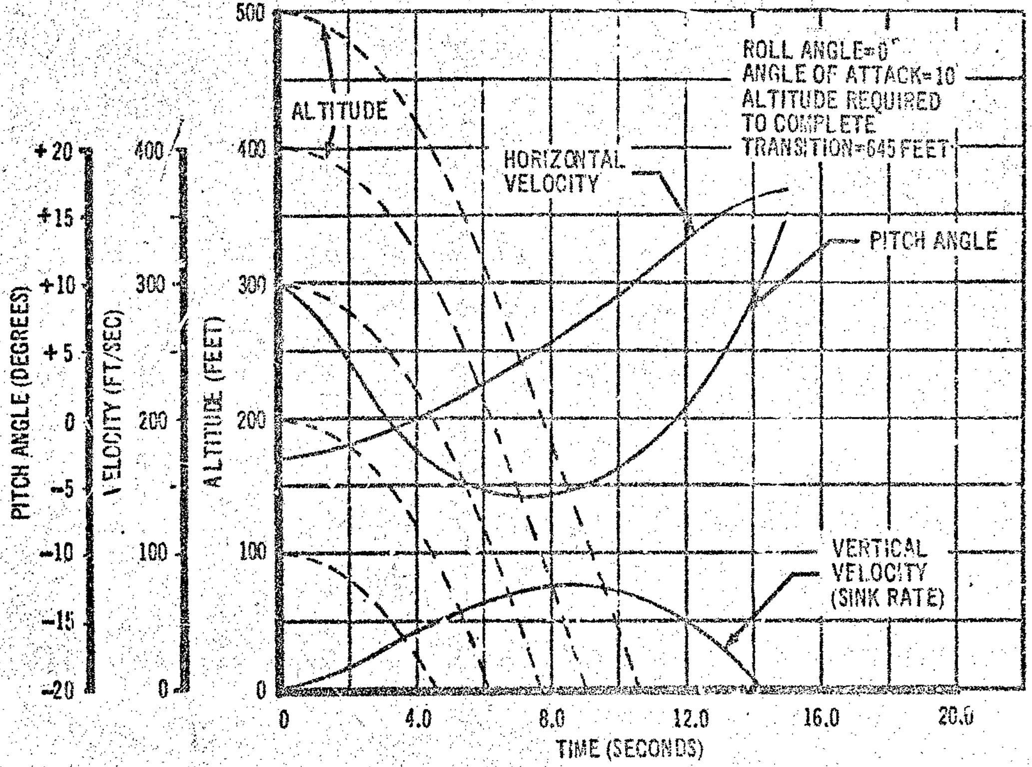


Figure 125. Escape Conditions for VTOL Cruise Engine Failure During Transition at 170 Ft/Sec EAS

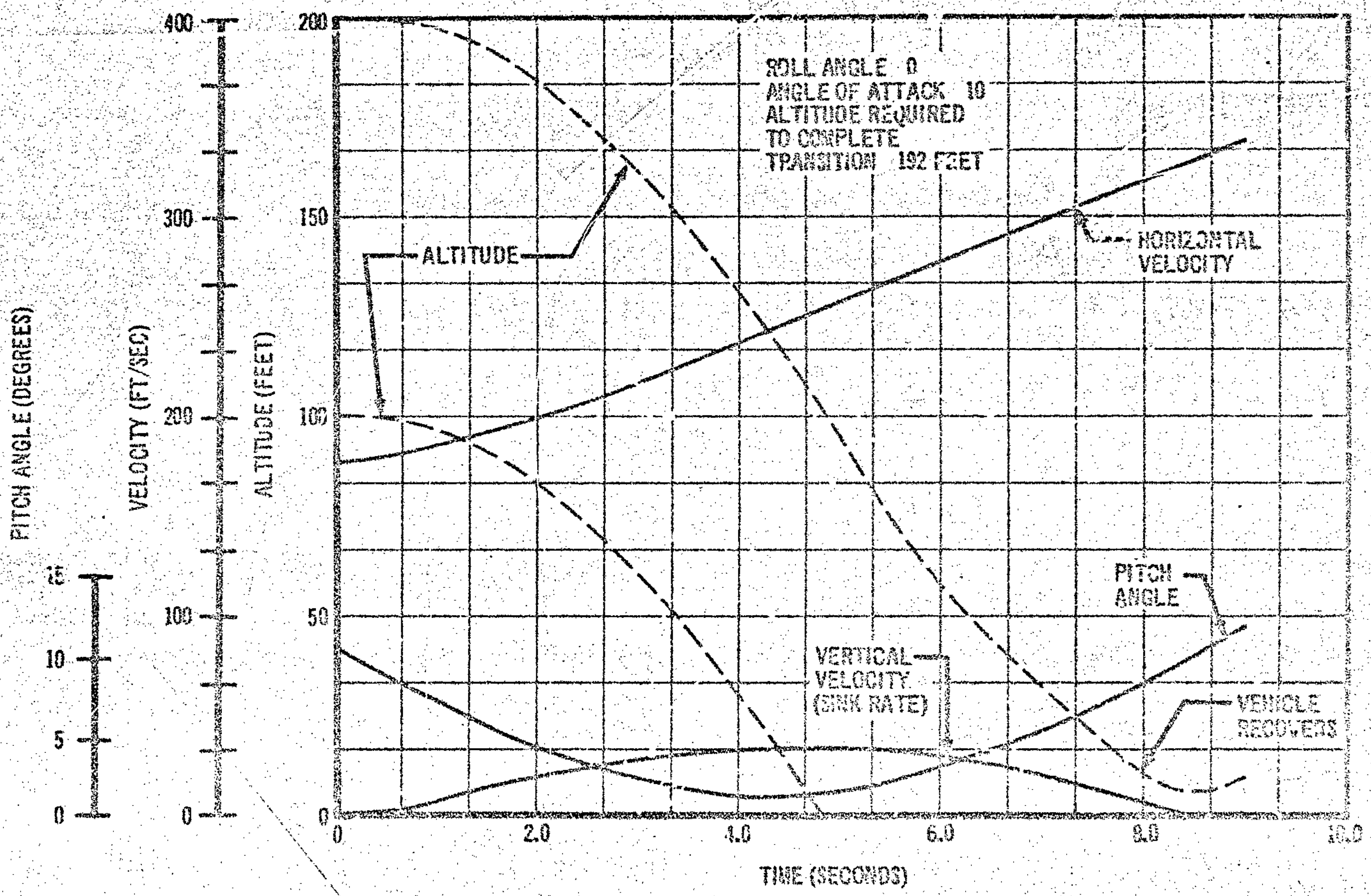


Figure 126. Escape Conditions for VTOL Lift Engine Failure During Transition at 170 Ft/Sec EAS

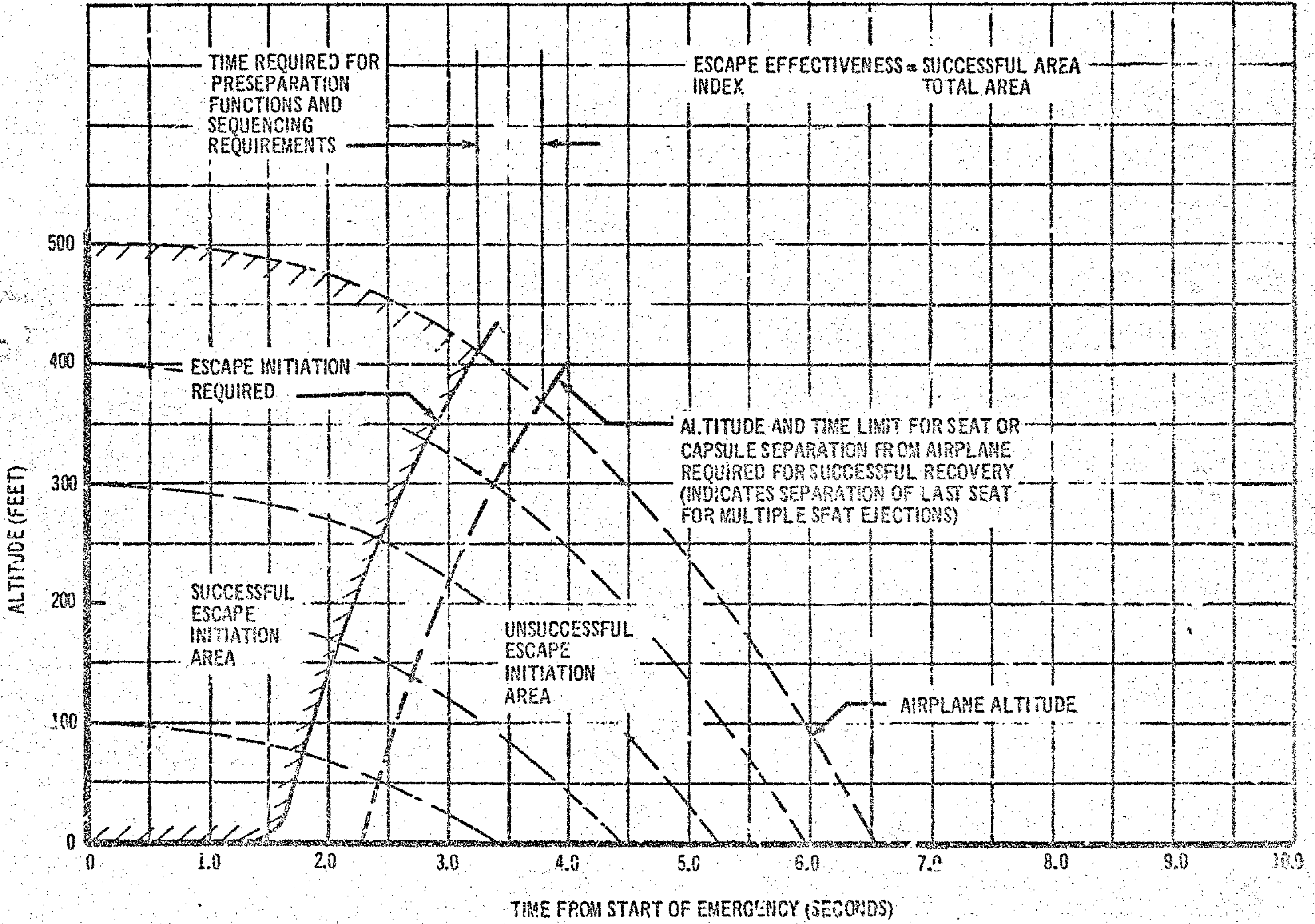


Figure 127. Illustration – Method of Determining Escape Effectiveness Index

Escape concept effectiveness indexes were determined for each escape concept for two-man and three-man VTOL vehicles. The escape effectiveness determinations were made for cruise and lift engine failure situations occurring at check points throughout the VTOL transition envelope as shown on Figure 117.

Figures 128 through 158 show the curves for escape concept effectiveness index determinations for the two-man vehicle. Figures 128, 129 and 130 show the effectiveness of the escape concepts for the special maximum stability (controlled flat attitude) case for any single engine failure situation as defined in Figure 112. Figures 131 through 138 show the effectiveness of the escape concepts for the boundary escape conditions for cruise and lift engine failures during hover flight defined on Figure 120. Figures 139 through 144 show the escape concept effectiveness for cruise and lift engine failure situations during transition at 85 ft/sec EAS as defined in Figures 121 and 122. Figures 145 through 150 show the escape concept effectiveness for cruise and lift engine failure situations at 120 ft/sec transition velocity as defined in Figures 123 and 124. Figures 151 through 156 show the escape concept effectiveness for the engine failure situations at 170 ft/sec as defined on Figures 125 and 126.

The escape concept effectiveness index versus transition velocity is shown for each escape concept for two-man subsonic VTOL vehicle cruise engine failures in Figure 157, and for lift engine failures in Figure 158. These graphs also show the mean effectiveness index for the entire VTOL transition envelope for each concept.

Figures 159 through 189 present the escape concept effectiveness data for VTOL hover and transition engine failure situations for the three-man combined capability vehicle.

Table VIII summarizes the escape concept effectiveness data for both vehicles.

c. Automatic Detection and Initiation Evaluation

During VTOL hover and transition flight, the time required for the pilot to detect and verify an emergency situation, make the decision to initiate escape, and actuate the escape control is a critical function of the escape process. To evaluate the need for, or benefits of, an automatic or semiautomatic emergency detection and escape initiation system, an analysis was made to determine the probability of escape initiation in time for successful escape during hover and transition flight emergencies for manual and for semiautomatic initiation.

To provide a basis for the analysis, normal distribution curves for escape initiation, relative to time from the start of an emergency situation, were constructed. Figures 190 and 191 show the estimated normal distribution curves for manual and semiautomatic detection and initiation.

Human engineering data relative to the time required for detection, decision, and reaction that are directly applicable to the escape problem are not available. However, data from References 1, 2, and 3 were compiled and used as a basis for developing the normal distribution curves. These curves are believed to provide a reasonable estimate of escape response times, with the possibility of being to some degree "optimistic" since they do not account for personal equipment (i.e., pressure suits, gloves, restraint systems, etc.)

For the manual detection and initiation case, the pilot would have normal instruments to monitor airplane subsystem and system status, plus caution and master warning lights. After an initial indication of trouble, the pilot would be required to make an emergency scan of subsystem displays and airplane flight conditions, make multiple assessments, and the decision to eject. Table IX lists mean times, ranges, and standard deviations for the various response and reaction elements, along with the combined times that were used in defining the normal distribution curve.

The semiautomatic system, status assessment, logic, decision, and "eject" display to the pilot is computerized and fully automatic. The pilot is trained and conditioned to have full confidence in the system and approaches near-conditioned reflex escape initiation performance. The pilot manually initiates ejection only. Table X lists the time data and basis for the normal distribution curve of Figure 191.

The two-man subsonic VTOL vehicle open ejection seats and cockpit pod capsule escape concepts were selected as a basis of the automatic detection and initiation evaluation. The escape conditions were considered to be those defined in Figures 120 through 126 for cruise and lift engine failure situations occurring at different points in the transition envelope from hover to 240 ft/sec EAS wingborne flight, and from ground level to 500 feet.

Figure 192 illustrates the method used for determining the probability of escape initiation in time for successful recovery relative to the vehicle altitude at the start of the emergency situation. This particular example is for the two-man vehicle cockpit pod capsule for escape following a cruise engine failure during transition at 85 ft/sec EAS, and corresponds to the conditions shown in Figure 141. The airplane altitude lines (Figure 192) indicate the loss of altitude with time from the start of emergency situations originating at altitudes from ground level to 500 feet (in 100-foot increments). The intersections of the airplane altitude lines with the escape initiation line indicates the time allowable for initiation of successful escape for each originating altitude situation. The probability that escape will be initiated in time to be successful is determined by taking the ratio of the area under the escape initiation normal distribution curve to the left of the safe escape time (Hashed Lines) to the total area under the curve.

Utilizing a digital computer program involving numerical integration procedures, the probability of successful escape initiation versus altitude at start of the emergency was determined for each escape concept and emergency situation for manual and semiautomatic initiation. These data were determined for engine failure situations occurring at transitional velocities of zero (hover), 85, 120, 170, and 240 ft/sec, and are shown plotted for the two-man vehicle open ejection seats for cruise engine failures in Figure 193, and for lift engine failures in Figure 194. Figures 195 and 196 show the curves for the two-man vehicle cockpit pod capsule escape concept.

Figures 197 through 200 are plots of the probability of successful escape versus vehicle transition velocity for cruise and lift engine failures for the two-man vehicle open ejection seat and cockpit pod escape concepts. These curves were derived from the data in Figures 193 through 196 by determining the mean probability of initiating successful escape for all engine failure situations occurring between zero and 500 feet for each transition velocity condition considered. Also indicated on these Figures and summarized in Table XI is the overall mean probability of successful escape for cruise and lift engine failures occurring throughout the entire VTOL hover and transition velocity-altitude envelope.

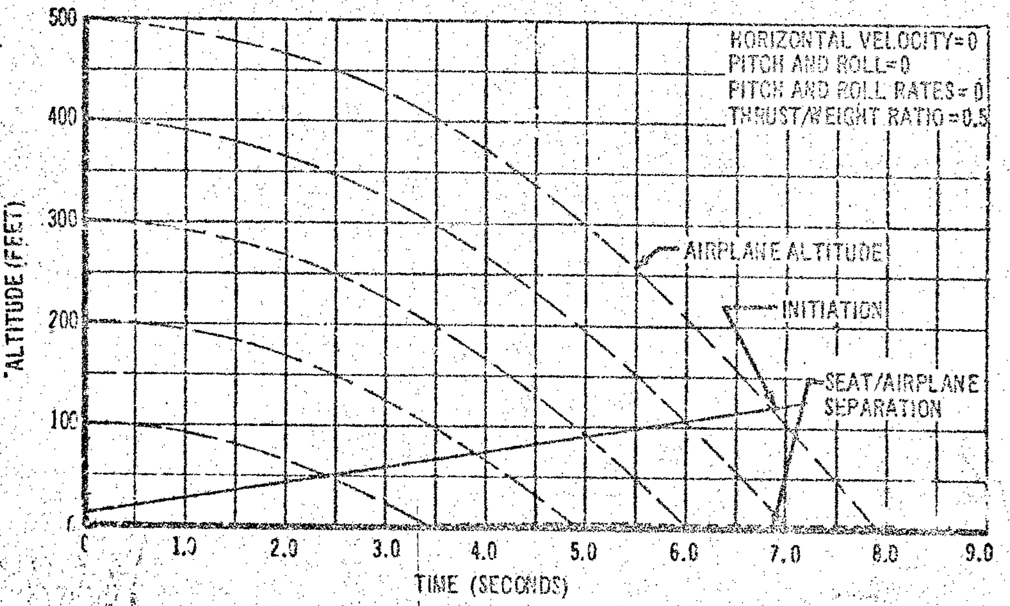


Figure 128. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Engine Failure – Maximum Stability Case

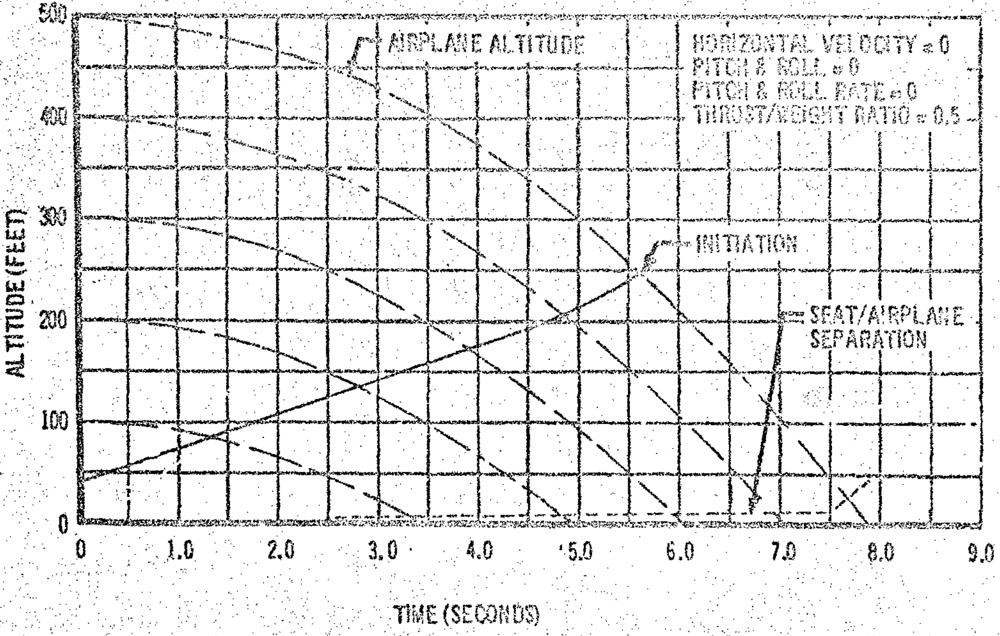


Figure 129. Two-Man Encapsulated Ejection Seats Minimum Escape Altitudes VTOL Hover Flight Engine Failure – Maximum Stability Case

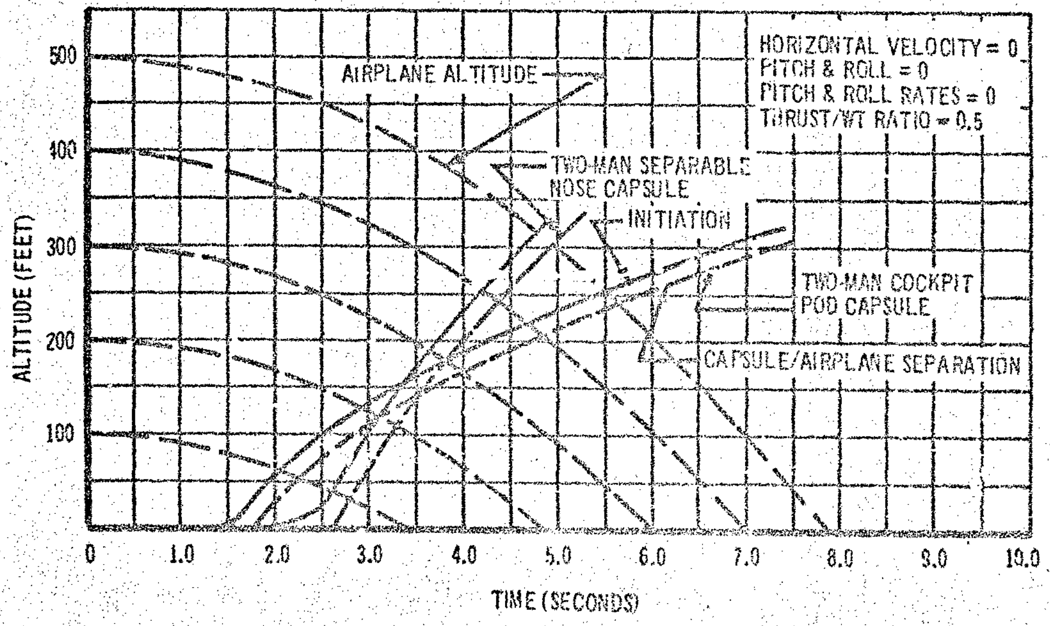


Figure 130. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitude VTOL Hover Flight Engine Failure – Maximum Stability Case

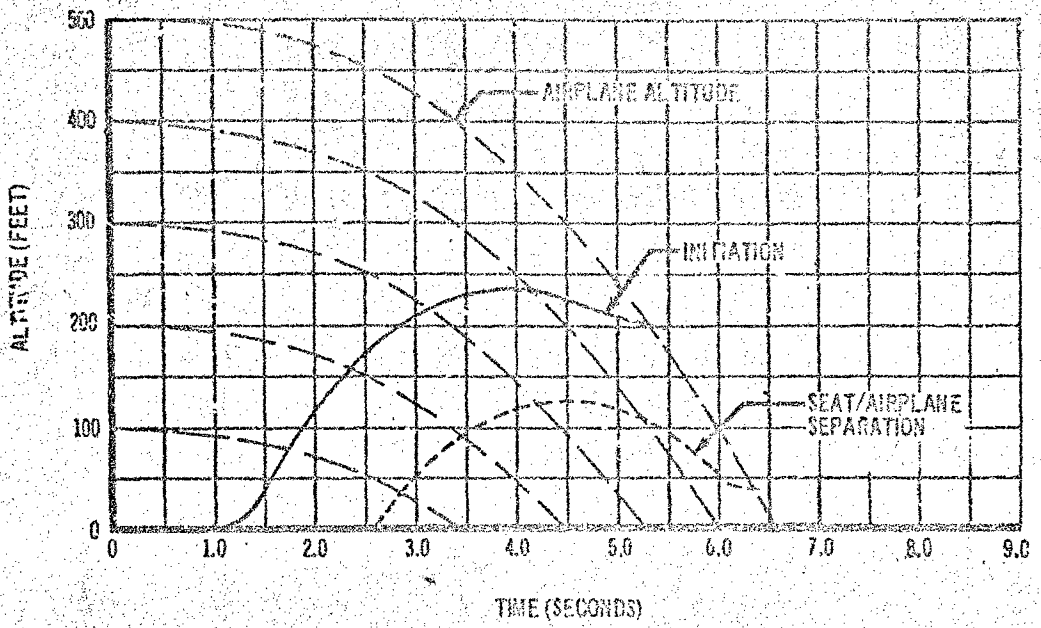


Figure 131. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

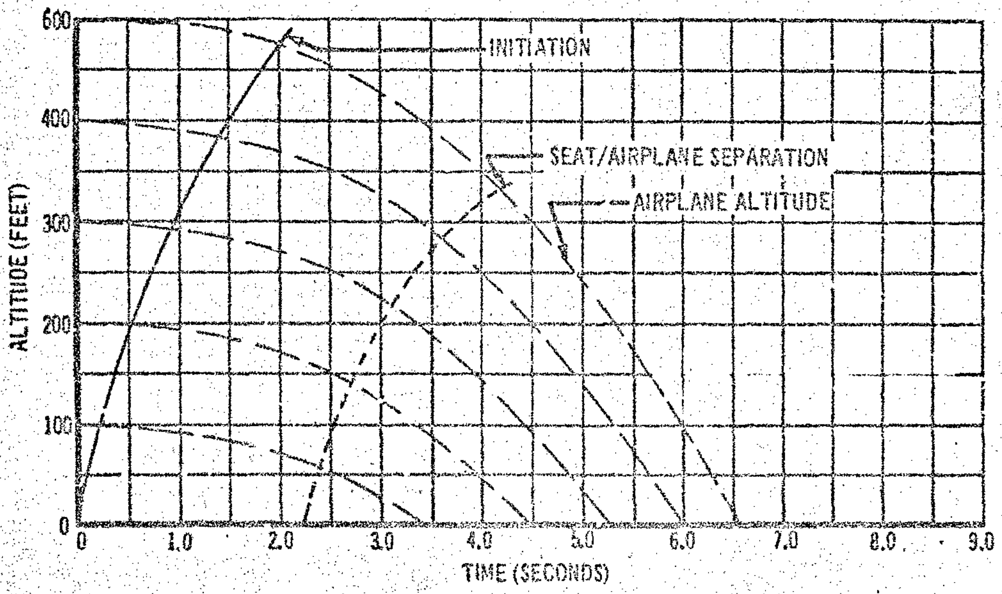


Figure 132. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

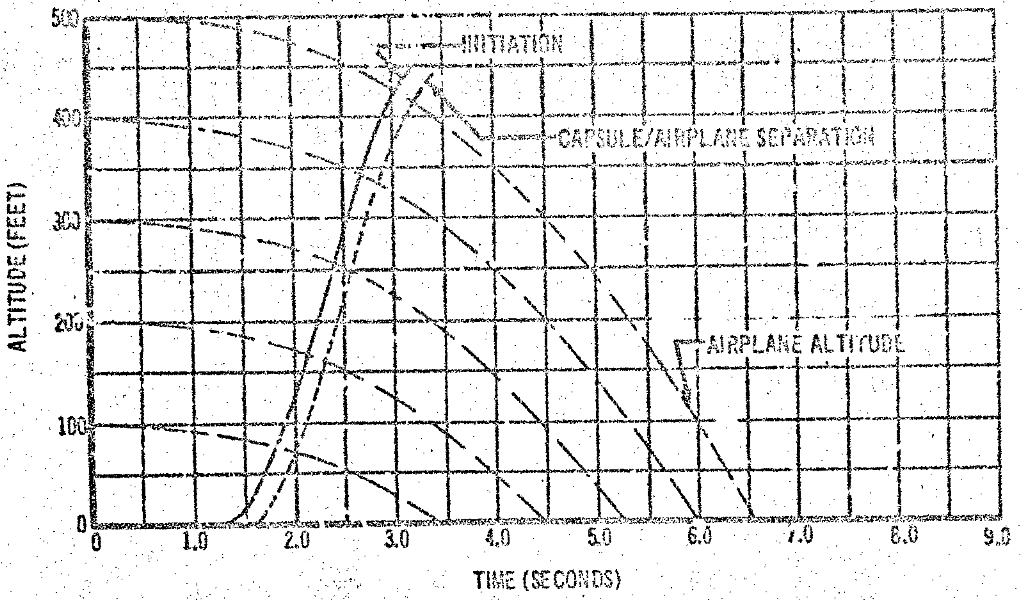


Figure 133. Two-Man Vehicle Cockpit Pod Capsule Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

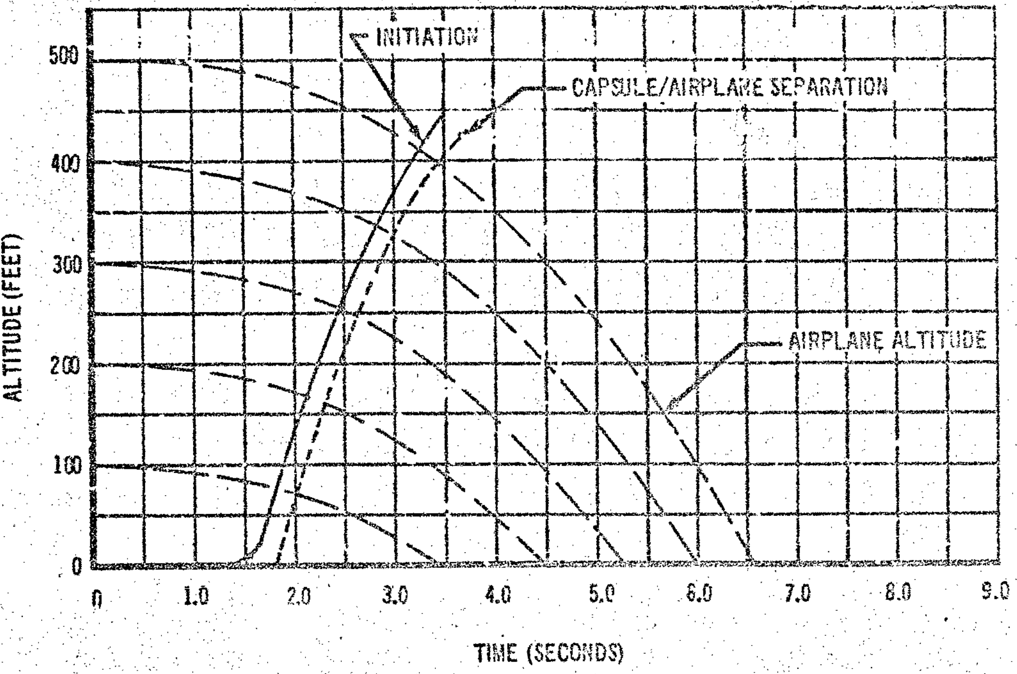


Figure 134. Two-Man Vehicle Separable Nose Capsule Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

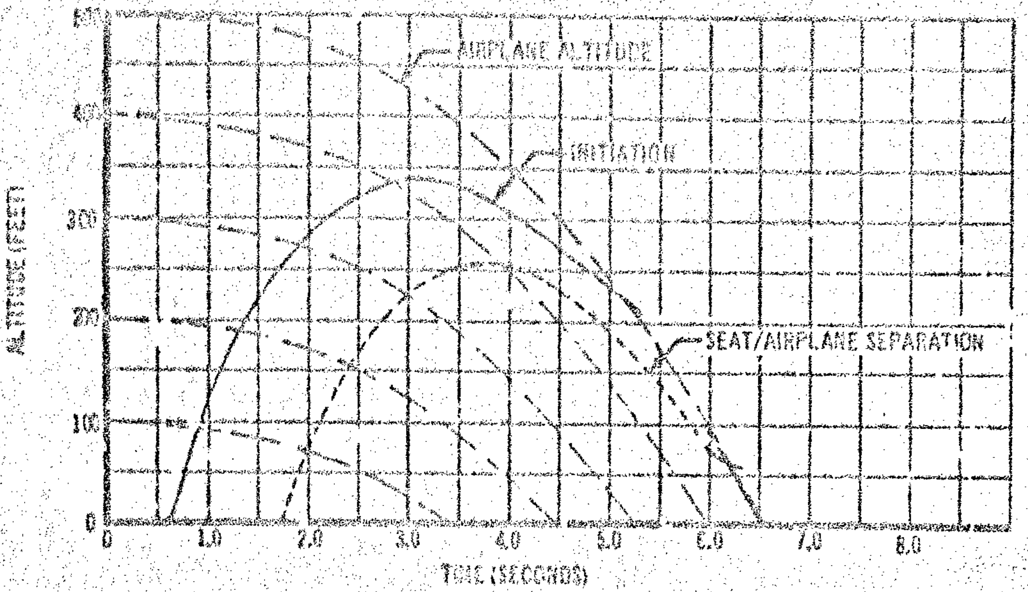


Figure 135. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

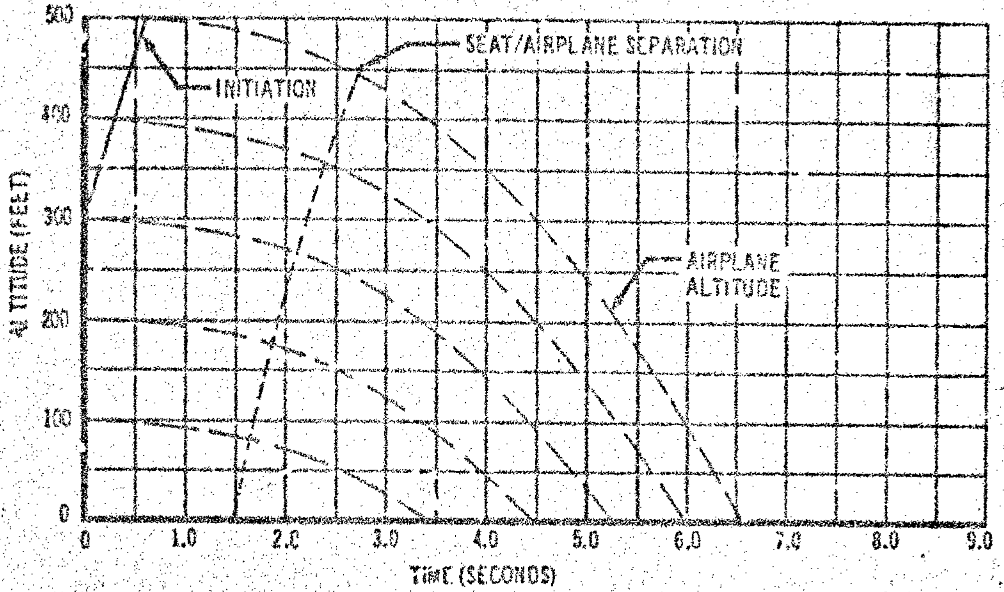


Figure 136. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude, VTOL Hover Flight Lift Engine Failure

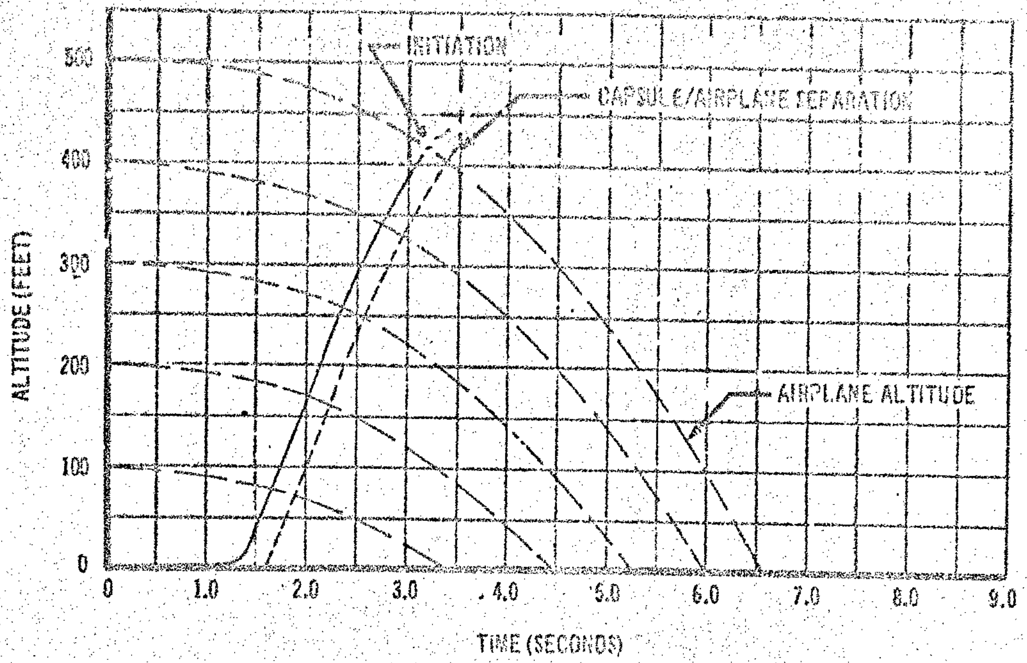


Figure 137. Two-Man Vehicle Cockpit Pod Capsule Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

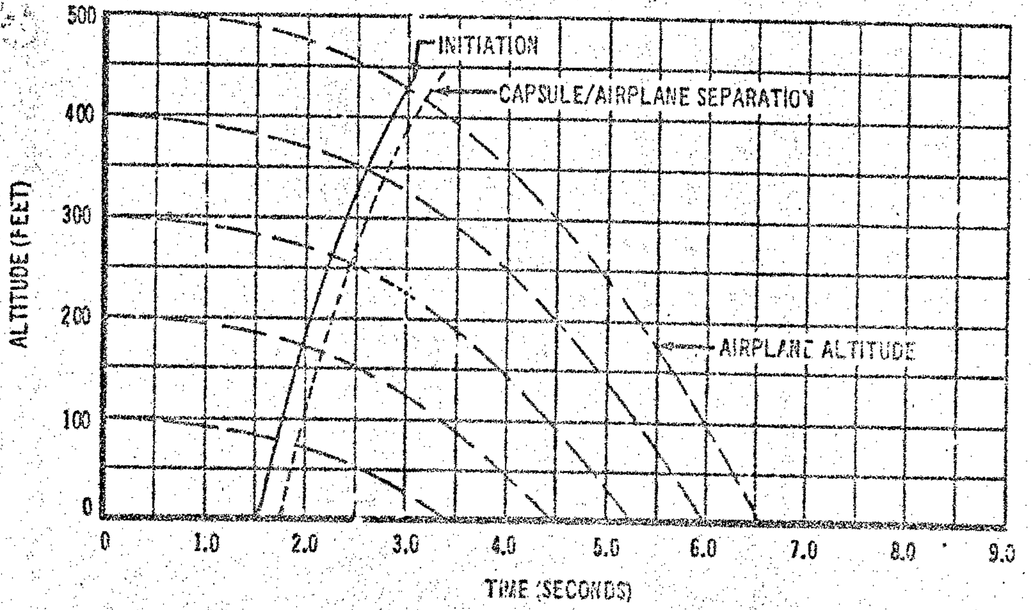


Figure 138. Two-Man Vehicle Separable Nose Capsule Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

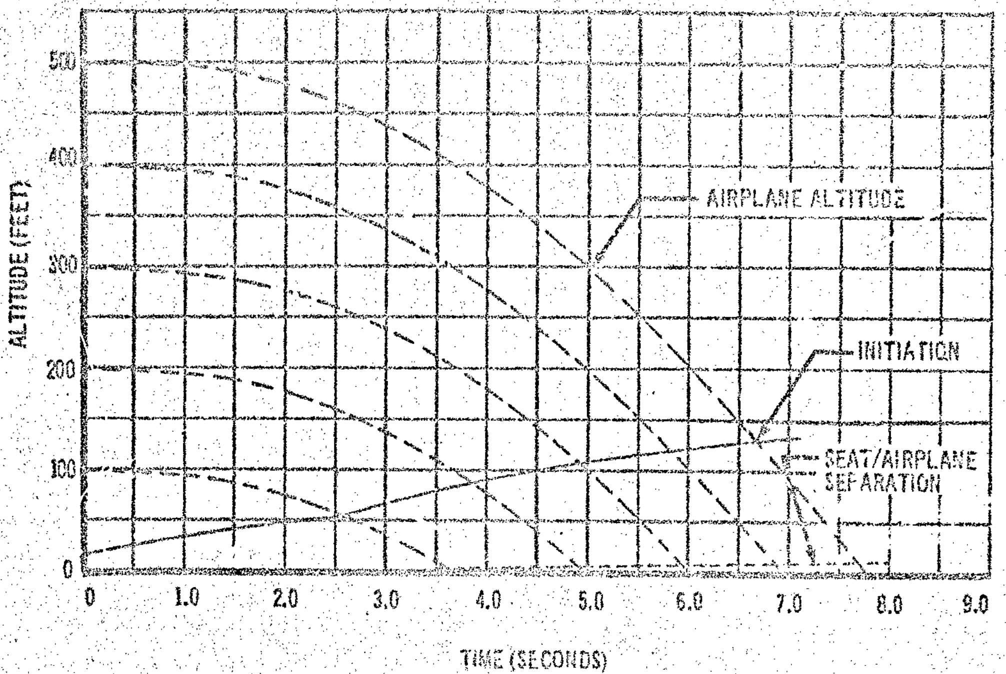


Figure 139. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitudes 85 Ft/Sec Transition Cruise Engine Failure

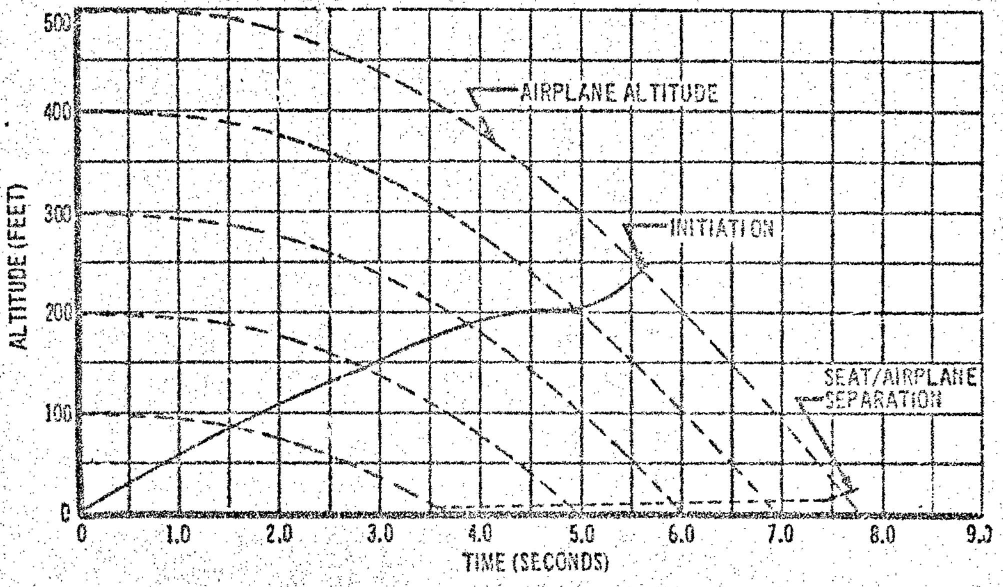


Figure 140. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 85 Ft/Sec Transition Cruise Engine Failure

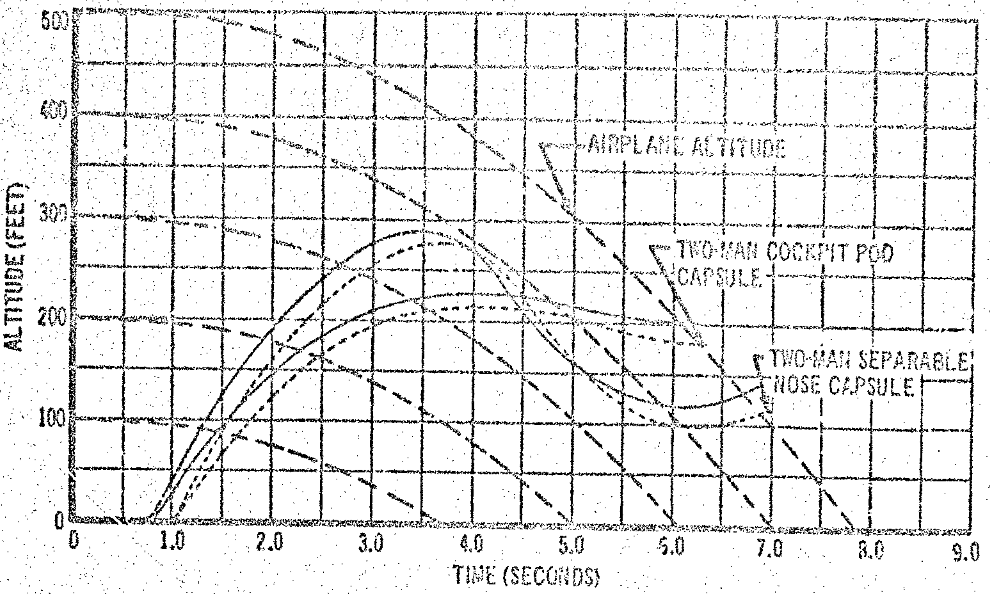


Figure 141. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 85 Ft./Sec Transition Cruise Engine Failure

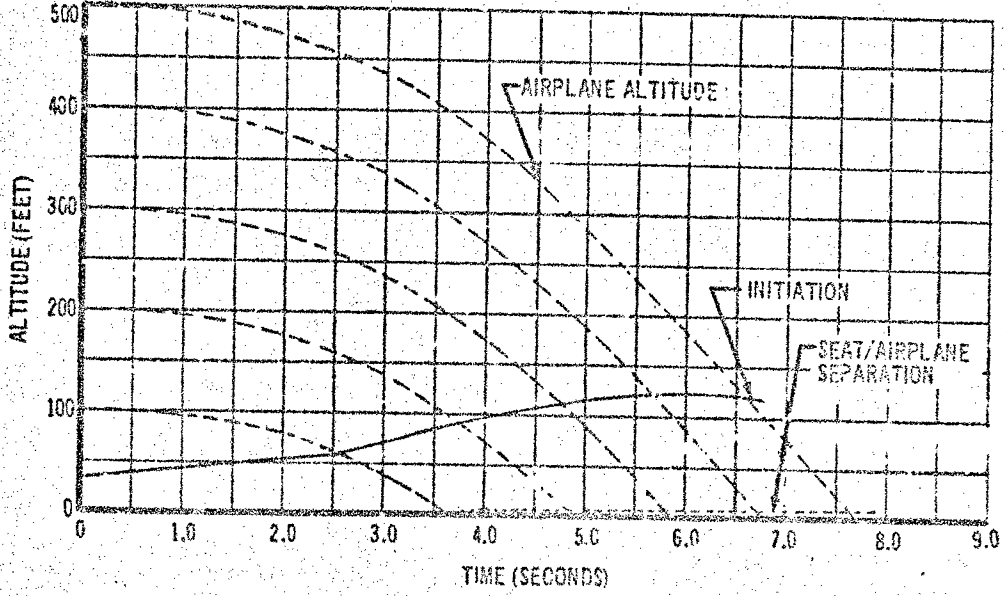


Figure 142. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitude 85 Ft/Sec Transition Lift Engine Failure

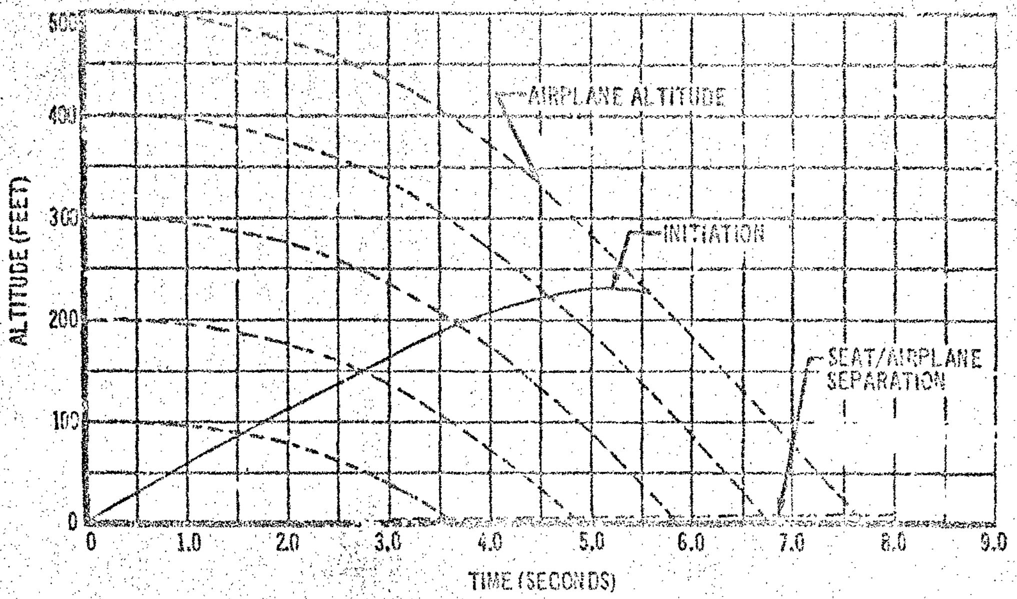


Figure 143. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude 85 Ft/Sec Transition Lift Engine Failure

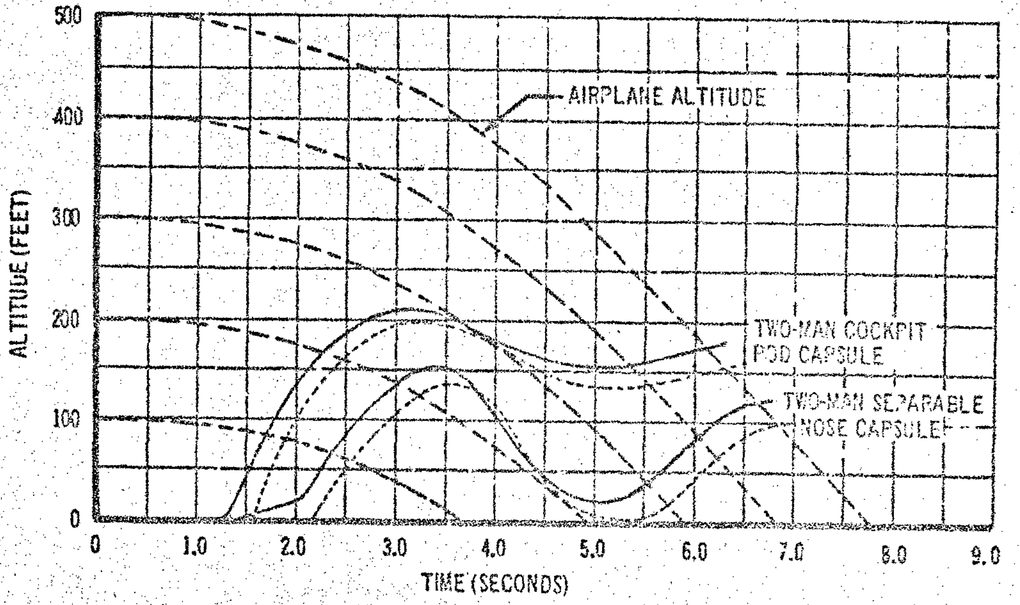


Figure 144. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitude 85 Ft/Sec Transition Lift Engine Failure

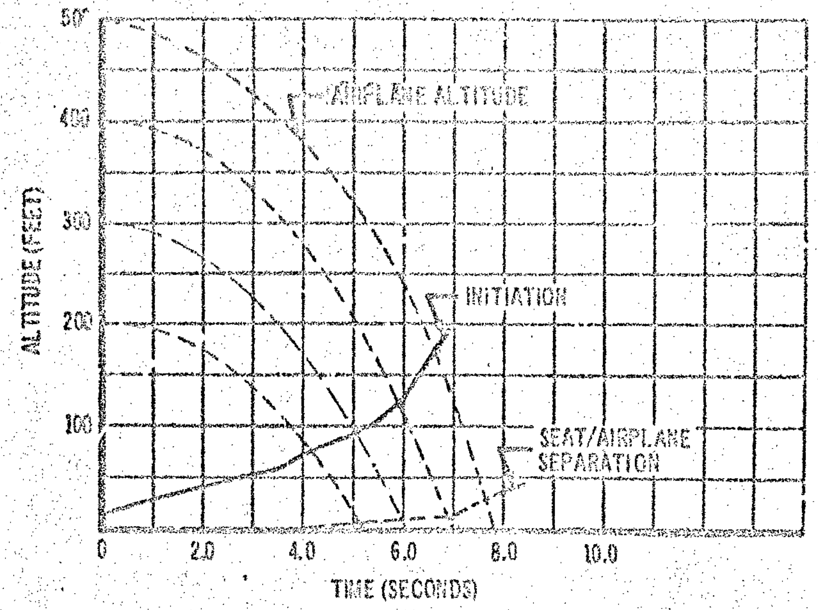


Figure 145. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitudes 120 Ft/Sec Transition Cruise Engine Failure

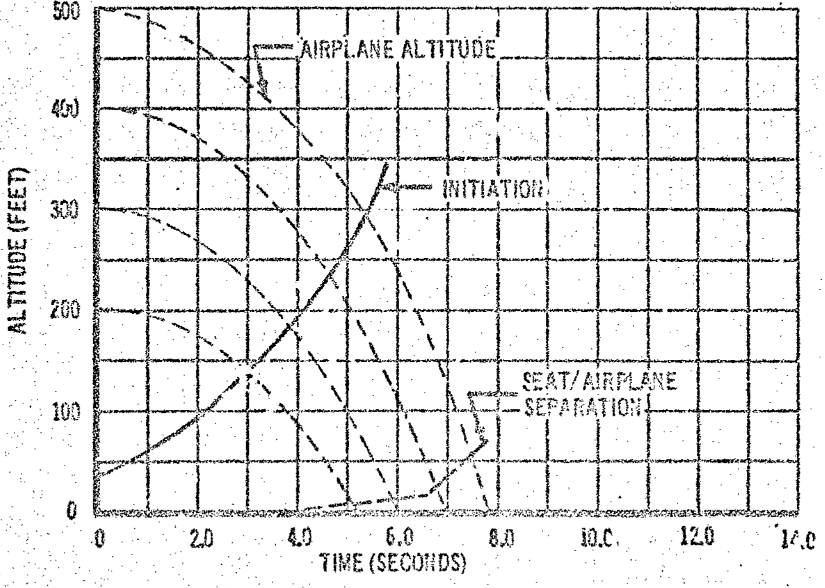


Figure 146. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 120 Ft/Sec Transition Cruise Engine Failure

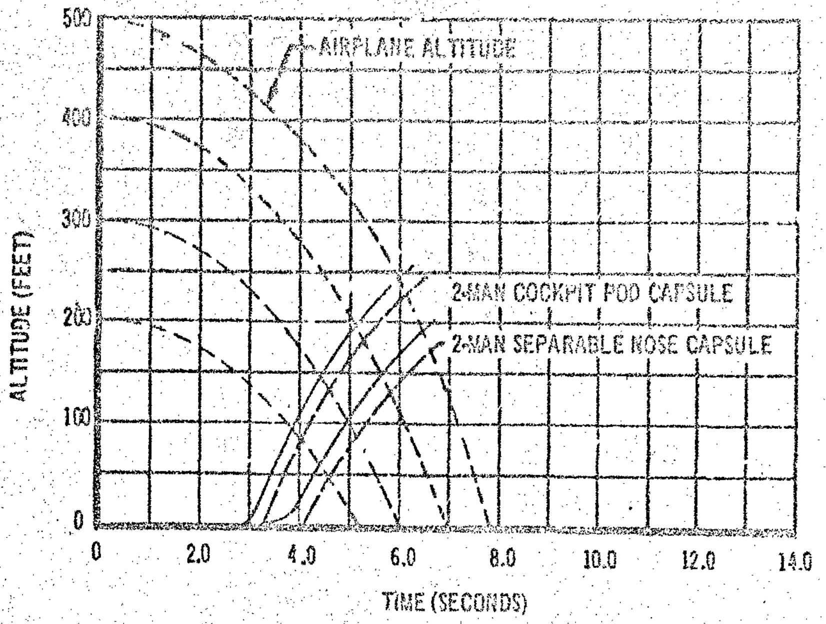


Figure 147. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 120 Ft/Sec Transition Cruise Engine Failure

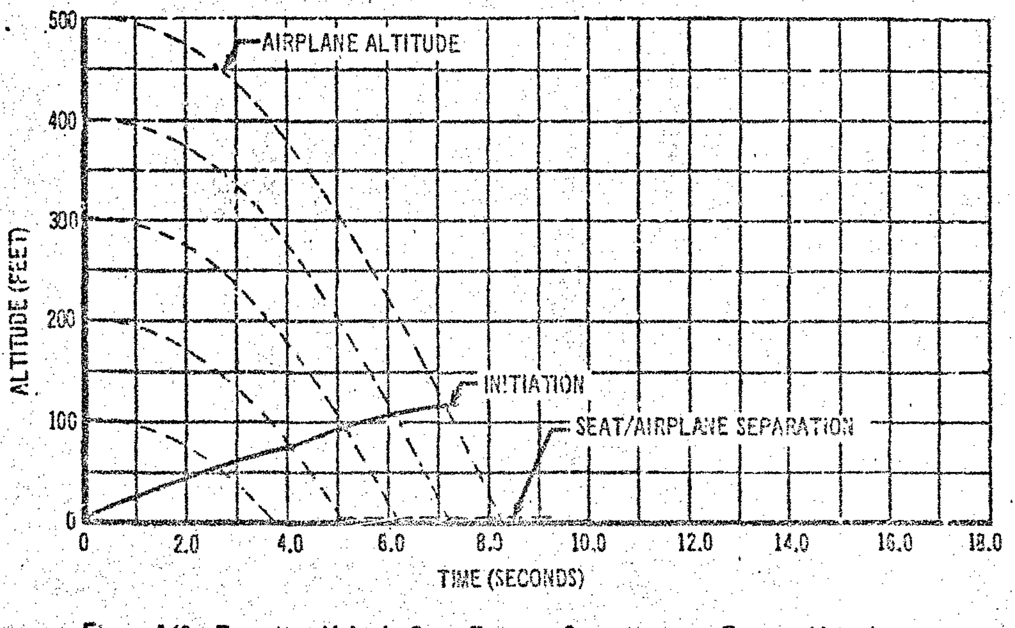


Figure 148. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitude 120 Ft/Sec Transition Lift Engine Failure

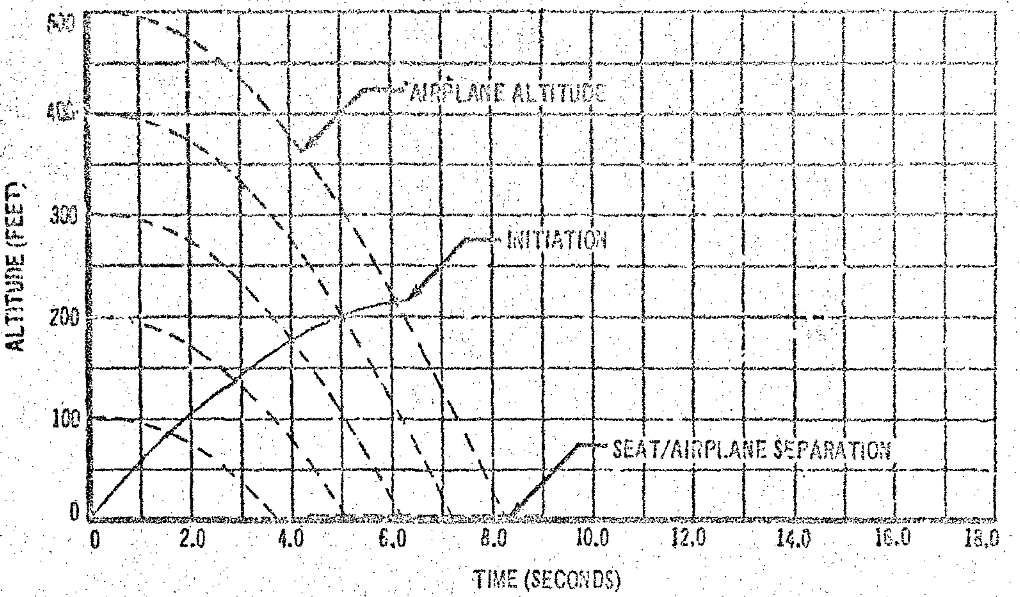


Figure 149. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude 120 Ft/Sec Transition Lift Engine Failure

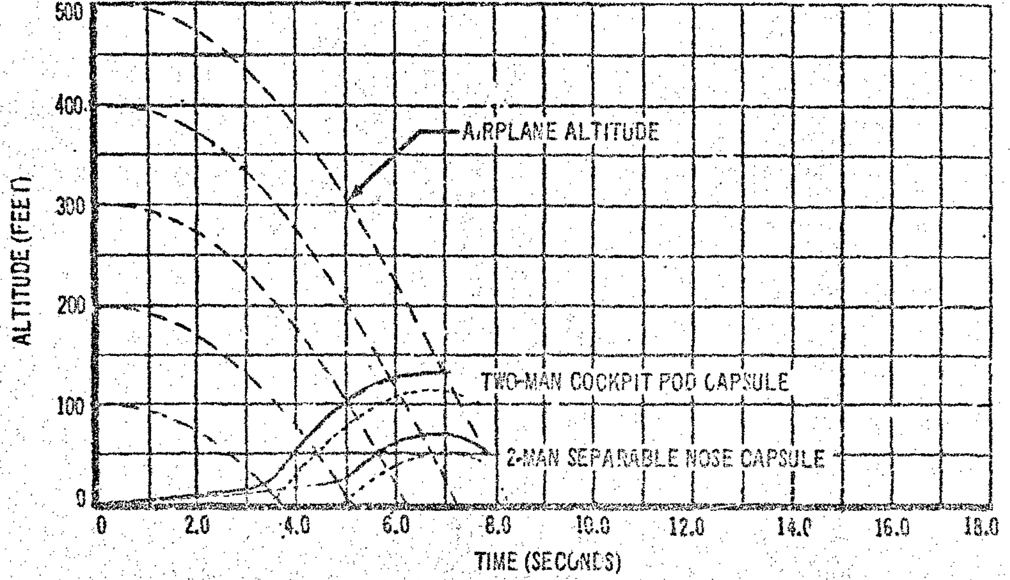


Figure 150. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitude 120 Ft/Sec Transition Lift Engine Failure

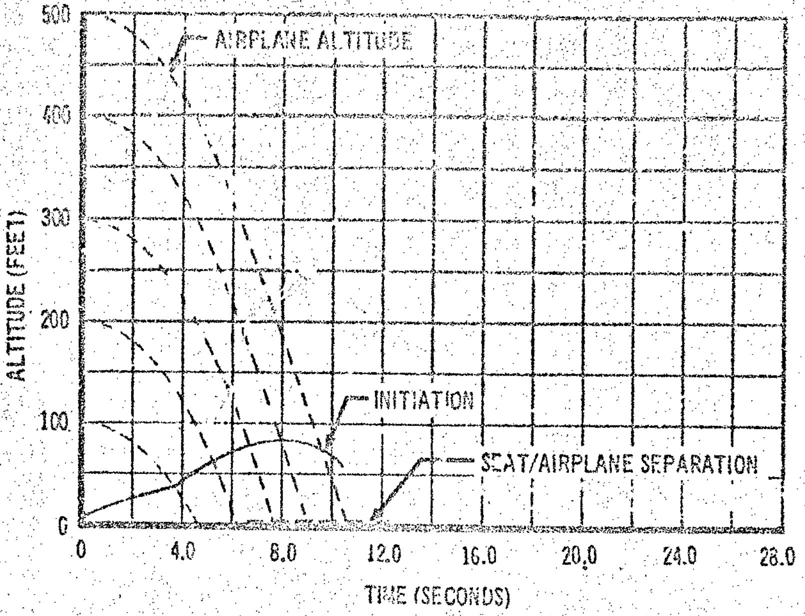


Figure 151. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitudes 170 Ft/Sec Transition Cruise Engine Failure

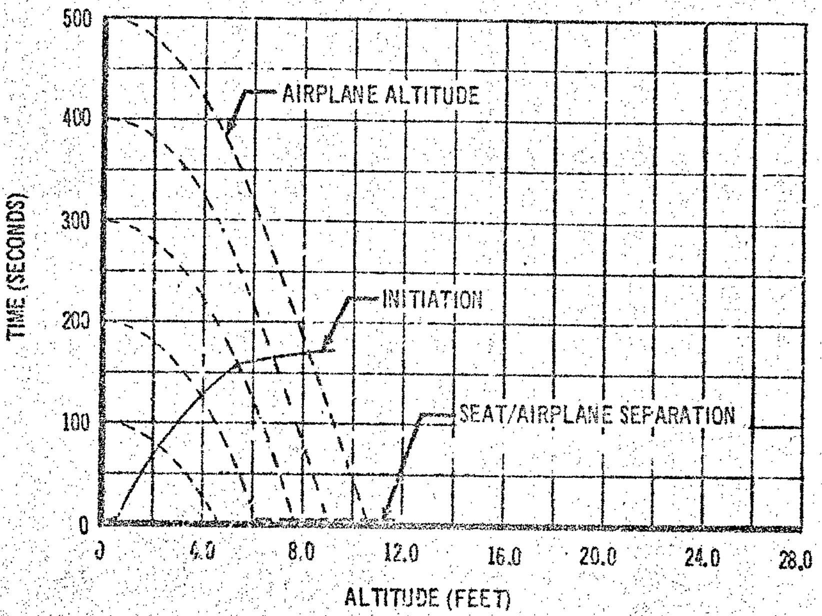


Figure 152. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 170 Ft/Sec Transition Cruise Engine Failure

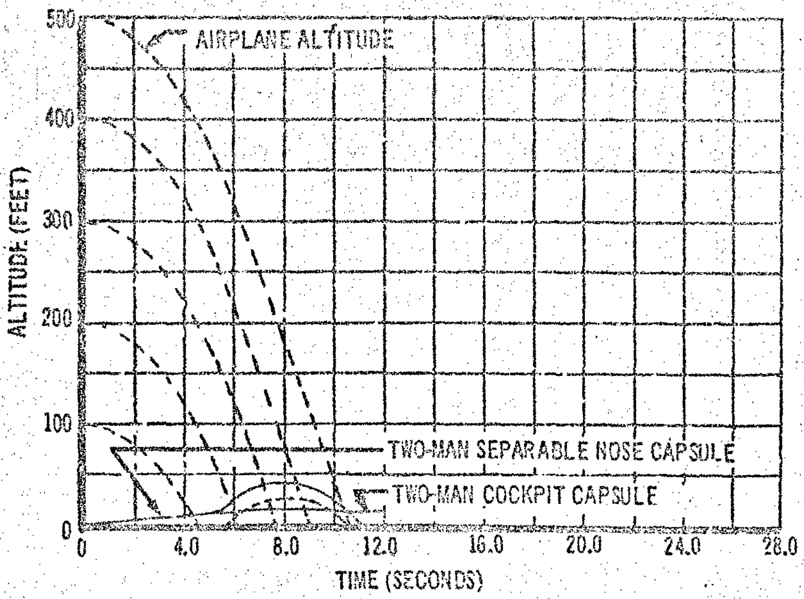


Figure 153. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 170 Ft/Sec Transition Cruise Engine Failure

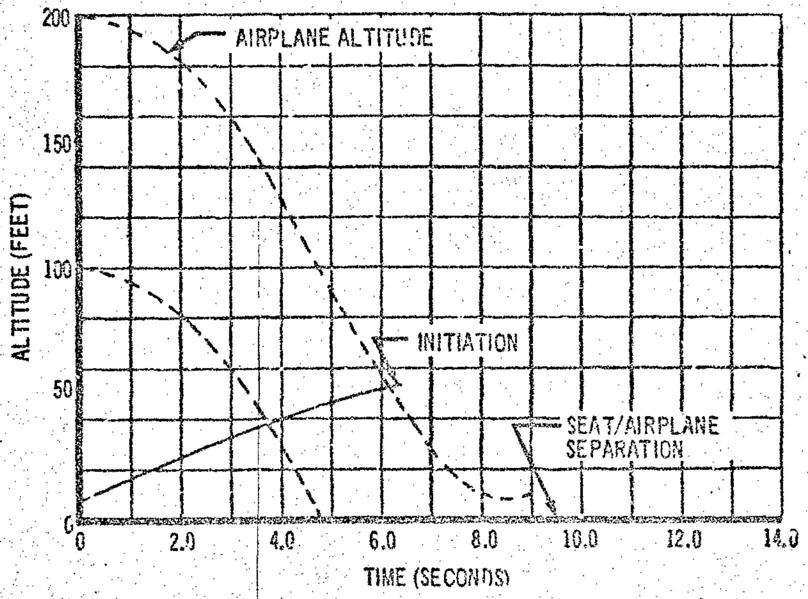


Figure 154. Two-Man Vehicle Open Ejection Seats Minimum Escape Altitude 170 Ft/Sec Transition Lift Engine Failure

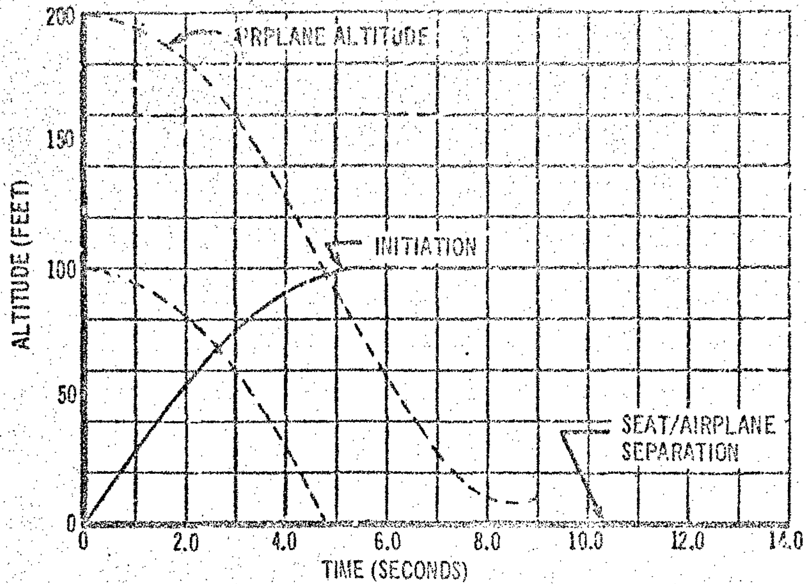


Figure 155. Two-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude 170 Ft/Sec Transition Lift Engine Failure

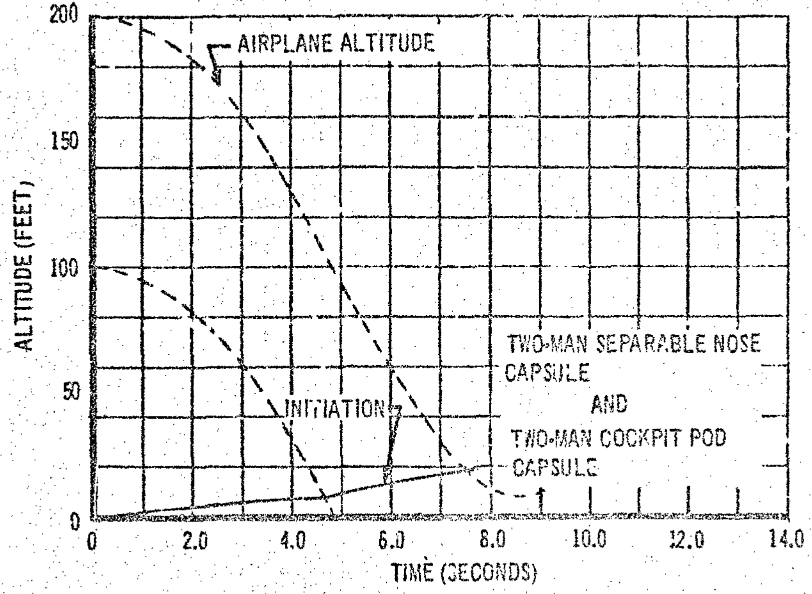


Figure 156. Two-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitude 170 Ft/Sec Transition Lift Engine Failure

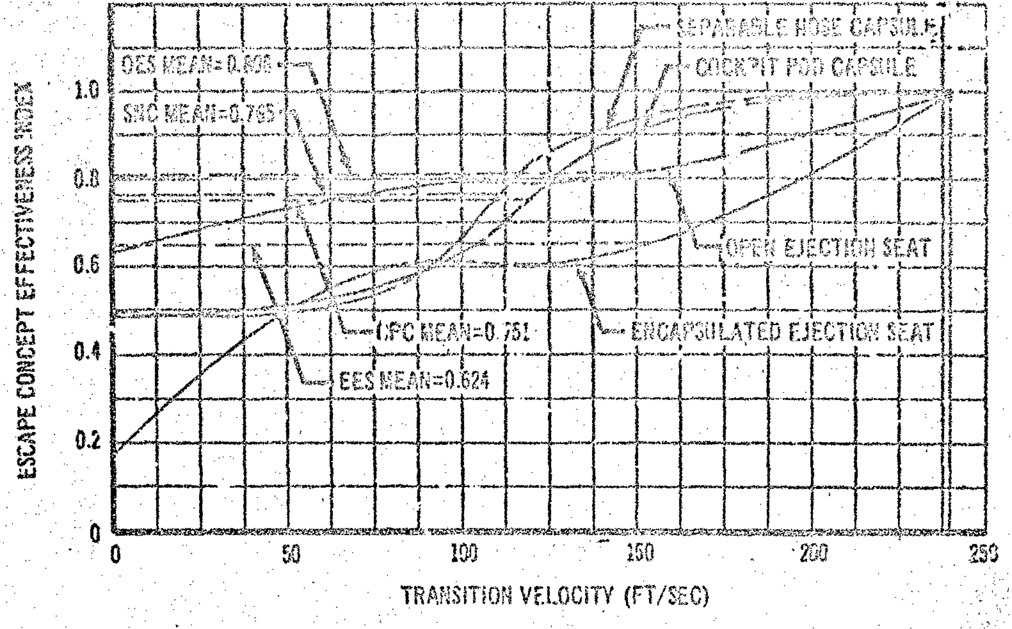


Figure 157. Two-Man Subsonic VTOL Vehicle Cruise Engine Failure During Transition Escape Concept Effectiveness Index

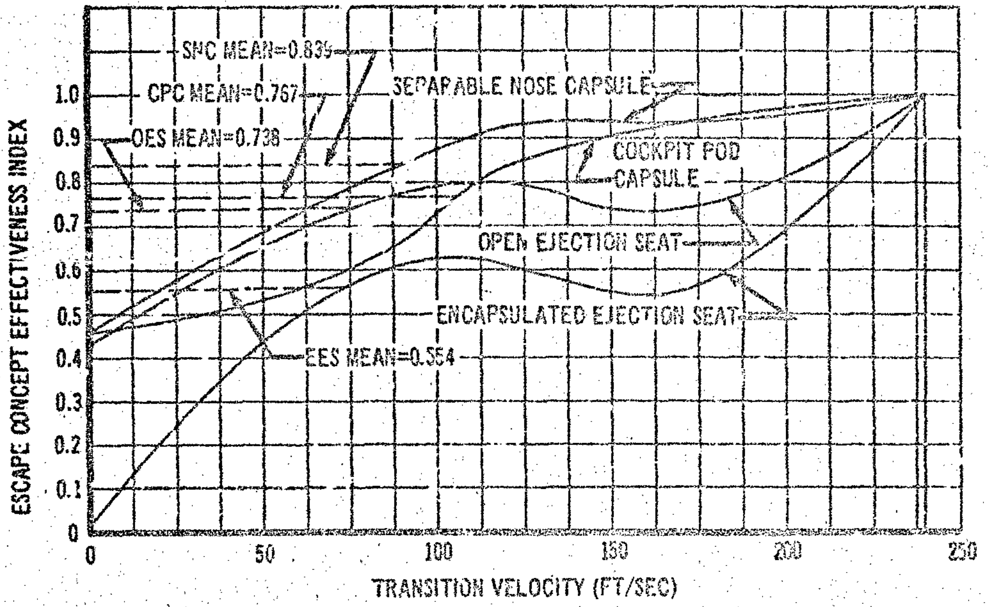


Figure 158. Two-Man Subsonic VTOL Vehicle Lift Engine Failure During Transition Escape Concept Effectiveness Index

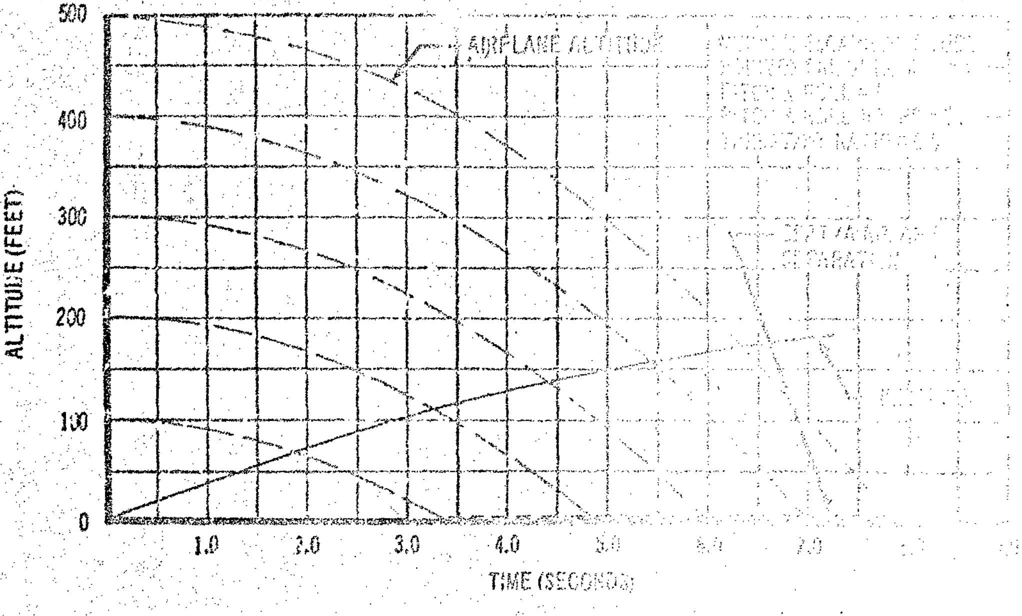


Figure 159. Three–Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Engine Failure – Maximum Stability Case

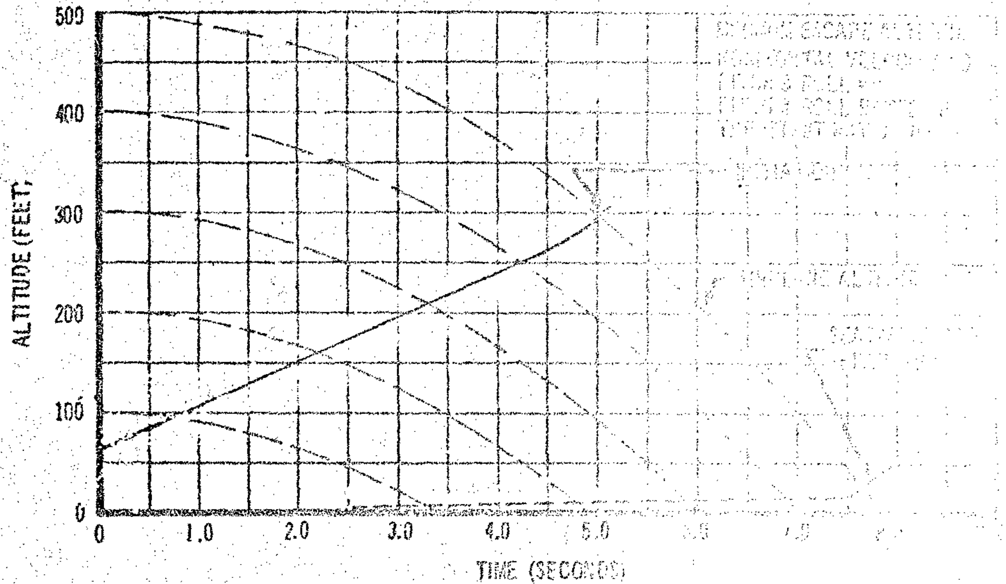


Figure 160. Three–Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude VTOL Hover Flight Engine Failure – Maximum Stability Case

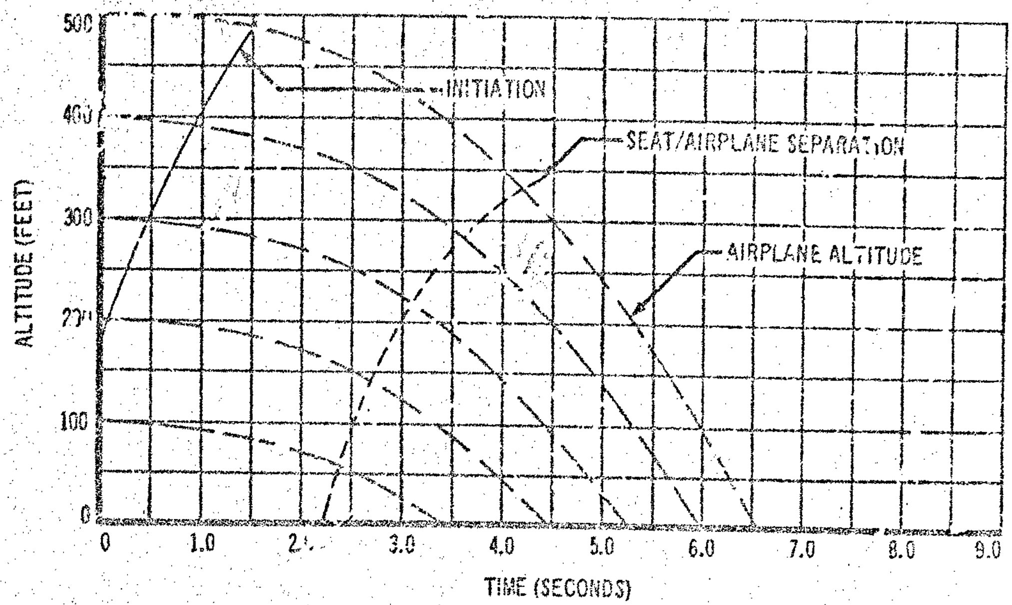


Figure 163. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

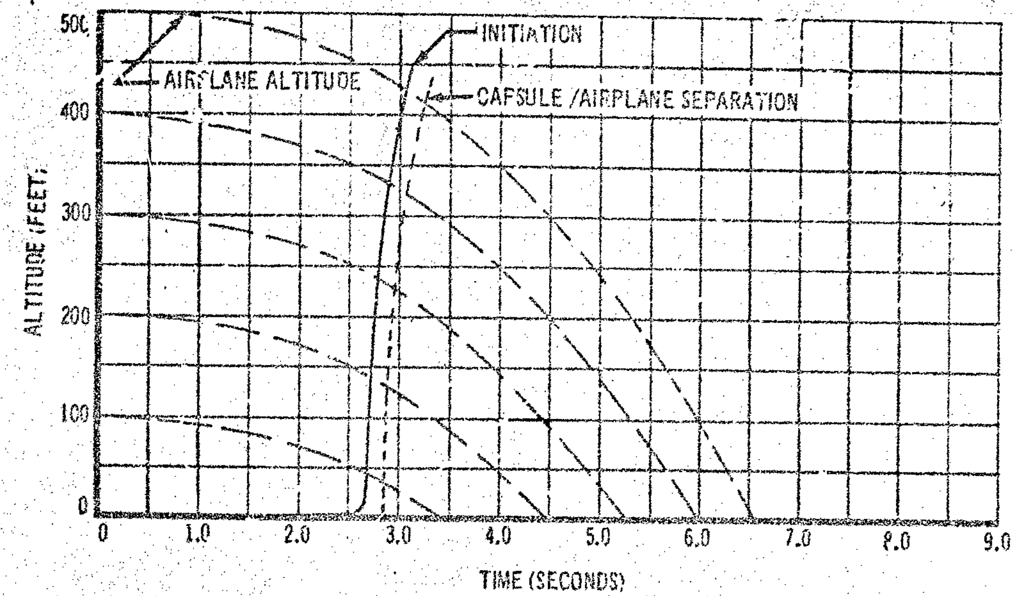


Figure 164. Three-Man Cockpit Pod Capsule Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

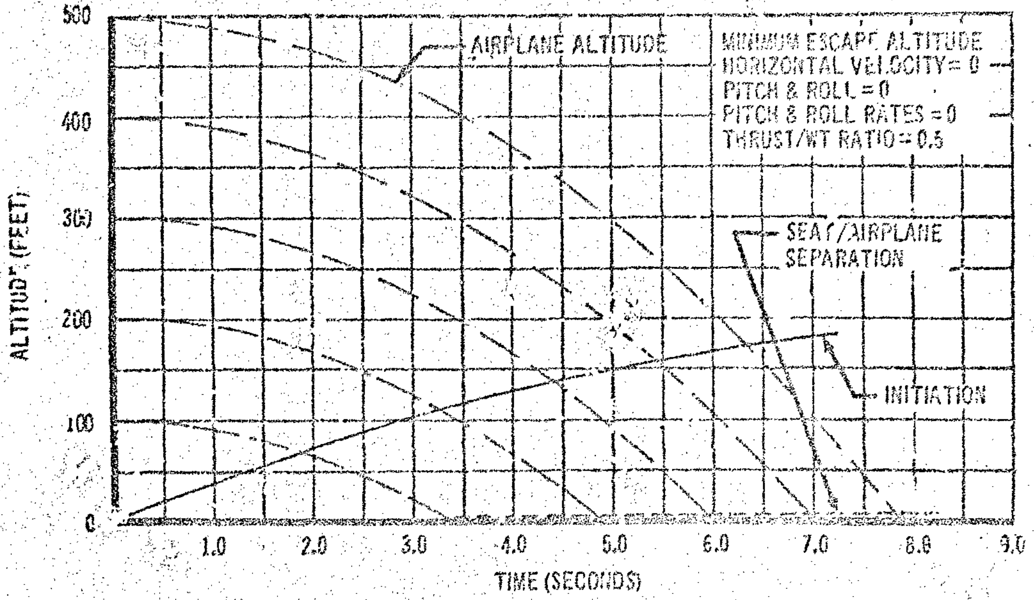


Figure 159. Three-Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Engine Failure – Maximum Stability Case

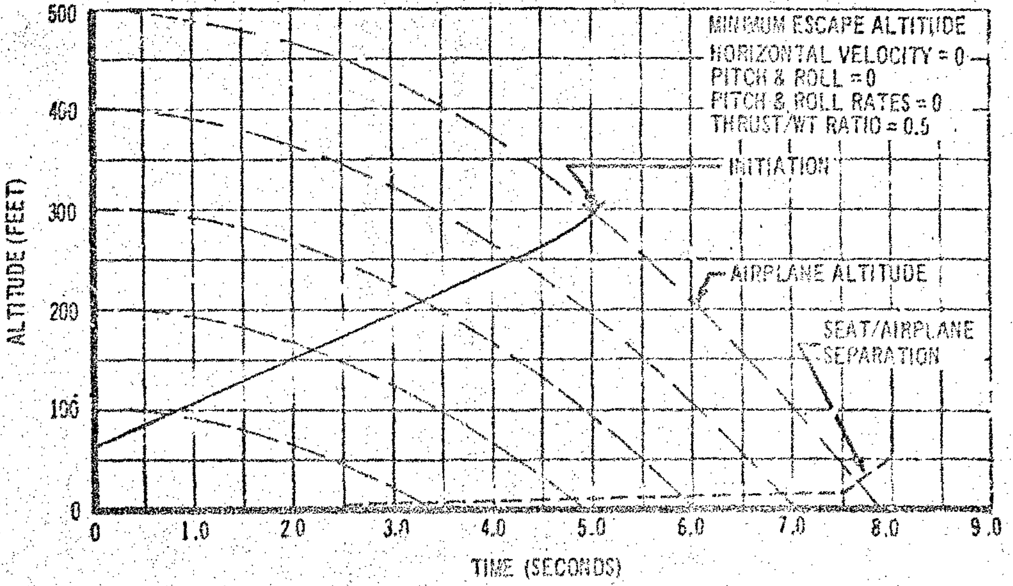


Figure 160. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude VTOL Hover Flight Engine Failure – Maximum Stability Case

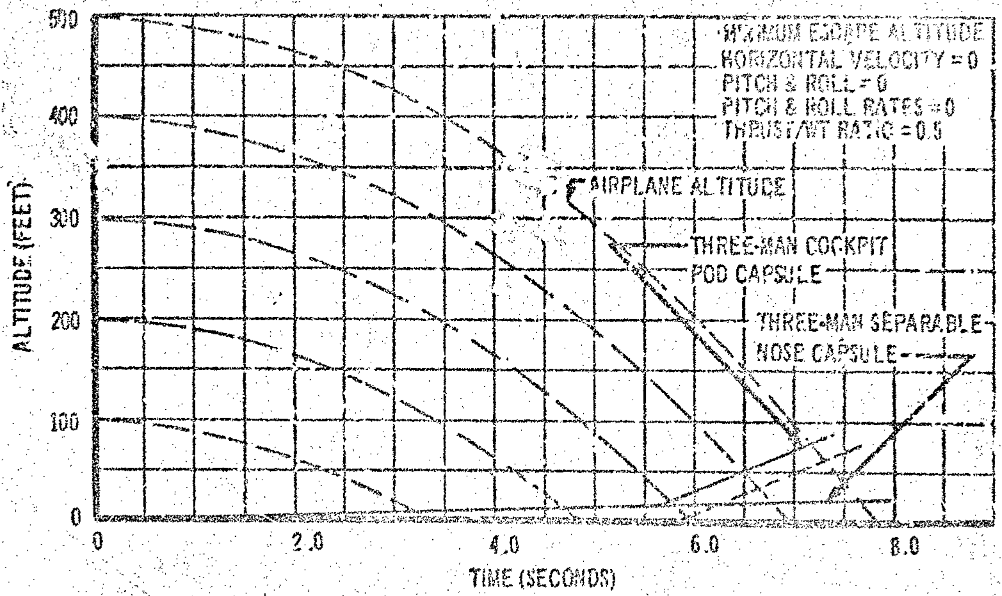


Figure 161. Three–Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes VTOL Hover Flight Engine Failure – Maximum Stability Case

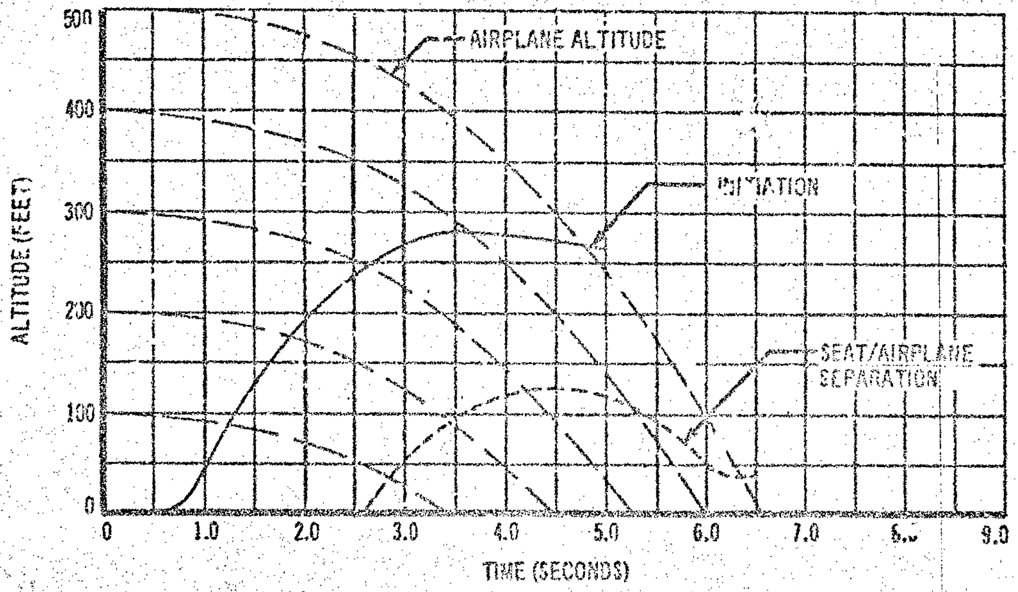


Figure 162. Three–Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

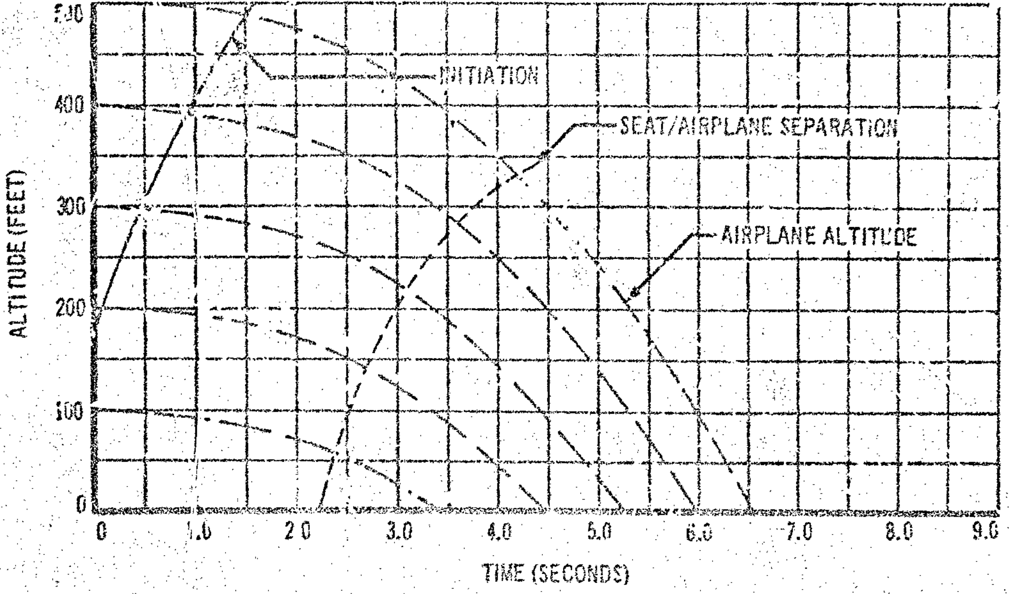


Figure 163. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

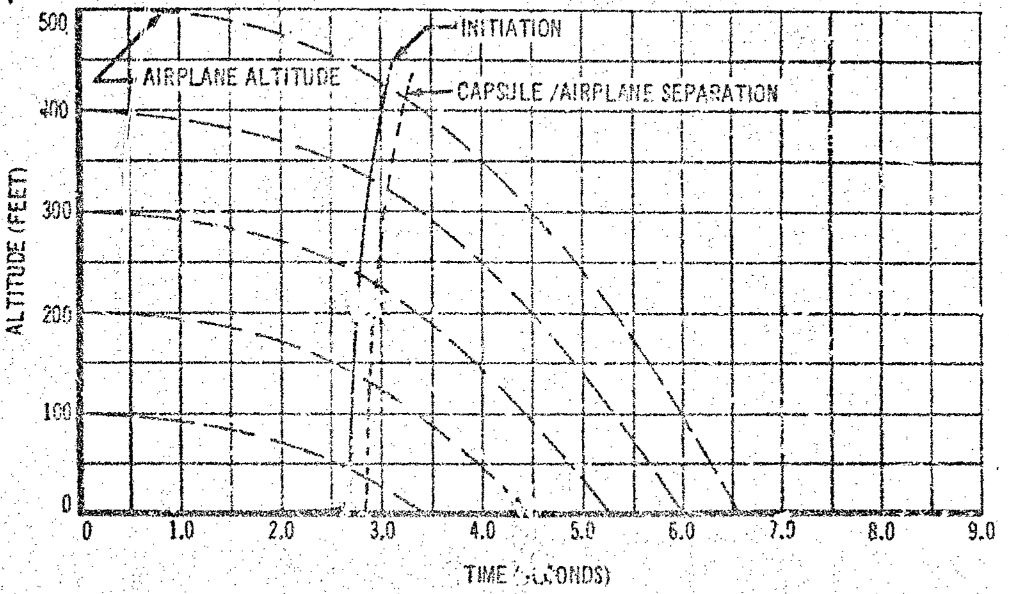


Figure 164. Three-Man Cockpit Pod Capsule Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

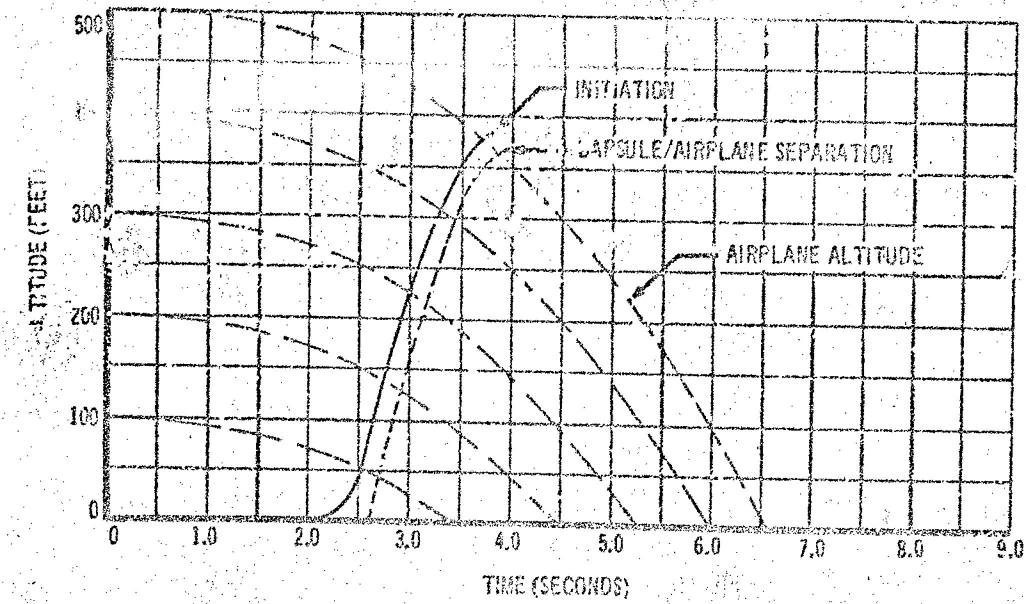


Figure 165. Three-Man Vehicle Separable Nose Capsule Minimum Escape Altitude VTOL Hover Flight Cruise Engine Failure

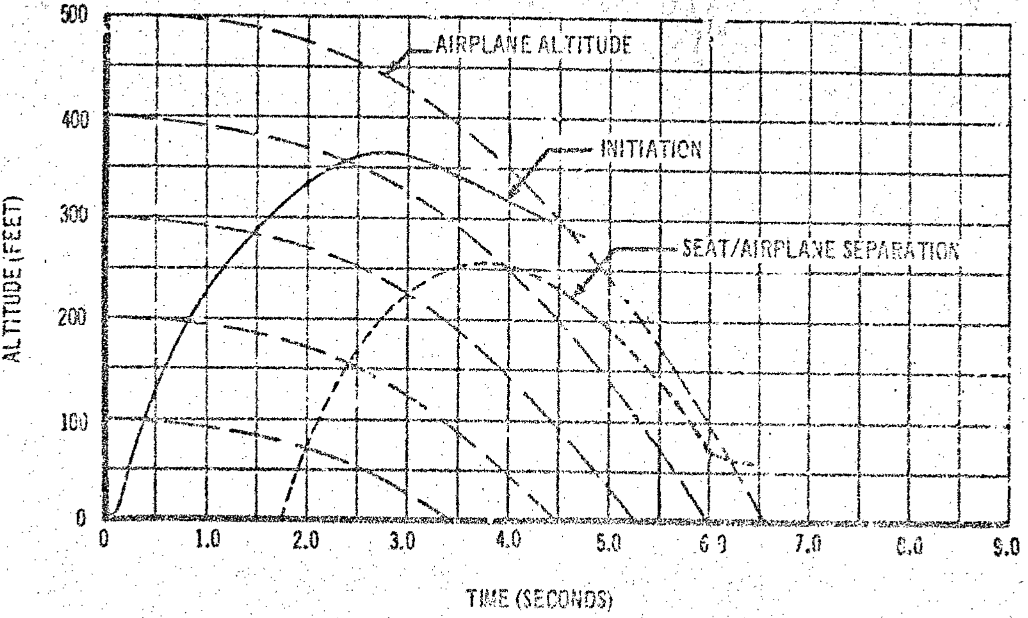


Figure 166. Three-Man Vehicle Open Ejection Seats Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

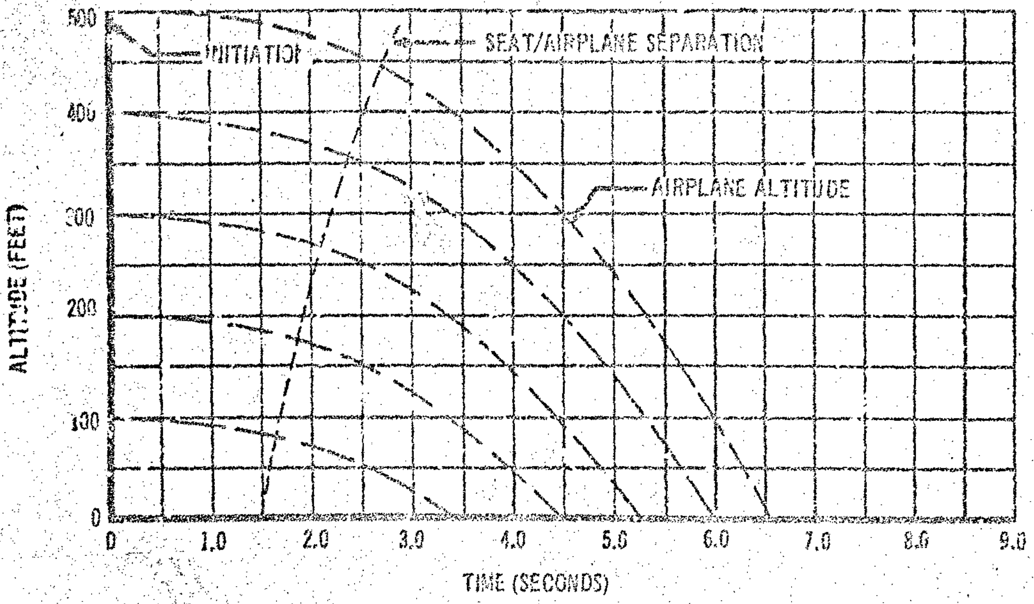


Figure 167. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

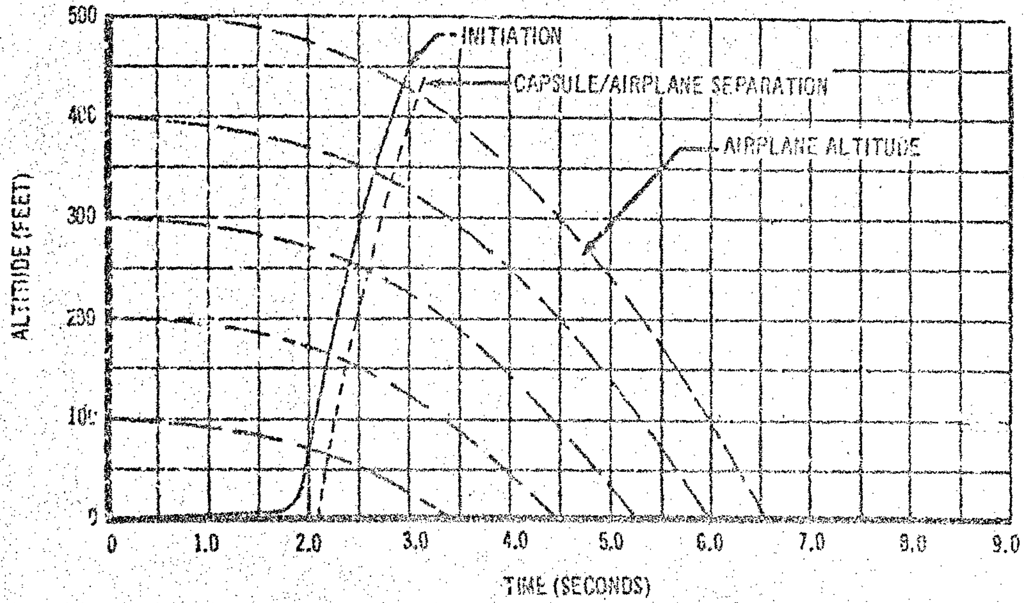


Figure 168. Three-Man Cockpit Pod Capsule Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

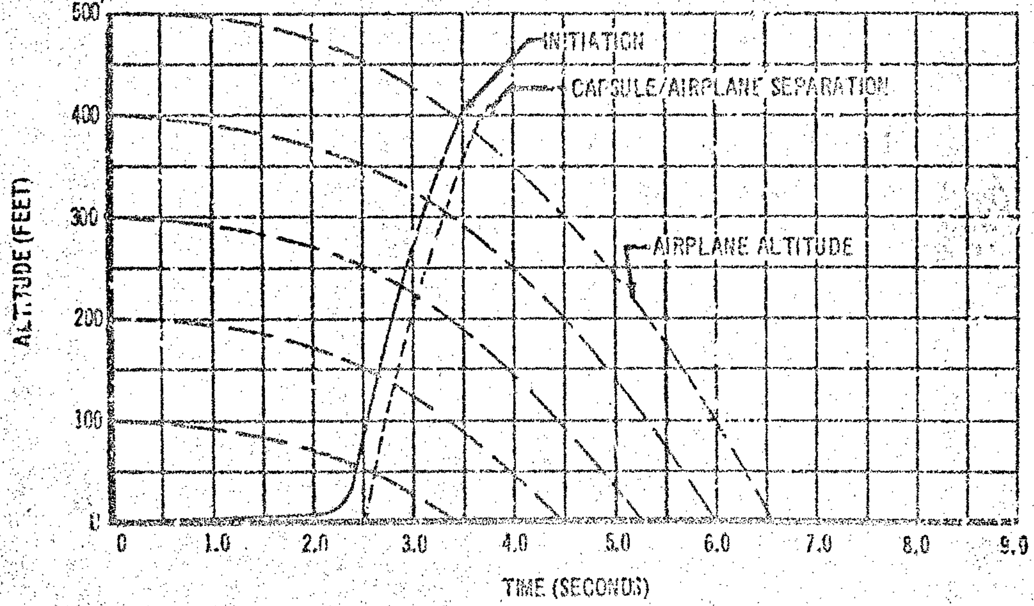


Figure 169. Three-Man Separable Nose Capsule Minimum Escape Altitude VTOL Hover Flight Lift Engine Failure

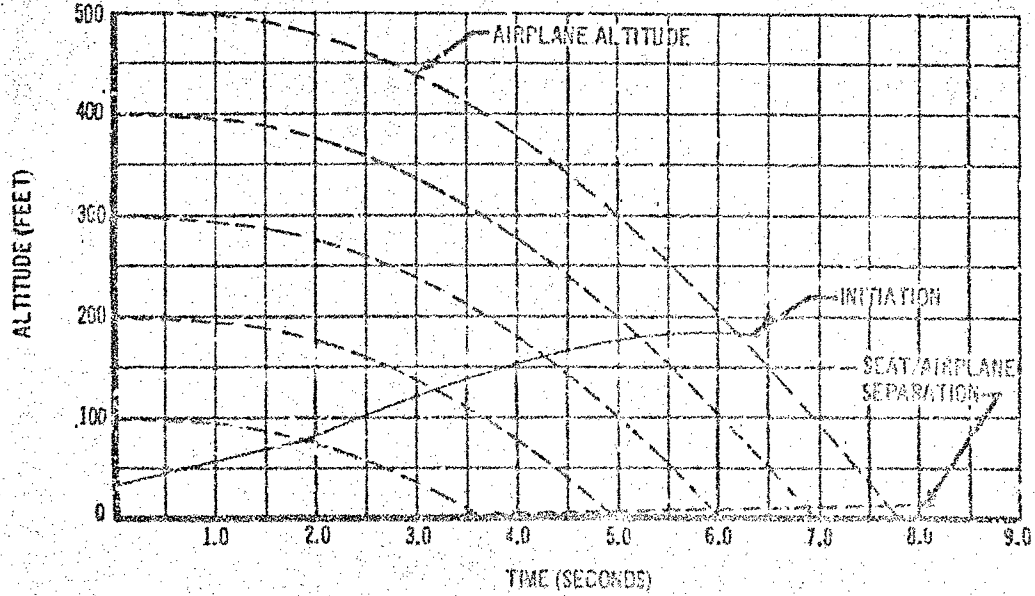


Figure 170. Three-Man Vehicle Open Ejection Seats Minimum Escape Altitudes 85 Ft/Sec Transition Cruise Engine Failure

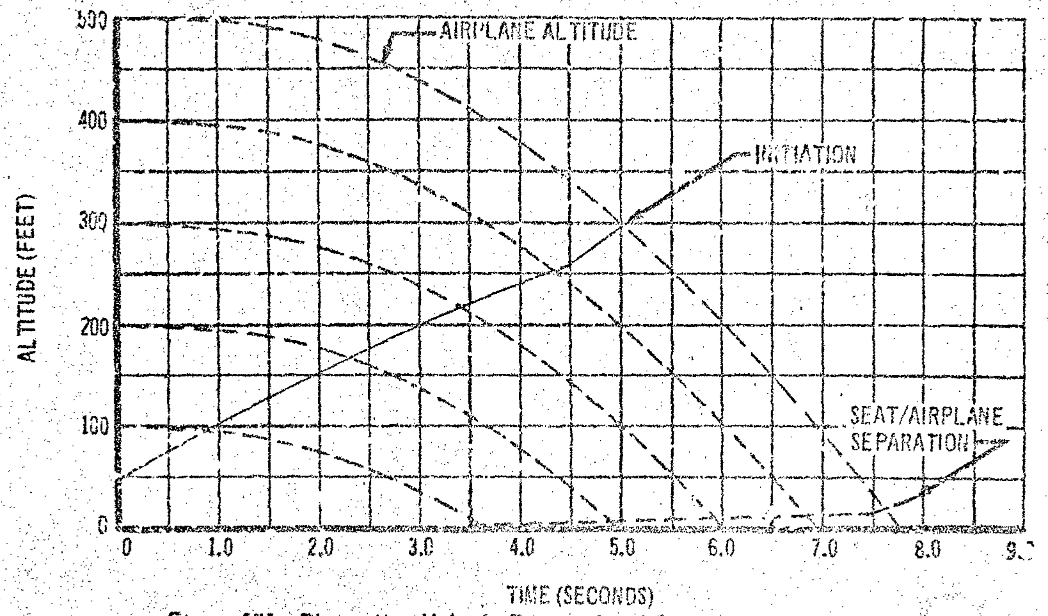


Figure 171. Three–Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 85 Ft/Sec Transition Cruise Engine Failure

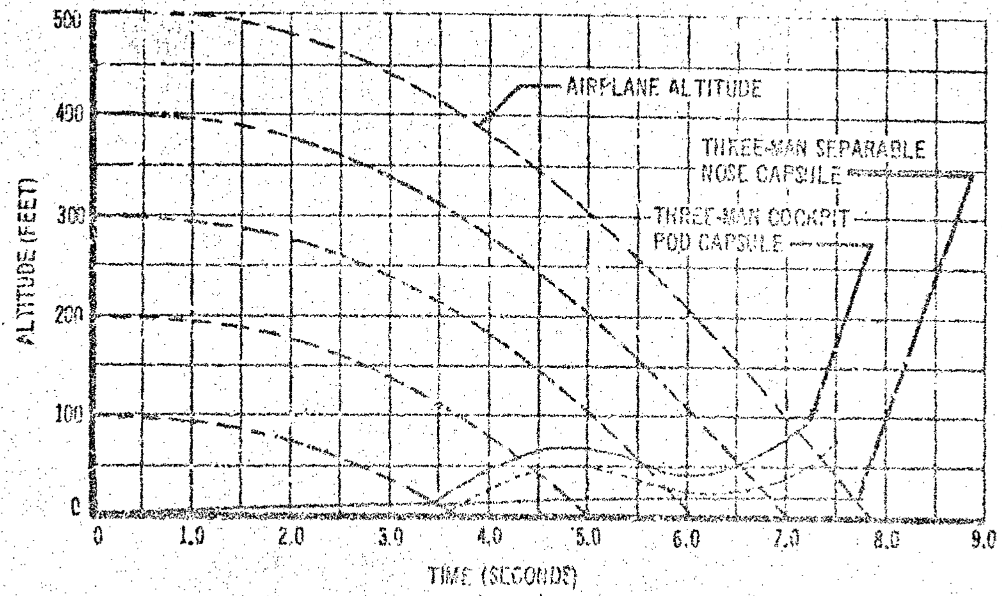


Figure 172. Three–Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 85 Ft/Sec Transition Cruise Engine Failure

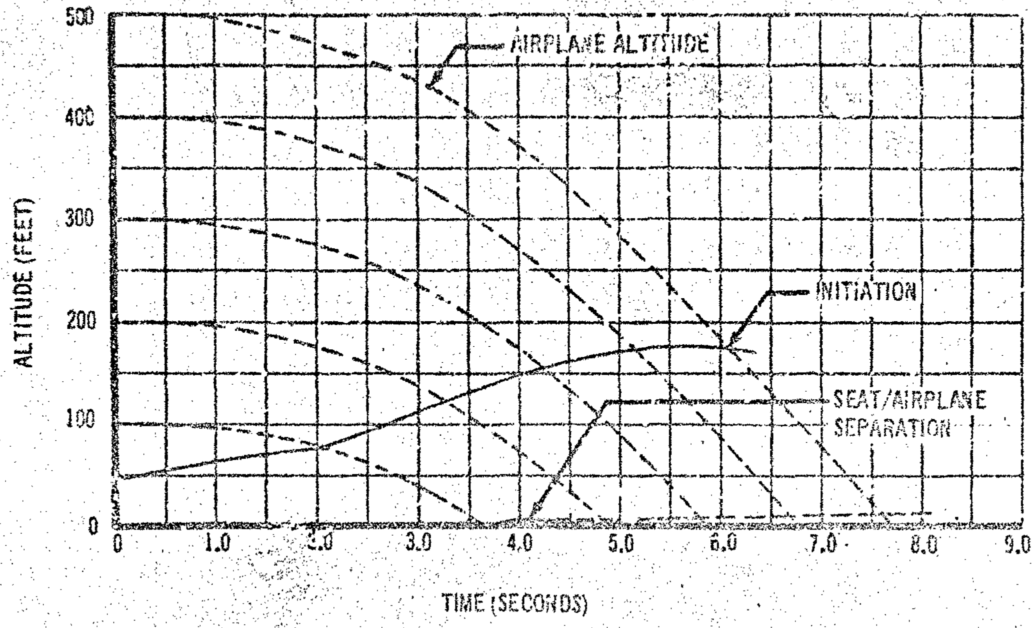


Figure 173. Three-Man Vehicle Open Ejection Seats Minimum Escape Altitude 85 Ft/Sec Transition Lift Engine Failure

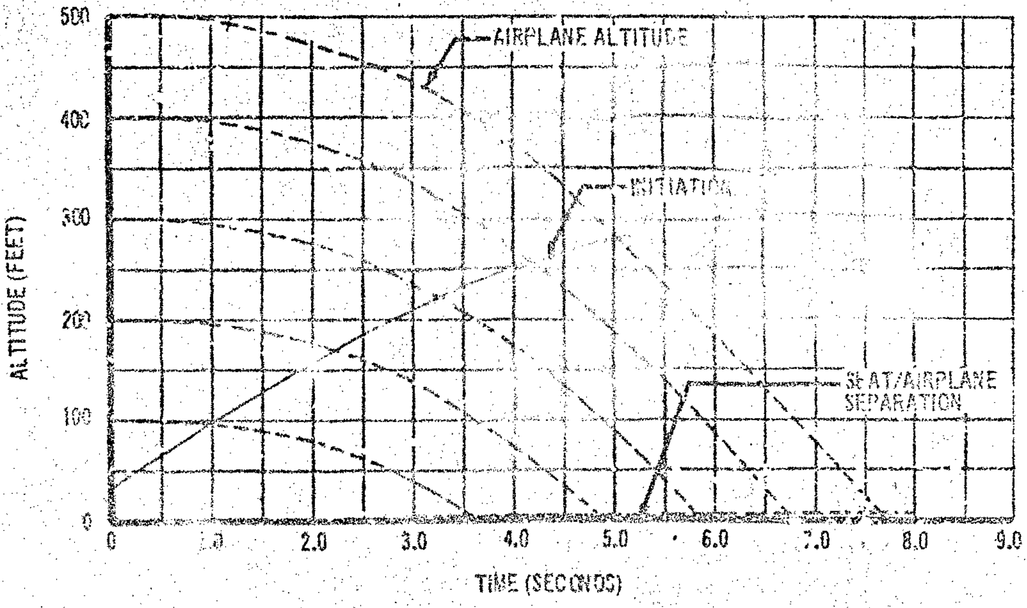


Figure 174. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 85 Ft/Sec Transition Lift Engine Failure

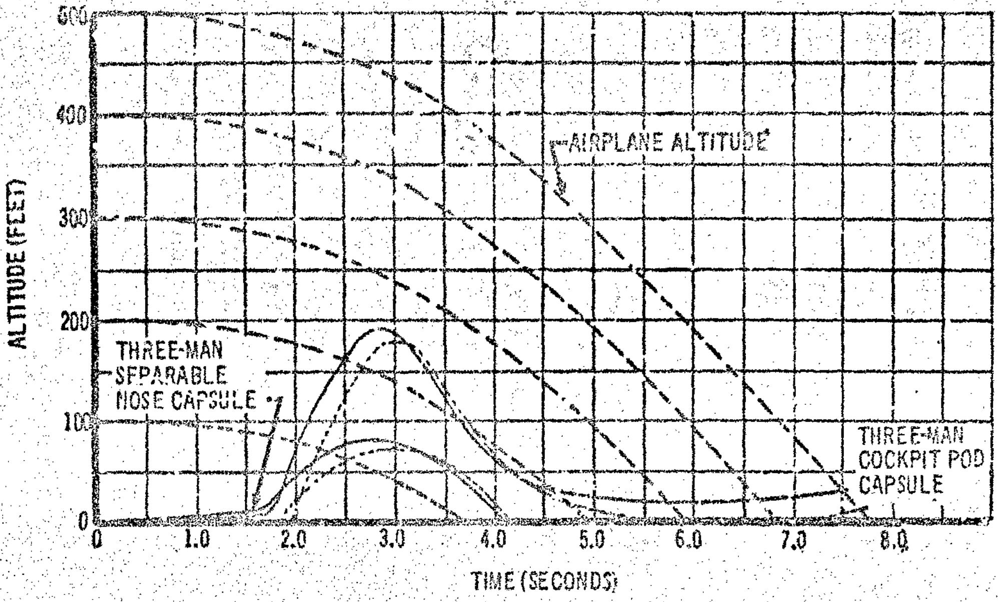


Figure 175. Three–Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitude 85 Ft/Sec Transition Lift Engine Failure

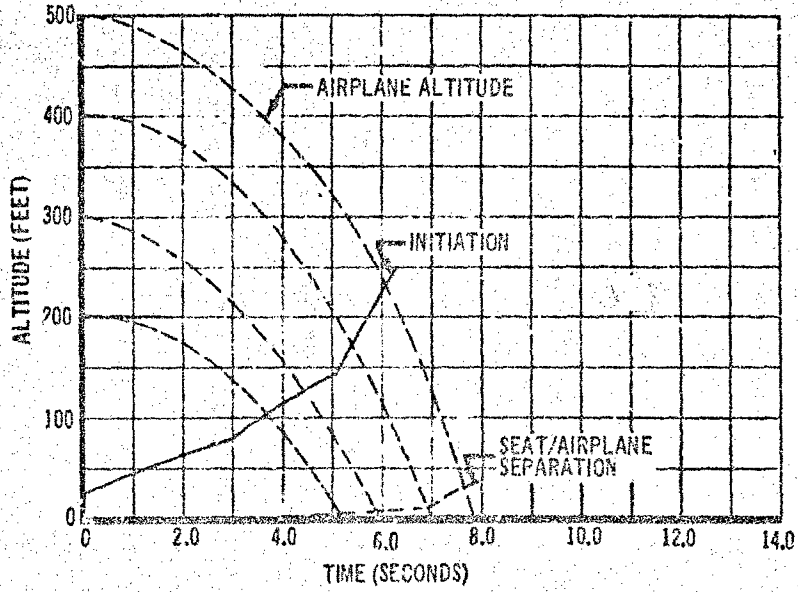


Figure 176. Three–Man Vehicle Open Ejection Seats Minimum Escape Altitude 120 Ft/Sec Transition Cruise Engine Failure

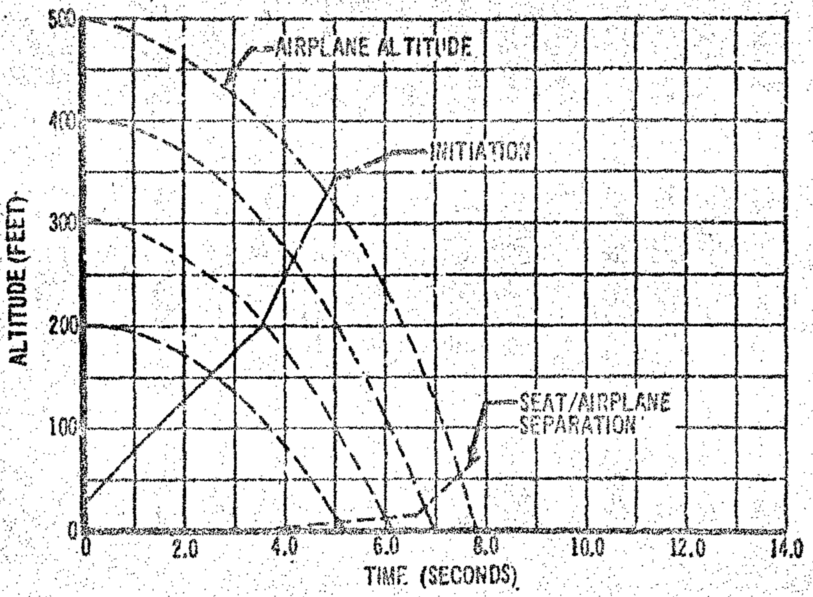


Figure 177. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude 120 Ft/Sec Transition Cruise Engine Failure

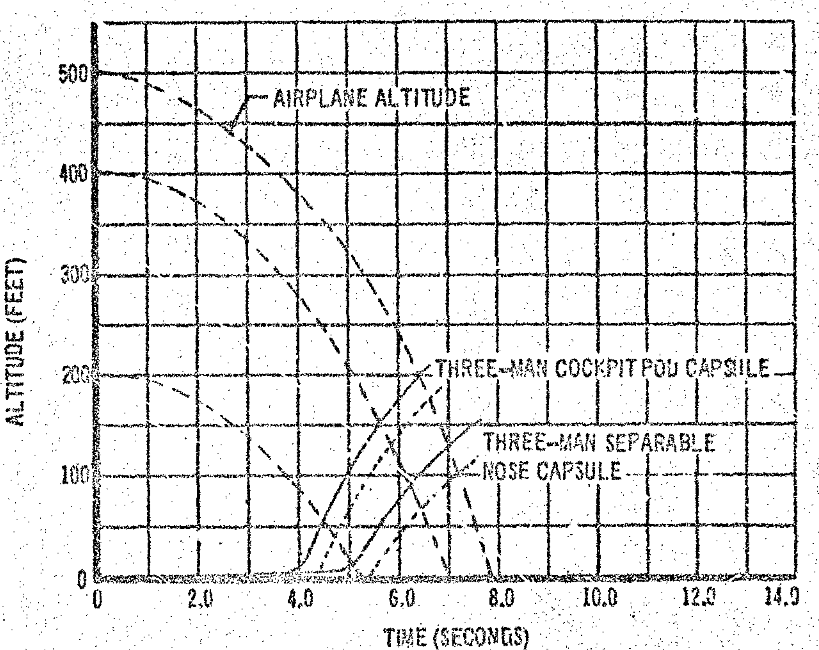


Figure 178. Three-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitude 120 Ft/Sec Transition Cruise Engine Failure

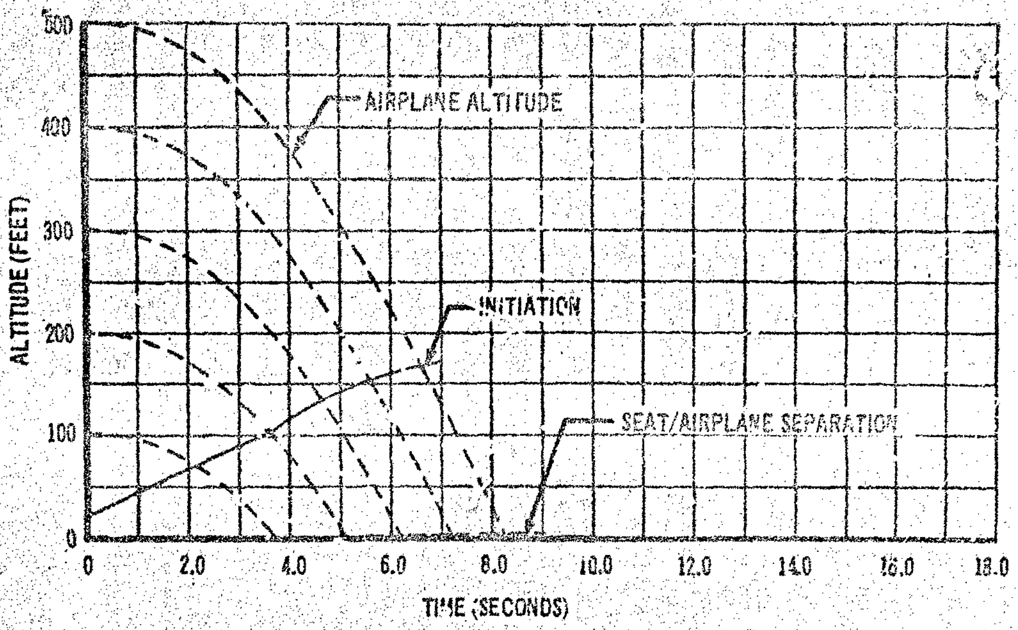


Figure 179. Three-Man Vehicle Open Ejection Seats Minimum Escape Altitudes 120 Ft/Sec Transition Lift Engine Failure

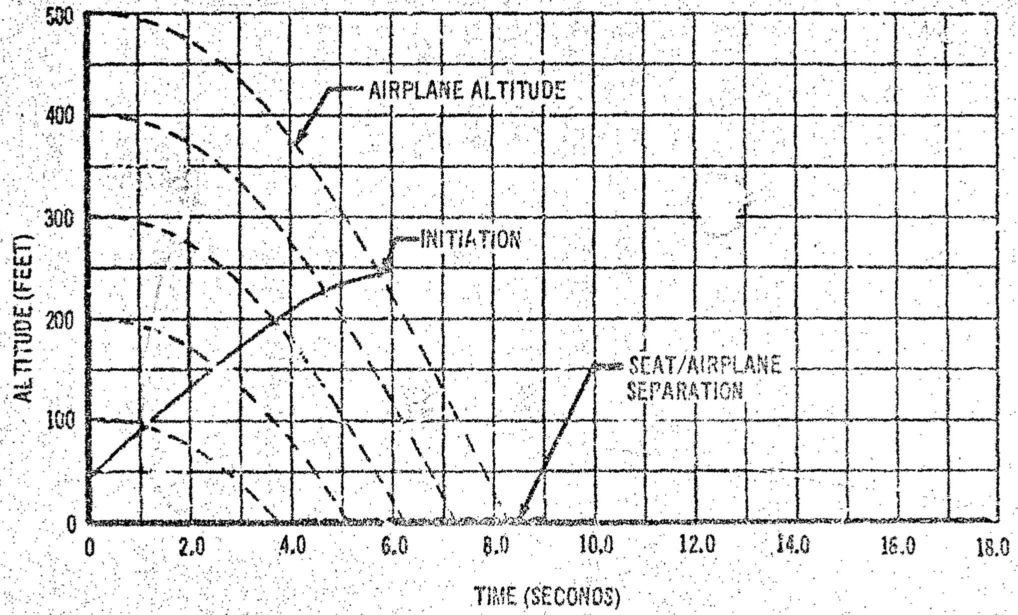


Figure 180. Three-Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 120 Ft/Sec Transition Lift Engine Failure

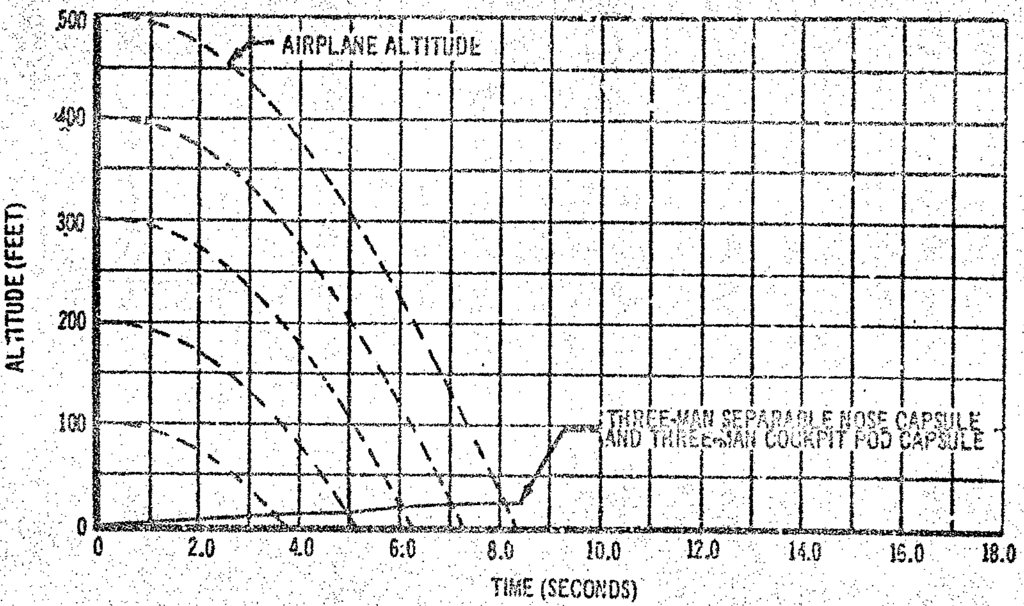


Figure 181. Three-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 120 Ft/Sec Transition Lift Engine Failure

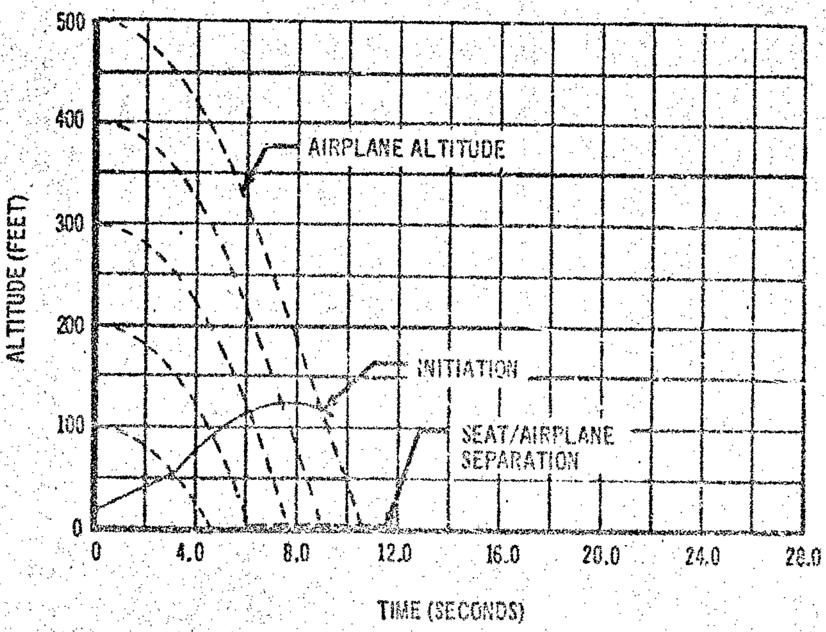


Figure 182. Three-Man Vehicle Open Ejection Seats Minimum Escape Altitudes 170 Ft/Sec Transition Cruise Engine Failure

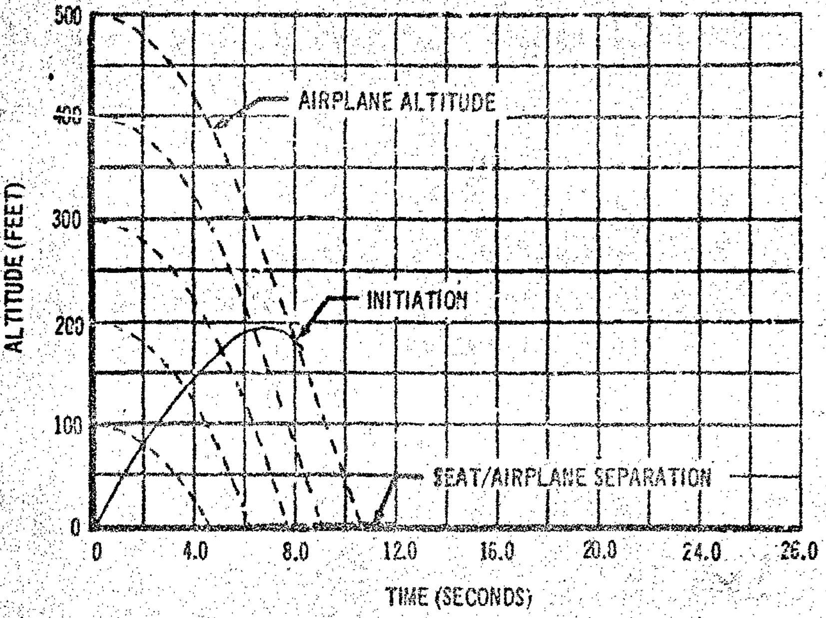


Figure 183. Three–Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitude 170 Ft/Sec Transition Cruise Engine Failure

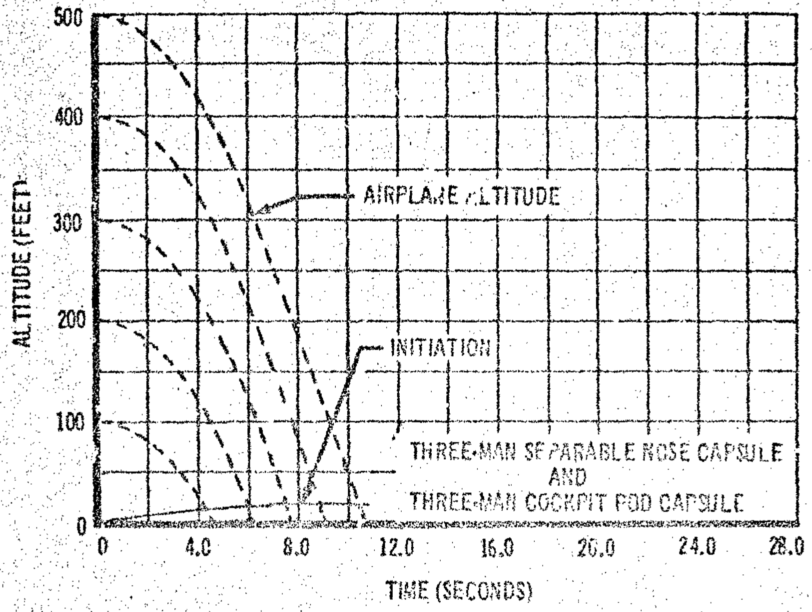


Figure 184. Three–Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 170 Ft/Sec Transition Cruise Engine Failure

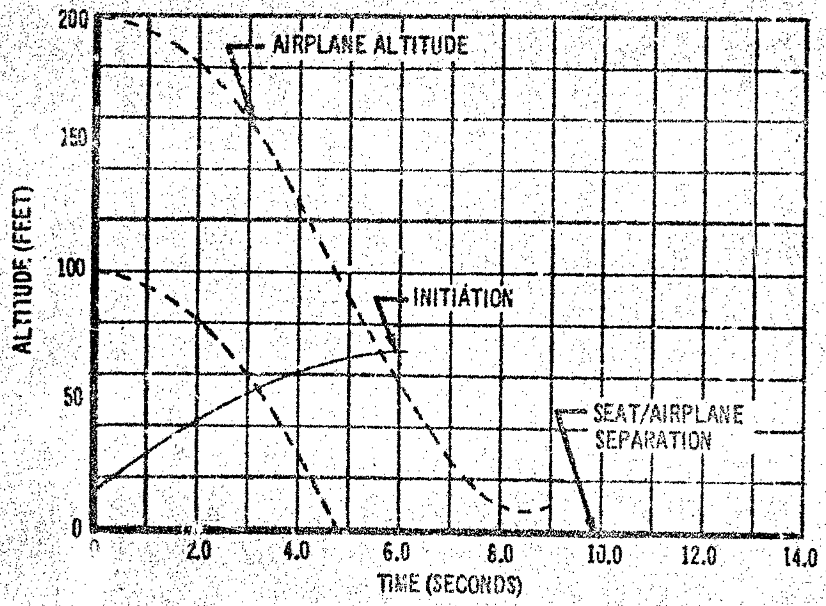


Figure 185. Three–Man Vehicle Open Ejection Seats Minimum Escape Altitudes170 Ft/Sec Transition Lift Engine Failure

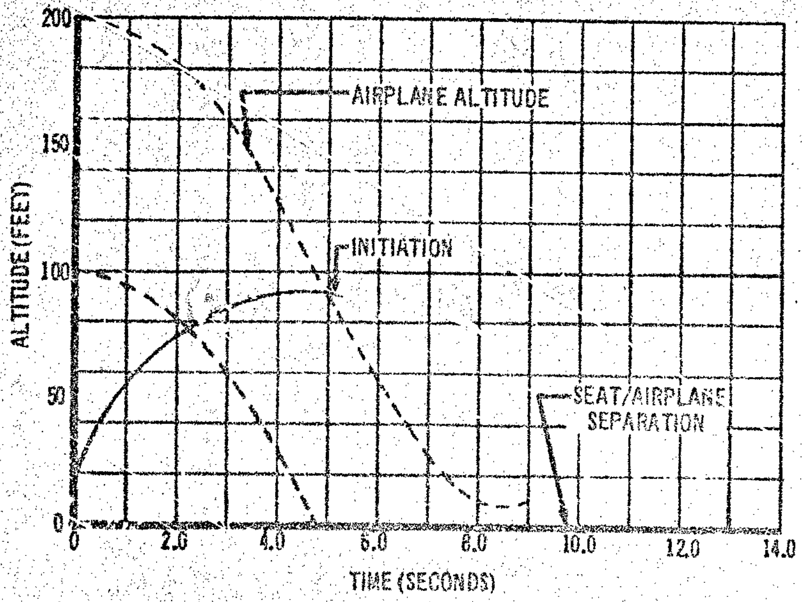


Figure 186. Three–Man Vehicle Encapsulated Ejection Seats Minimum Escape Altitudes 170 Ft/Sec Transition Lift Engine Failure

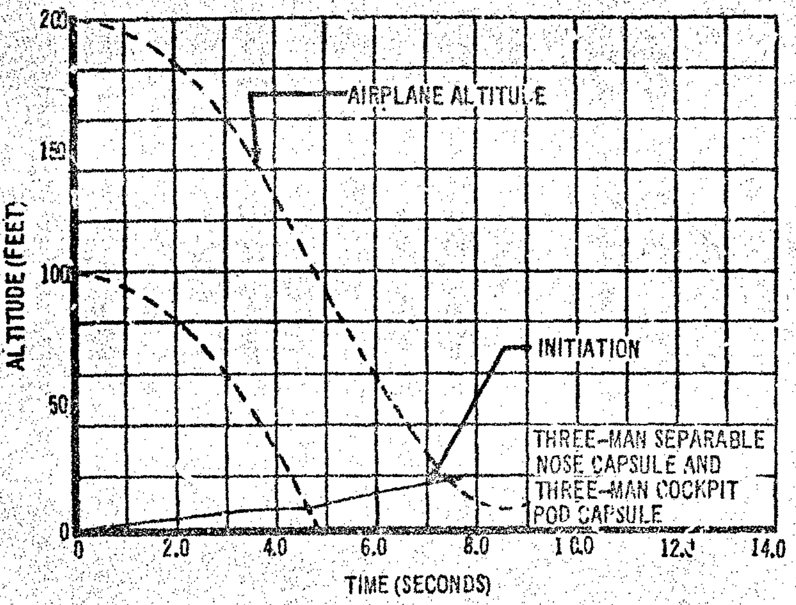


Figure 187. Three-Man Vehicle Cockpit Pod and Separable Nose Capsule Minimum Escape Altitudes 170 Ft/Sec Transition Lift Engine Failure

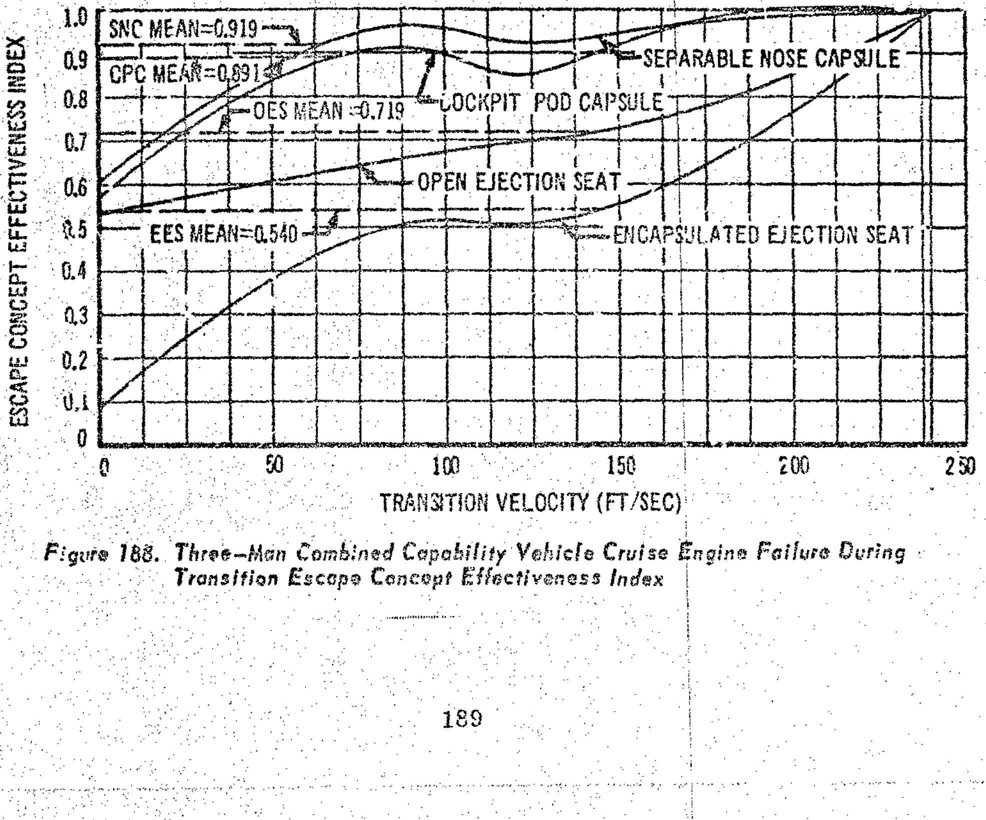


Figure 188. Three-Man Combined Capability Vehicle Cruise Engine Failure During Transition Escape Concept Effectiveness Index

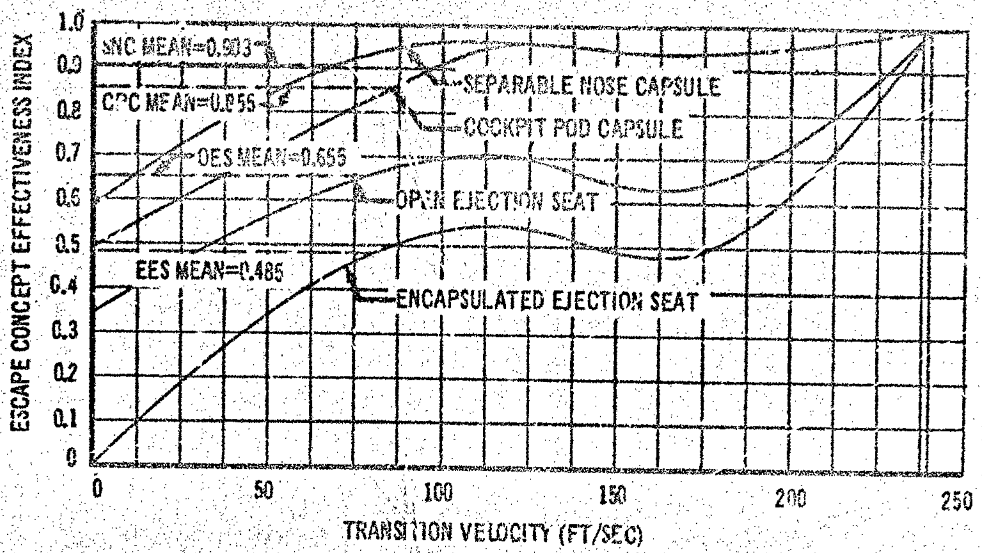


Figure 189. Three-Man Combined Capability Vehicle Lift Engine Failure During Transition Escape Concept Effectiveness Index

Table VIII. VTOL Hover and Transition Flight Regime Escape Concept Effectiveness Summary (Engine Failure Analysis)

Escape Concept Effectiveness Index				
ESCAPE CONCEPT	Maximum Stability Case- (Hover Only)	Cruise Engine Failure	Lift Engine Failure	Average
	Two-Man Vehicle			
Open Ejection Seat	0.805	0.808	0.738	0.773
Encapsulated Ejection Seat	0.597	0.624	0.554	0.589
Cockpit Pod Capsule	0.646	0.751	0.767	0.759
Separable Nose Capsule	0.643	0.765	0.839	0.807
	Three-Man Vehicle			
Open Ejection Seat	0.703	0.719	0.655	0.687
Encapsulated Ejection Seat	0.509	0.540	0.485	0.512
Cockpit Pod Capsule	0.925	0.891	0.855	0.873
Separable Nose Capsule	0.945	0.919	0.903	0.911

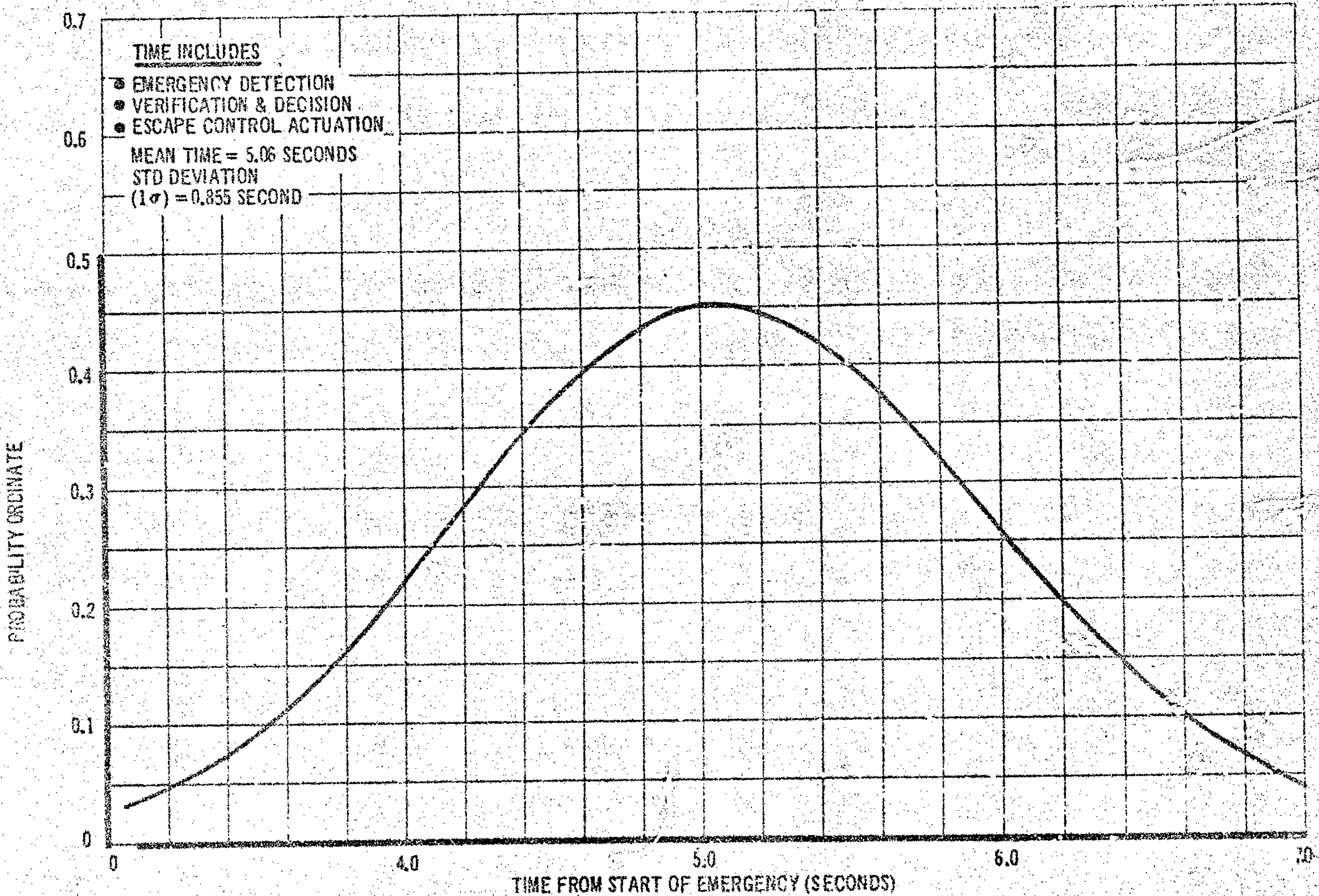


Figure 190. Normal Distribution for Manual Escape Initiation

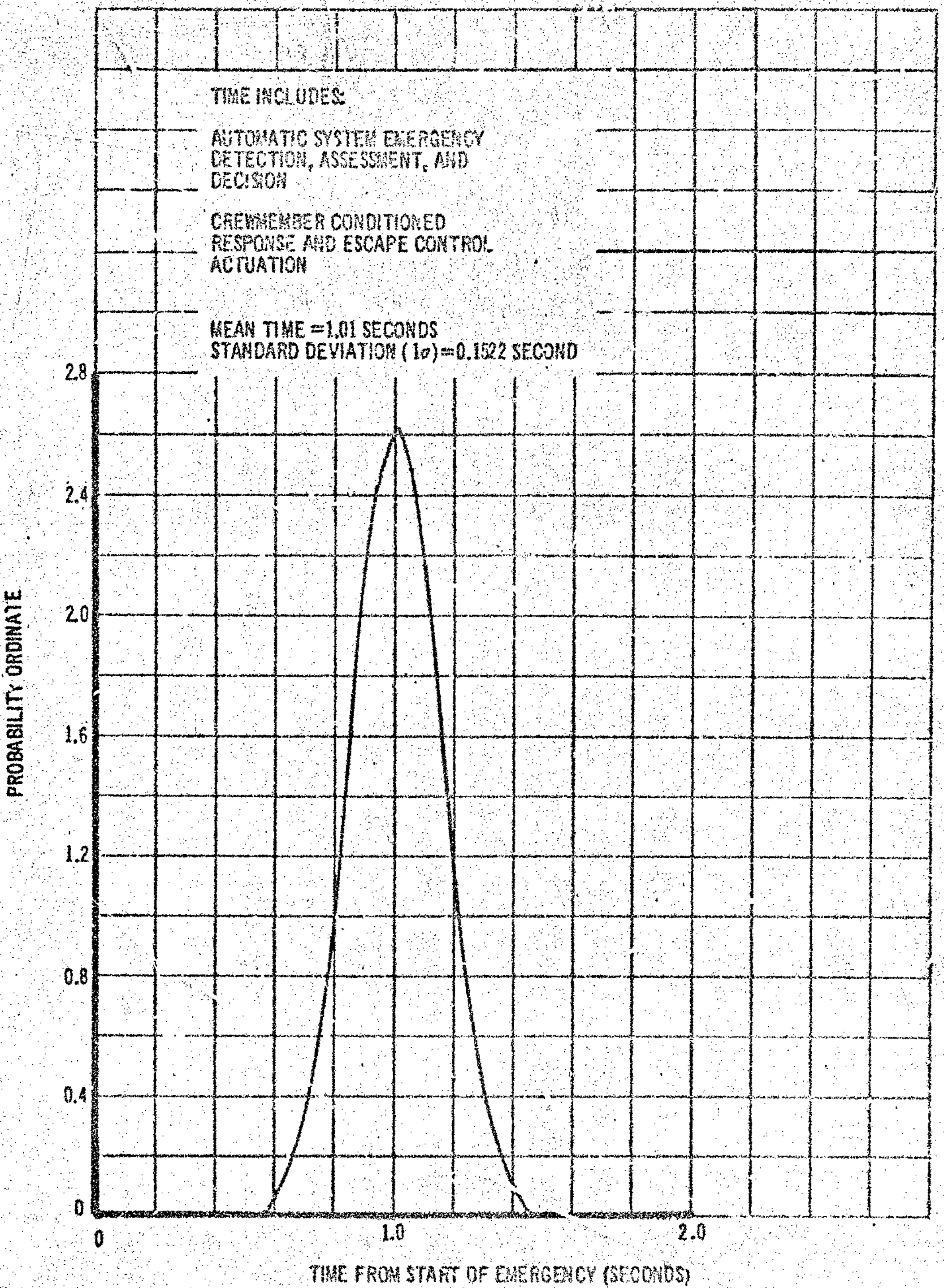


Figure 191. Normal Distribution for Semiautomatic Escape Initiation

Table IX. Manual Escape Initiation Time Normal Distribution Data

Reaction Time Elements	Mean Time (Seconds)	Standard Deviation (σ)	Range (Seconds)	
			Minimum	Maximum
(1) Visual stimulus response to master warn light	0.288	0.0425	0.121	0.432
(2) Refocus to vehicle flight instruments and subsystem status displays (Binocular near accommodation and convergence)	0.900	0.155	0.50	1.45
(3) Scan and verification that an "escape" emergency condition exists (Complex visual discrimination of displayed elements — reaction time longer the more elements to assess)	3.270	(Not Given)	1.55	5.00
(4) Time to initiate discrete movement (release grip on stick, move hand 20 centimeters, and grip D-ring)	0.257	0.06	0.108 (Estimated)	0.386 (Estimated)
(5) Armpull of D-ring (over 8 oz resistance)	0.300	(Not Given)	0.126 (Estimated)	0.45 (Estimated)

Combined Minimum Times	2.405	Seconds
Combined Maximum Times	7.718	Seconds
Mean Time (Average)	5.0615	Seconds
Std. Deviation (1 σ) (Based on 3 σ Distribution)	0.8855	Seconds

Table X. Semiautomatic Escape Initiation Time Normal Distribution Data

Reaction Time Elements	Mean Time (Seconds)	Standard Deviation (σ)	Range (Seconds)	
			Minimum	Maximum
(1) Time allowance for automatic system sensing, assessment, decision, and "eject" display	0.2		0.2	0.2
(2) Visual stimulus to "eject" light	0.288	0.0425	0.121	0.432
(3) Time to initiate discrete movement (release stick, move hand 20 centimeters, and grasp D-ring)	0.257	0.06	0.108 (Estimated)	0.386 (Estimated)
(4) Armpull of D-ring	0.300		0.126 (Estimated)	0.450 (Estimated)

Combined Minimum Times	0.555	Second
Combined Maximum Times	1.468	Seconds
Mean Time (Average)	1.0115	Seconds
Std. Deviation (1 σ)	0.1522	Second

(Based on 3 σ distribution)

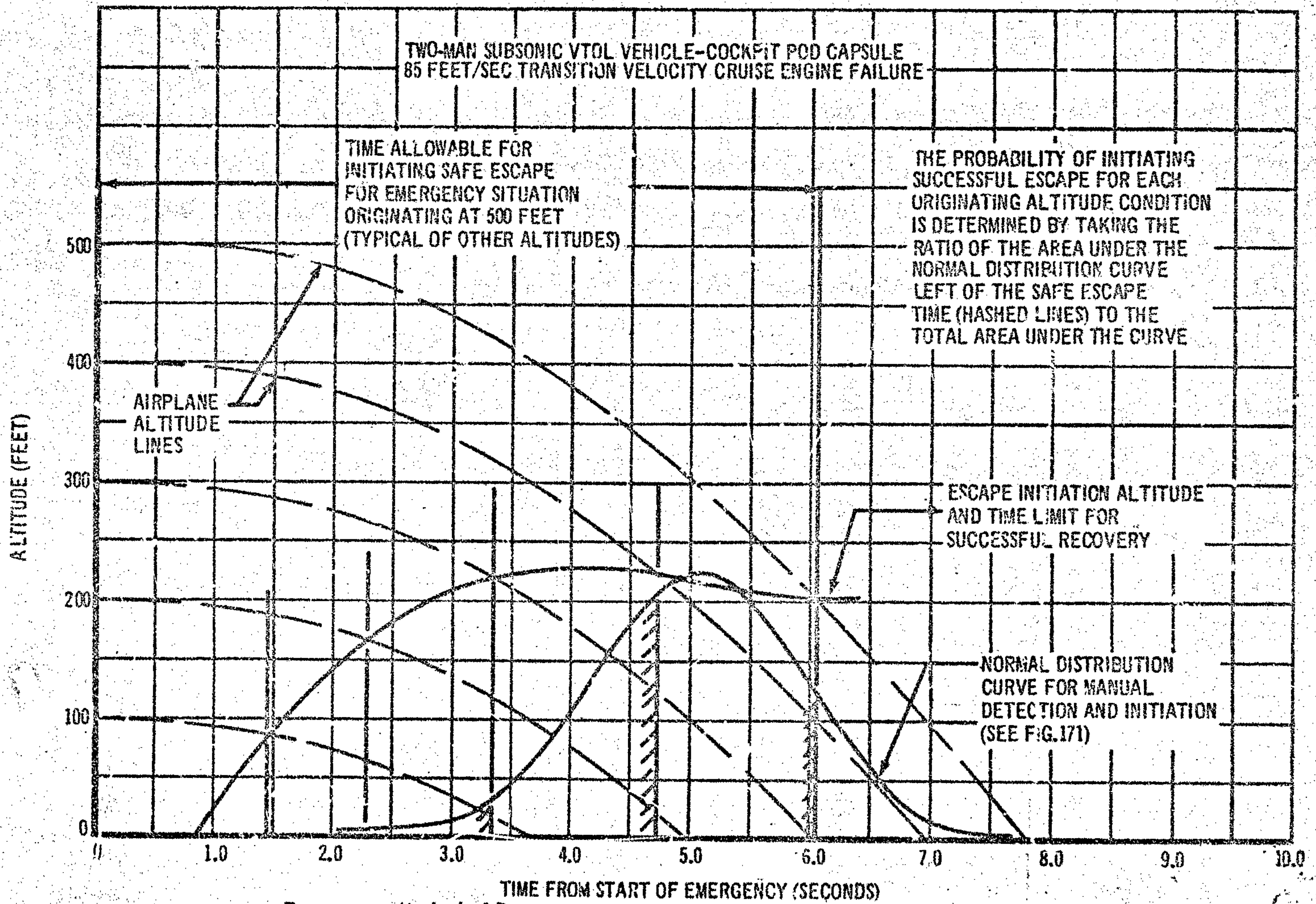


Figure 192. Method of Determining the Probability of Escape Initiation in Time for Successful Recovery for VTOL Hover and Transition Situations

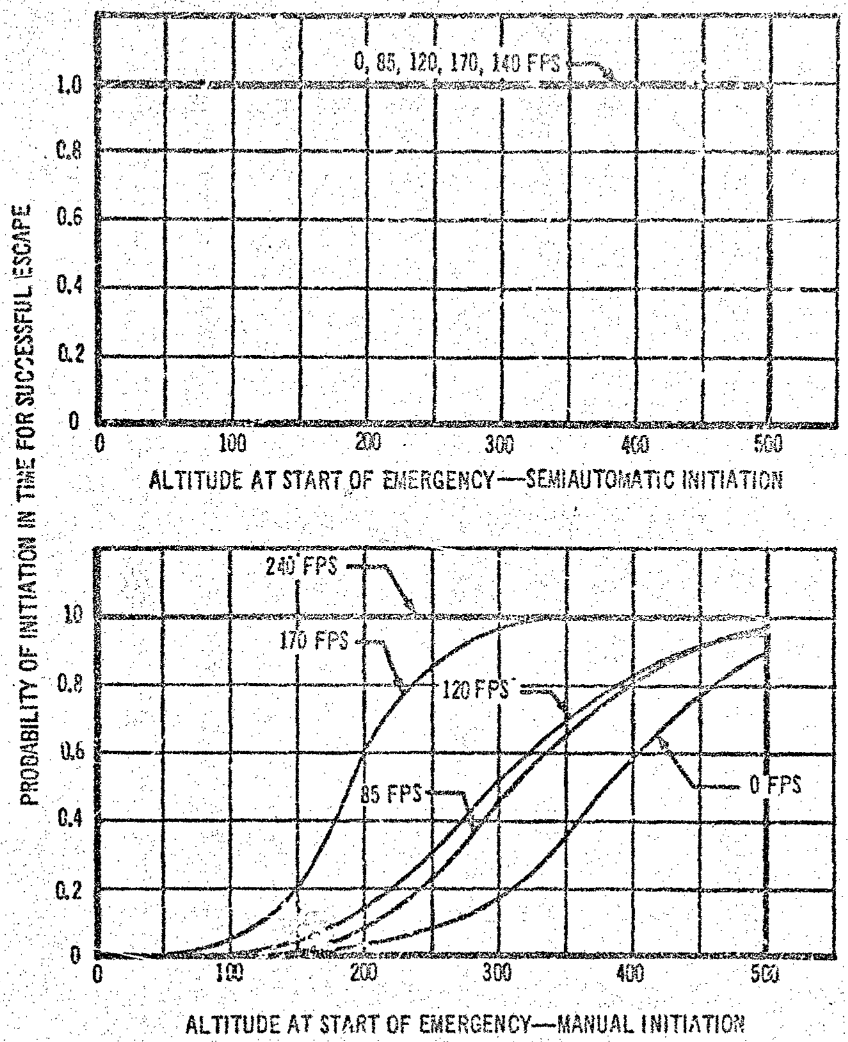


Figure 193. Probability of Successful Escape During VTOL Transition for Two-Man Vehicle Open Ejection Seats Cruise Engine Failure

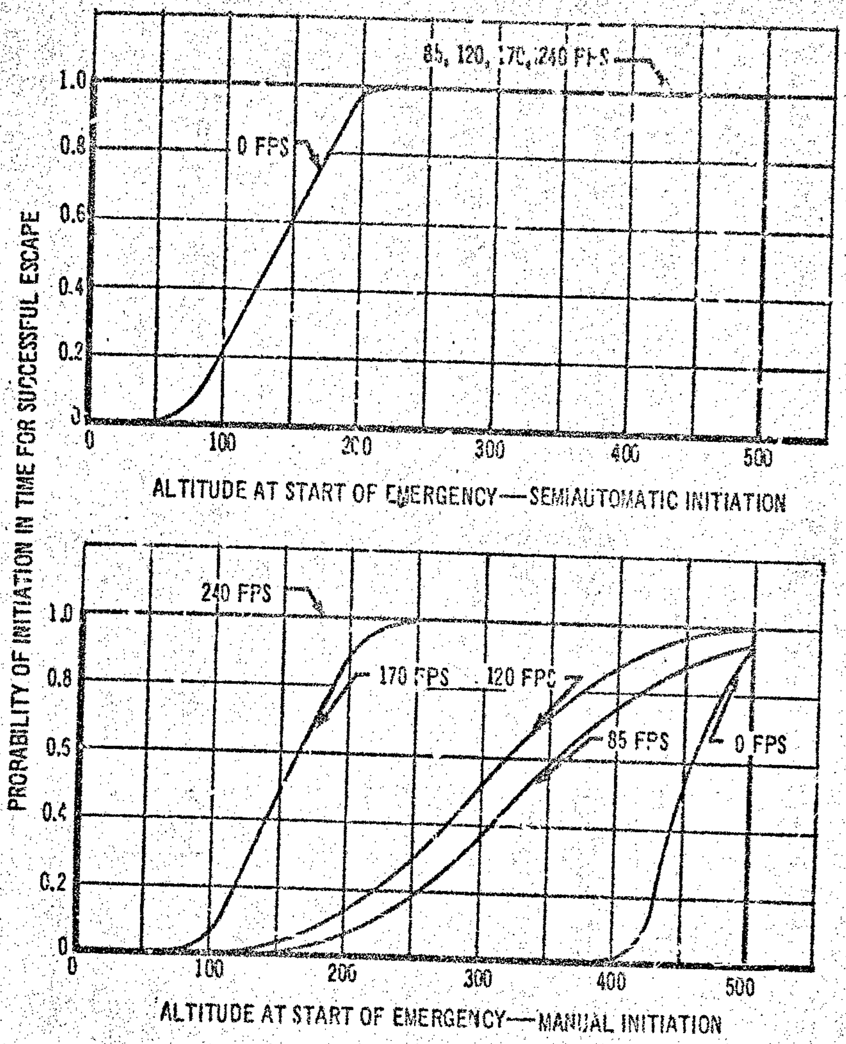


Figure 194. Probability of Successful Escape During VTOL Transition for Two-Man Vehicle Open Ejection Seats Lift Engine Failure

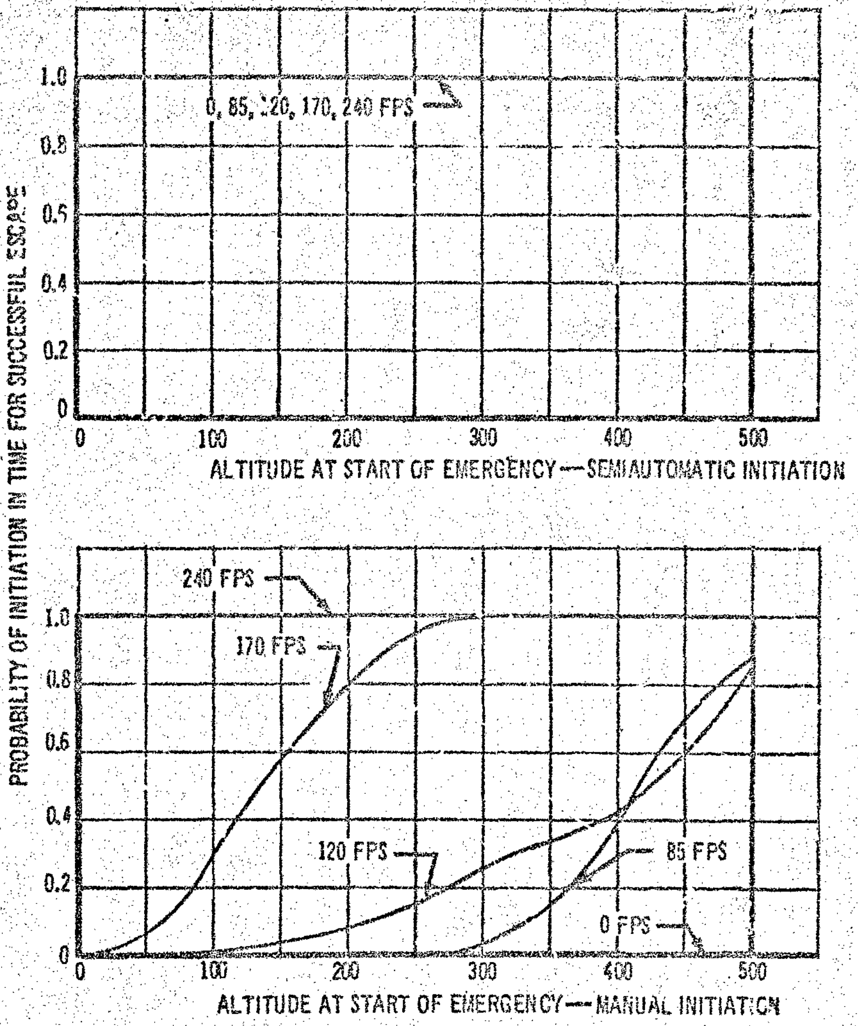


Figure 195. Probability of Successful Escape During VTOL Transition for Two-Man Vehicle Cockpit Pod Capsule Cruise Engine Failure

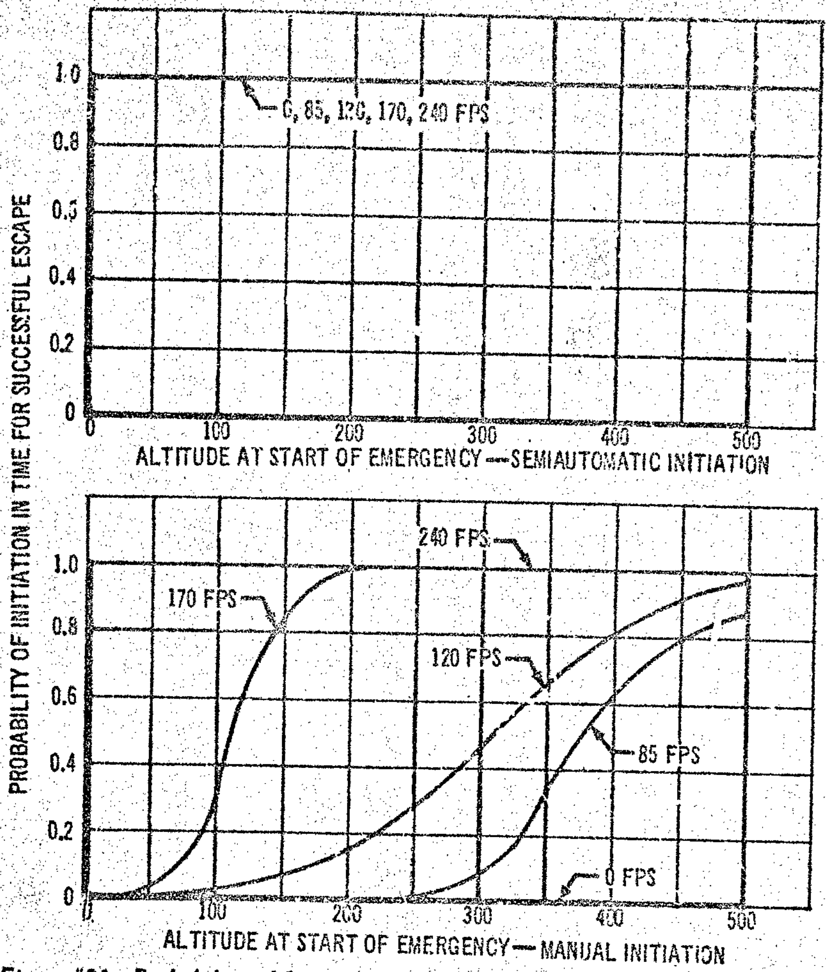


Figure 196. Probability of Successful Escape During VTOL Transition for Two-Man Vehicle Cockpit Pod Capsule Lift Engine Failure

Table XI. VTOL Hover and Transition Flight Automatic Detection and Initiation Evaluation Summary

TWO-MAN SUBSONIC VTOL VEHICLE	Probability of Successful Escape Initiation					
	Manual Initiation			Semiautomatic Initiation		
	Cruise Engine Failure	Lift Engine Failure	Avg	Cruise Engine Failure	Lift Engine Failure	Avg
Open Ejection Seats	0.502	0.466	0.484	1.000	1.000	1.000
Cockpit Pod Capsule	0.405	0.485	0.445	1.000	0.95	0.975

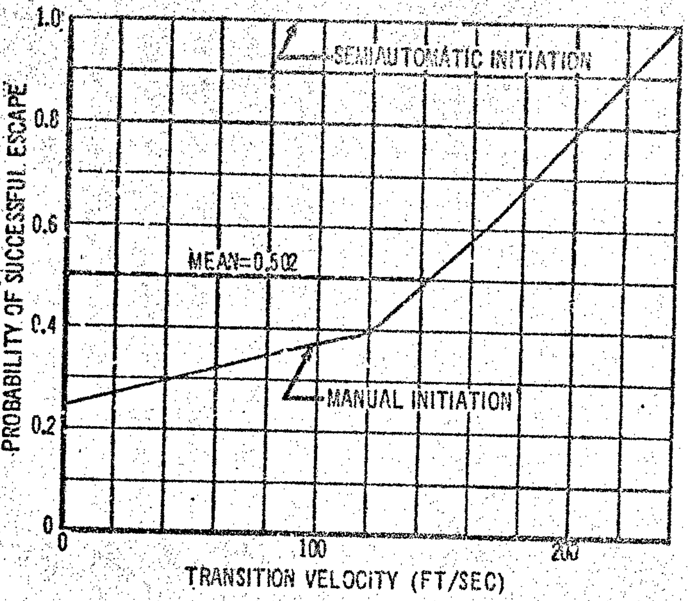


Figure 197. Probability of Successful Escape Versus Transition Velocity Two-Man Subsonic VTOL Vehicle, Cruise Engine Failure, Open Ejection Seats

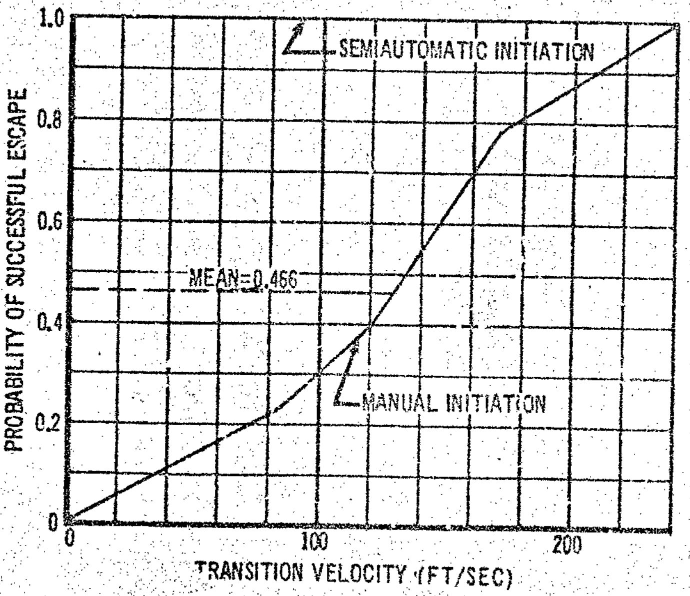


Figure 198. Probability of Successful Escape Versus Transition Velocity Two-Man Subsonic VTOL Vehicle Lift Engine Failure Open Ejection Seats

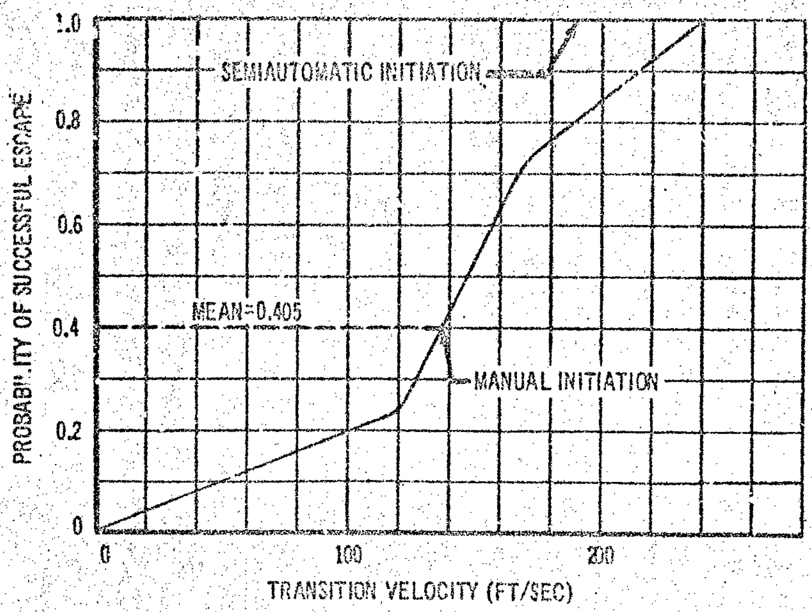


Figure 199. Probability of Successful Escape Versus Transition Velocity Two-Man Subsonic VTOL Vehicle, Cruise Engine Failure Cockpit Pod Capsule

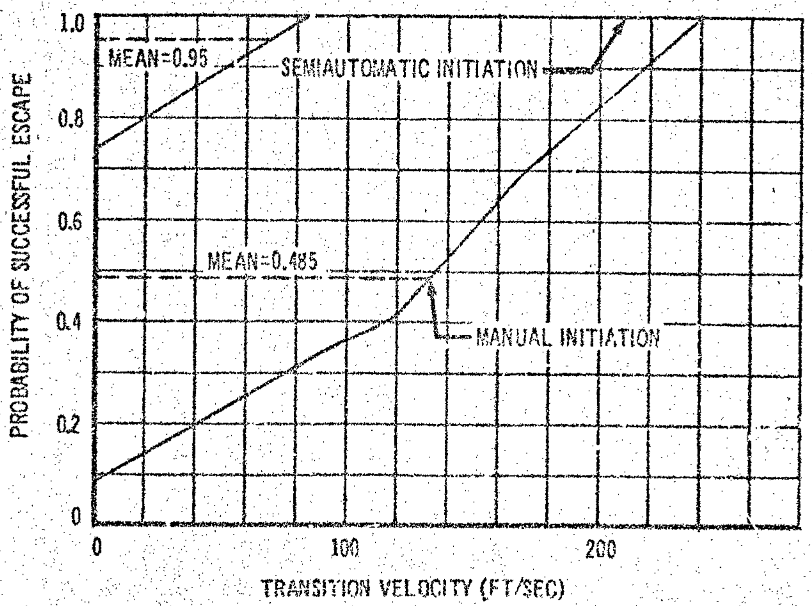


Figure 200. Probability of Successful Escape Versus Transition Velocity Two-Man Subsonic VTOL Vehicle, Lift Engine Failure Cockpit Pod Capsule

2. CONVENTIONAL TAKEOFF AND LANDING

a. Escape Conditions

To evaluate the relative effectiveness of the various escape concepts for emergencies that might occur during conventional takeoff and landing, certain representative emergency flight conditions were established. Figures 201 through 204 define the escape situations in terms of altitude above the terrain, velocity, and flight path (descent angle) versus time following the start of the emergency situation. For this study, the emergency situations were considered to start at any altitude from ground level to 500 feet, and the vehicle velocity was considered to be 250 ft/sec at the start of the emergency for all cases. The emergency flight conditions range from level flight to a maximum vehicle aerodynamic pushover capability of -0.6g. The conditions defined on the figures are for -0.6g, -0.1g, +0.4g, and +0.8g pushovers.

b. Escape Concept Effectiveness

The four-man supersonic low-altitude dash vehicle was used as a basis for evaluating and comparing the effectiveness of open ejection seats, encapsulated ejection seats, cockpit pod, and separable nose capsule escape concepts for the conventional takeoff and landing flight regime. Figures 205 through 220 show the capabilities of the escape concepts with respect to the emergency flight conditions defined in Figures 201 through 204. The escape capabilities were computed based on the escape system configurations described in Section III. The time required for preseparation functions and sequencing requirements (see Figure 127) for the four-man vehicle is 0.2 seconds for the cockpit pod and separable nose capsule concepts. For the open ejection seat concept, 2.06 seconds is required from initiation until the fourth crewman clears the vehicle. For the encapsulated ejection seat concept 3.15 seconds is required.

Escape concept effectiveness indexes were determined for each of the flight conditions and escape concepts. The method of analysis is the same as shown in Figure 127 and described in Section V.1.b. Figure 221 is a plot of the results of the analysis and shows, for each escape concept, the escape effectiveness index versus pushover normal load factor (n). Also shown on the figure is the mean escape effectiveness index for the entire takeoff and landing emergency flight regime for each concept.

c. Automatic Detection and Initiation Evaluation

For insight into the possible need for, or benefits of, automatic or semiautomatic emergency detection and escape initiation in the takeoff and landing flight regime, a special analysis was made. For each emergency situation defined in Figures 201 through 204, the time allowable after the start of the emergency situation, during which escape initiation would result in successful recovery of the entire crew, was compared with the time required for the pilot to manually detect and initiate escape to determine the probability of successful escape for manual initiation. The probability of escape initiation in time for successful recovery also was determined for a semiautomatic system in which the airplane conditions are automatically sensed and escape decision is computerized; the pilot's function being only to actuate the escape control.

Normal distribution curves for escape initiation relative to time are shown in Figures 190 and 191. The method of determining the probabilities of successful escape initiation for each emergency situation is the same as described in Section V.1.c and in Figure 192.

The probabilities of successful escape, relative to altitude above the terrain at the start of the emergency, were determined (based on data from Figures 205 through 220) for the four-man vehicle open ejection seat and cockpit pod capsule concepts for each emergency pushover situation. These data are shown plotted in Figures 222 and 223 for manual and semiautomatic initiation.

From the data shown on Figures 222 and 223, the mean probabilities for the total altitude range (0 to 500 feet) were determined for each g pushover condition. Figures 224 and 225 show the probability of successful escape versus pushover load factor for manual and semiautomatic initiation for open ejection seats and cockpit pod capsules. Also shown is the average or overall total probability of successful escape initiation for the entire takeoff and landing emergency spectrum defined.

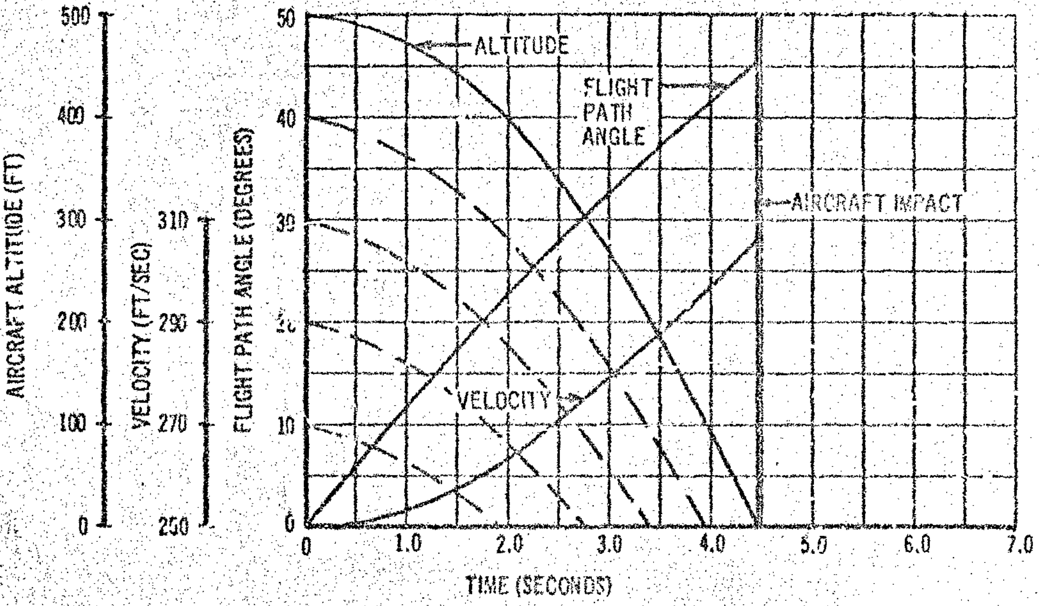


Figure 201. -0.6 g Aircraft Pushover During Conventional Takeoff or Landing Situations. Initial Velocity 250 Ft/Sec Altitude 0 to 500 Feet

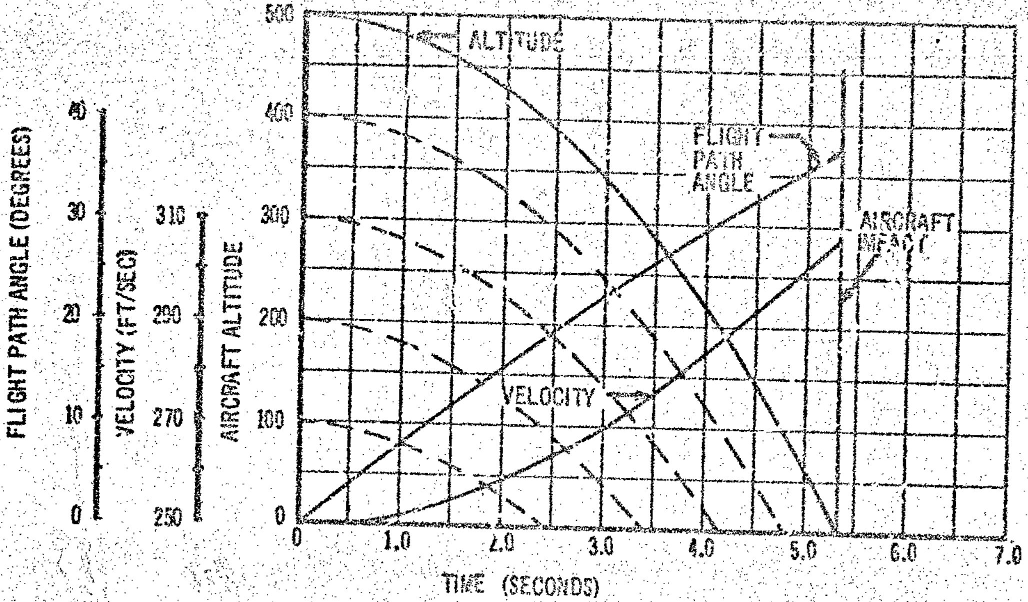


Figure 202. -0.1 g Aircraft Pushover During Conventional Takeoff or Landing Situations. Initial Velocity 250 Ft/Sec Altitude 0 to 500 Feet

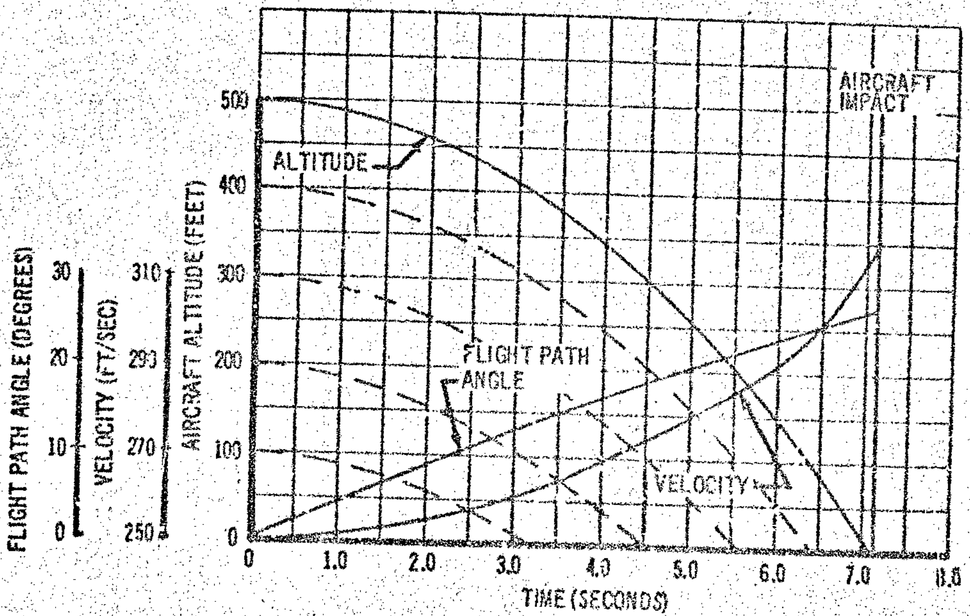


Figure 203. 0.4 g Aircraft Pushover During Conventional Takeoff or Landing Situations. Initial Velocity 250 Ft/Sec Altitude 0 to 500 Feet

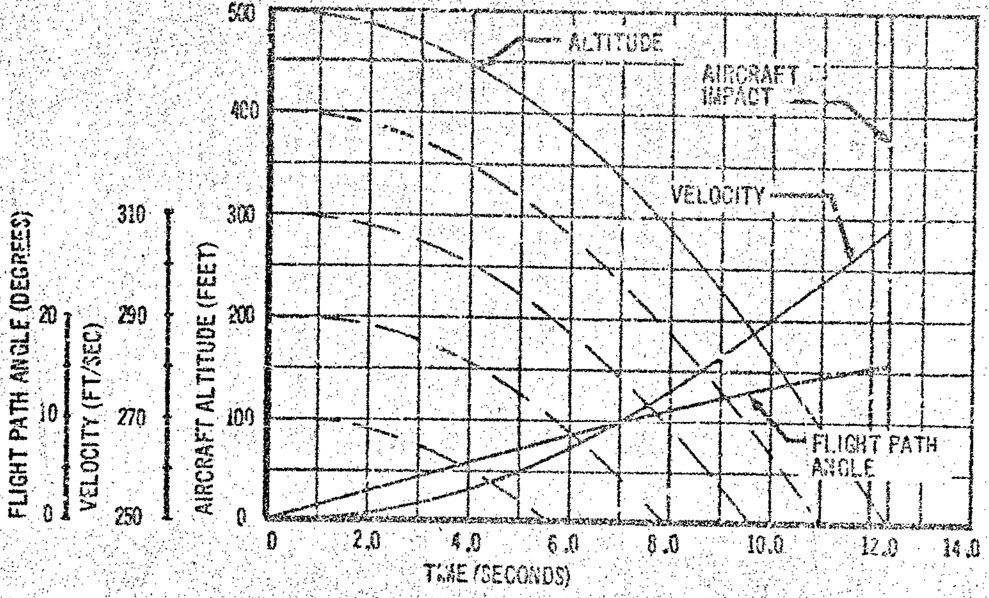


Figure 204. 0.8 g Aircraft Pushover During Conventional Takeoff or Landing Situations. Initial Velocity 250 Ft/Sec Altitude 0 to 500 Feet

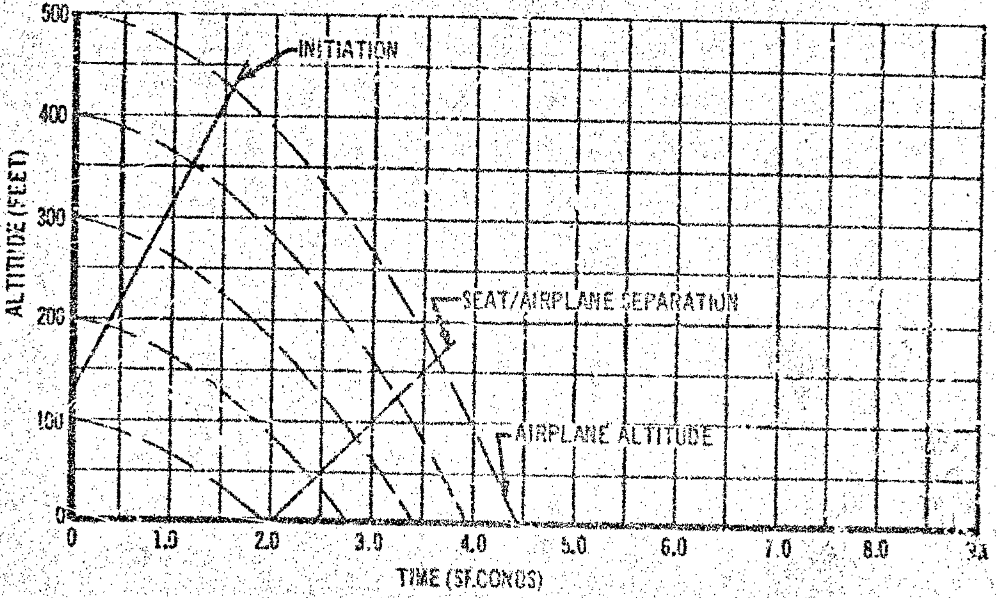


Figure 205. Four-Man Vehicle Landing and Takeoff Emergency Open Ejection Seat Minimum Escape Altitude -0.6 g Pushover

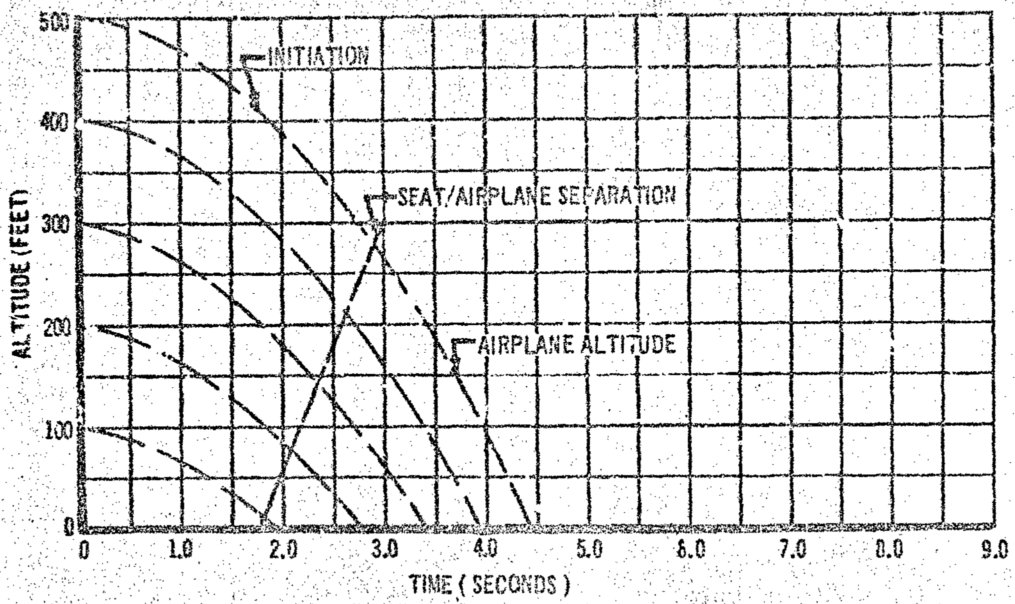


Figure 206. Four-Man Vehicle Landing and Takeoff Emergency Encapsulated Ejection Seat Minimum Escape Altitude -0.6 g Pushover

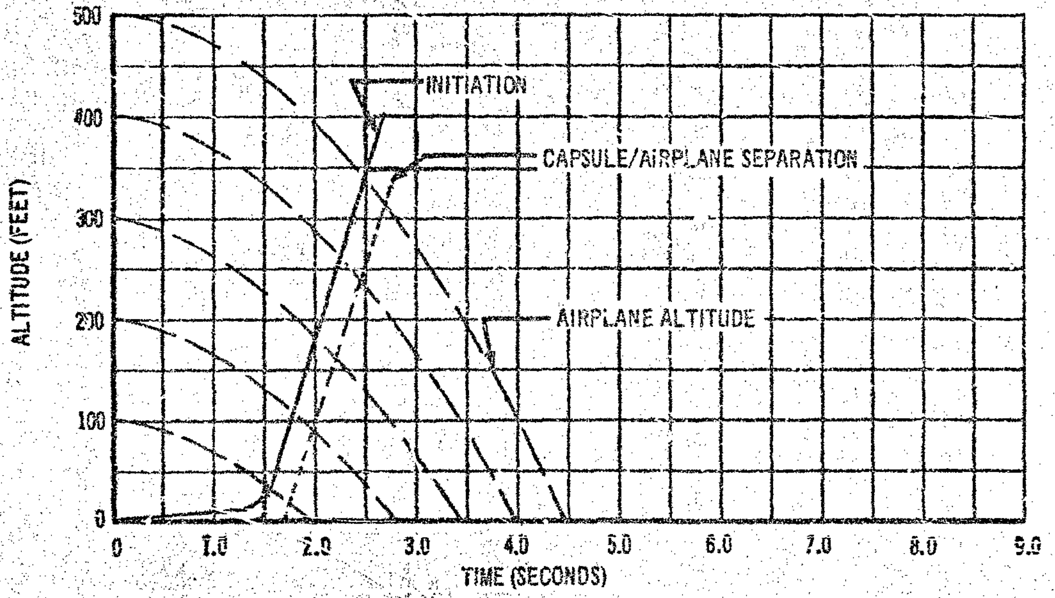


Figure 207. Four-Man Cockpit Pod Capsule Takeoff and Landing Emergency Minimum Escape Altitude -0.6 g Pushover

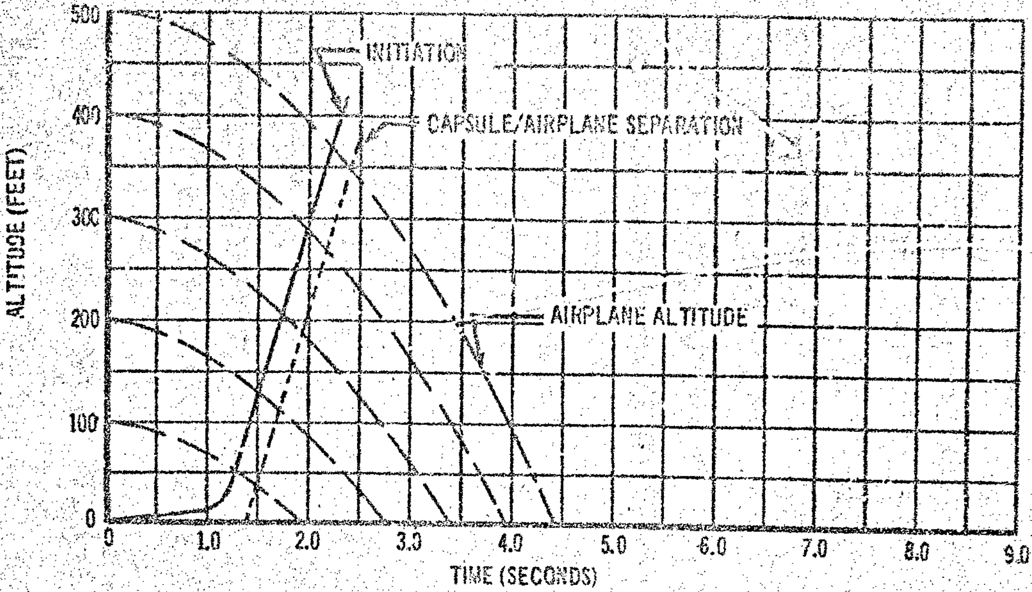


Figure 208. Four-Man Separable Nose Capsule Landing and Takeoff Emergency Minimum Escape Altitude –0.6 g Pushover

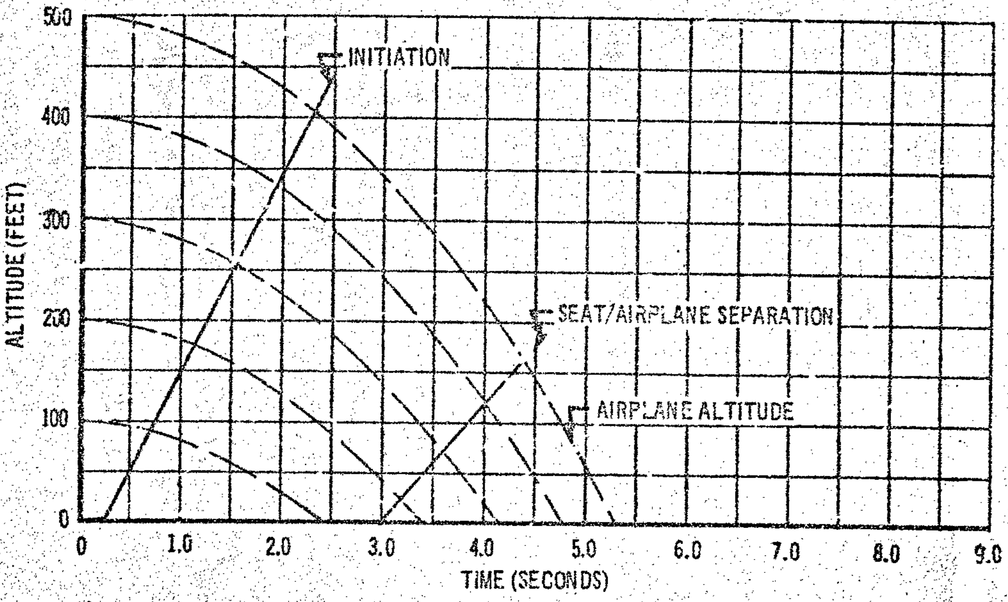


Figure 209. Four-Man Vehicle Landing and Takeoff Emergency Open Ejection Seat Minimum Escape Altitude –0.1 g Pushover

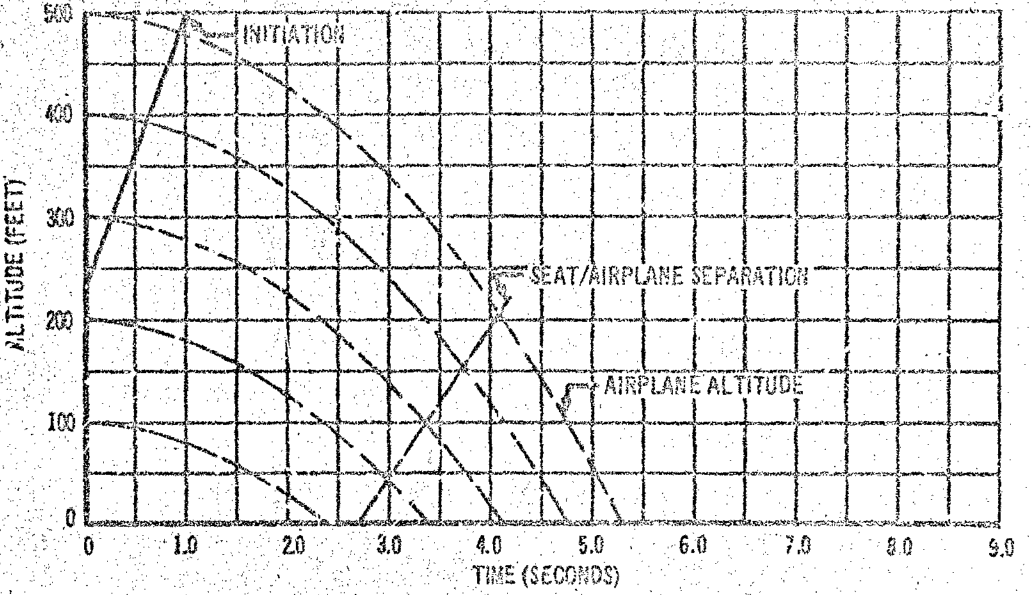


Figure 210. Four-Man Vehicle Landing and Takeoff Emergency Encapsulated Ejection Seat Minimum Escape Altitude –0.1 g Pushover

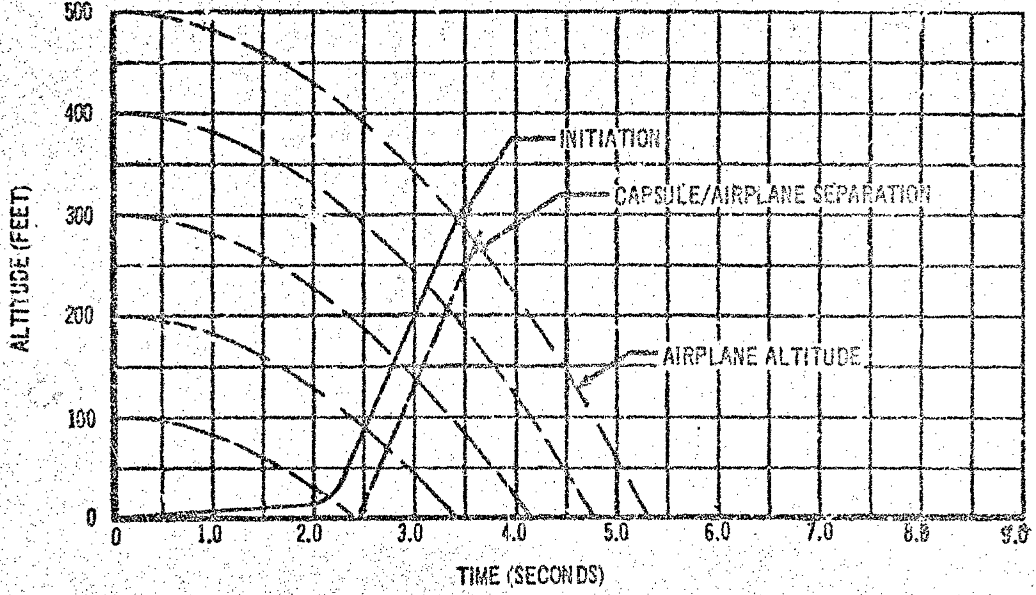


Figure 211. Four-Man Cockpit Pod Capsule Landing and Takeoff Emergency Minimum Escape Altitude – 0.1 g Pushover

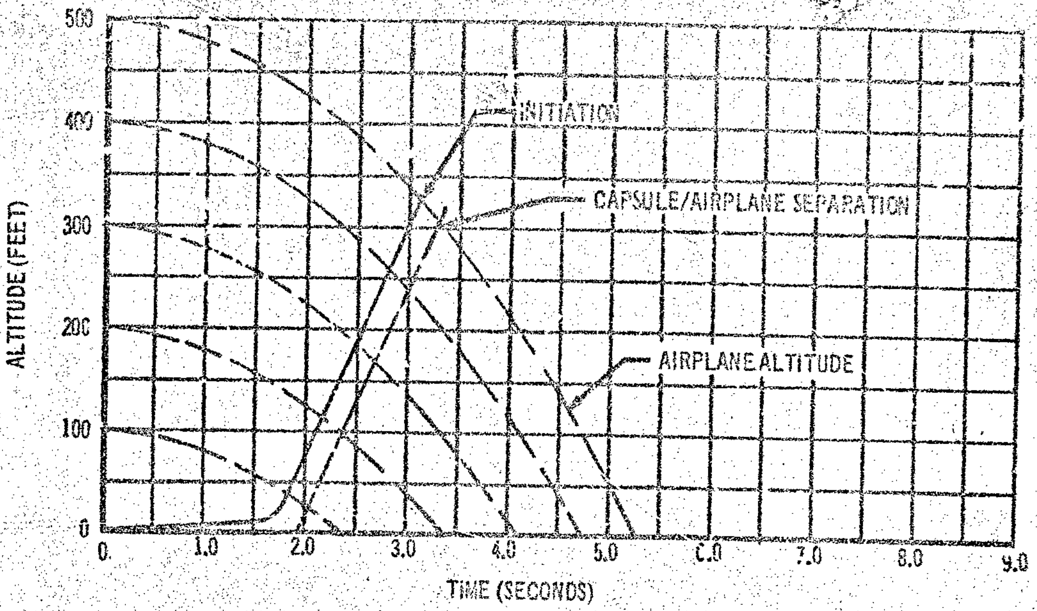


Figure 212. Four-Man Separable Nose Capsule Landing and Takeoff Emergency Minimum Escape Altitude –0.1 g Pushover

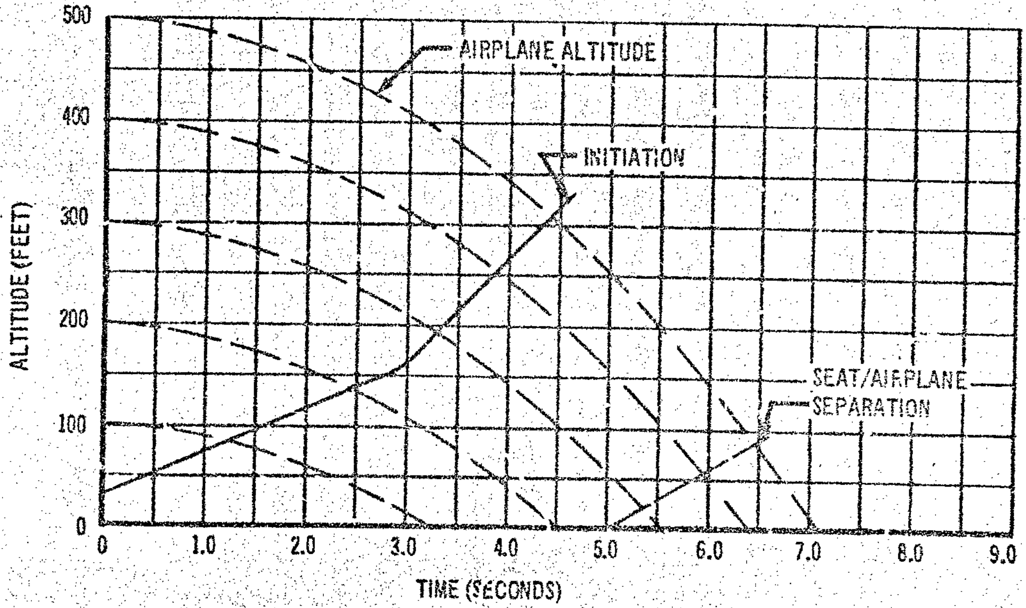


Figure 213. Four-Man Vehicle Landing and Takeoff Emergency Open Ejection Seat Minimum Escape Altitude 0.4 g Pushover

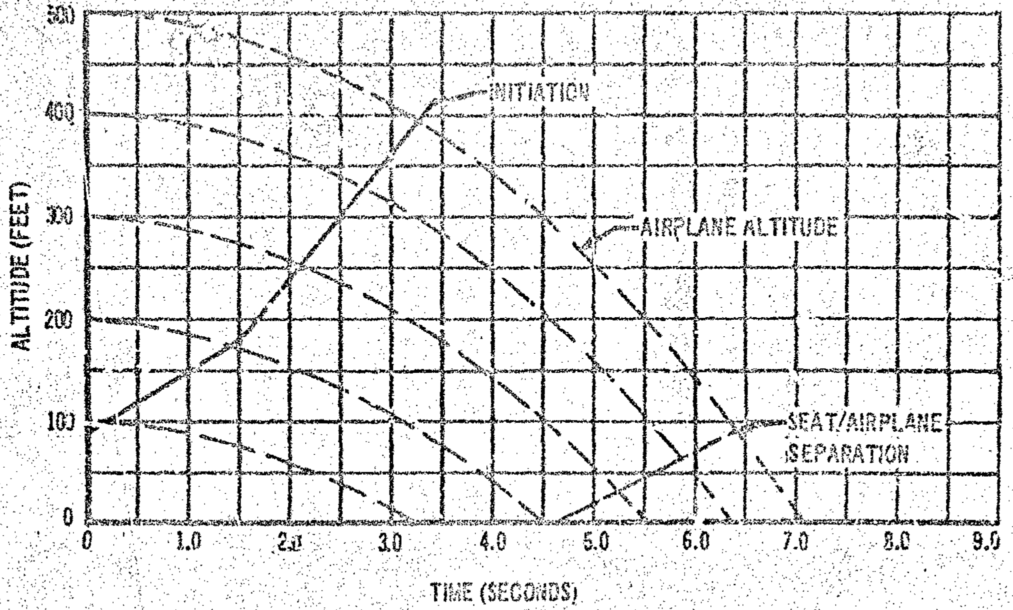


Figure 214. Four–Man Vehicle Landing and Takeoff Emergency Encapsulated Ejection Seat Minimum Escape Altitude 0.4 g Pushover

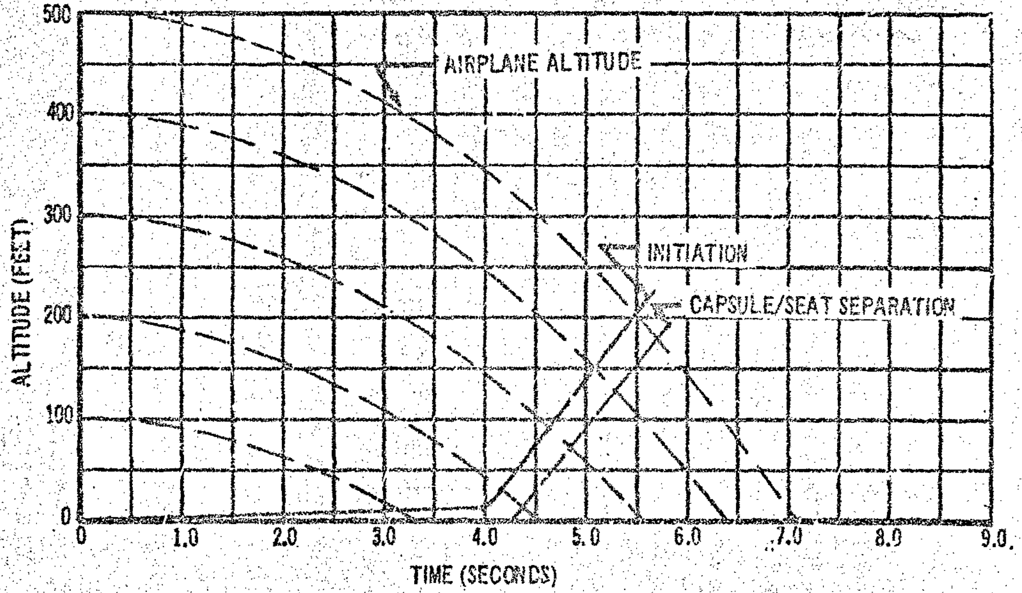


Figure 215. Four–Man Cockpit Pod Capsule Landing and Takeoff Emergency Minimum Escape Altitude 0.4 g Pushover

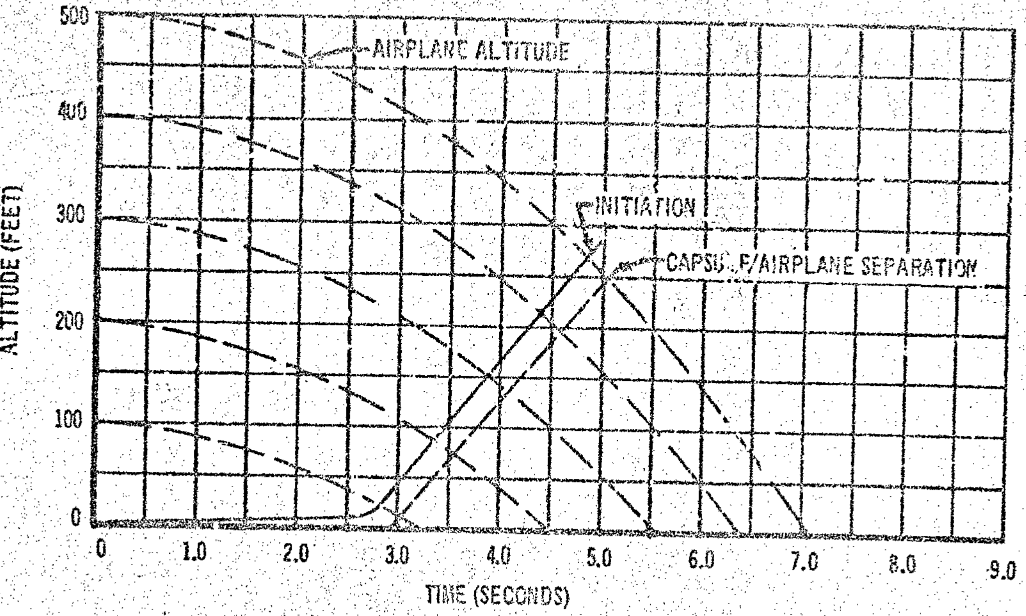


Figure 216. Four-Man Separable Nose Capsule Landing and Takeoff Emergency Minimum Escape Altitude 0.4 g Pushover

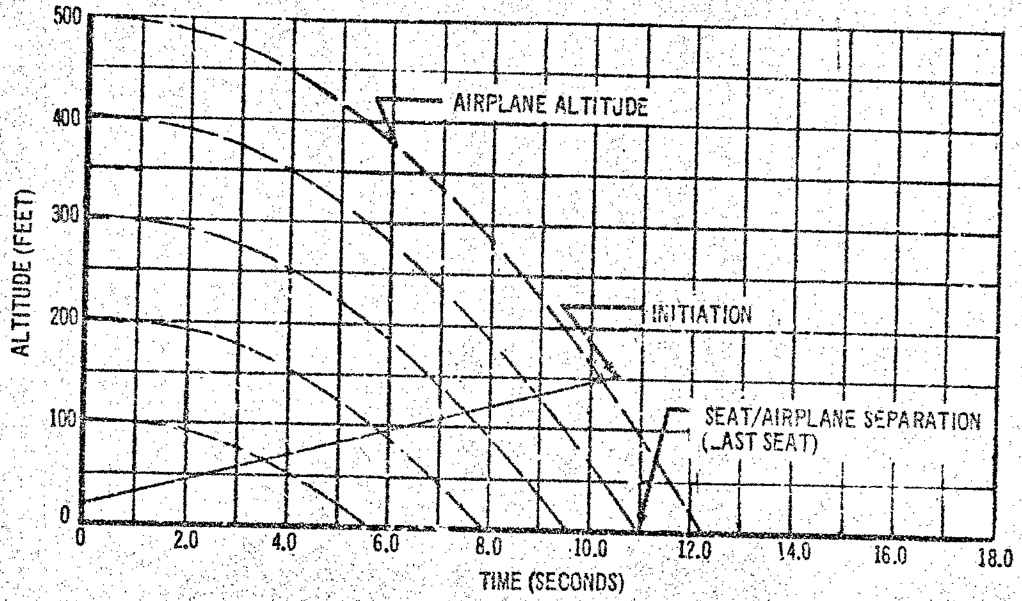


Figure 217. Four-Man Vehicle Landing and Takeoff Emergency Open Ejection Seat Minimum Escape Altitude 0.8 g Pushover

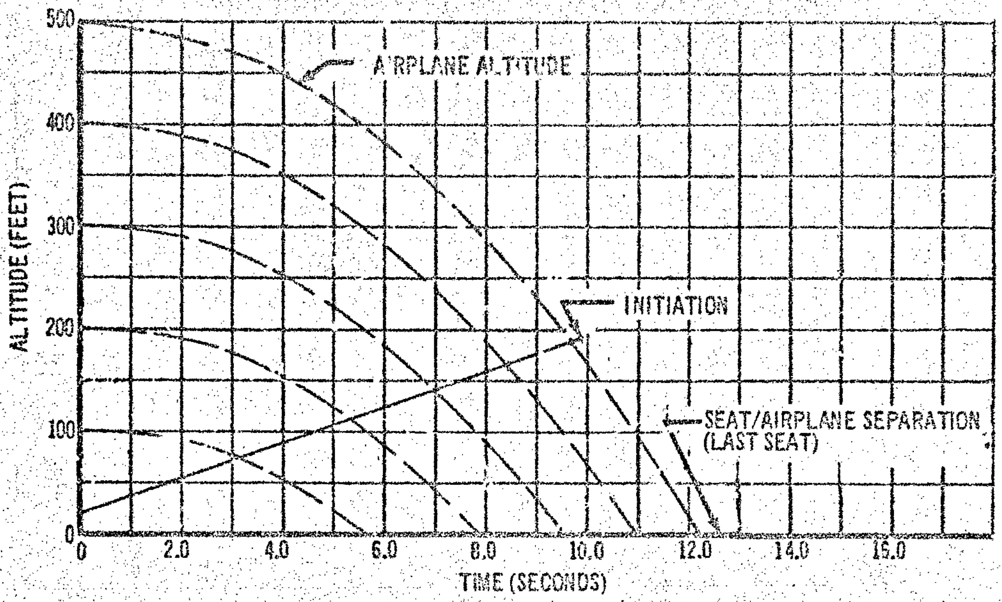


Figure 218. Four-Man Vehicle Landing and Takeoff Emergency Encapsulated Ejection Seat Minimum Escape Altitude 0.8 g Pushover

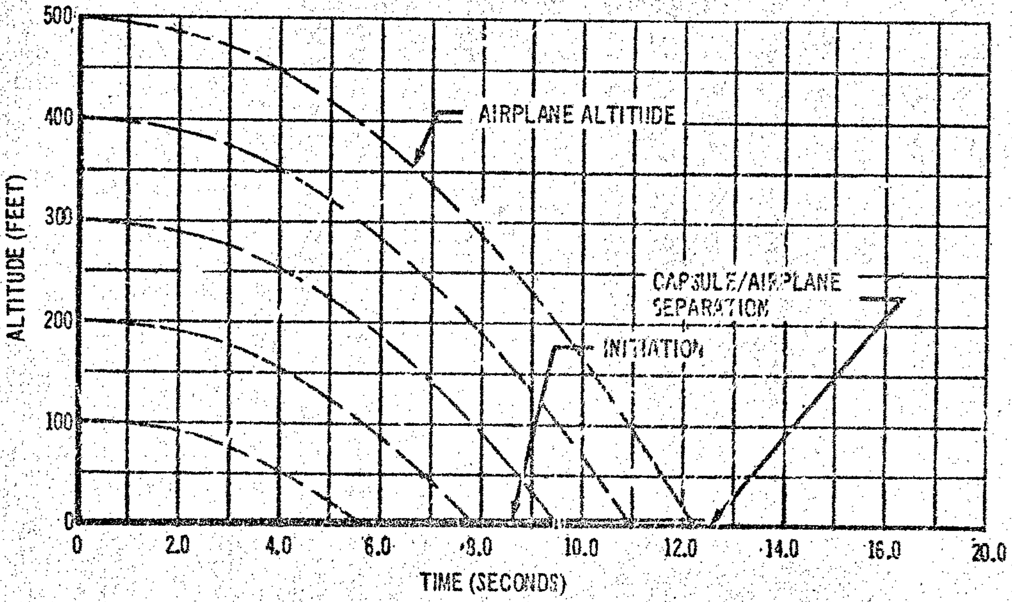


Figure 219. Four-Man Cockpit Pod Capsule Landing and Takeoff Emergency Minimum Escape Altitude 0.8 g Pushover

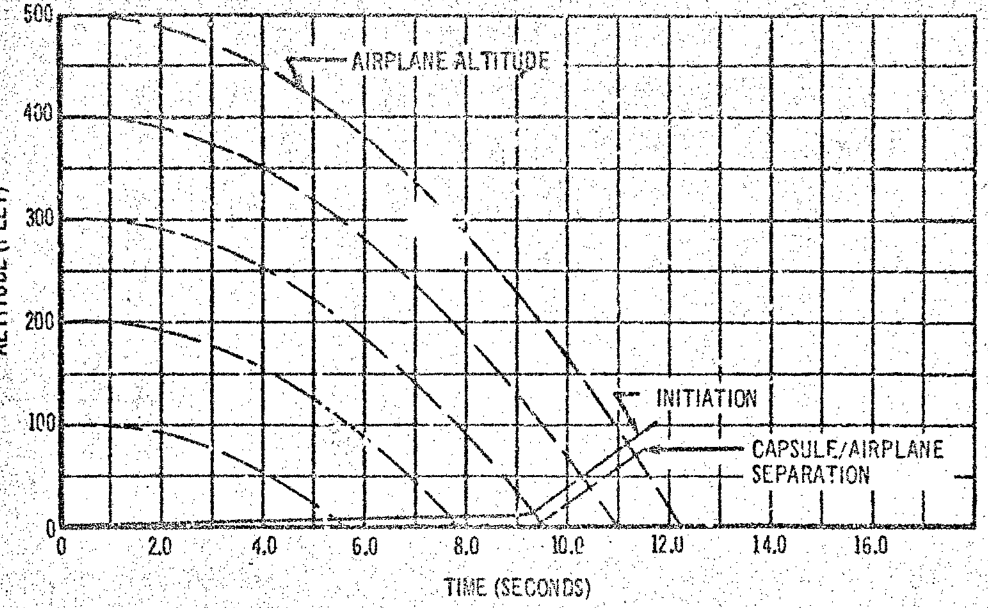


Figure 220. Four-Man Separable Nose Capsule Landing and Takeoff Emergency Minimum Escape Altitude 0.8 g Pushover

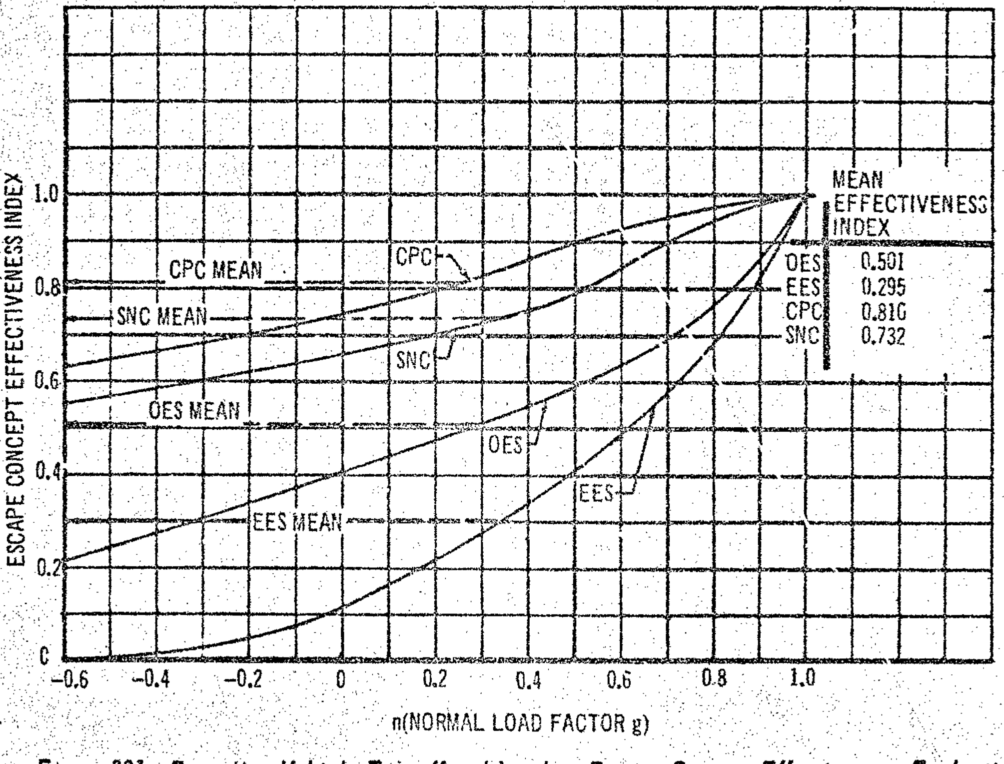


Figure 221. Four-Man Vehicle Takeoff and Landing Escape Concept Effectiveness Evaluation

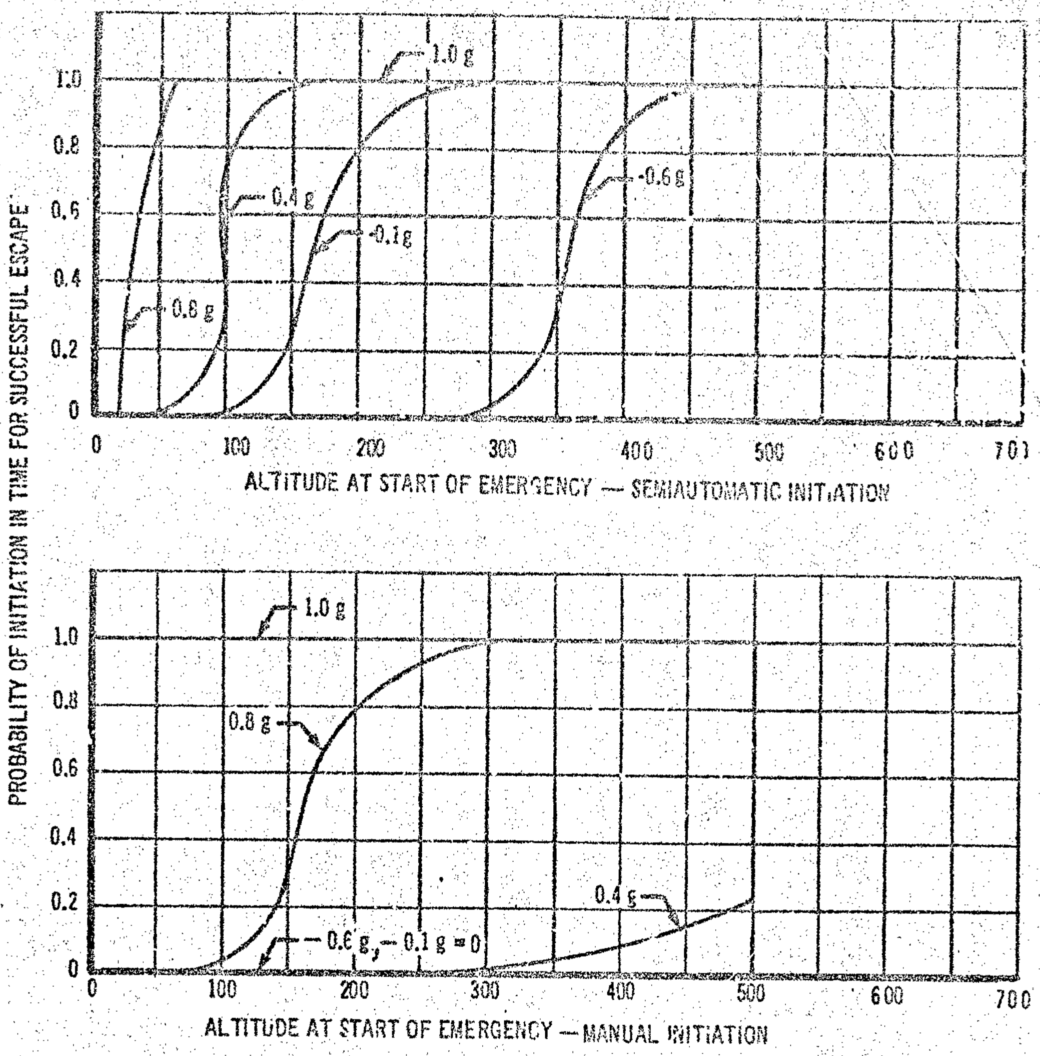


Figure 222. Probability of Successful Escape Versus Altitude for Four-Man Vehicle Open Ejection Seats – Takeoff or Landing Emergency

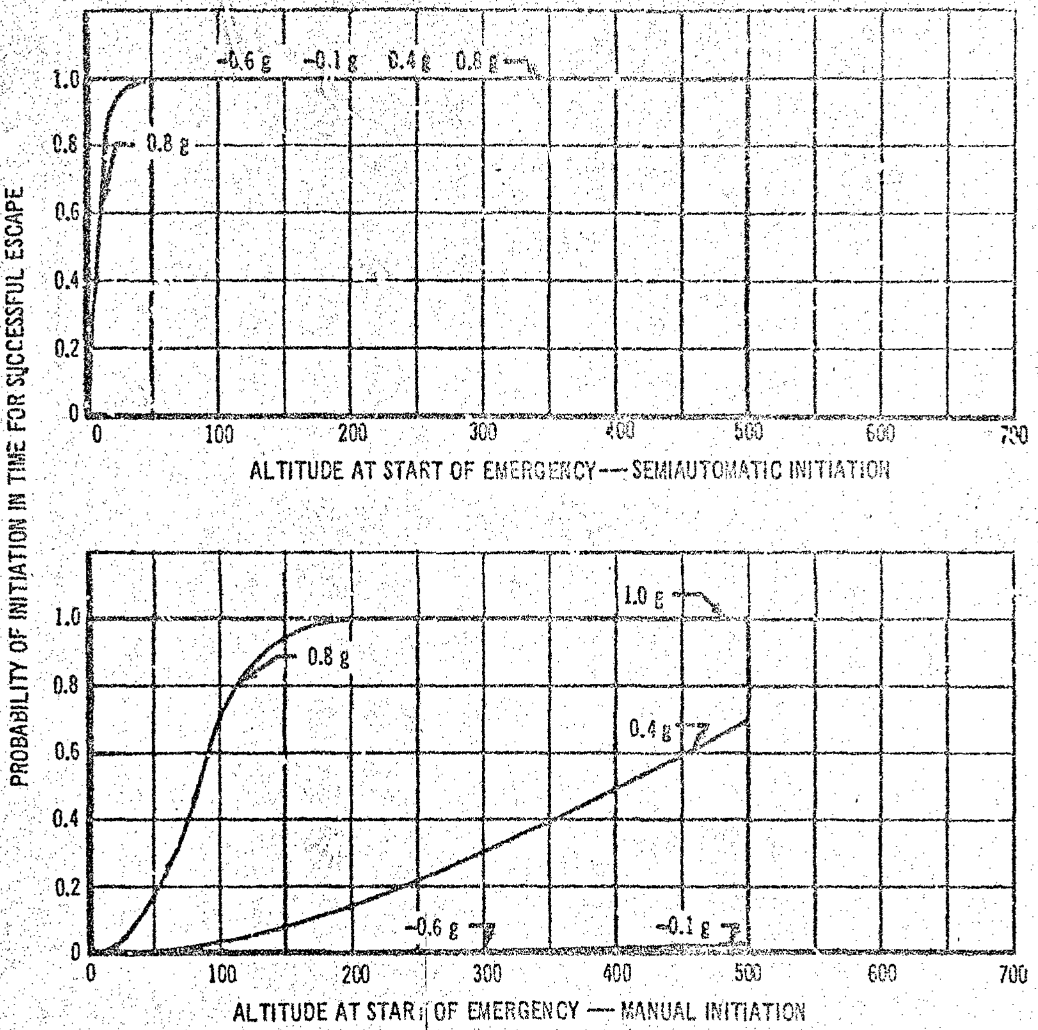


Figure 223. Probability of Successful Escape Versus Altitude for Four-Man Vehicle Cockpit Pod Capsule – Takeoff or Landing Emergency

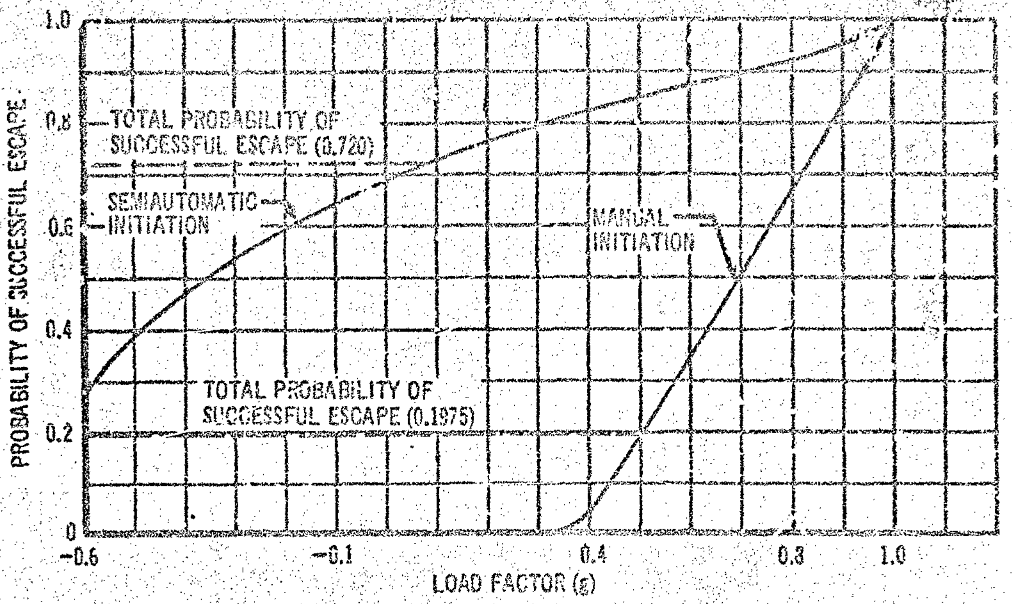


Figure 224. Probability of Successful Escape Versus Pushover Load Factor Four-Man Vehicle Open Ejection Seats – Takeoff or Landing Emergency

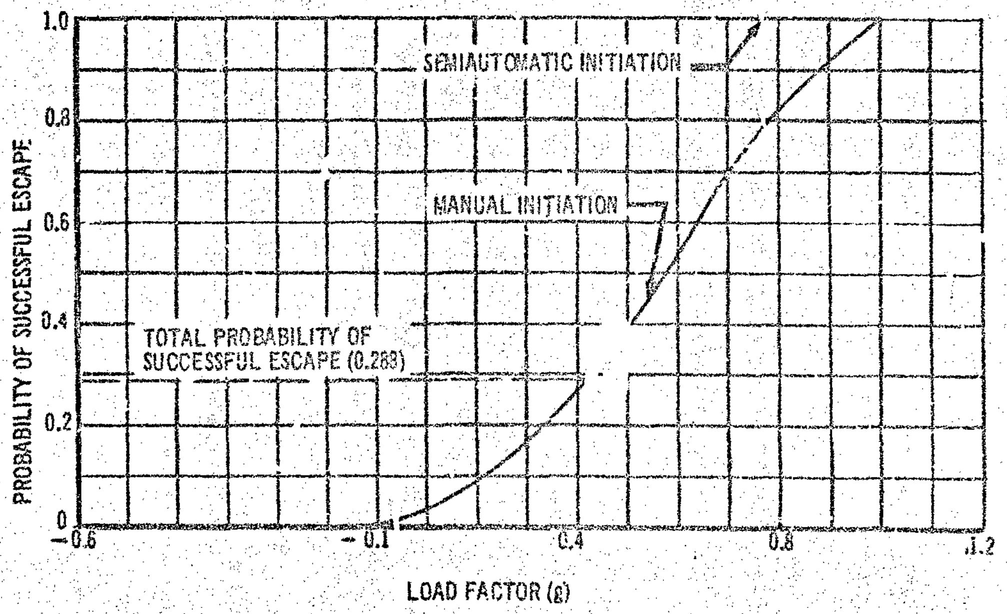


Figure 225. Probability of Successful Escape Versus Pushover Load Factor Four-Man Vehicle Cockpit Pod Capsule – Takeoff or Landing Emergency

3. LOW-ALTITUDE DASH

a. Escape Conditions

Emergency flight situations, representative of the escape conditions that might exist during low-altitude dash, were established as a basis for evaluation and comparison of the effectiveness of the various escape concepts.

For these analyses, the low-altitude dash flight regime was considered to range from 200 to 500 feet above the terrain and to encompass a speed range from Mach 0.9 to 1.2. Emergency flight conditions with respect to airplane velocity, altitude, and descent angle were computed for various situations from level flight to a maximum pushover structural limit of -3.0g. Figures 226 227, and 228 show the low-altitude dash emergency flight conditions for +1.0g (level flight), 0g, -1.0g, -2.0g, and -3.0g pushovers for initial airplane speeds of Mach 0.9, 1.1, and 1.2, respectively.

b. Escape Concept Effectiveness

Escape concept effectiveness analyses were accomplished for the three-man combined capability vehicle and the four-man supersonic low-altitude dash vehicle. Effectiveness indexes were determined for each escape concept relative to each of the normal load factor pushover g and velocity situations defined on Figures 226, 227, and 228. To obtain a mean overall effectiveness index for each concept, integration procedures involving the use of digital computers are used to sum and average the escape concept effectiveness indexes throughout the low-altitude dash speed and altitude flight regime and range of pushover g's.

The method of determining the escape concept effectiveness index for each flight condition is similar to that shown in Figure 127 and described in Sections V.1.b and V.2.b.

Figures 229 through 280 show data pertaining to escape concept effectiveness determinations for the three-man combined capability vehicle. Figures 229 through 244 show the escape concept capabilities relative to emergency situations originating at altitudes between 200 and 500 feet and Mach 0.9, as defined in Figure 226. Figures 245 through 260 show the escape concept capabilities for escape conditions at Mach 1.1 as defined in Figure 227. Figures 261 through 276 show the escape capability data for the conditions at Mach 1.2, as defined in Figure 228. For these figures, escape concept capability data from Section III were used to define the altitude versus time limit for separation of the seats or capsules required for successful recovery (see Figure 127). Escape initiation lines were constructed by taking into account the time required for preseparation and sequencing requirements. These are: 0.2 second for the cockpit pod and separable nose capsule concepts; 1.56 seconds for the open ejection seat concept; and 2.65 seconds for the encapsulated ejection seat concept. The longer times for the open seats and encapsulated seats are primarily due to ejection sequencing required for all three of the crewmembers to clear the aircraft.

Figures 277, 278, and 279 show the escape concept effective indexes, as determined from the data of Figures 229 through 276, plotted versus airplane pushover load factor for Mach 0.9, 1.1, and 1.2. Figure 280 shows a plot of the mean escape concept effectiveness indexes versus Mach number derived from summing and averaging data for the complete range of pushover g from +1g to -3.0g from Figures 277, 278, and 279. Also listed on the figure is the mean overall effectiveness index for each escape concept for the entire low-altitude dash flight regime. This is obtained by summing and averaging the effectiveness index data on the figure for the complete Mach number range from 0.9 to 1.2.

This analysis was accomplished on the basis of the escape concepts' capabilities to recover the crewmembers prior to ground impact. For the open ejection seat concept, the mean overall effectiveness index listed on Figure 265 has been reduced by the factor 0.175 to account for its reduced capability at high speed due to deceleration, windblast, and flailing fatalities (see Section V.4).

Figures 281 through 332 present data pertaining to the escape concept effectiveness analysis for the four-man supersonic dash vehicle. The method of analysis and sequence of data presentation is the same as described for the three-man vehicle. However, for the four-man vehicle the time required for pre-ejection and sequencing requirements is 2.06 seconds for open ejection seats and 3.15 seconds for encapsulated ejection seats.

The mean overall effectiveness indexes for each escape concept for the low-altitude dash flight regime are summarized in Table XII for both the three-man and four-man vehicle.

Table XII. Low Altitude Flight Regime Escape Concept Effectiveness Summary

Escape Concept	Low Altitude Dash Escape Effectiveness Index	
	Three-man Vehicle	Four-man Vehicle
Open Ejection Seats	0.058	0.042
Encapsulated Ejection Seats	0.226	0.170
Cockpit Pod Capsule	0.938	0.928
Separable Nose Capsule	0.794	0.609

c. Automatic Detection and Initiation Evaluation

For emergencies occurring during high-speed low-altitude dash the time available for the pilot to detect and verify the emergency situation, make the decision to initiate escape, and to actuate the escape control is extremely critical. This section presents the results of an analysis to determine the probability of escape initiation in time for successful recovery of the crew for manual detection and initiation and for semiautomatic detection and initiation. Thus, the need for or benefits of automatic or semiautomatic systems may be assessed.

The method of analysis is similar to that described for the VTOL and conventional takeoff and landing flight regimes in Sections V.1.c. and V.2.c. Manual and semiautomatic initiation as used in this study are defined in Section V.1.c. Tables IX and X and Figures 190 and 191 define the estimated normal distribution curves for manual and for semiautomatic initiation relative to time from the start of the emergency situation. Figure 192 illustrates the method of determining the probability of escape initiation in time for successful recovery of the crew relative to altitude at the start of the emergency situation.

The four-man supersonic dash vehicle, and open ejection seats and cockpit pod capsule concepts were selected for use as a basis for this analysis. Successful recovery for each emergency situation was considered to include successful recovery of the entire crew. Therefore, for the open ejection seat concept, a successful recovery was considered one in which the last of the four crewmembers, in sequenced ejections, would be successfully recovered.

The probabilities of initiating escape in time for successful recovery relative to altitude at the beginning of the emergency were determined for each of the emergency situations defined on Figures 226, 227, and 228. For this analysis the escape concept capabilities with respect to each emergency situation are the same as those used in the escape concept effectiveness analysis. These are, for the open ejection seat, shown on Figures 281 through 284 for Mach number 0.9, Figures 297 through 300 for Mach number 1.1, and Figures 313 through 316 for Mach number 1.2. For the cockpit pod capsule they are shown on Figures 289 through 292 for Mach number 0.9, Figures 305 through 308 for Mach number 1.1, and Figures 321 through 324 for Mach number 1.2.

The probabilities of initiating escape in time for successful recovery are shown plotted versus altitude at the beginning of the emergency for each pushover g condition for Mach numbers 0.9, 1.1 and 1.2 on Figures 333, 334, and 335 for the open ejection seat concept and on Figures 336, 337, and 338 for the cockpit capsule concept. These figures include plots for both manual initiating and semiautomatic initiation.

The probabilities of initiating escape in time for successful recovery versus pushover g load factor for each speed condition are shown in Figures 339, 340, and 341 for open ejection seats and Figures 342, 343, and 344 for the cockpit pod capsule. These data were derived by determining the mean probability for the total altitude range of 200 to 500 feet for each g condition from data shown in Figures 333 through 338.

Figures 345 and 346 show the probability of successful recovery for both manual and semiautomatic initiation versus Mach number at start of emergency for the open ejection seat and cockpit pod capsule concepts. These data were derived by determining the mean probability for the entire range of pushover load factors from -3.0g to +1.0g from the data of Figures 339 through 344.

The overall mean probabilities of initiating successful escape for the entire low-altitude dash flight regime were derived from the data of Figures 345 and 346 and is indicated on the figures. This value for the open ejection seat concept has been reduced by the high speed survivability factor 0.175 (see Section V.4).

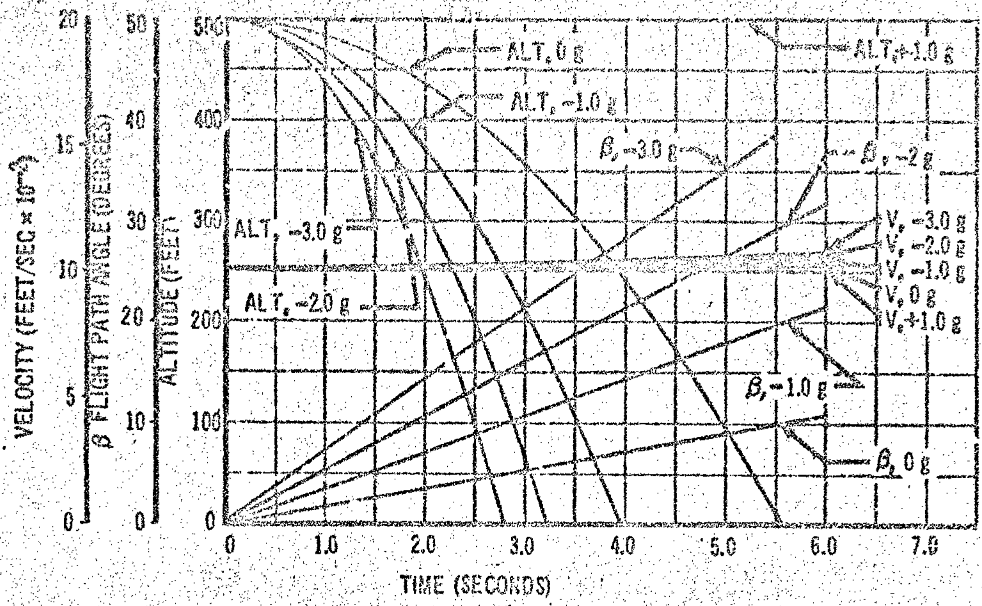


Figure 226. Escape Conditions for Low Altitude Dash Mach 0.9

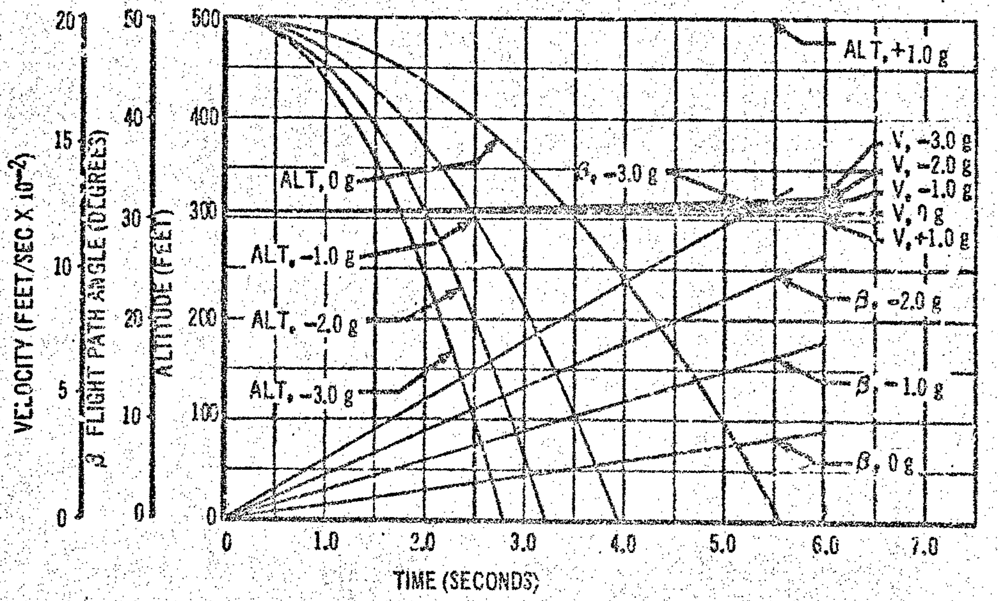


Figure 227. Escape Conditions for Low Altitude Dash Mach 1.1

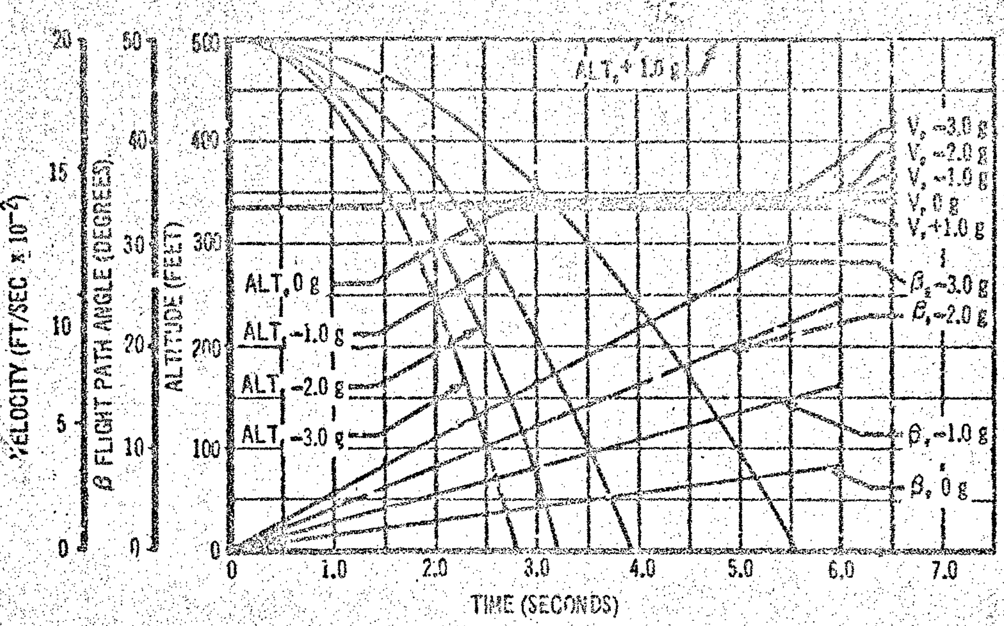


Figure 228. Escape Conditions for Low Altitude Dash Mach 1.2

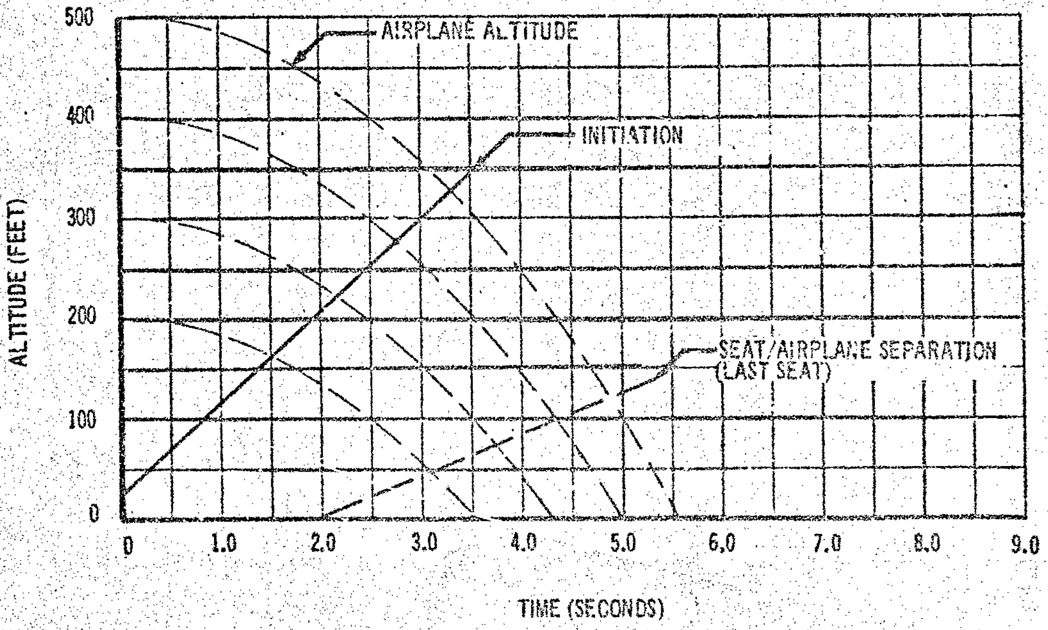


Figure 229. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Open Ejection Seat Minimum Escape Altitude Zero g Pushover

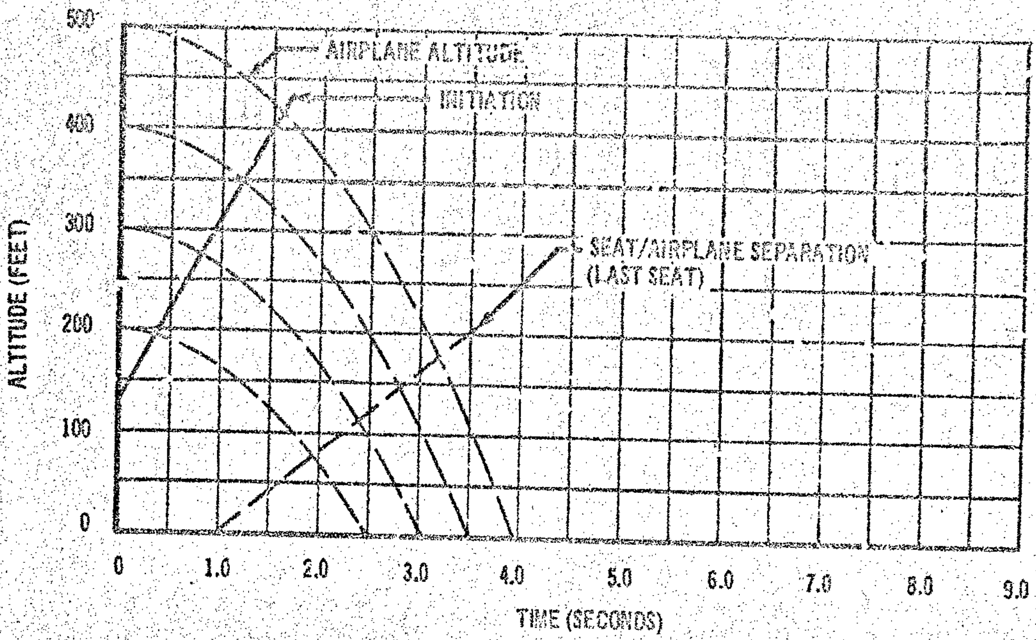


Figure 230. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Open Ejection Seat Minimum Escape Altitude –1.0 g Pushover

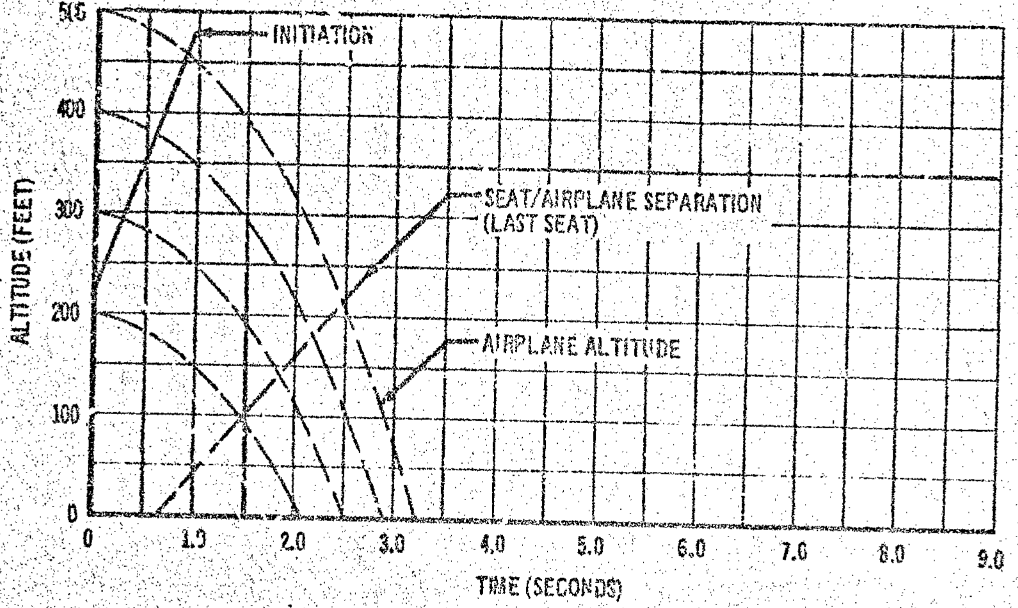


Figure 231. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Open Ejection Seat Minimum Escape Altitude –2.0 g Pushover

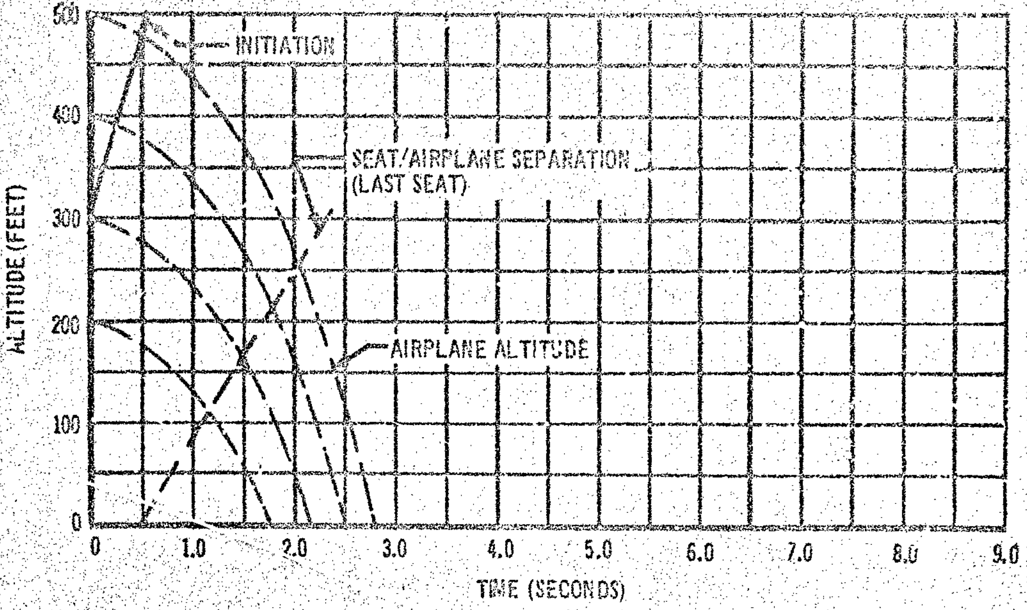


Figure 232. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Open Ejection Seat Minimum Escape Altitude -3.0 g Pushover

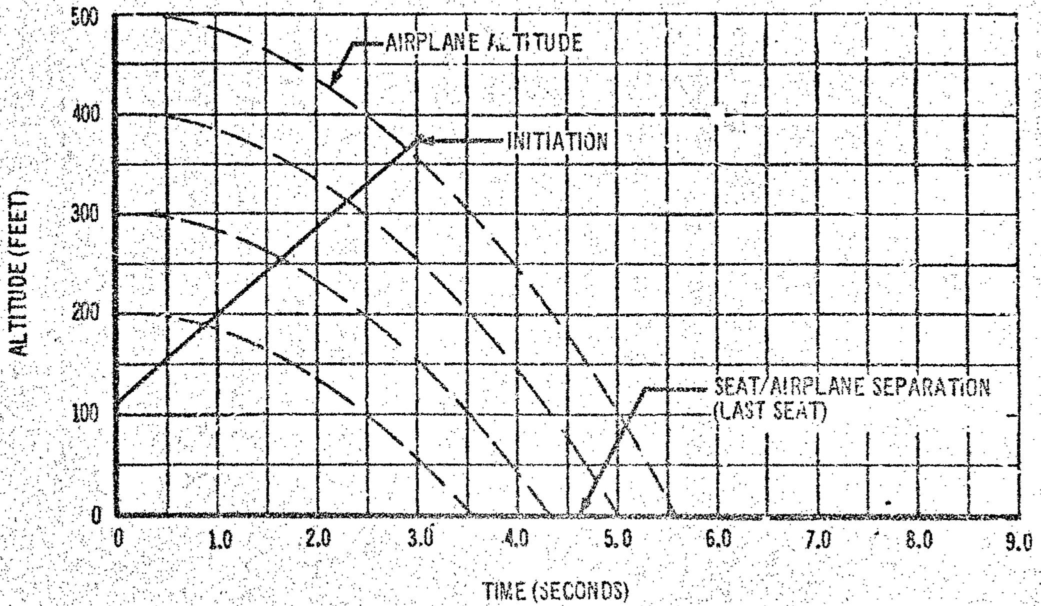


Figure 233. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude Zero g Pushover

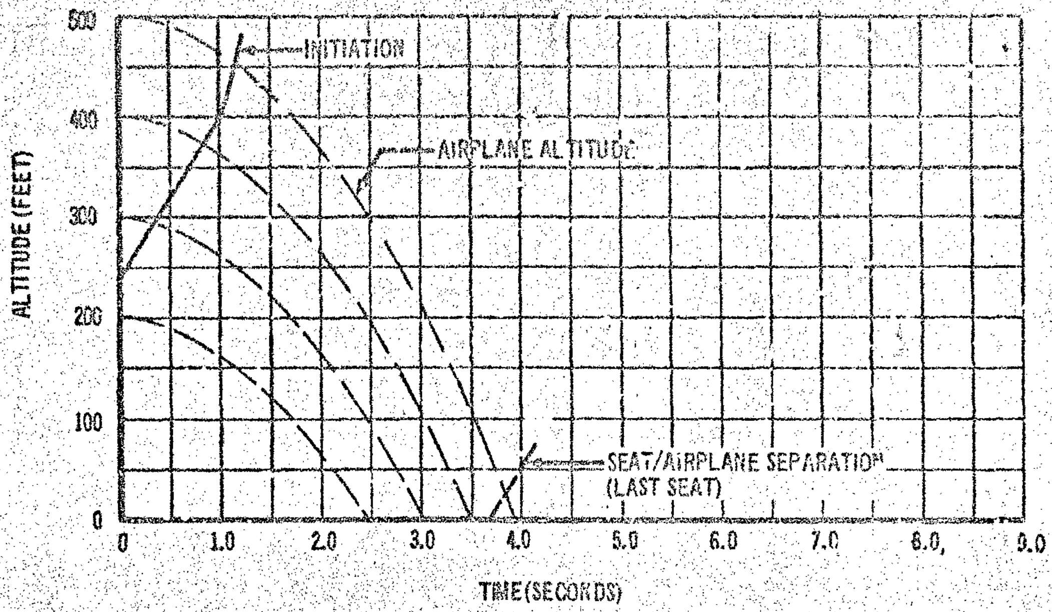


Figure 234. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude –1.0 g Pushover

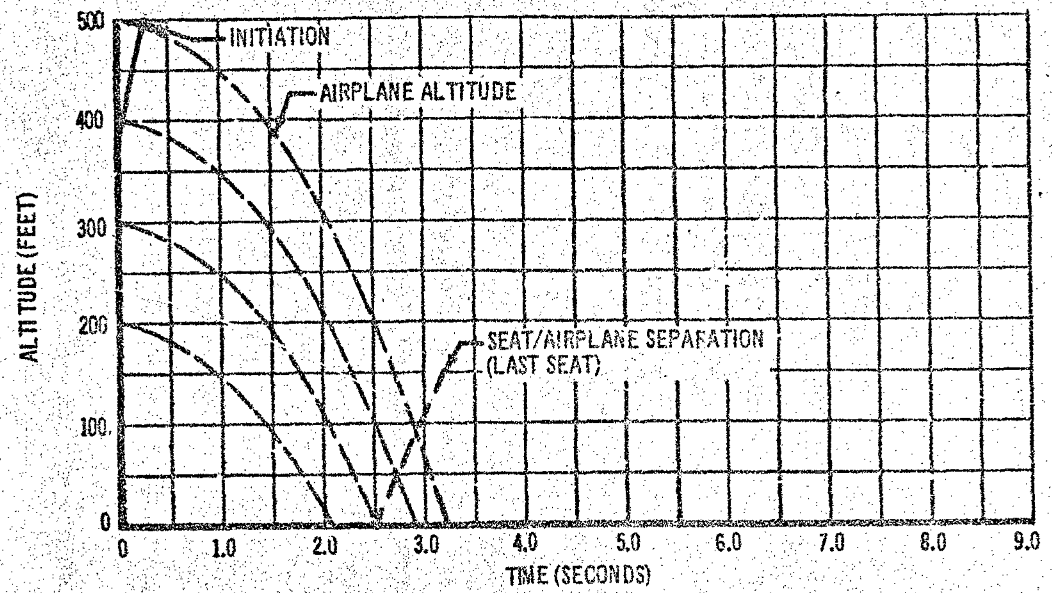


Figure 235. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude –2.0 g Pushover

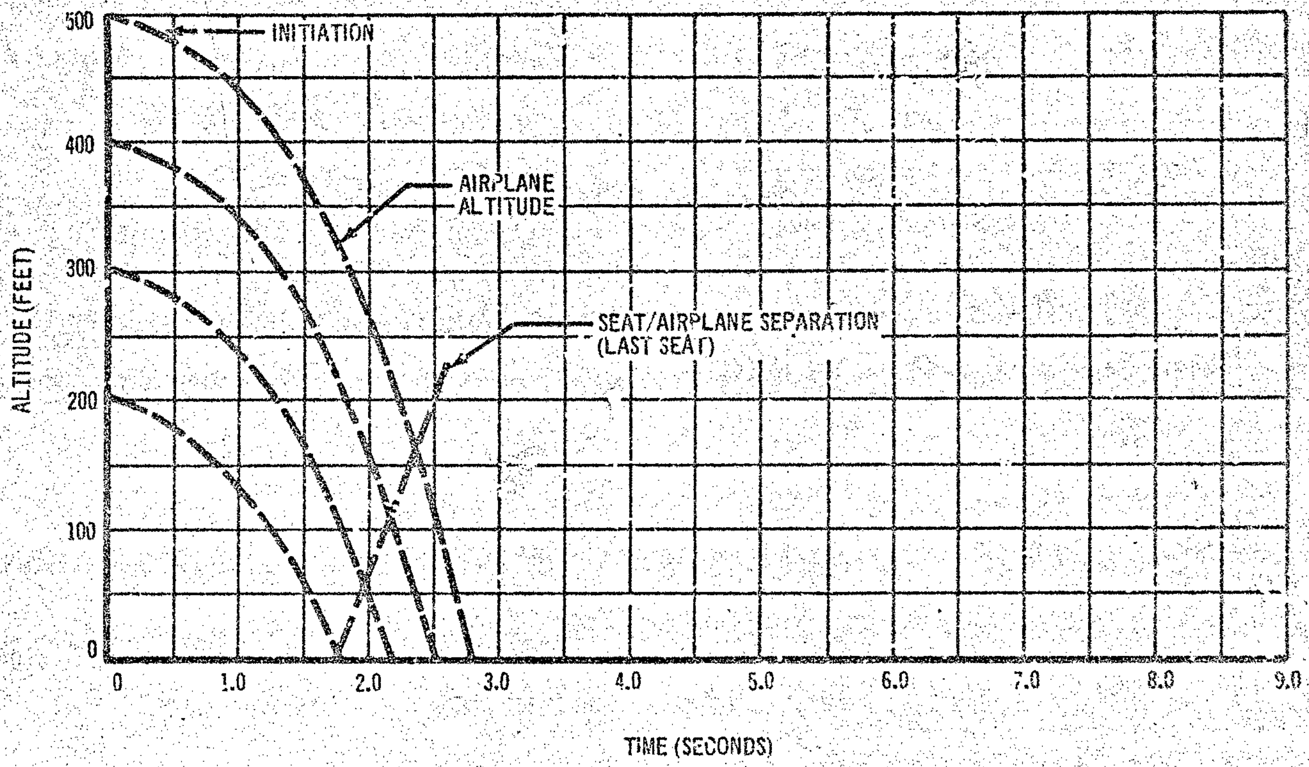


Figure 236. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude –3.0 g Pushover

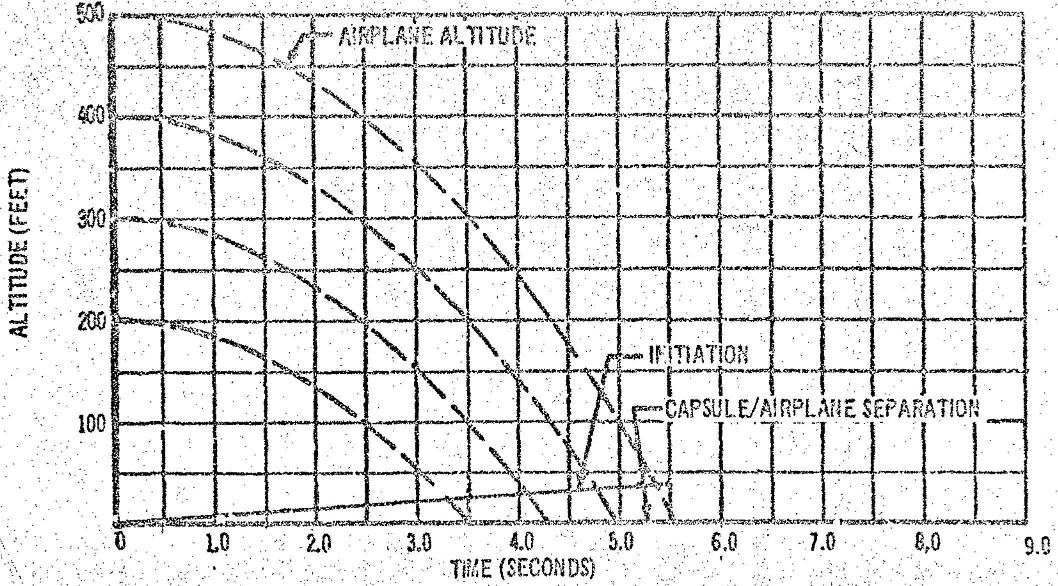


Figure 237. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude Zero g Pushover

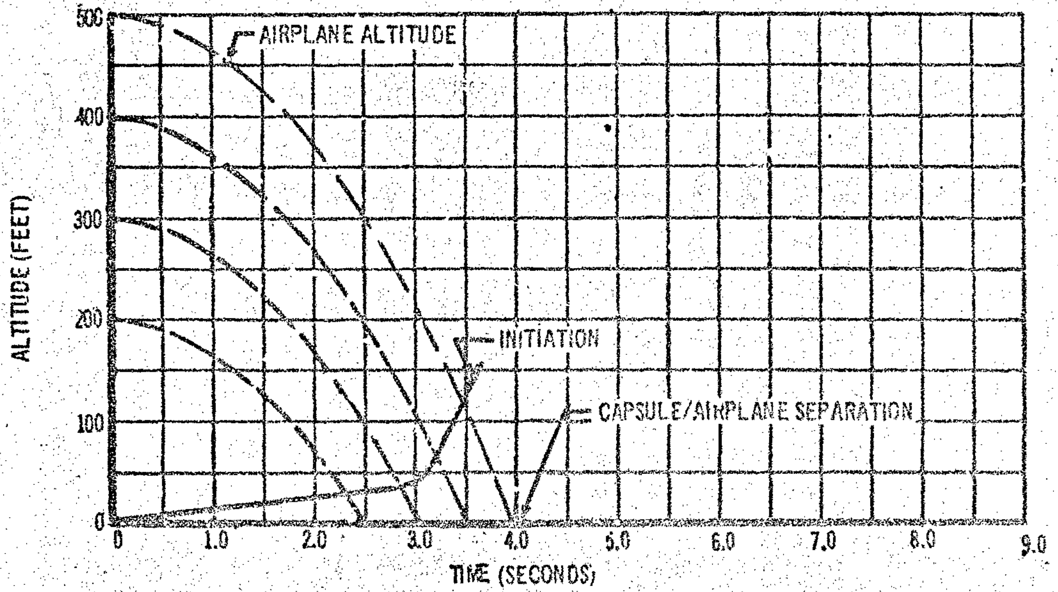


Figure 238. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude −1.0 g Pushover

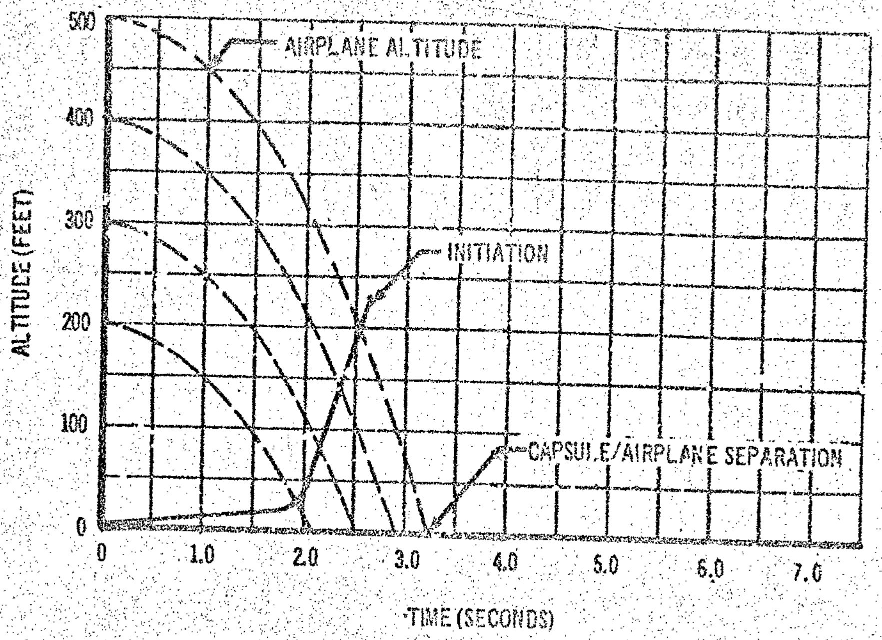


Figure 239. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude –2.0 g Pushover

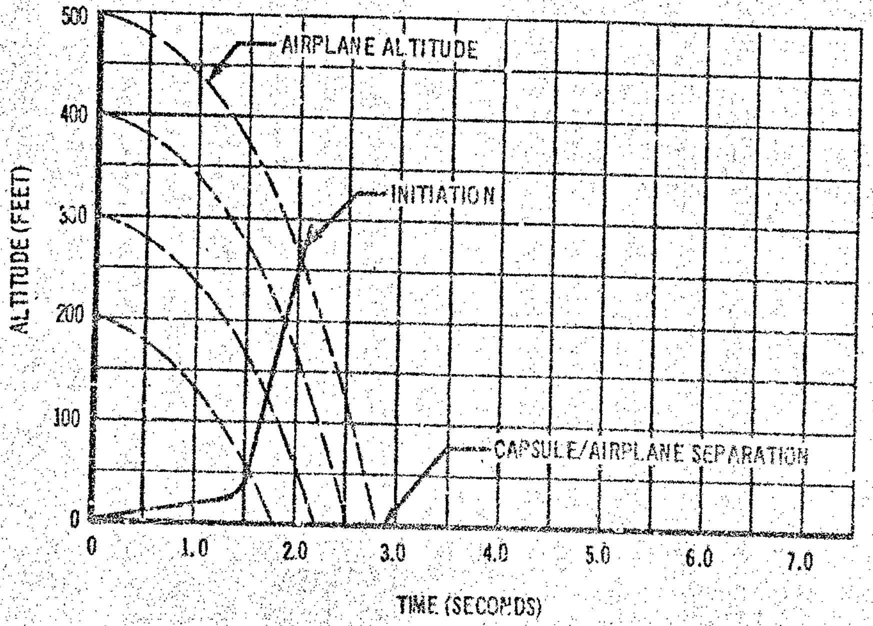


Figure 240. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude –3.0 g Pushover

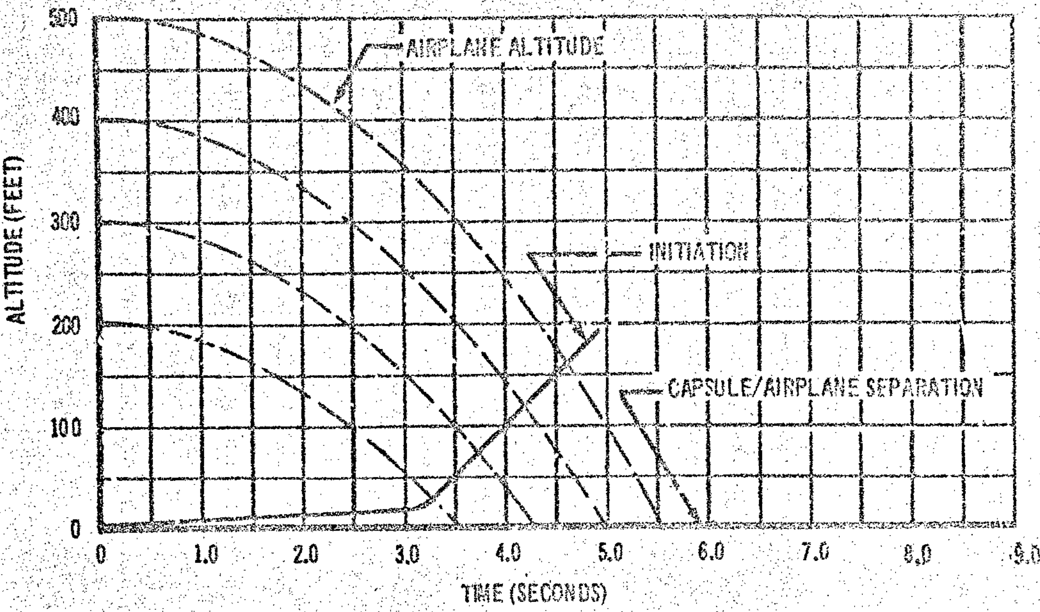


Figure 241. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Separable Nose Capsule Minimum Escape Altitude Zero g Pushover

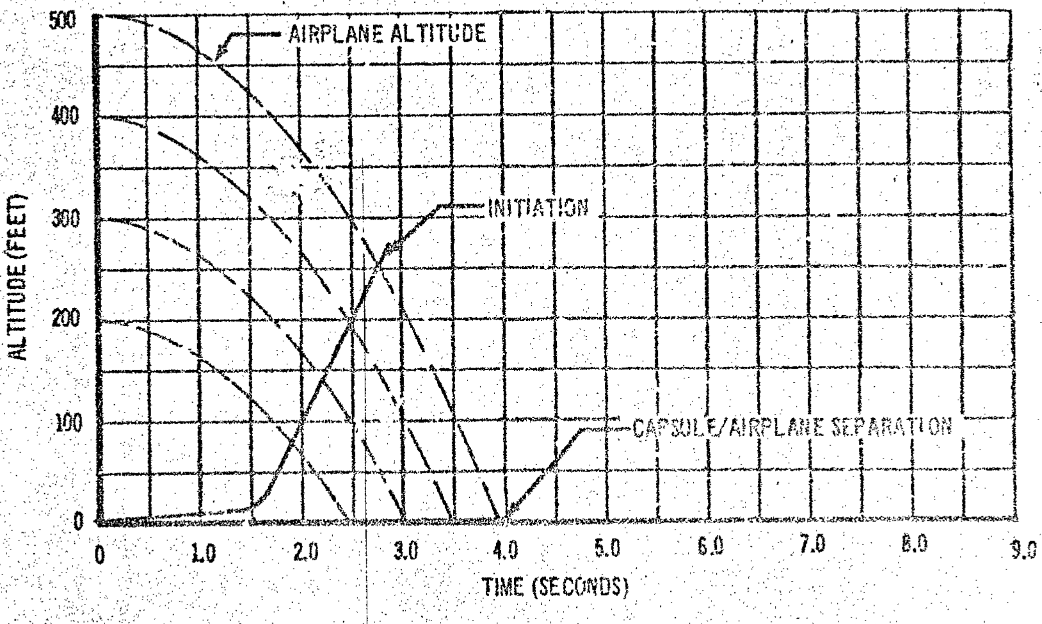


Figure 242. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Separable Nose Capsule Minimum Escape Altitude −1.0 g Pushover

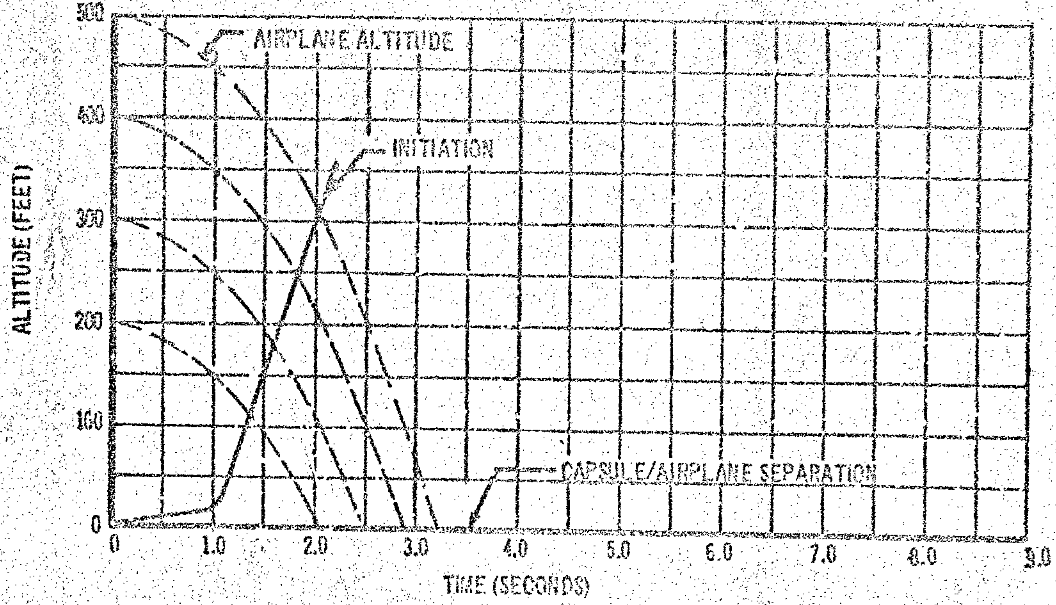


Figure 243. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Separable Nose Capsule Minimum Escape Altitude ~2.0 g Pushover

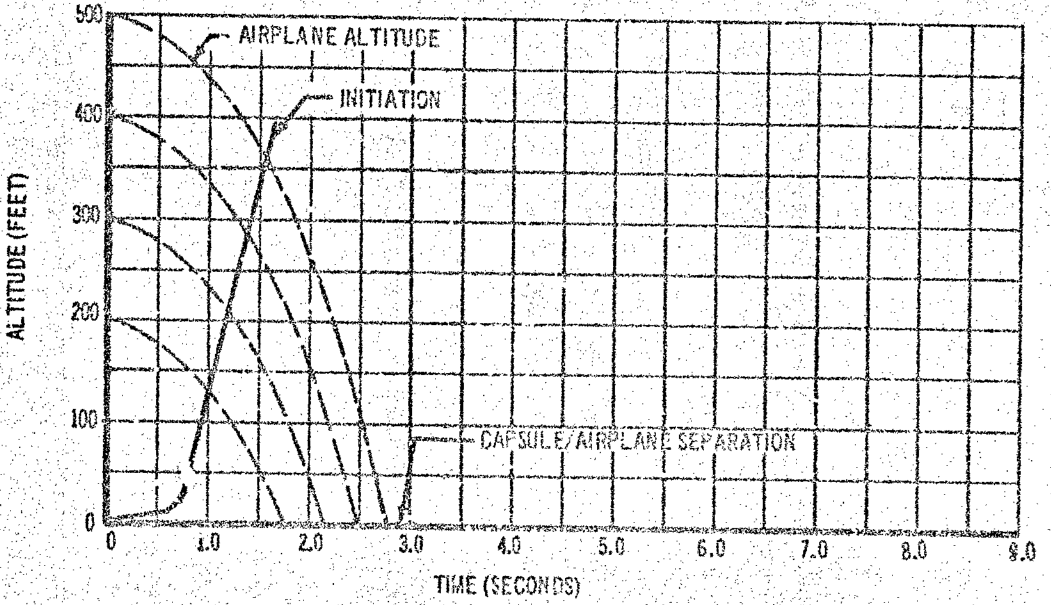


Figure 244. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 0.9 Separable Nose Capsule Minimum Escape Altitude ~3.0 g Pushover

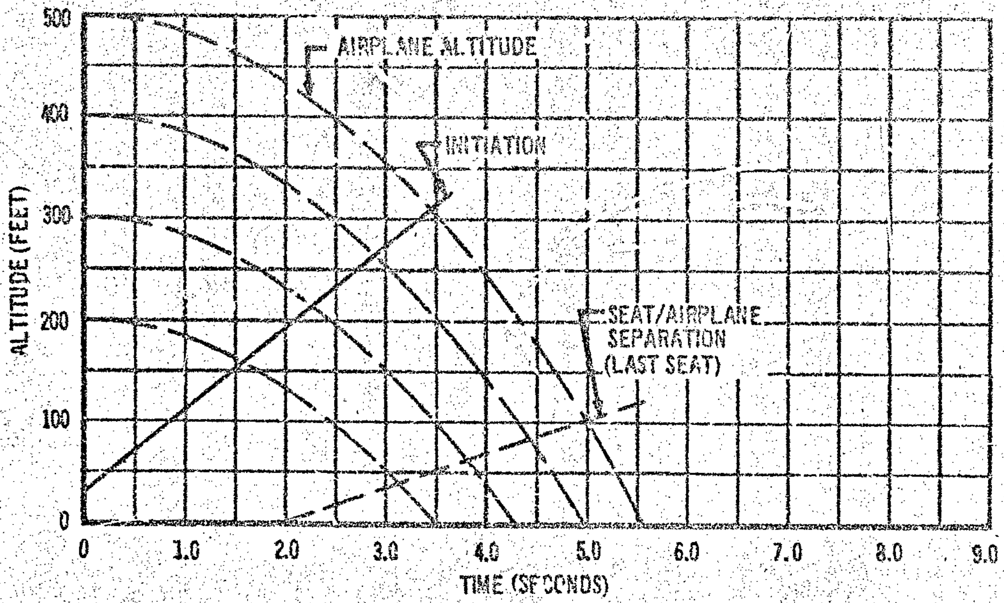


Figure 245. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Open Ejection Seat Minimum Escape Altitude Zero g Pushover

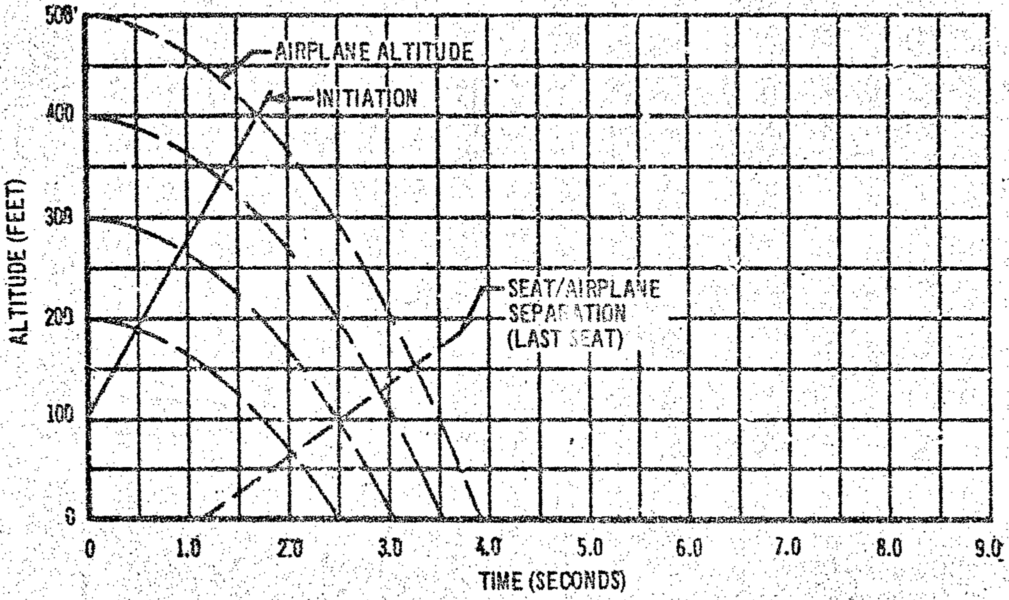


Figure 246. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Open Ejection Seat Minimum Escape Altitude -1.0 g Pushover

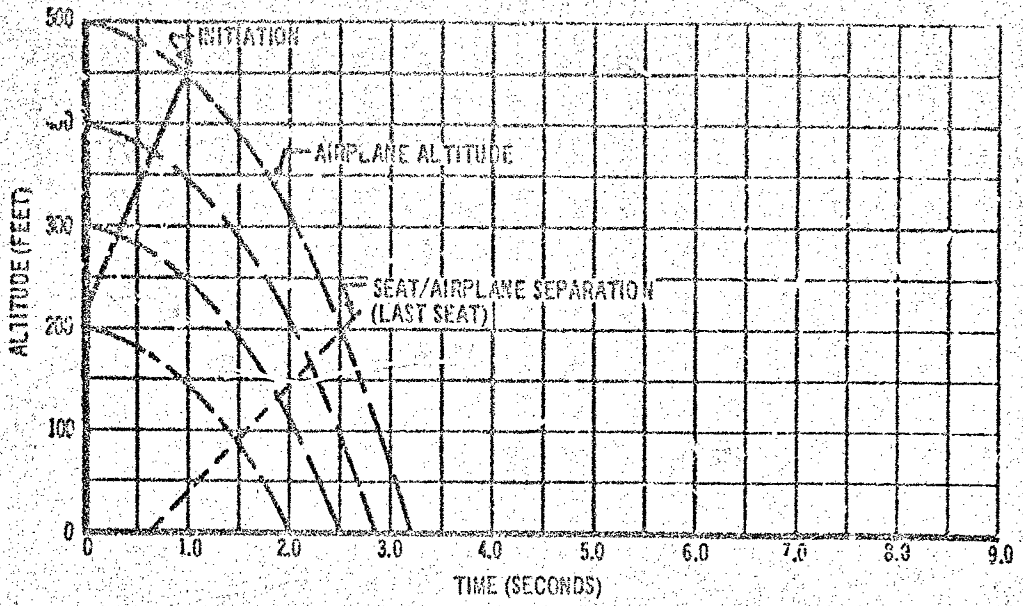


Figure 247. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Open Ejection Seat Minimum Escape Altitude –2.0 g Pushover

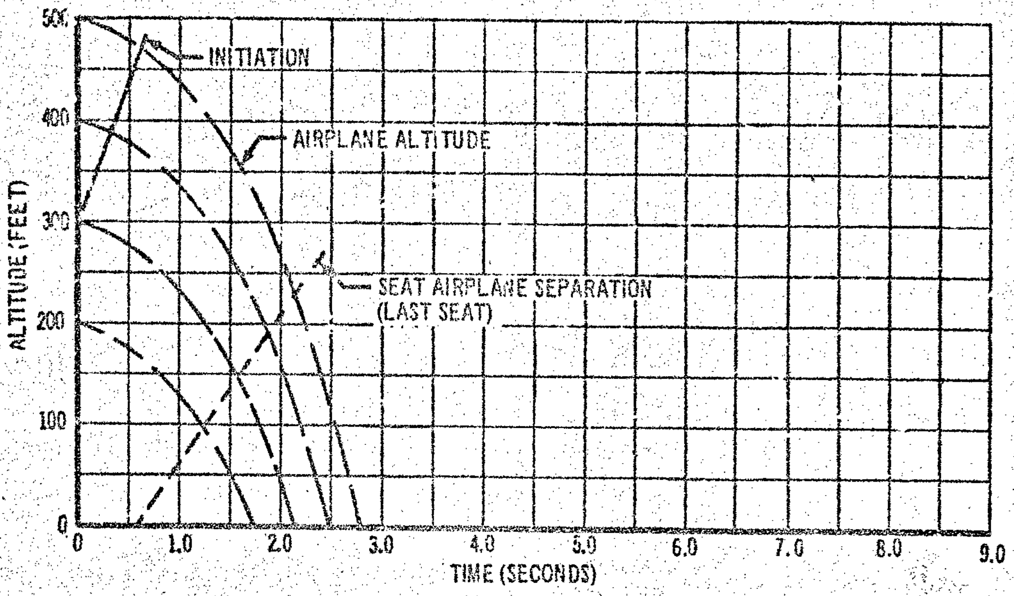


Figure 248. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Open Ejection Seat Minimum Escape Altitude –3.0 g Pushover

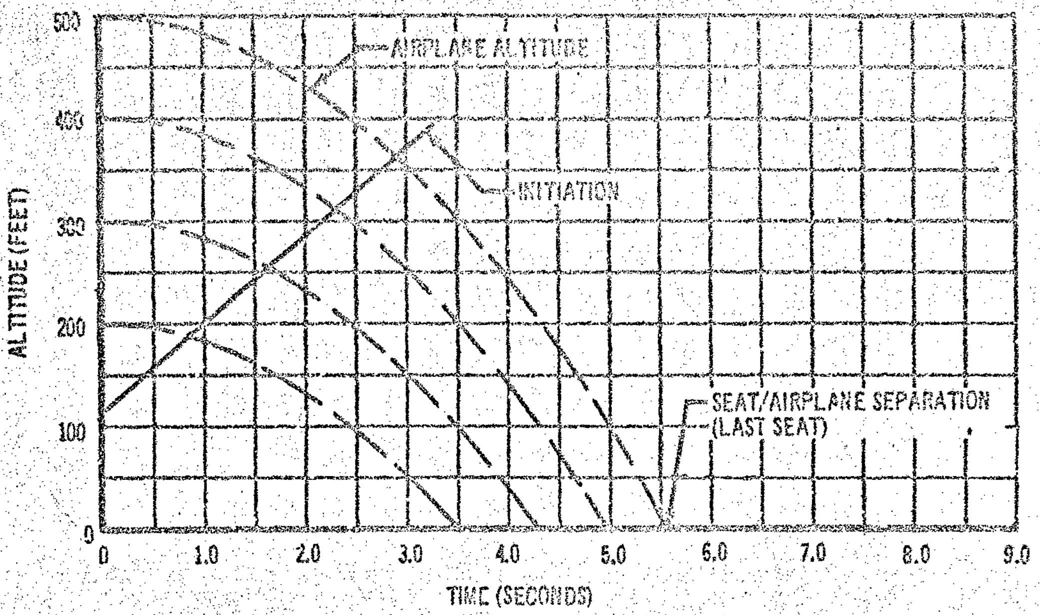


Figure 249. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude Zero g Pushover

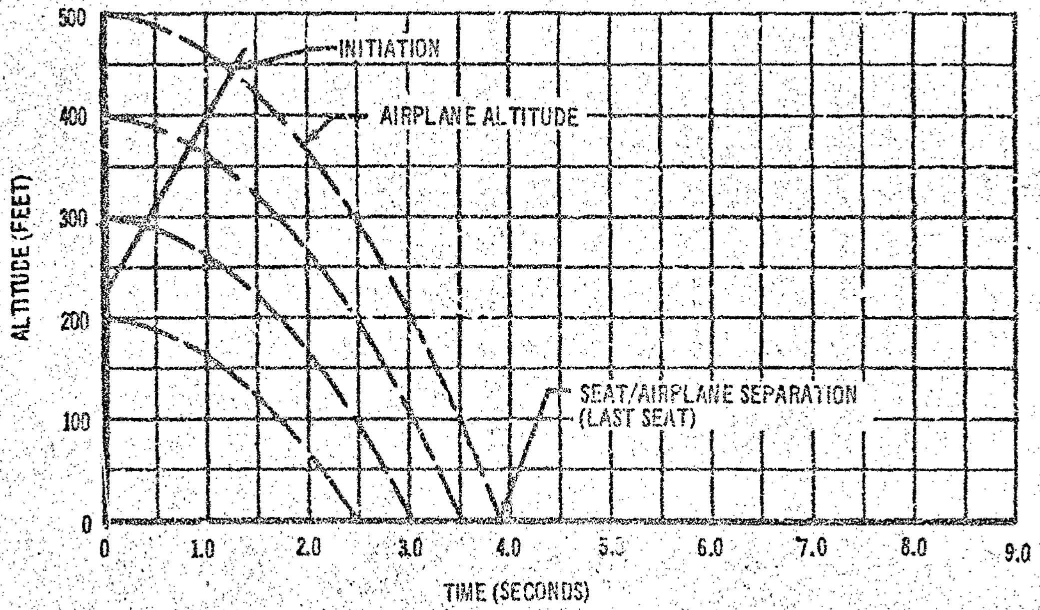


Figure 250. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude -1.0 g Pushover

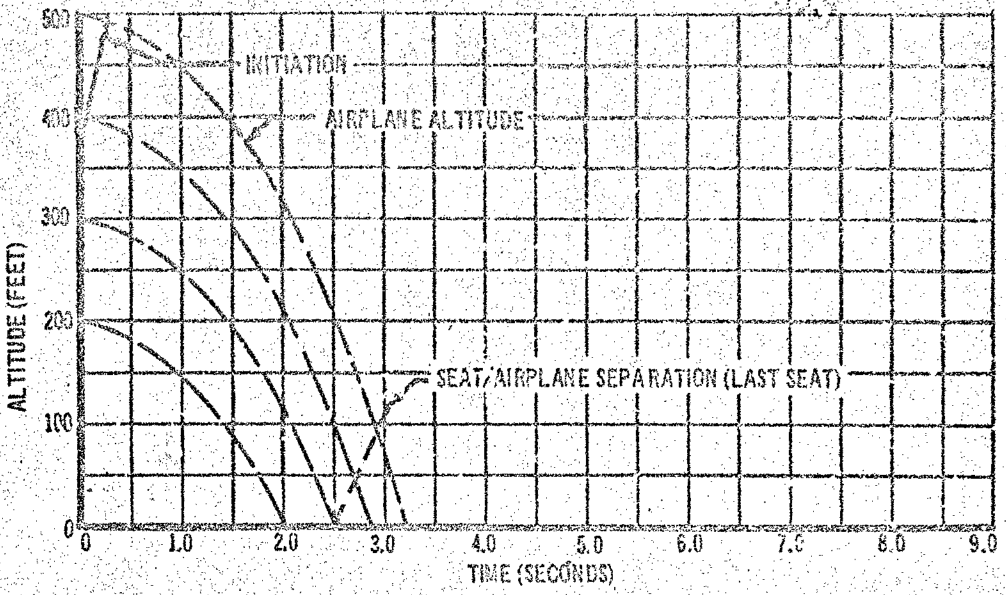


Figure 251. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude -2.0 g Pushover

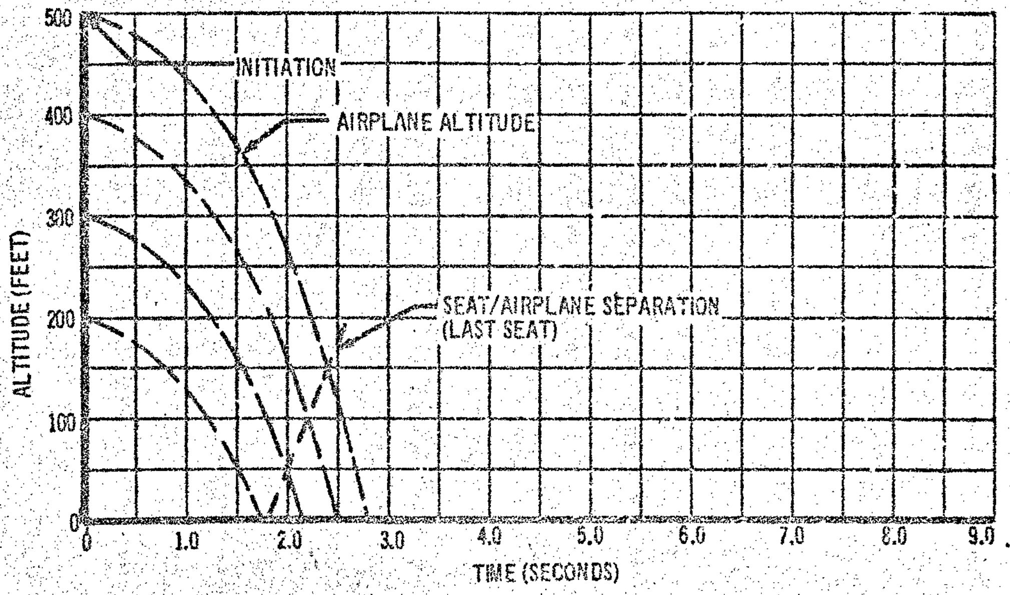


Figure 252. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude -3.0 g Pushover

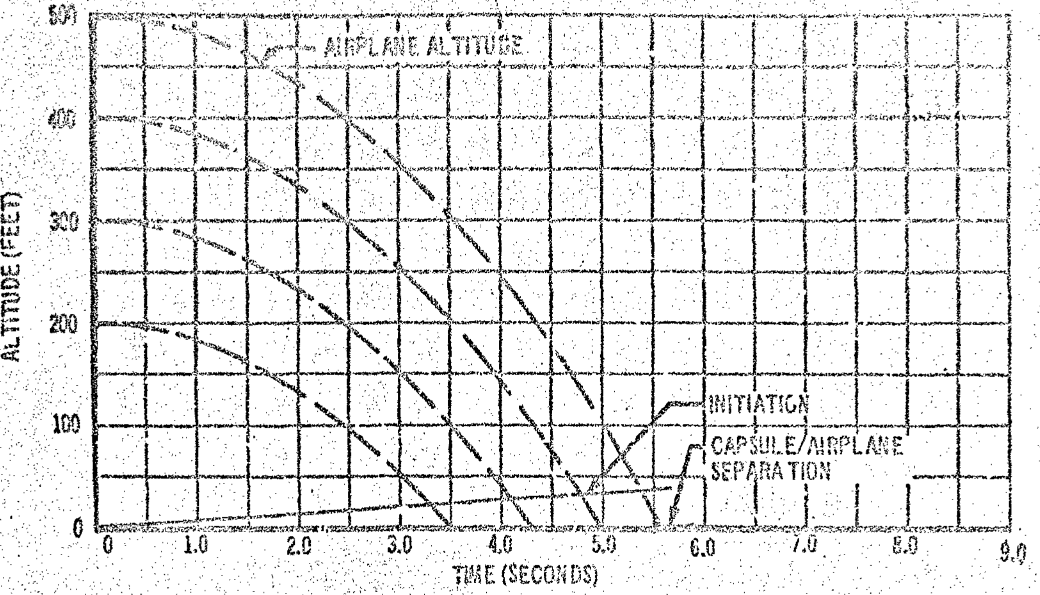


Figure 253. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude Zero g Pushover

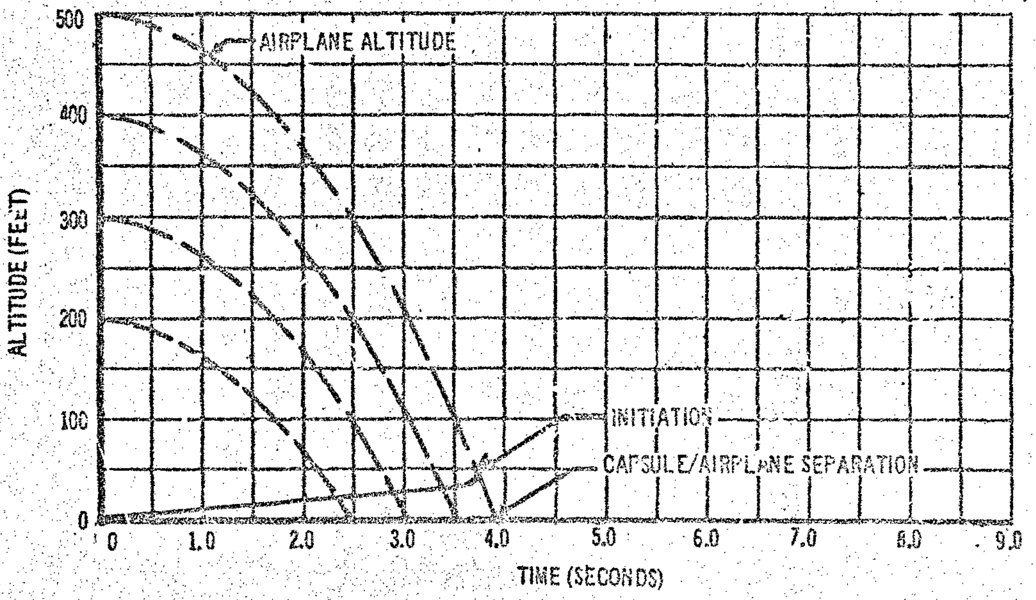


Figure 254. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude -1.0 g Pushover

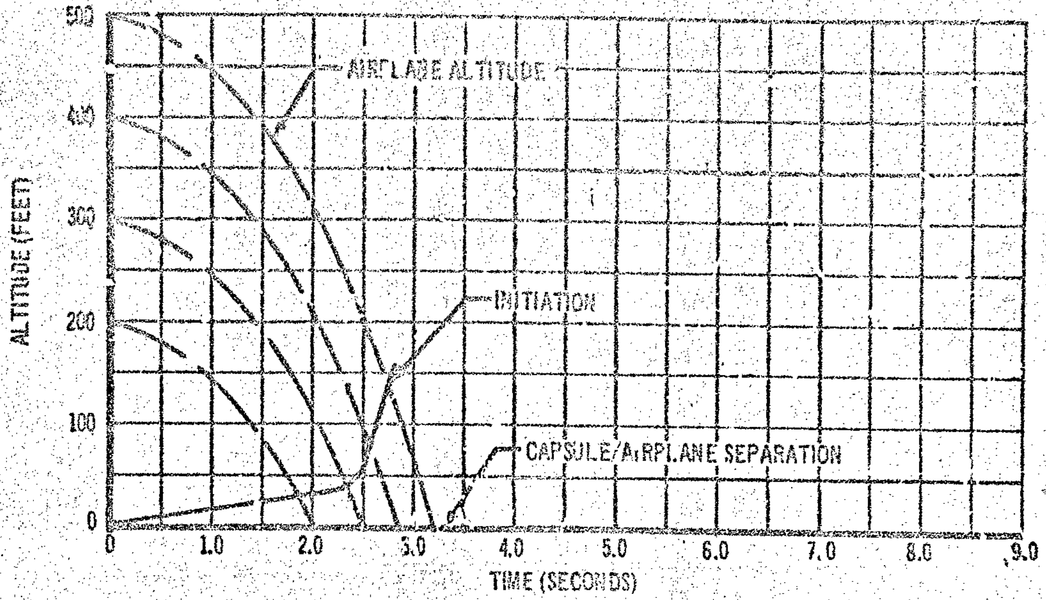


Figure 255. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude -2.0 g Pushover

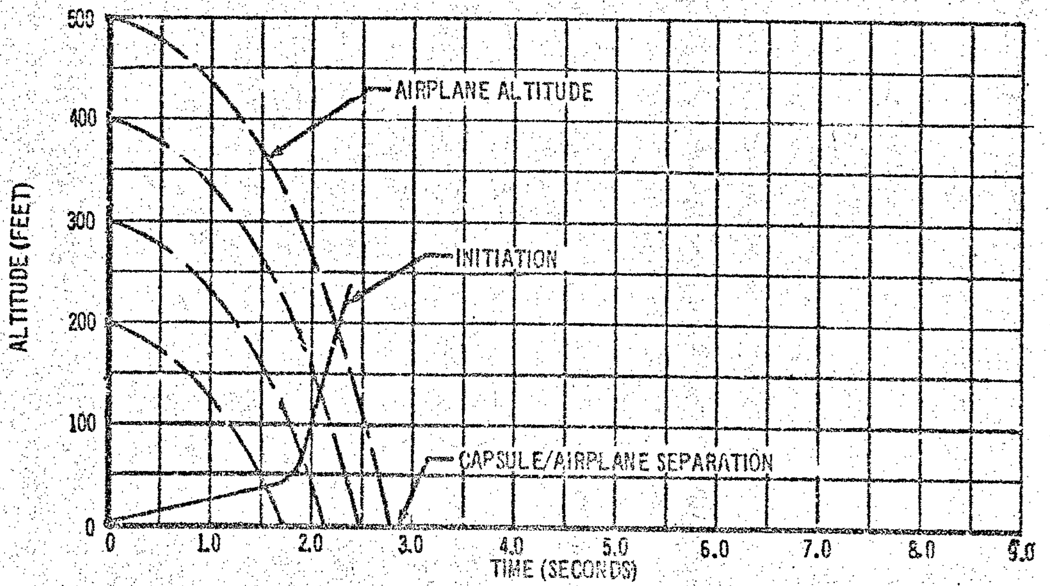


Figure 256. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude -3.0 g Pushover

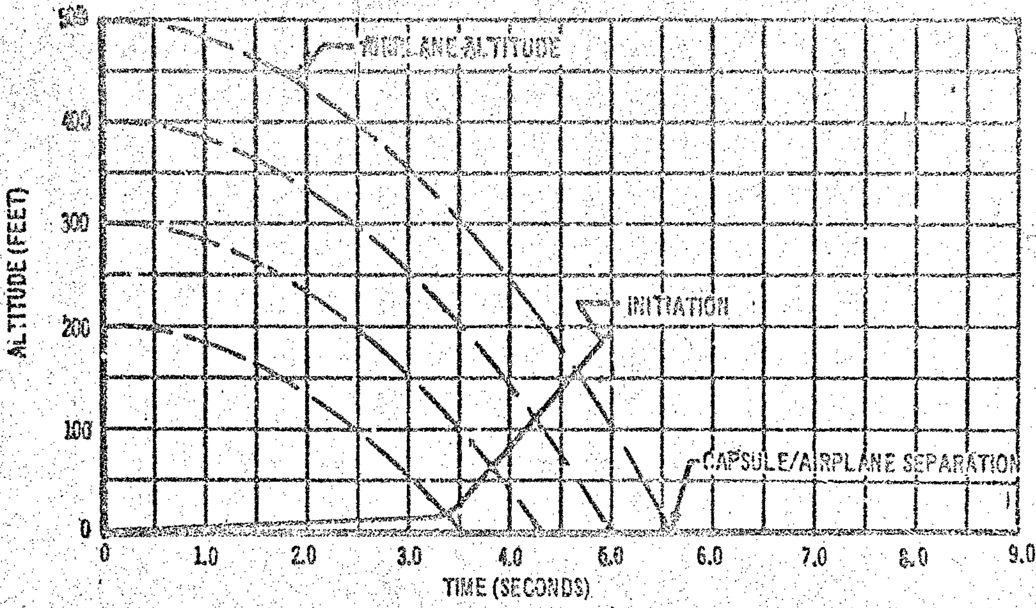


Figure 257. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Separable Nose Capsule Minimum Escape Altitude Zero g Pushover

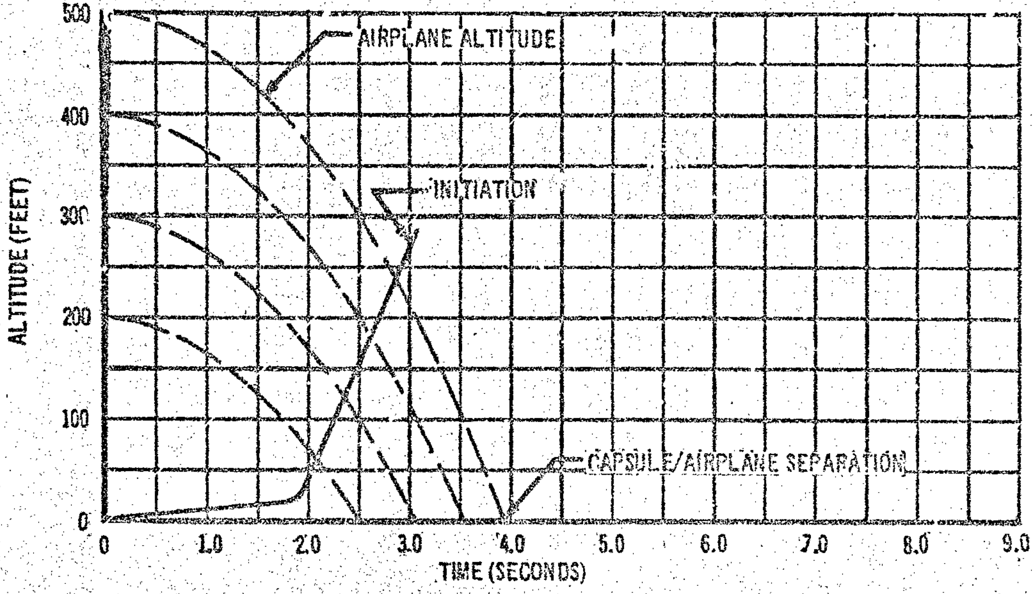


Figure 258. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Separable Nose Capsule Minimum Escape Altitude –1.0 g Pushover

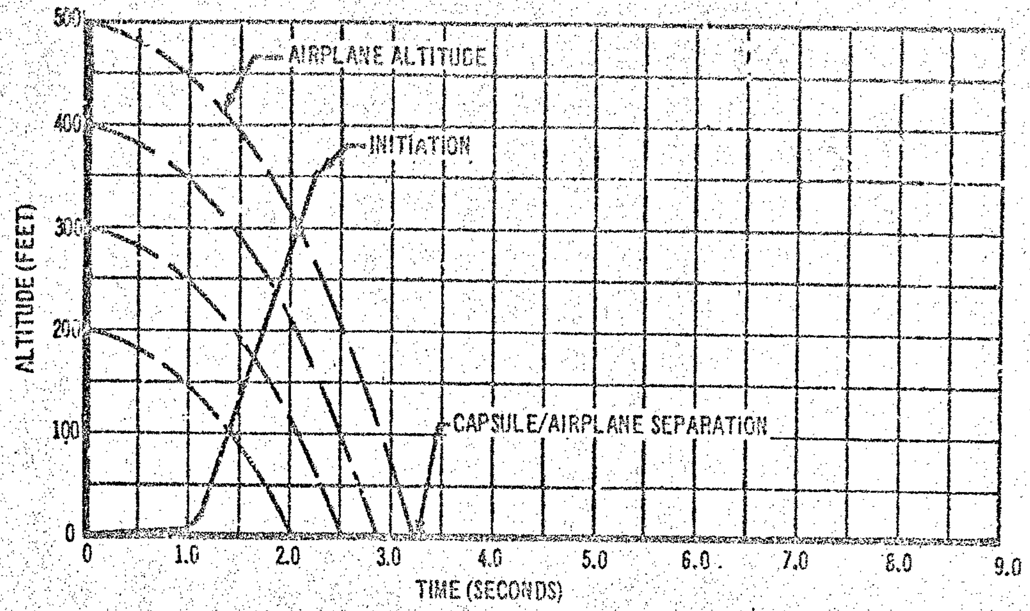


Figure 259. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Separable Nose Capsule Minimum Escape Altitude –2.0 g Pushover

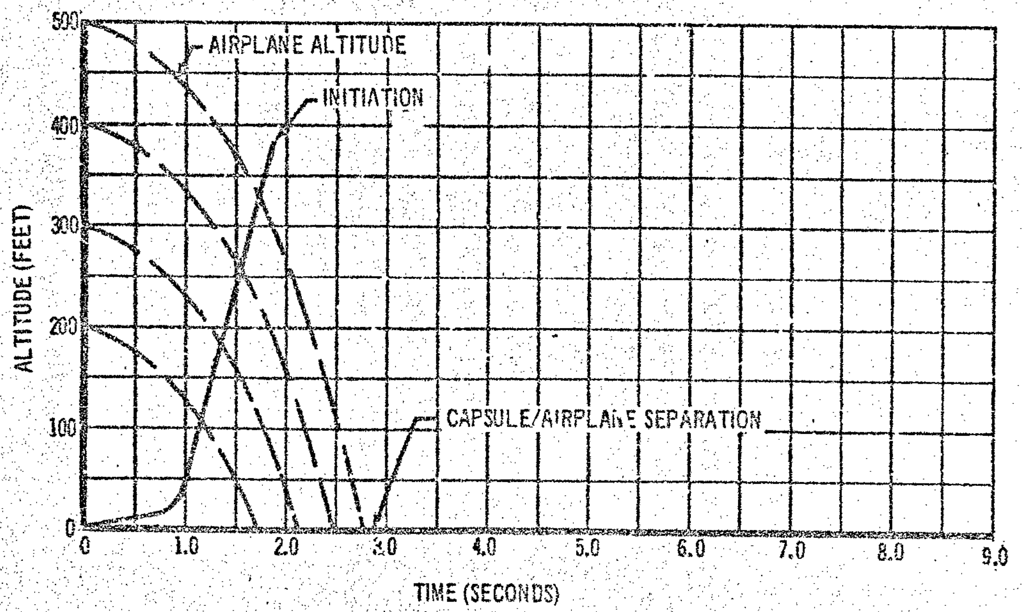


Figure 260. Three–Man Combined Capability Vehicle Low Altitude Dash Mach 1.1 Separable Nose Capsule Minimum Escape Altitude –3.0 g Pushover

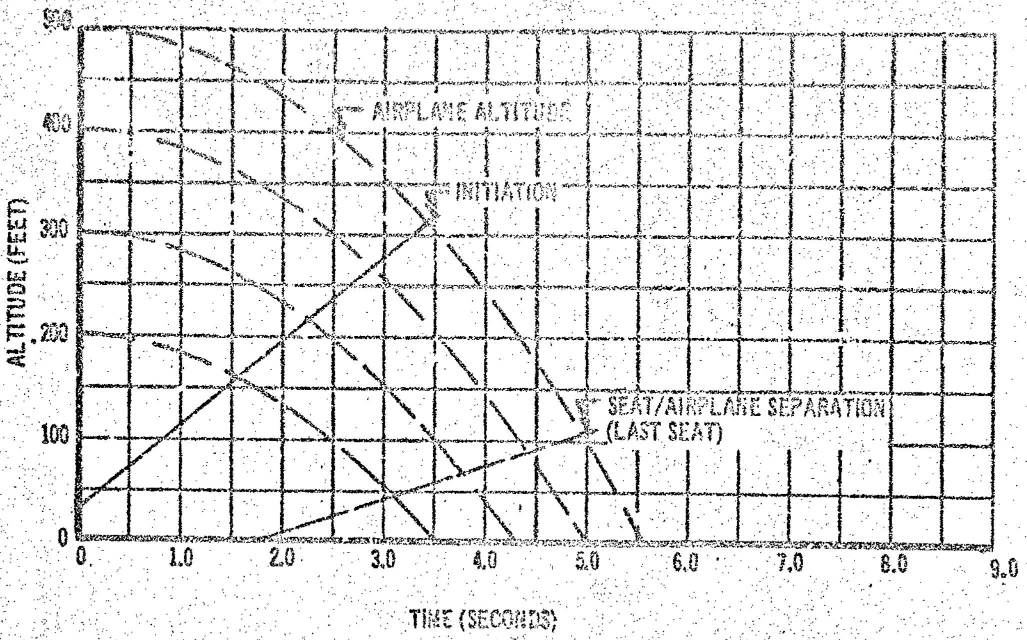


Figure 261. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Open Ejection Seat Minimum Escape Altitude Zero g Pushover

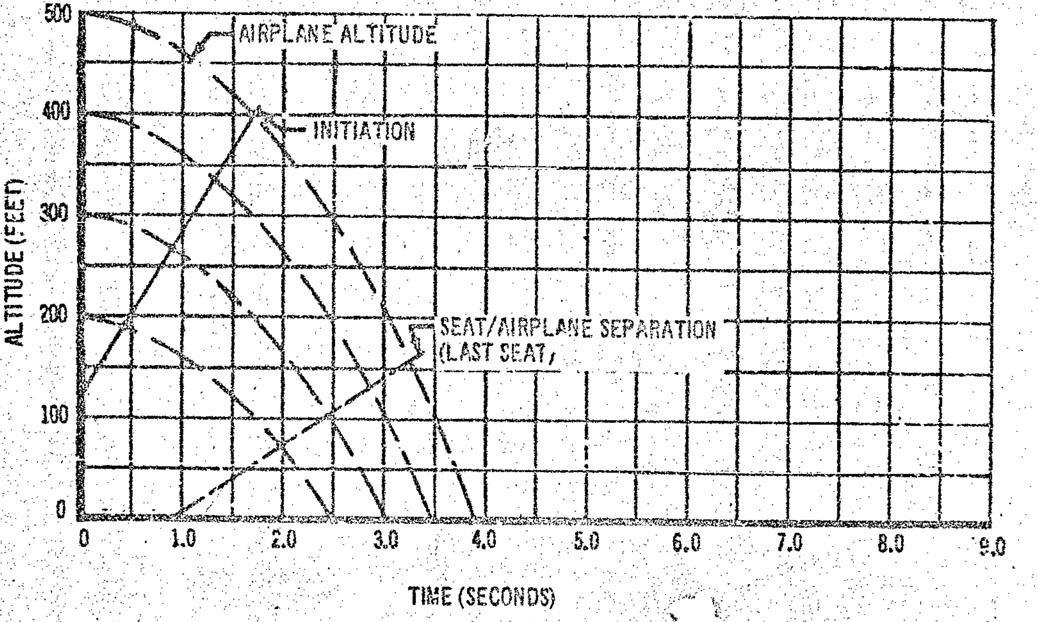


Figure 262. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Open Ejection Seat Minimum Escape Altitude -1.0 g Pushover

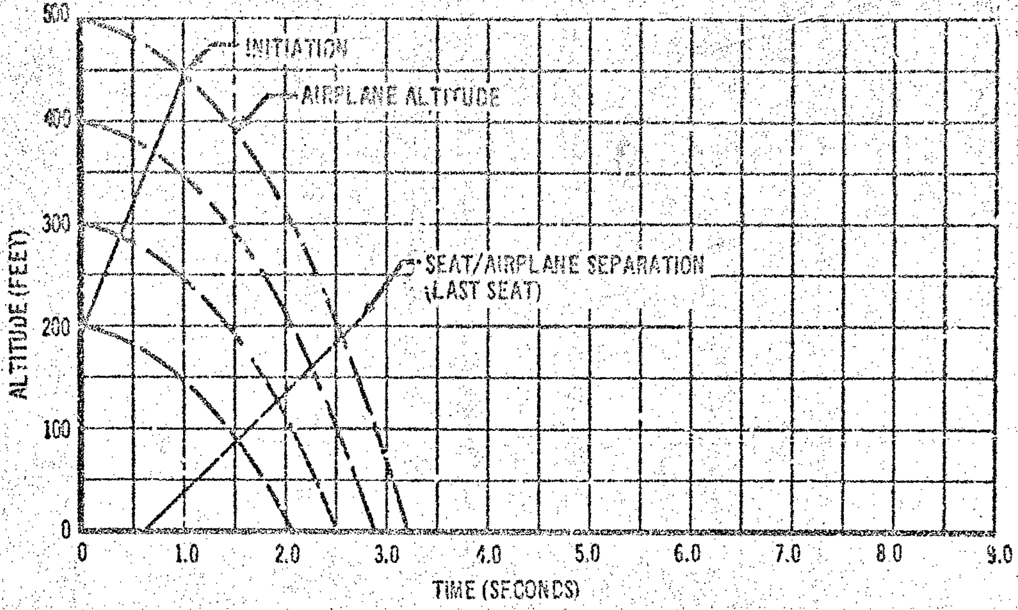


Figure 263. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Open Ejection Seat Minimum Escape Altitude -2.0 g Pushover

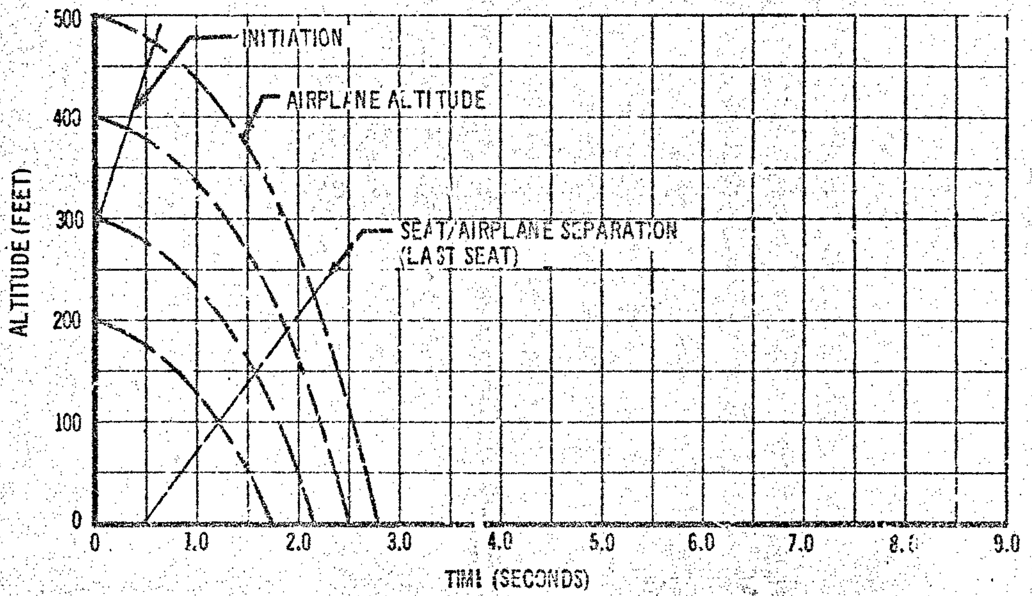


Figure 264. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Open Ejection Seat Minimum Escape Altitude -3.0 g Pushover

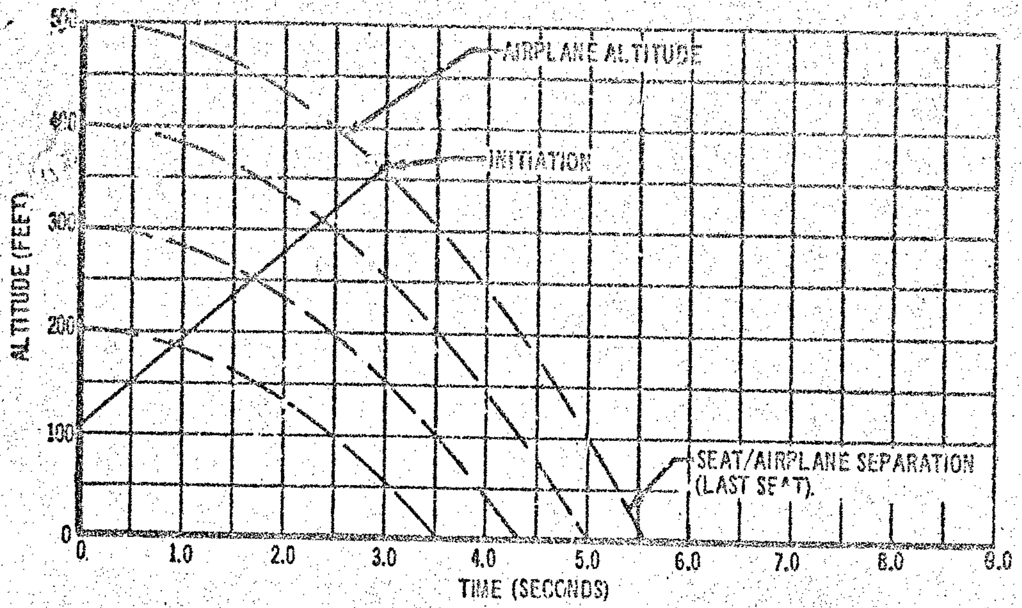


Figure 265. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude Zero g Pushover

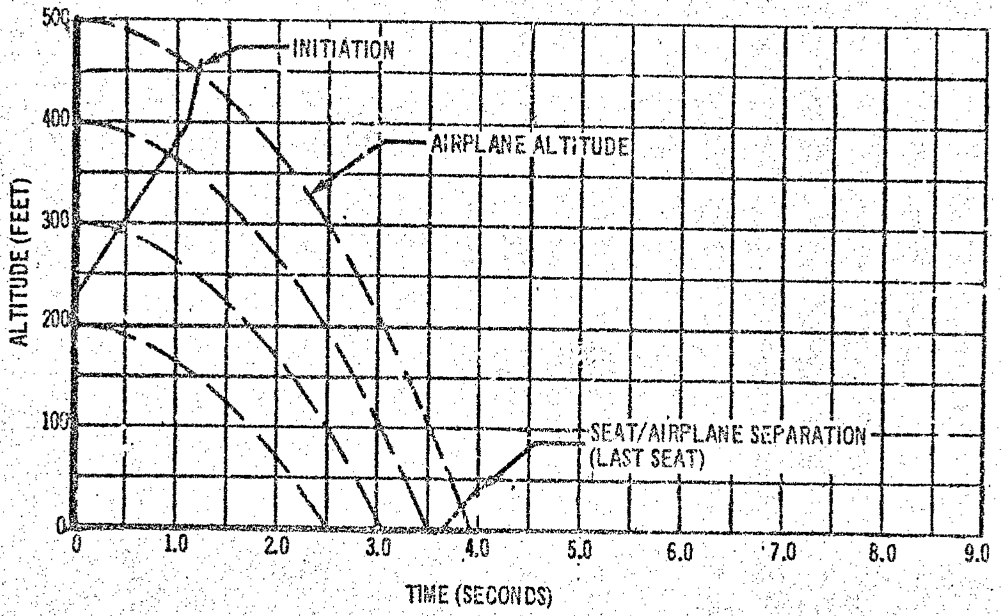


Figure 266. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude -1.0 g Pushover

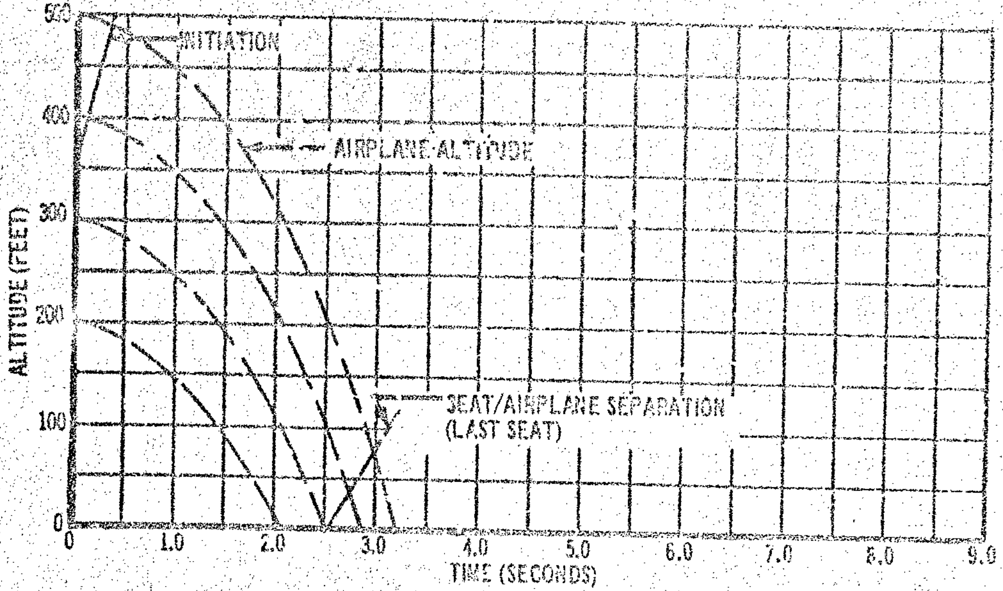


Figure 267. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude –2.0 g Pushover

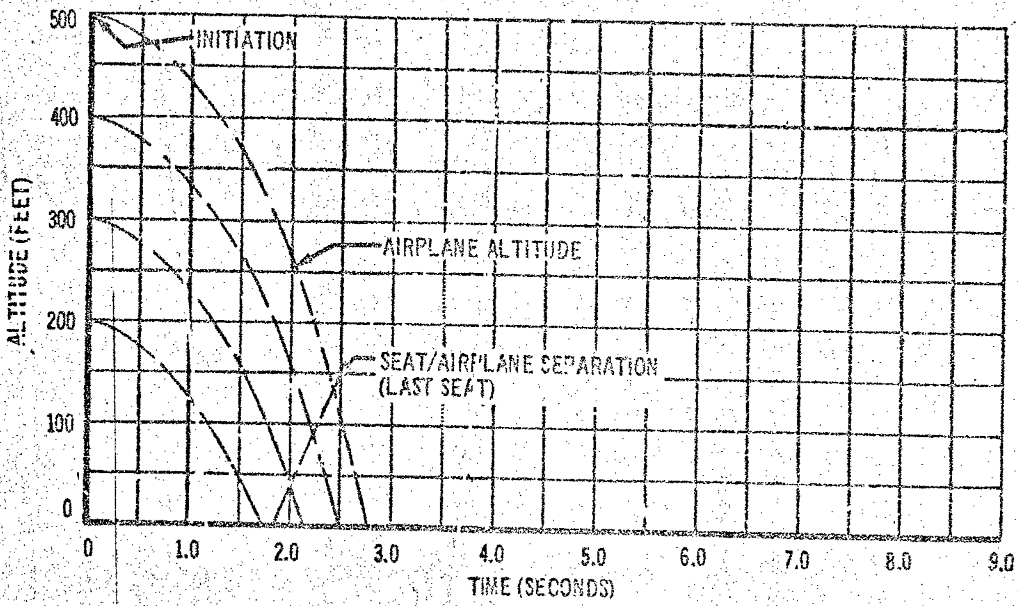


Figure 268. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude –3.0 g Pushover

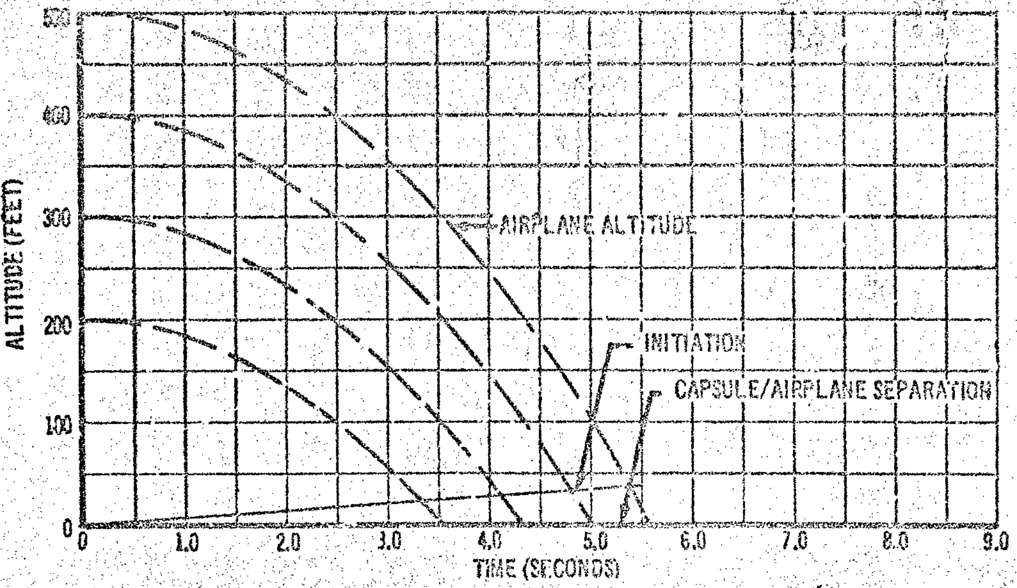


Figure 269. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude Zero g Pushover

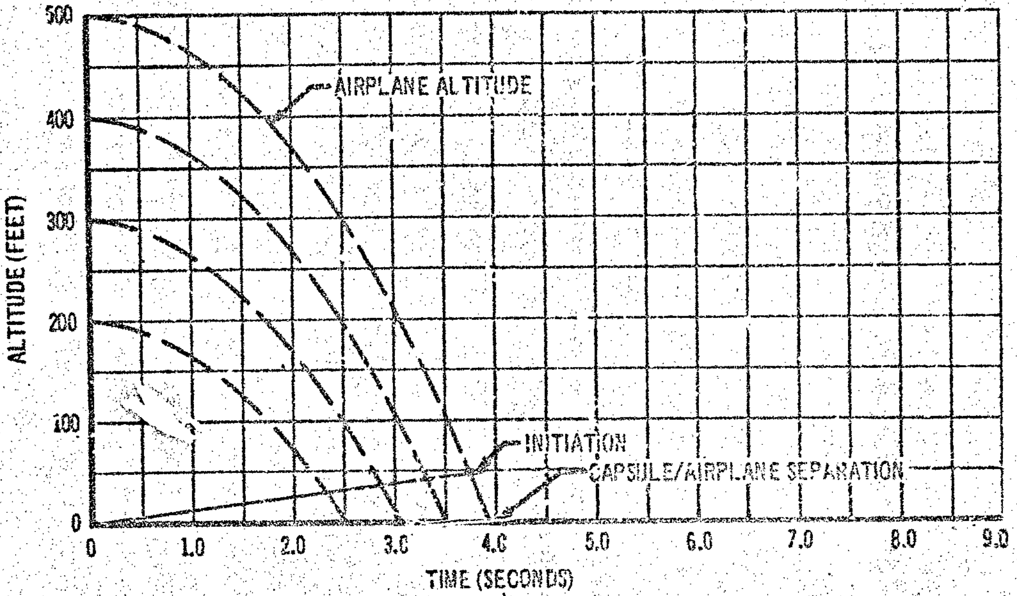


Figure 270. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude -1.0 g Pushover

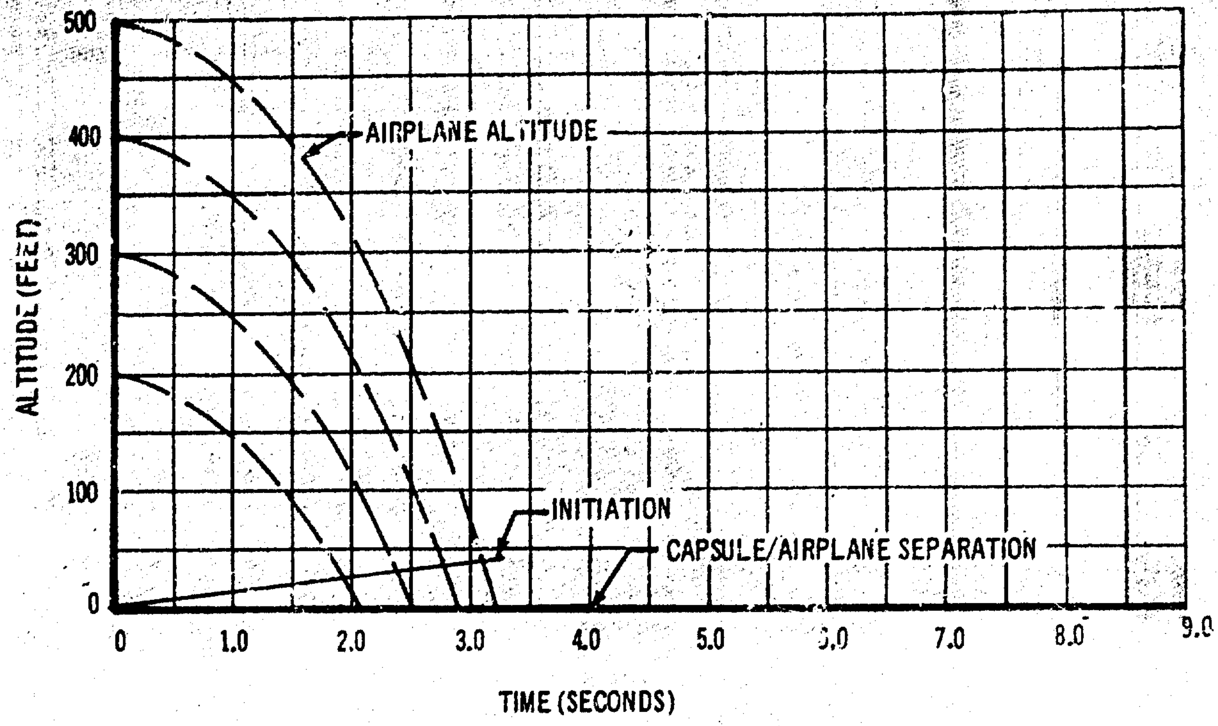


Figure 271. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude -2.0 g Pushover

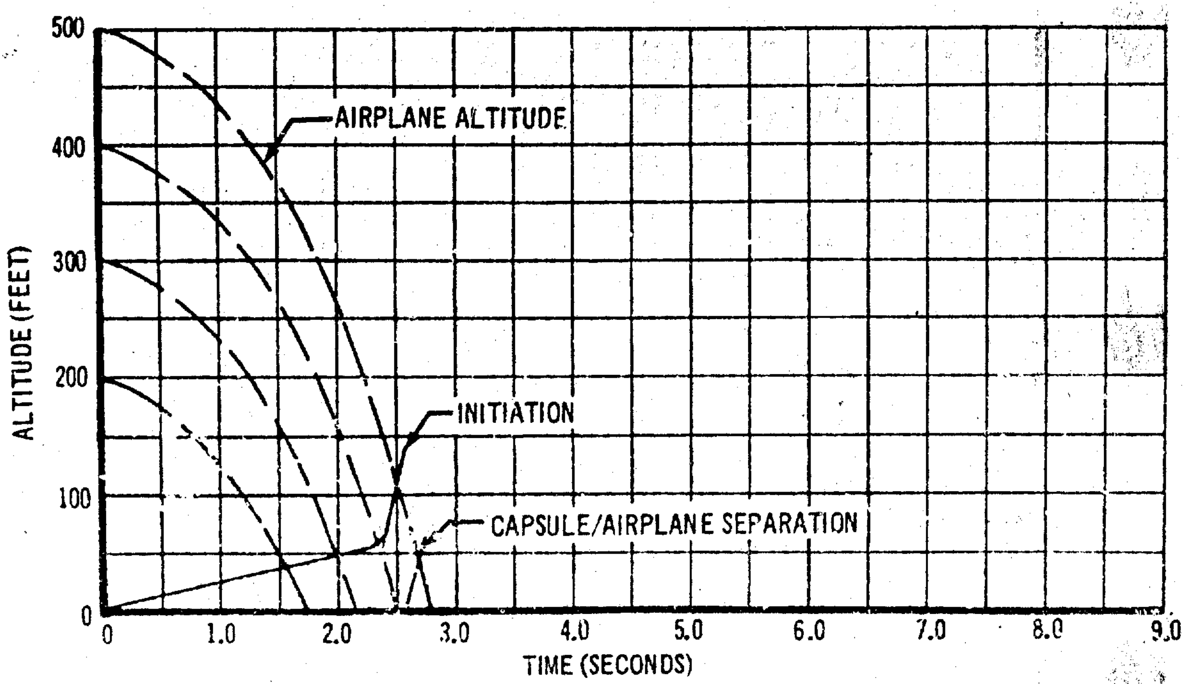


Figure 272. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Cockpit Pod Capsule Minimum Escare Altitude -3.0 g Pushover

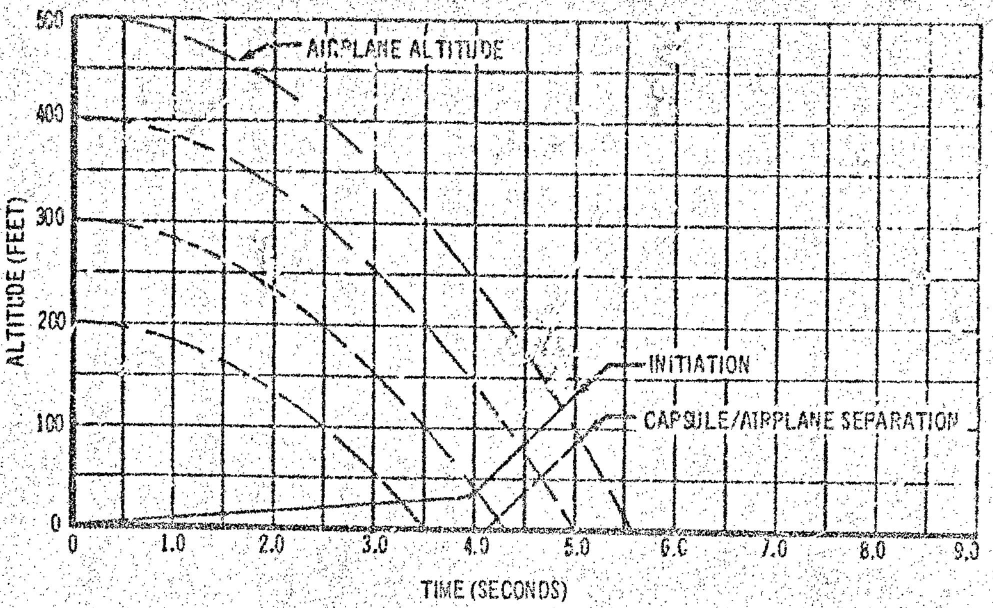


Figure 273. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Separable Nose Capsule Minimum Escape Altitude Zero g Pushover

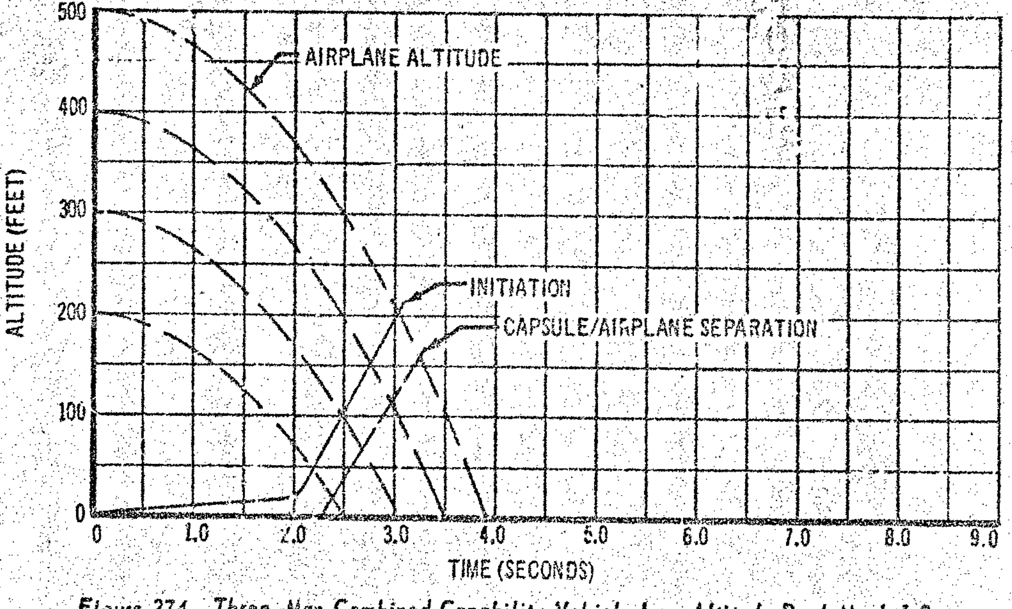


Figure 274. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Separable Nose Capsule Minimum Escape Altitude -1.0 g Pushover

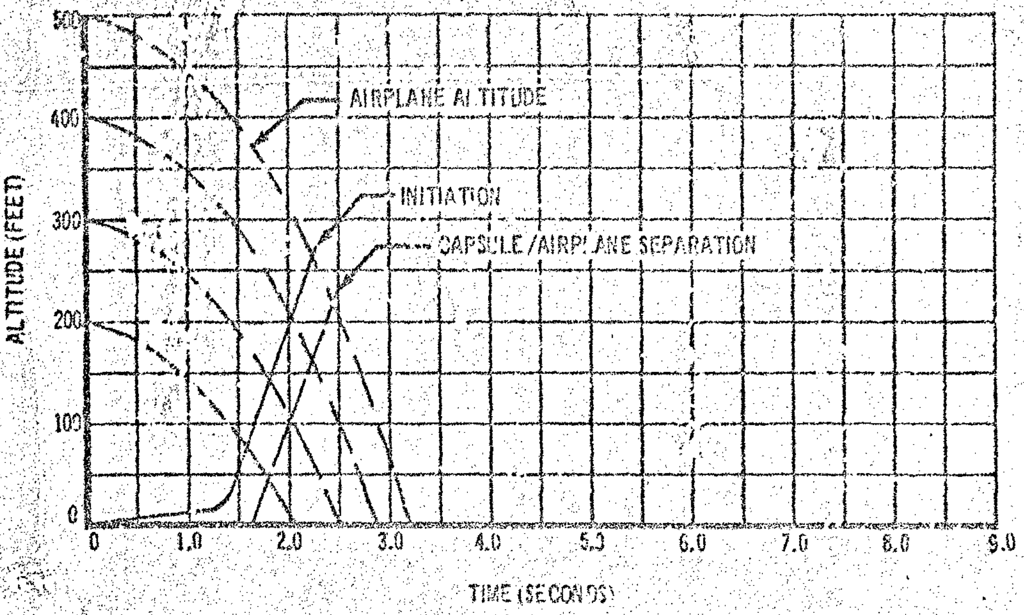


Figure 275. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Separable Nose Capsule Minimum Escape Altitude -2.0 g Pushover

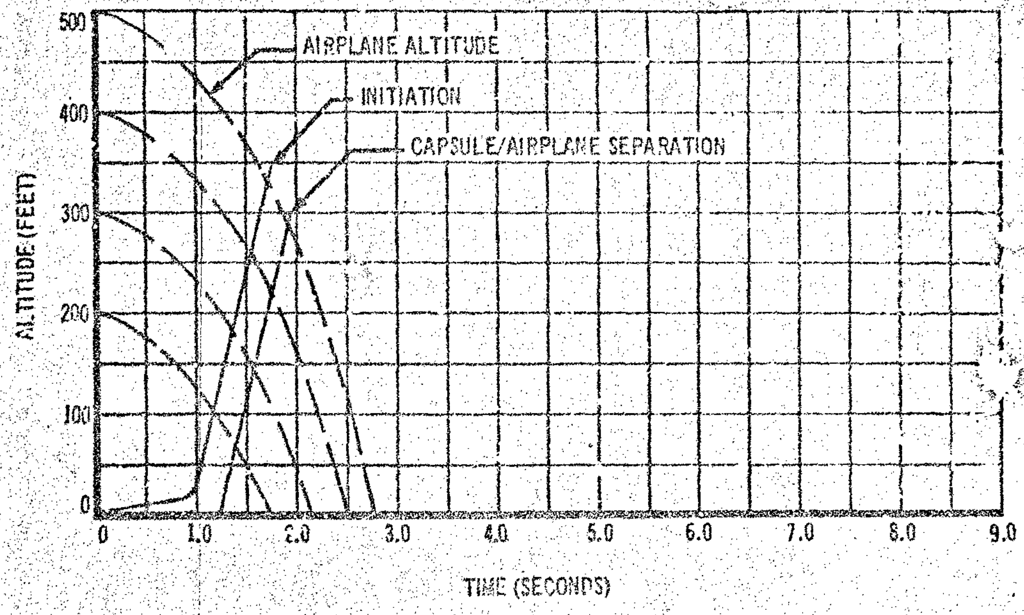


Figure 276. Three-Man Combined Capability Vehicle Low Altitude Dash Mach 1.2 Separable Nose Capsule Minimum Escape Altitude -3.0 g Pushover

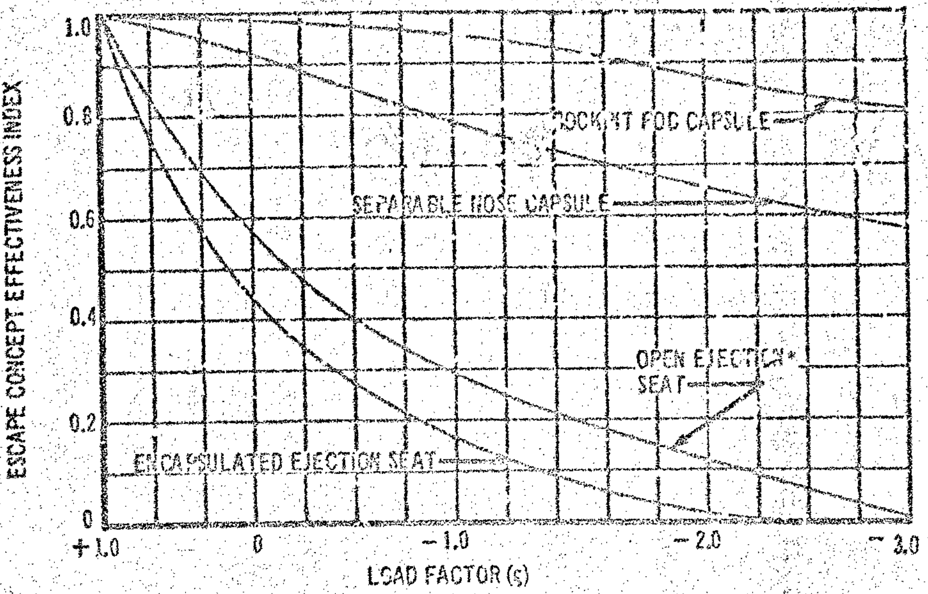


Figure 277. Three–Man Combined Capability Vehicle Low Altitude Dash Escape Concept Effectiveness Index Versus Normal Load Factor During Pushover, Mach 0.9

*DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEATS DUE TO HIGH SPEED.

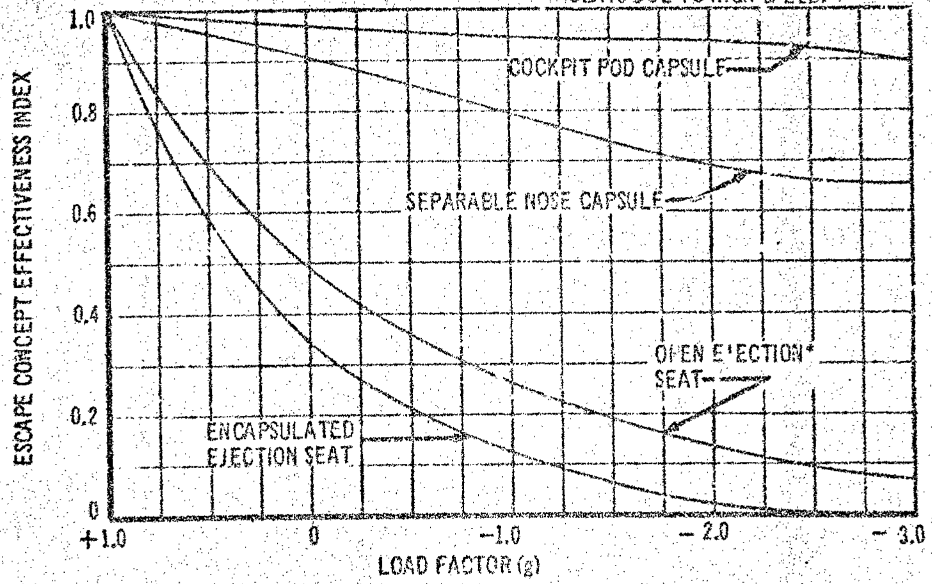


Figure 278. Three–Man Combined Capability Vehicle Low Altitude Dash Escape Concept Effectiveness Index Versus Normal Load Factor During Pushover, Mach 1.1

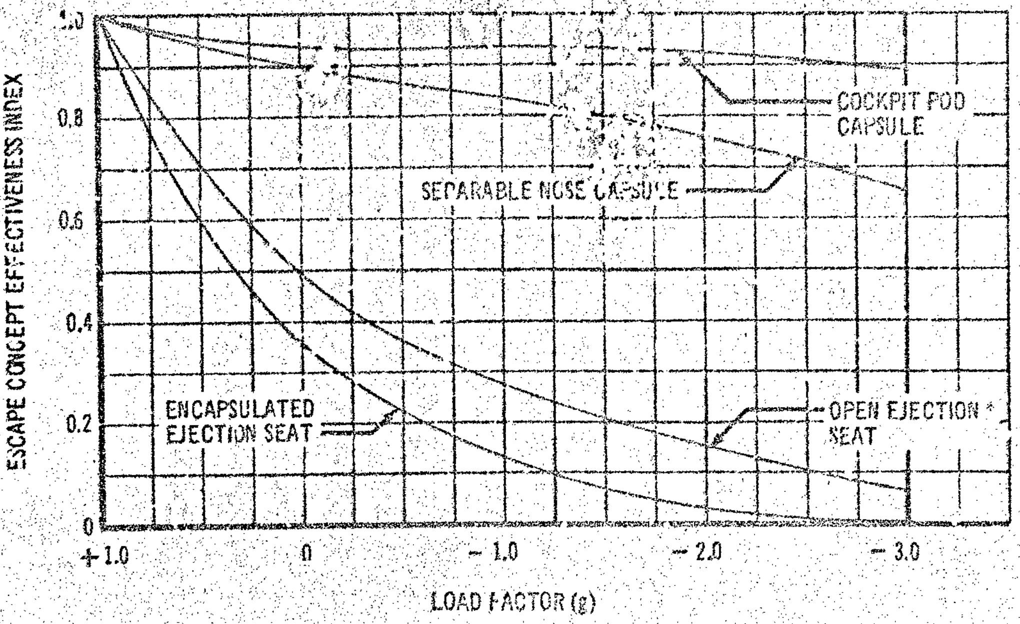
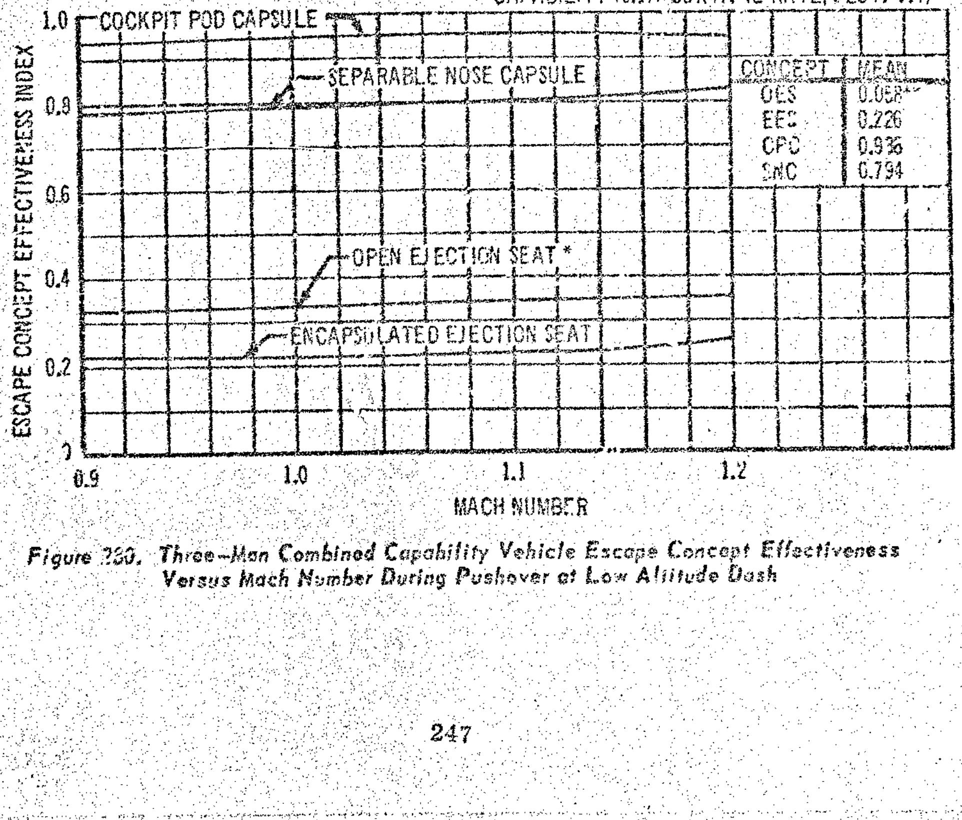


Figure 279. Three-Man Combined Capability Vehicle Low Altitude Dash Escape Concept Effectiveness Index Versus Normal Load Factor During Pushover, Mach 1.2

*DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEATS DUE TO HIGH SPEED

**CORRECTED FOR REDUCED HIGH SPEED CAPABILITY (0.175 SURVIVAL RATE, SECT. V.4)



CONCEPT	MEAN
OES	0.058**
EES	0.226
CPC	0.936
SNC	0.794

Figure 280. Three-Man Combined Capability Vehicle Escape Concept Effectiveness Versus Mach Number During Pushover at Low Altitude Dash

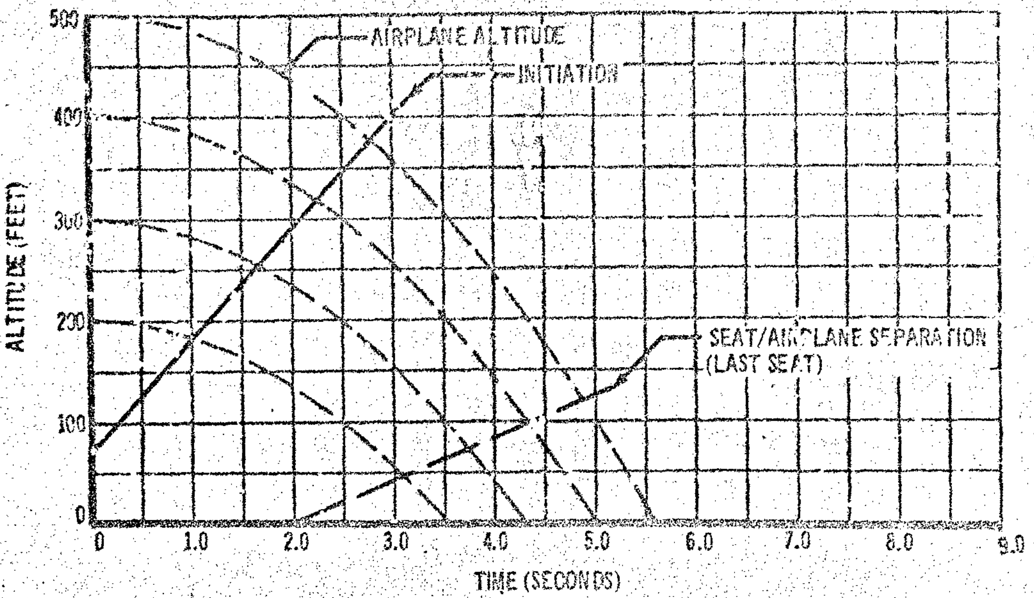


Figure 281. Four-Man Supersonic Dash Vehicle Mach 0.9 Open Ejection Seat Minimum Escape Altitude Zero g Pushover

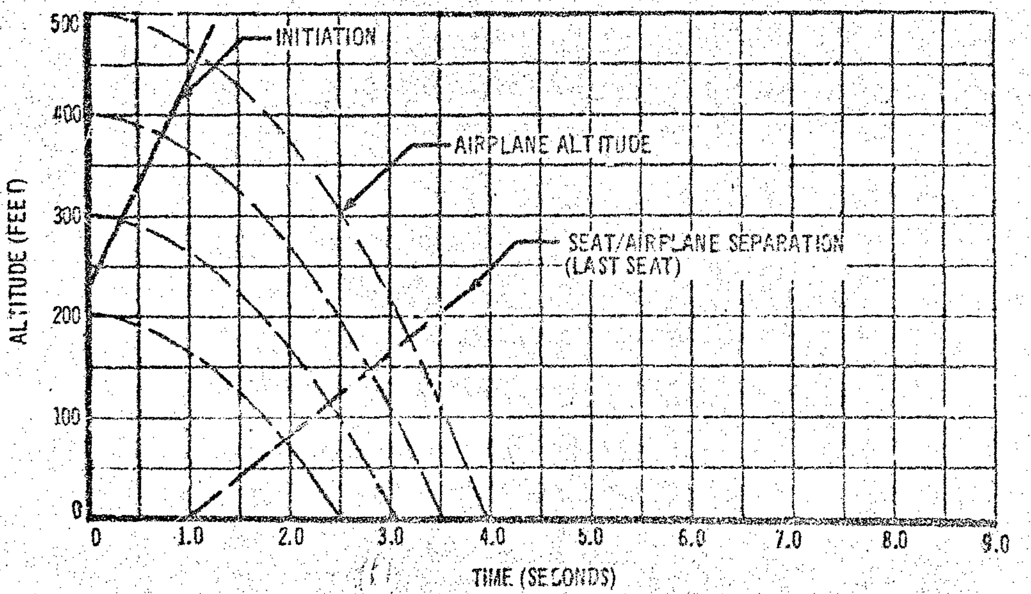


Figure 282. Four-Man Supersonic Dash Vehicle Mach 0.9 Open Ejection Seat Minimum Escape Altitude -1.0 g Pushover

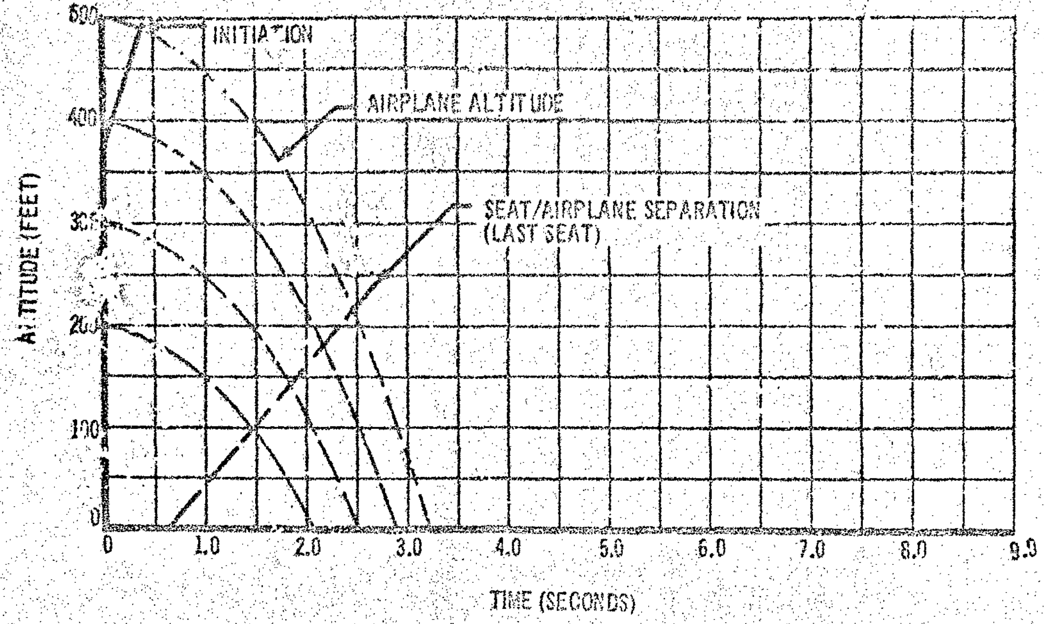


Figure 283. Four-Man Supersonic Dash Vehicle Mach 0.9 Open Ejection Seat Minimum Escape Altitude -2.0 g Pushover

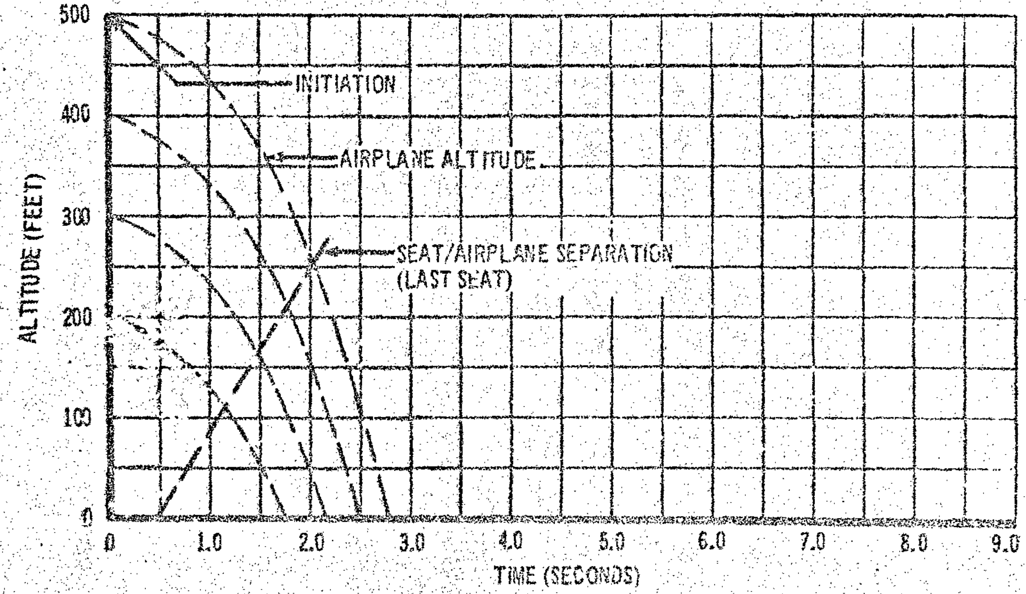


Figure 284. Four-Man Supersonic Dash Vehicle Mach 0.9 Open Ejection Seat Minimum Escape Altitude -3.0 g Pushover

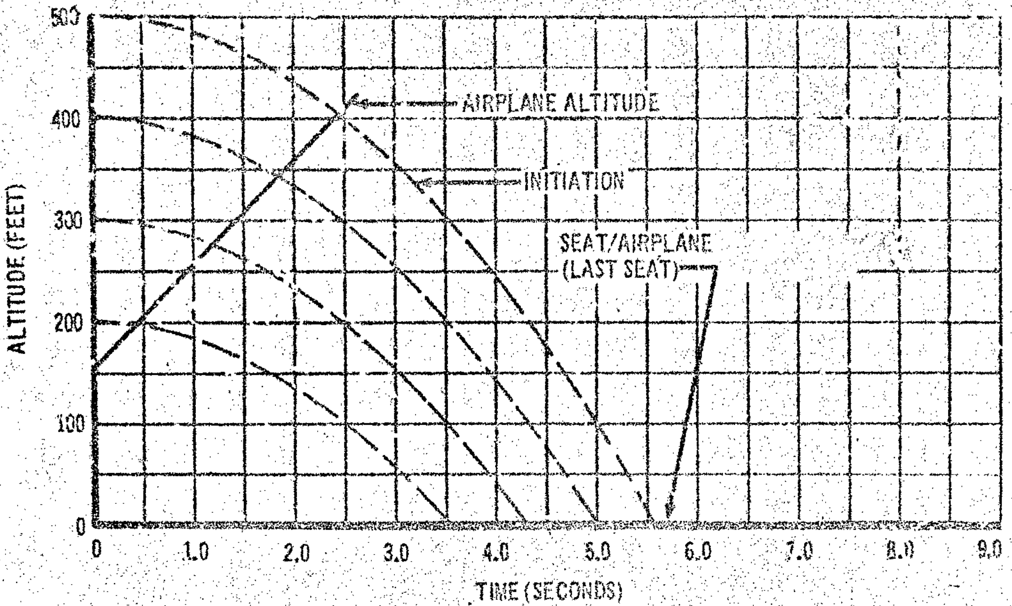


Figure 285. Four–Man Supersonic Dash Vehicle Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude Zero g Pushover

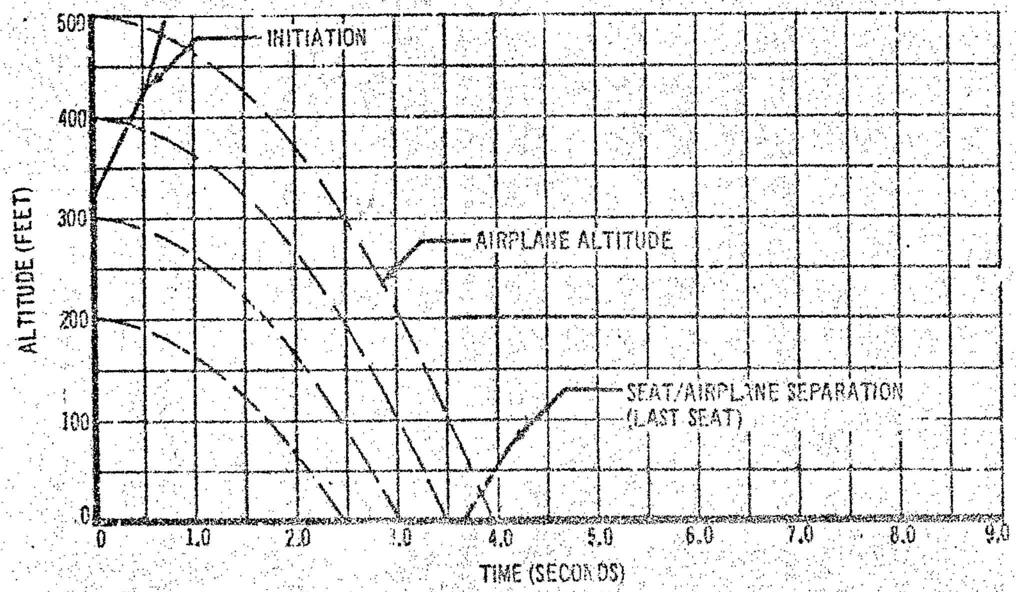


Figure 286. Four–Man Supersonic Dash Vehicle Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude –1.0 g Pushover

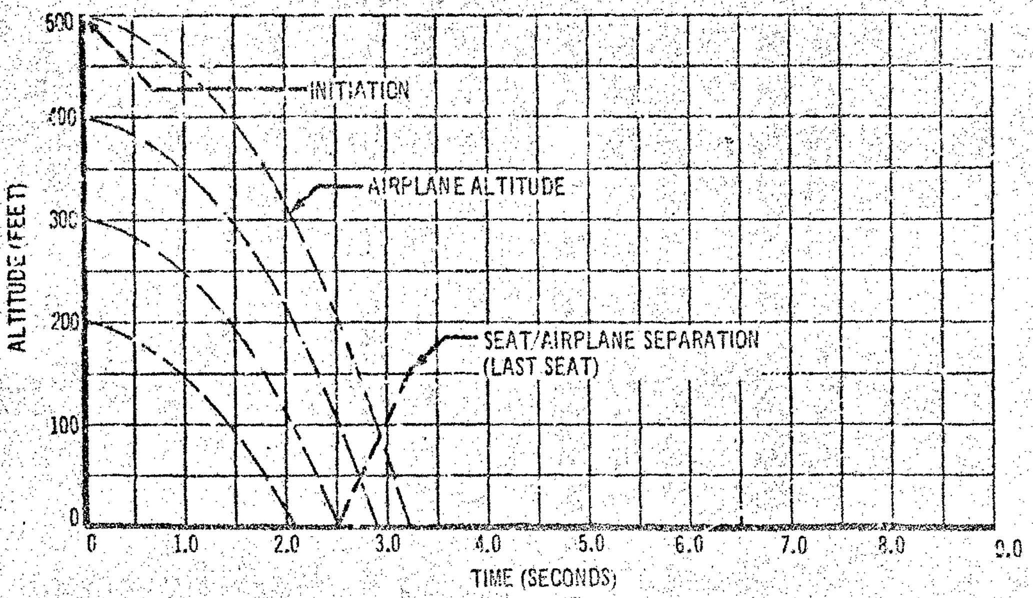


Figure 287. Four-Man Supersonic Dash Vehicle Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude –2.0 g Pushover

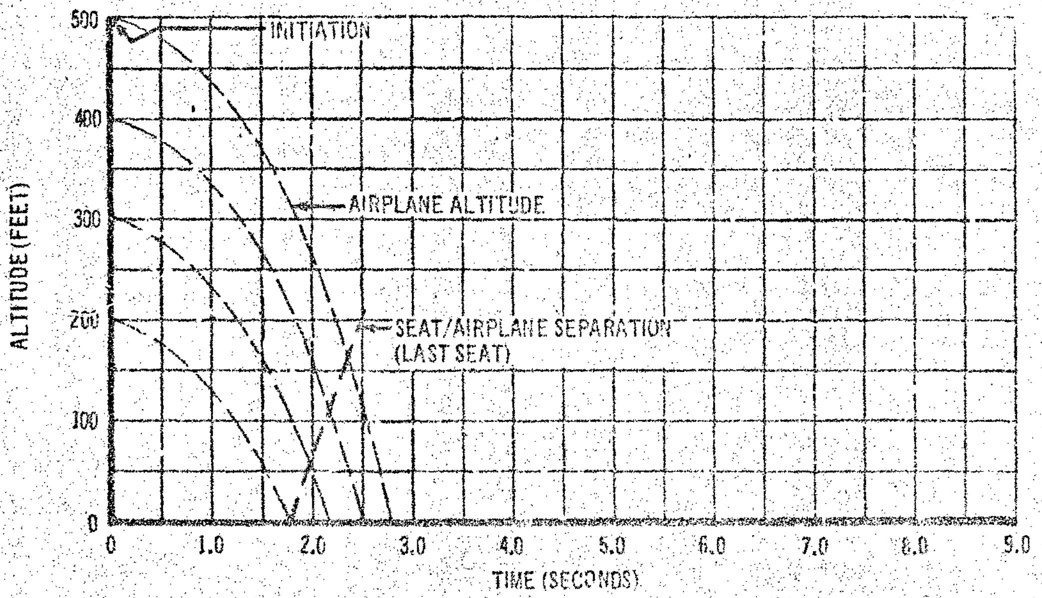


Figure 288. Four-Man Supersonic Dash Vehicle Mach 0.9 Encapsulated Ejection Seat Minimum Escape Altitude –3.0 g Pushover

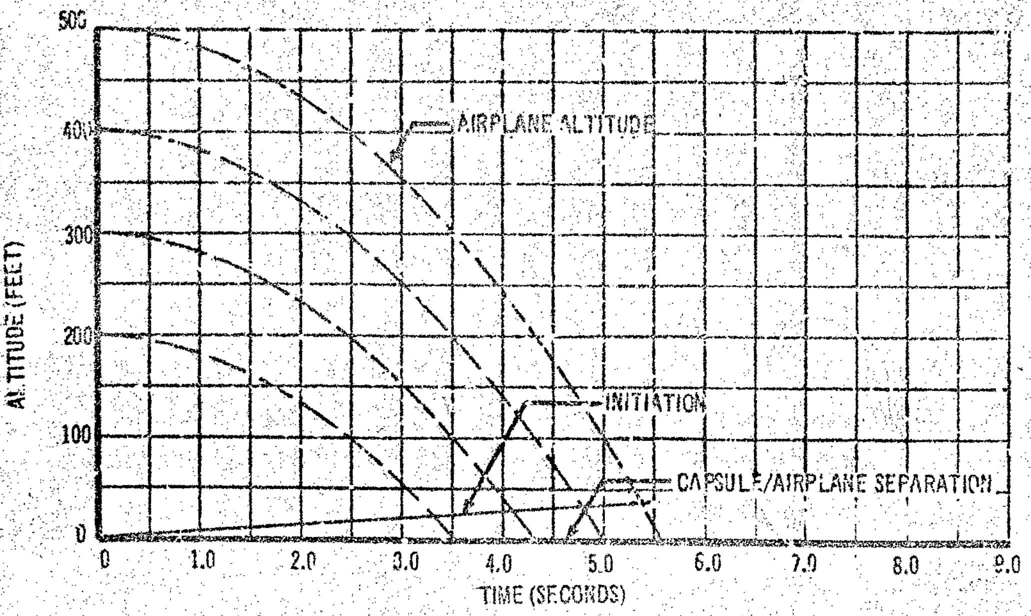


Figure 289. Four–Man Supersonic Dash Vehicle Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude Zero g Pushover

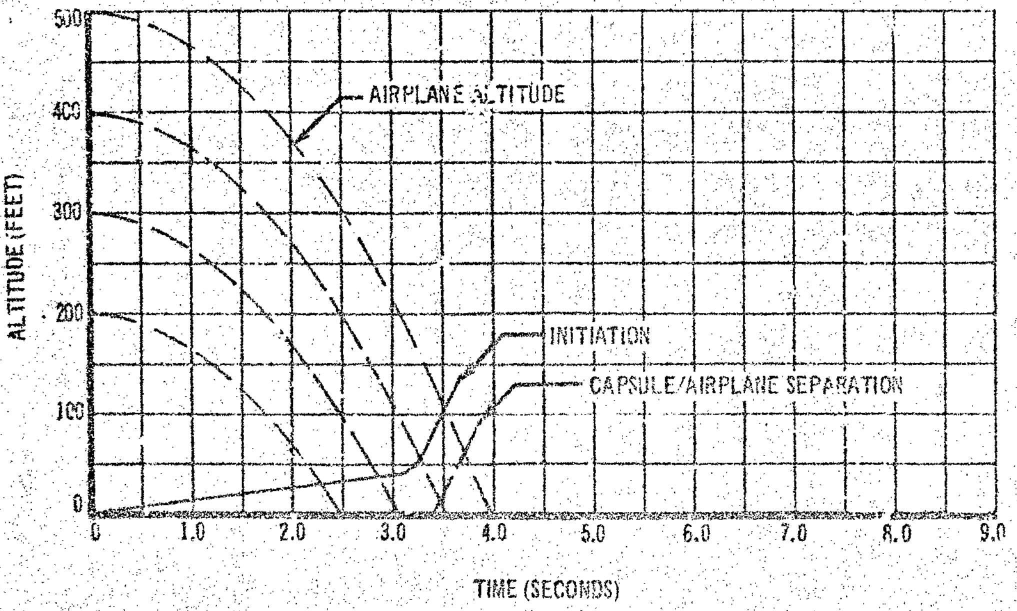


Figure 290. Four–Man Supersonic Dash Vehicle Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude –1.0 g Pushover

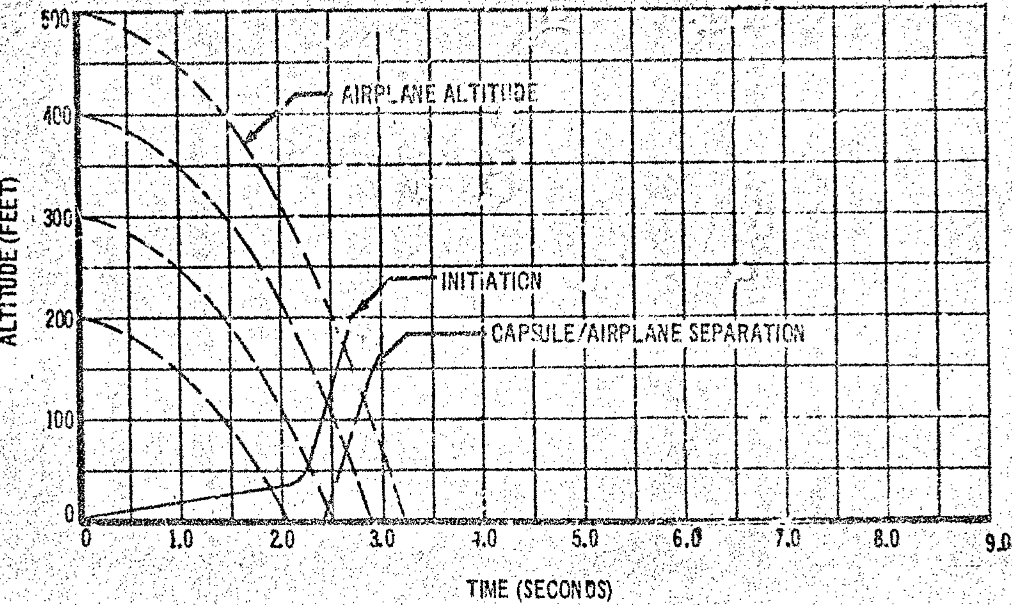


Figure 291. Four-Man Supersonic Dash Vehicle Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude -2.0 g Pushover

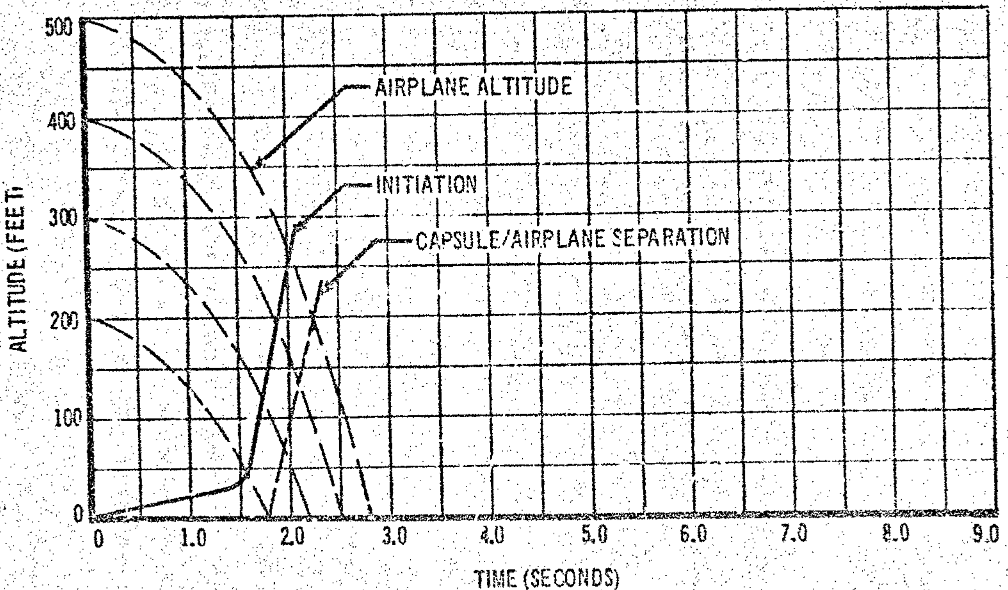


Figure 292. Four-Man Supersonic Dash Vehicle Mach 0.9 Cockpit Pod Capsule Minimum Escape Altitude -3.0 g Pushover

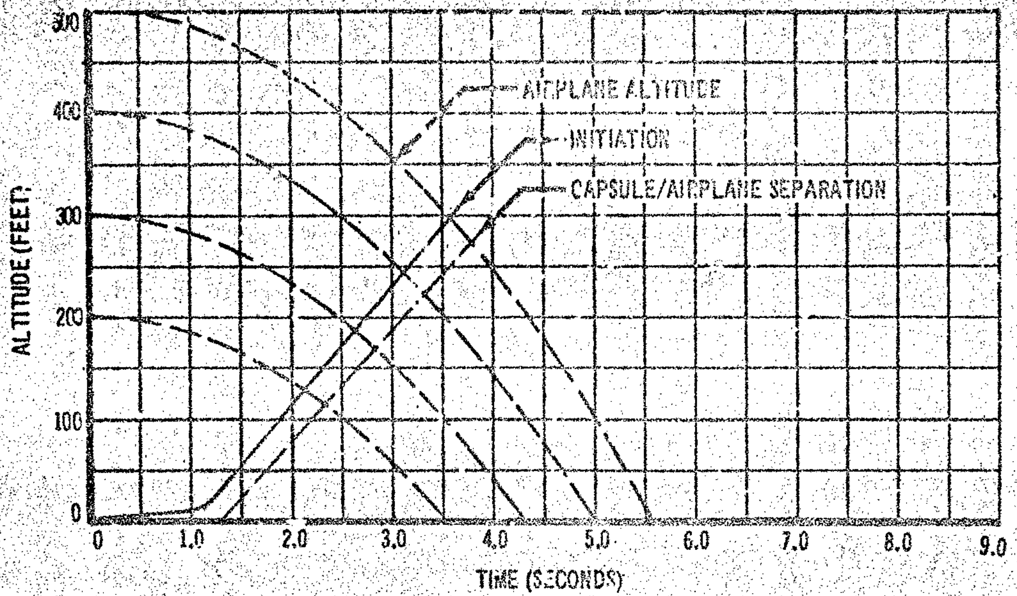


Figure 293. Four-Man Supersonic Dash Vehicle Mach 0.9 Separable Nose Capsule Minimum Escape Altitude Zero g Pushover

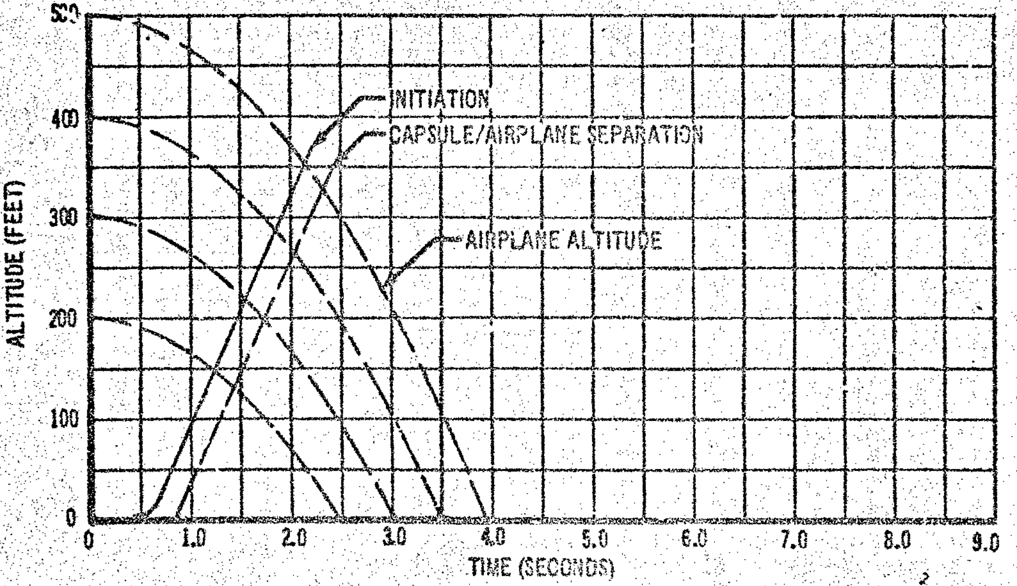


Figure 294. Four-Man Supersonic Dash Vehicle Mach 0.9 Separable Nose Capsule Minimum Escape Altitude −1.0 g Pushover

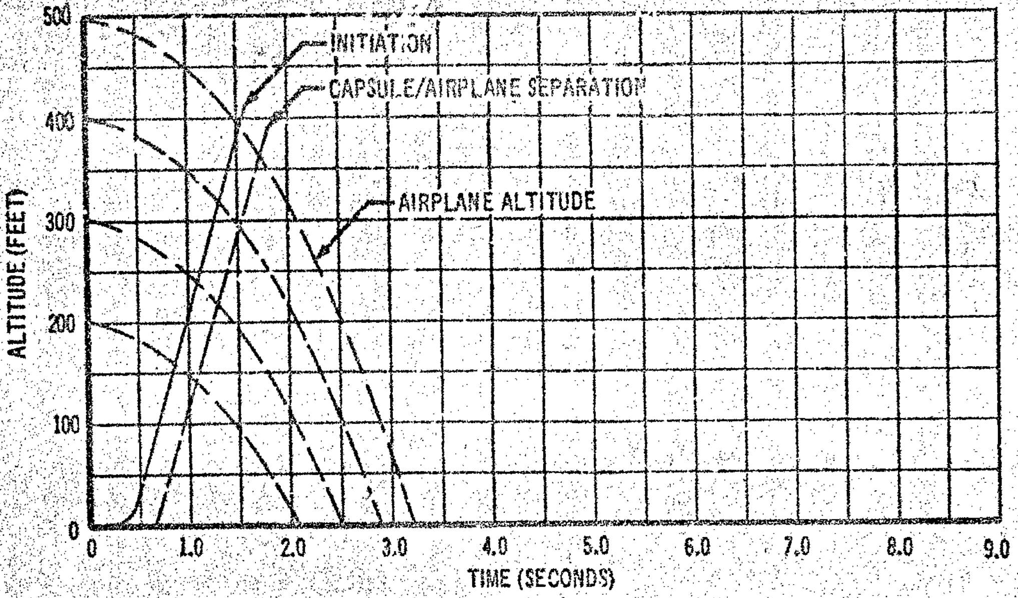


Figure 295. Four–Man Supersonic Dash Vehicle Mach 0.9 Separable Nose Capsule Minimum Escape Altitude –2.0 g Pushover

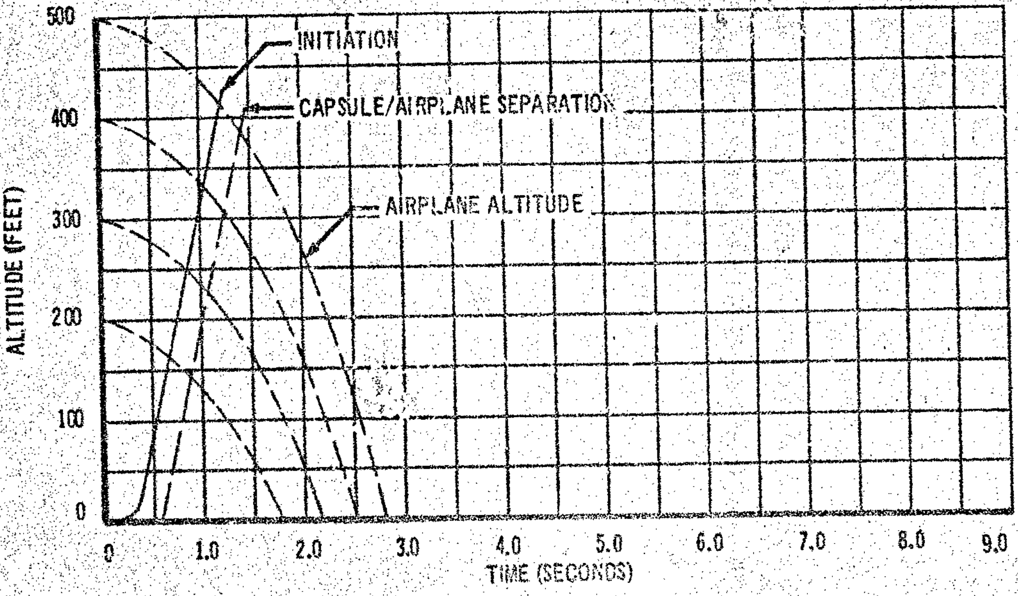


Figure 296. Four–Man Supersonic Dash Vehicle Mach 0.9 Separable Nose Capsule Minimum Escape Altitude –3.0 g Pushover

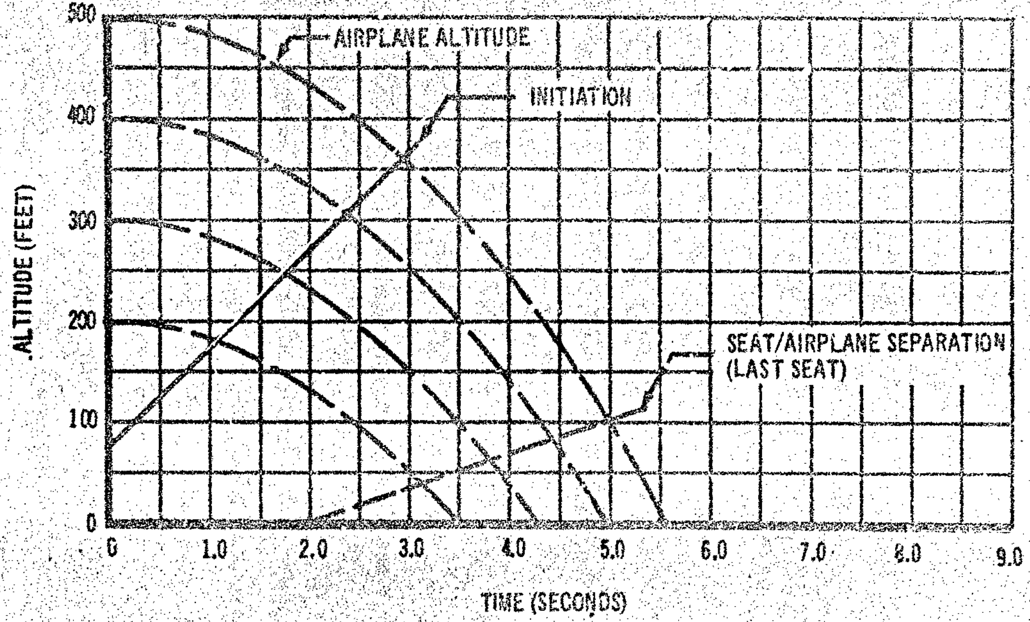


Figure 297. Four-Man Supersonic Dash Vehicle Mach 1.1 Open Ejection Seat Minimum Escape Altitude Zero g Pushover

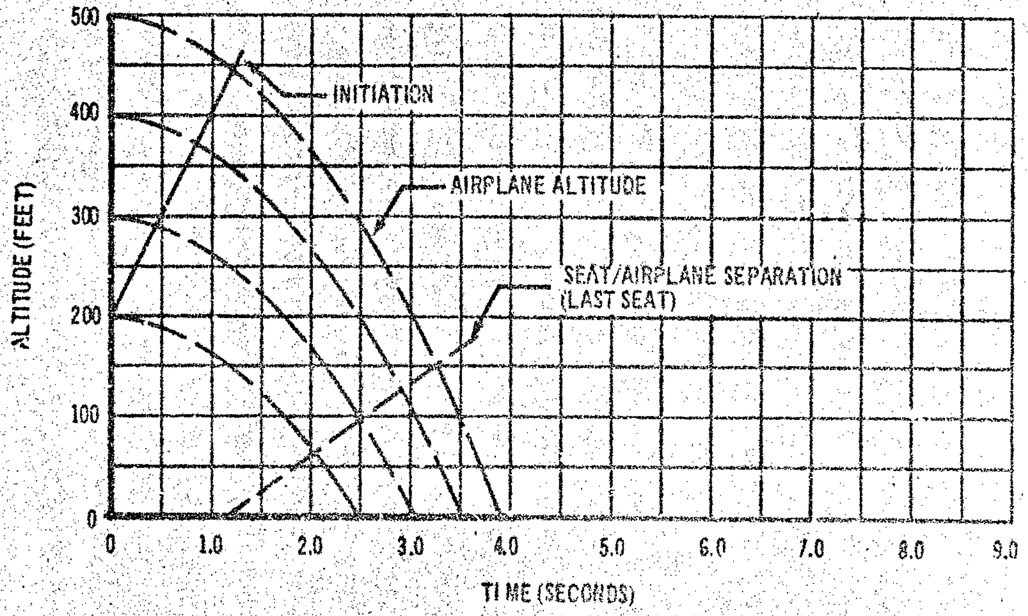


Figure 298. Four-Man Supersonic Dash Vehicle Mach 1.1 Open Ejection Seat Minimum Escape Altitude -1.0 g Pushover

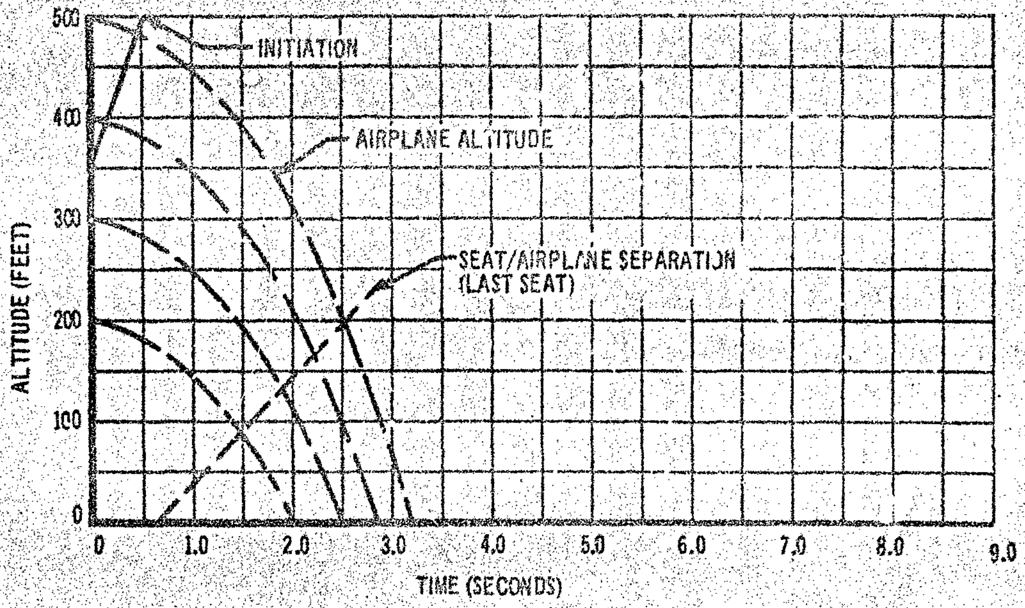


Figure 299. Four-Man Supersonic Dash Vehicle Mach 1.1 Open Ejection Seat Minimum Escape Altitude –2.0 g Pushover

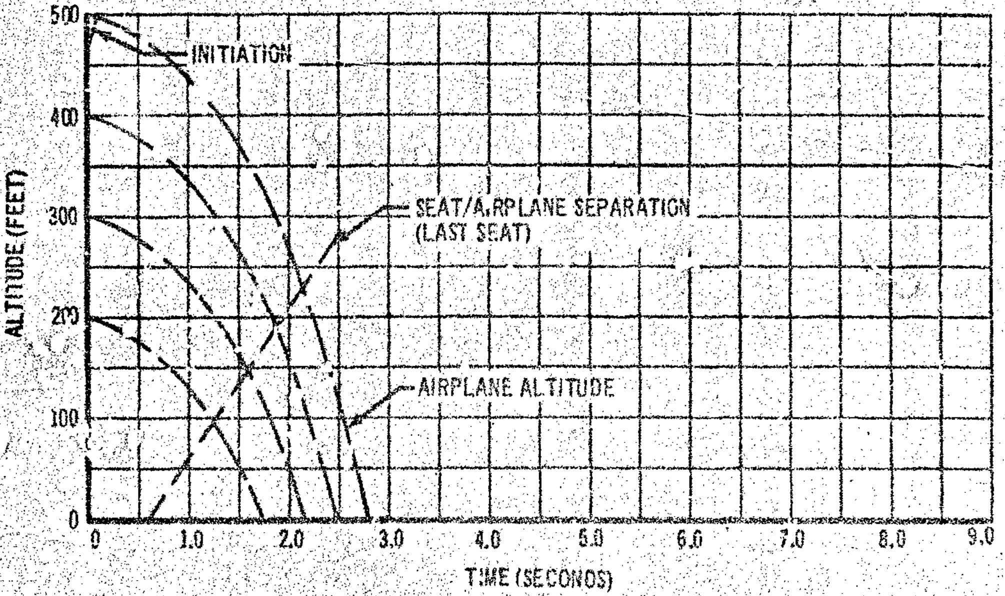


Figure 300. Four-Man Supersonic Dash Vehicle Mach 1.1 Open Ejection Seat Minimum Escape Altitude –3.0 g Pushover

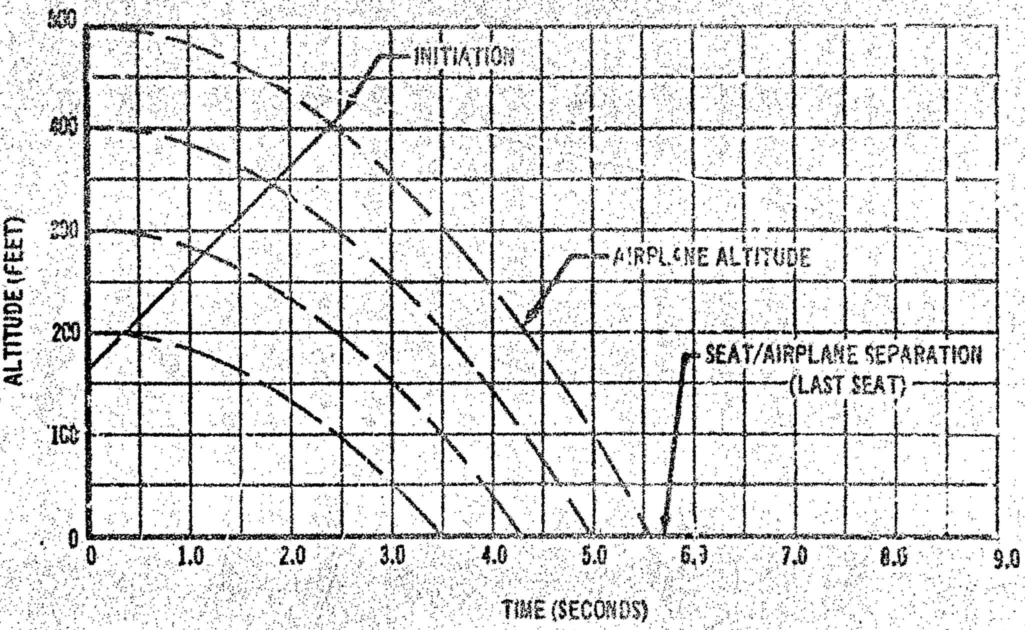


Figure 301. Four-Man Supersonic Dash Vehicle Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude Zero g Pushover

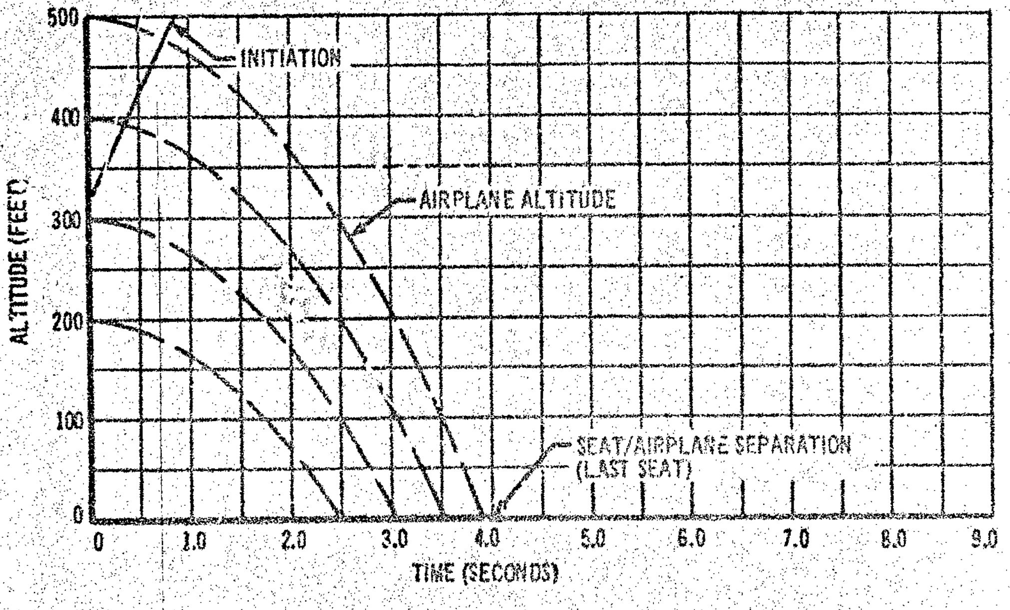


Figure 302. Four-Man Supersonic Dash Vehicle Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude -1.0 g Pushover

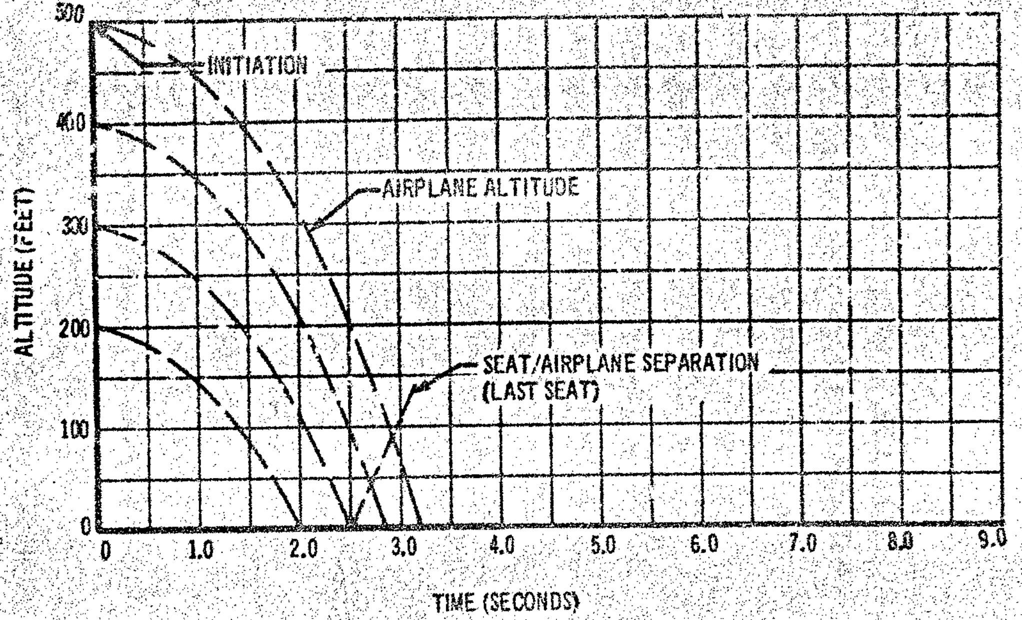


Figure 303. Four-Man Supersonic Dash Vehicle Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude –2.0 g Pushover

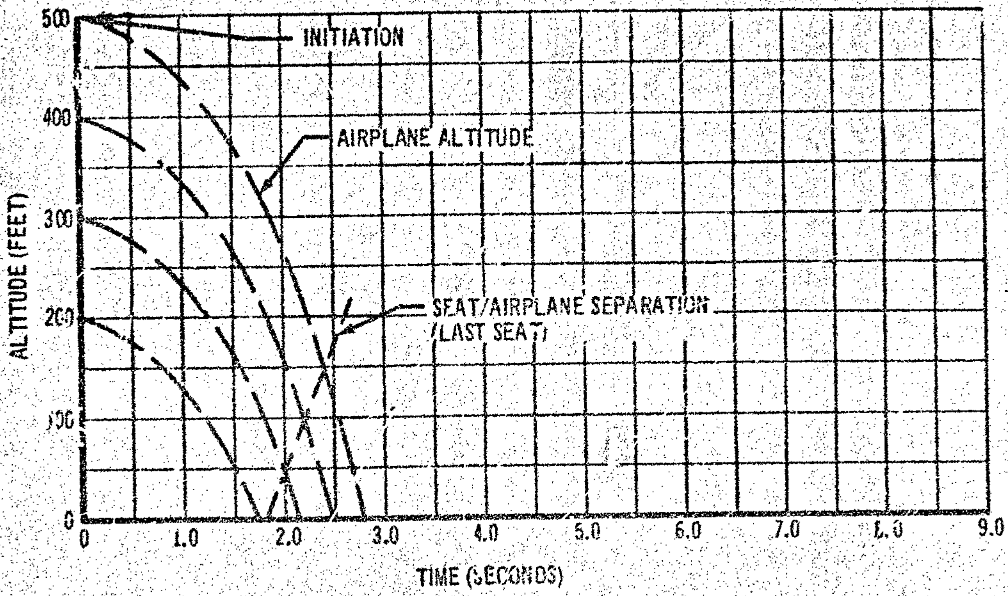


Figure 304. Four-Man Supersonic Dash Vehicle Mach 1.1 Encapsulated Ejection Seat Minimum Escape Altitude –3.0 g Pushover

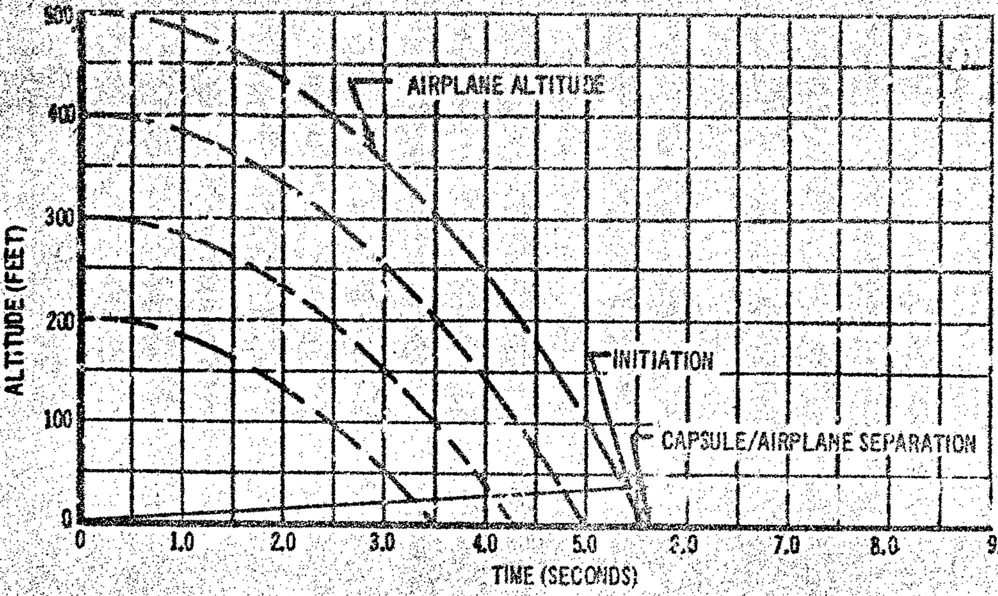


Figure 305. Four-Man Supersonic Dash Vehicle Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude Zero g Pushover

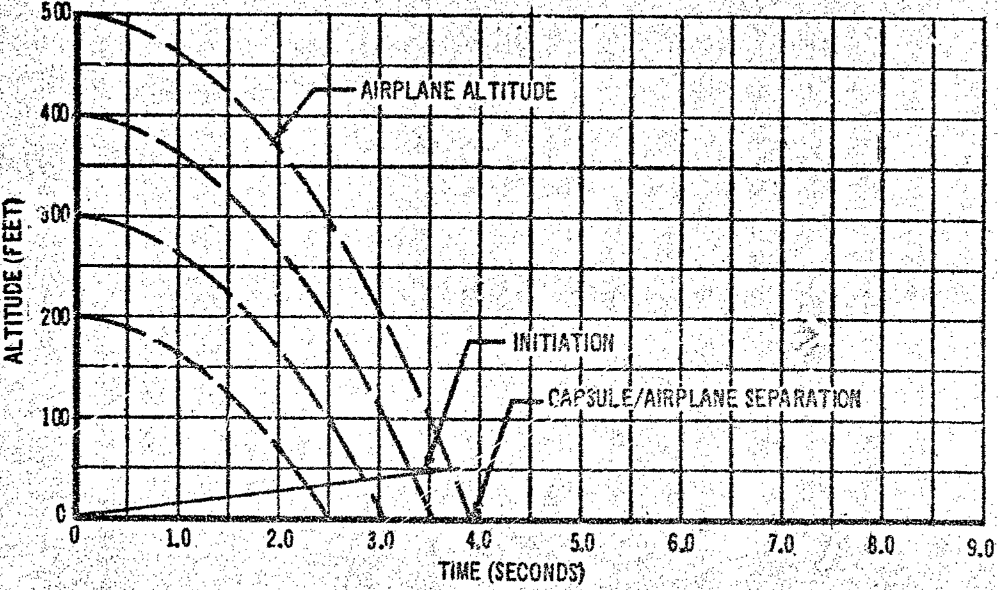


Figure 306. Four-Man Supersonic Dash Vehicle Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude -1.0 g Pushover

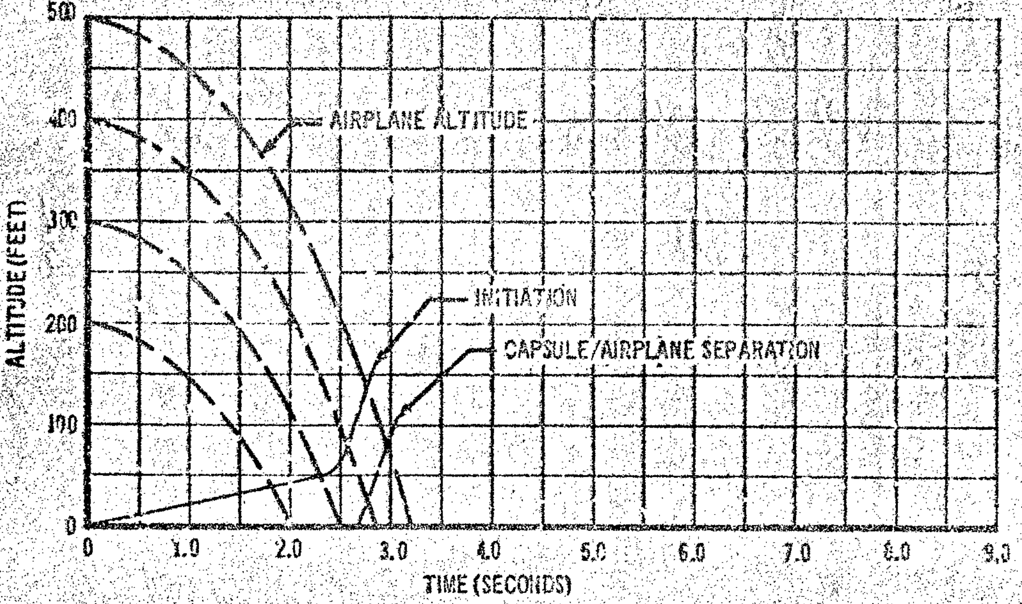


Figure 307. Four-Man Supersonic Dash Vehicle Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude -2.0 g Pushover

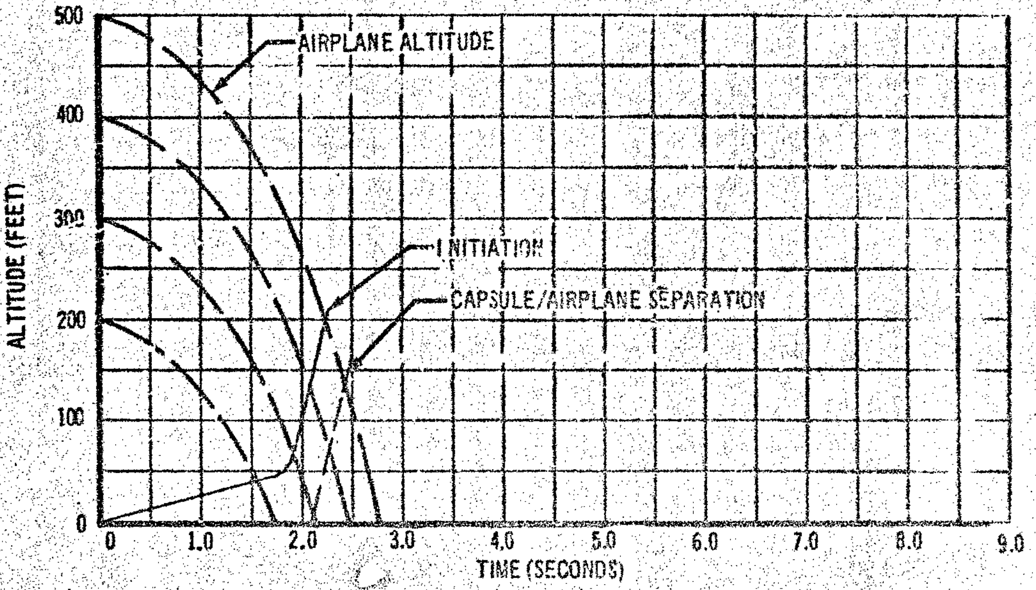


Figure 308. Four-Man Supersonic Dash Vehicle Mach 1.1 Cockpit Pod Capsule Minimum Escape Altitude -3.0 g Pushover

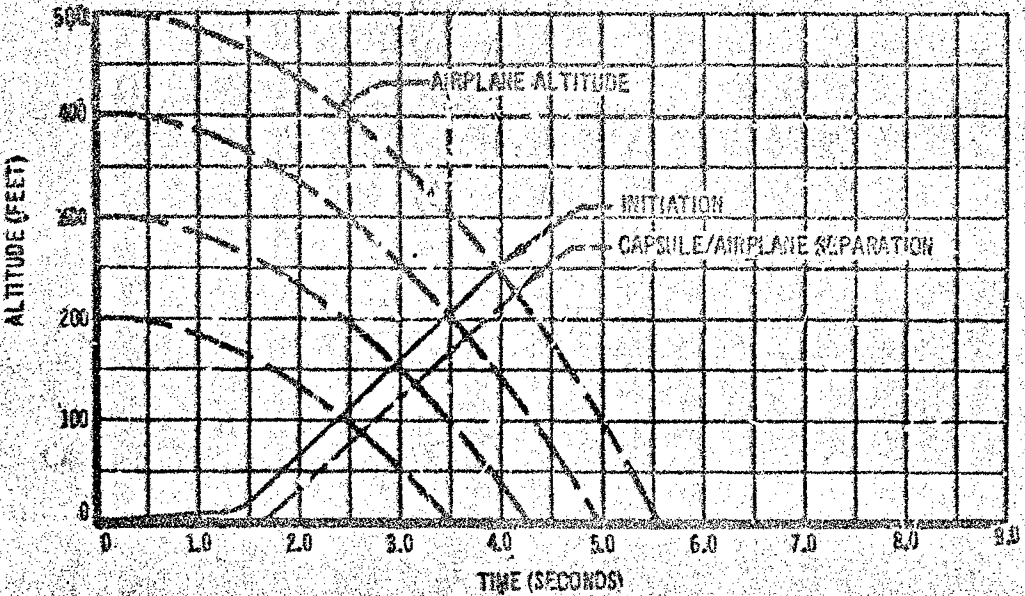


Figure 309. Four-Man Supersonic Dash Vehicle Mach 1.1 Separable Nose Capsule Minimum Escape Altitude Zero g Pushover

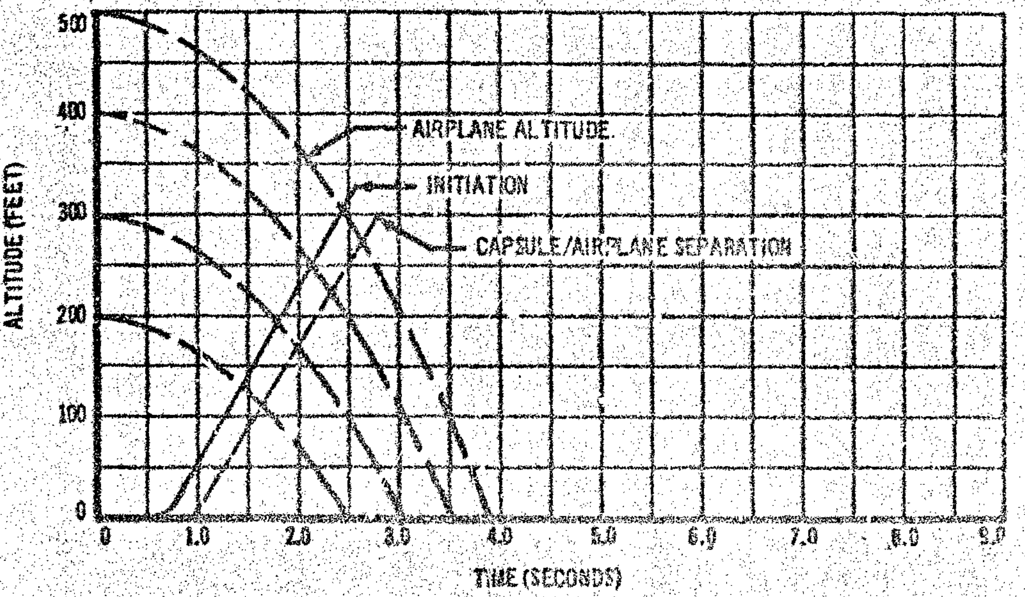


Figure 310. Four-Man Supersonic Dash Vehicle Mach 1.1 Separable Nose Capsule Minimum Escape Altitude -1.0 g Pushover

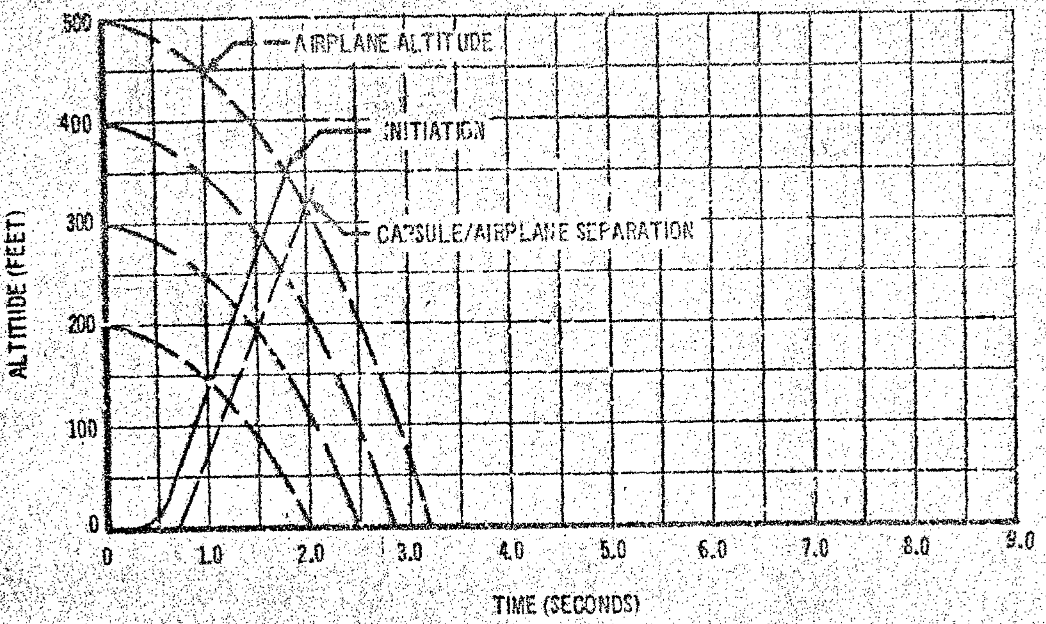


Figure 311. Four-Man Supersonic Dash Vehicle Mach 1.1 Separable Nose Capsule Minimum Escape Altitude –2.0 g Pushover

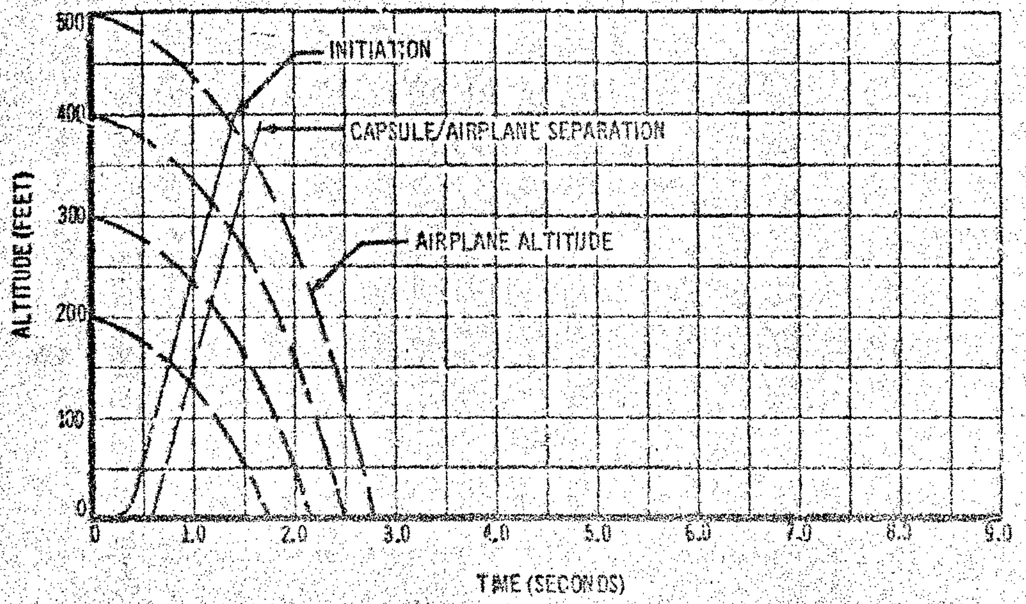


Figure 312. Four-Man Supersonic Dash Vehicle Mach 1.1 Separable Nose Capsule Minimum Escape Altitude –3.0 g Pushover

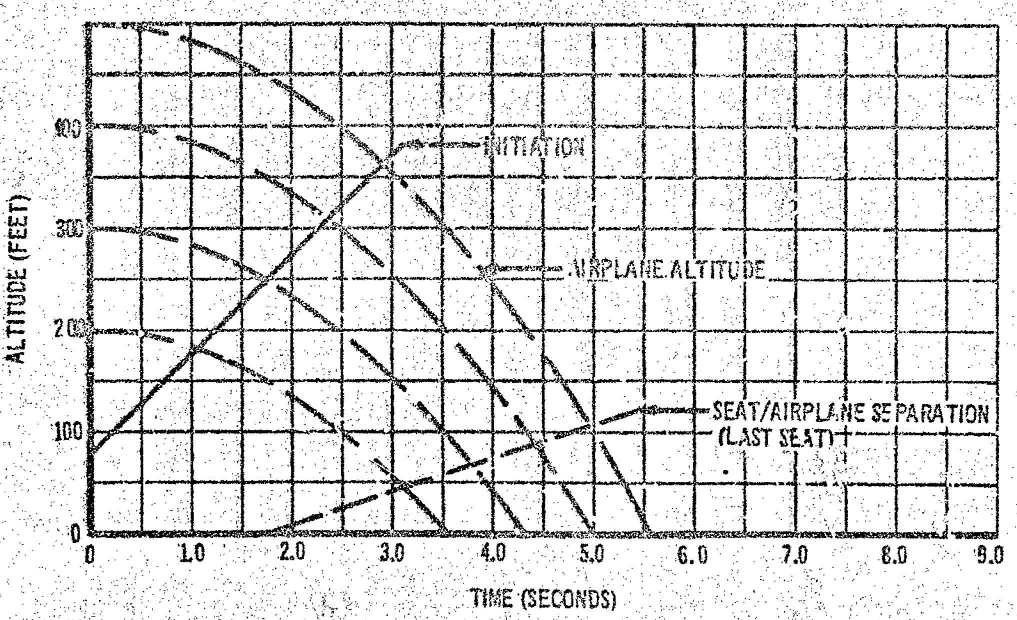


Figure 313. Four-Man Supersonic Dash Vehicle Mach 1.2 Open Ejection Seat Minimum Escape Altitude Zero g Pushover

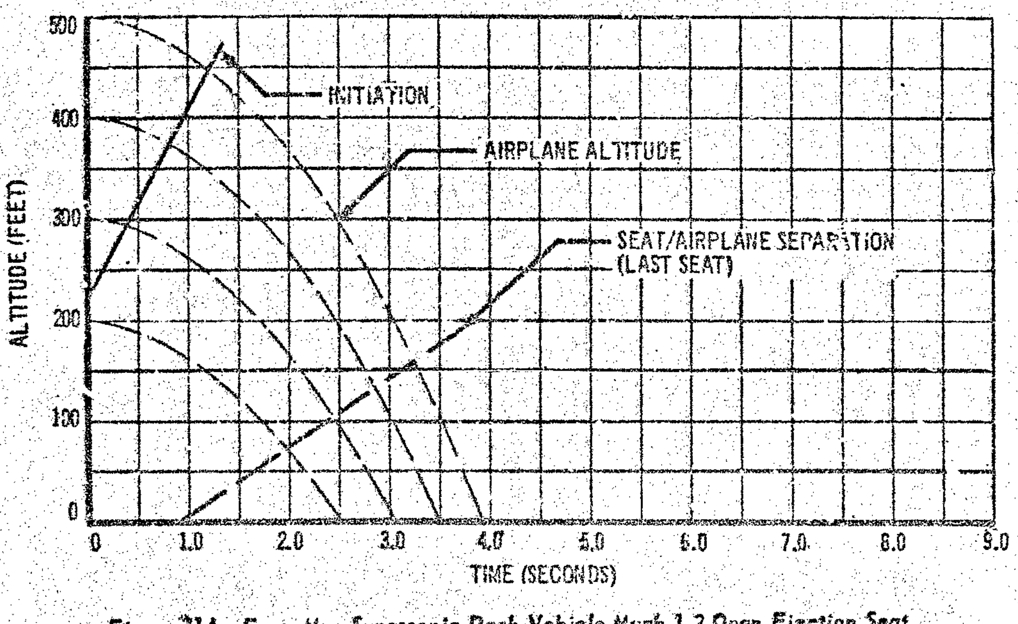


Figure 314. Four-Man Supersonic Dash Vehicle Mach 1.2 Open Ejection Seat Minimum Escape Altitude -1.0 g Pushover

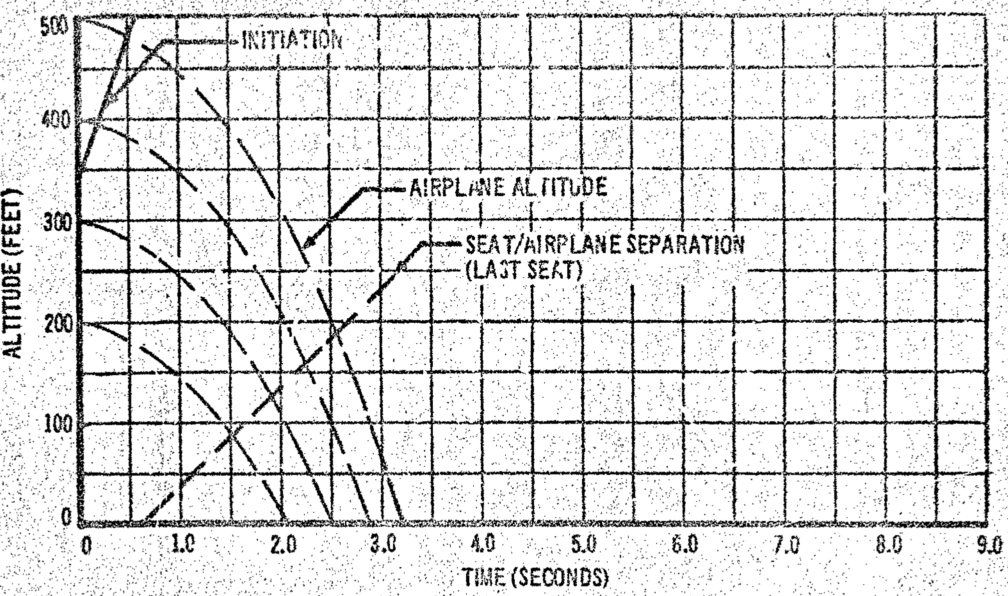


Figure 315. Four-Man Supersonic Dash Vehicle Mach 1.2 Open Ejection Seat Minimum Escape Altitude −2.0 g Pushover

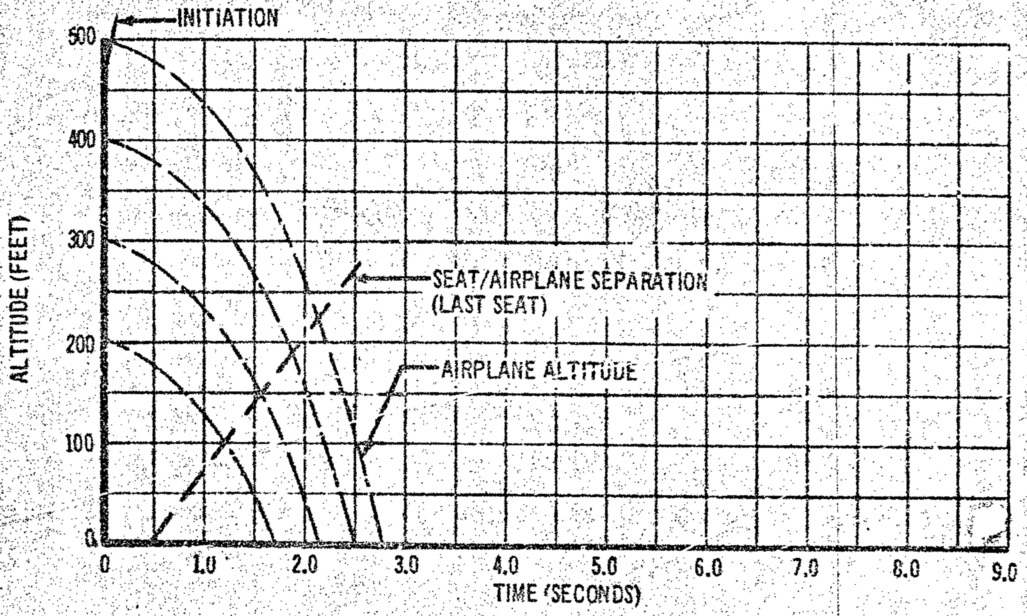


Figure 316. Four-Man Supersonic Dash Vehicle Mach 1.2 Open Ejection Seat Minimum Escape Altitude −3.0 g Pushover

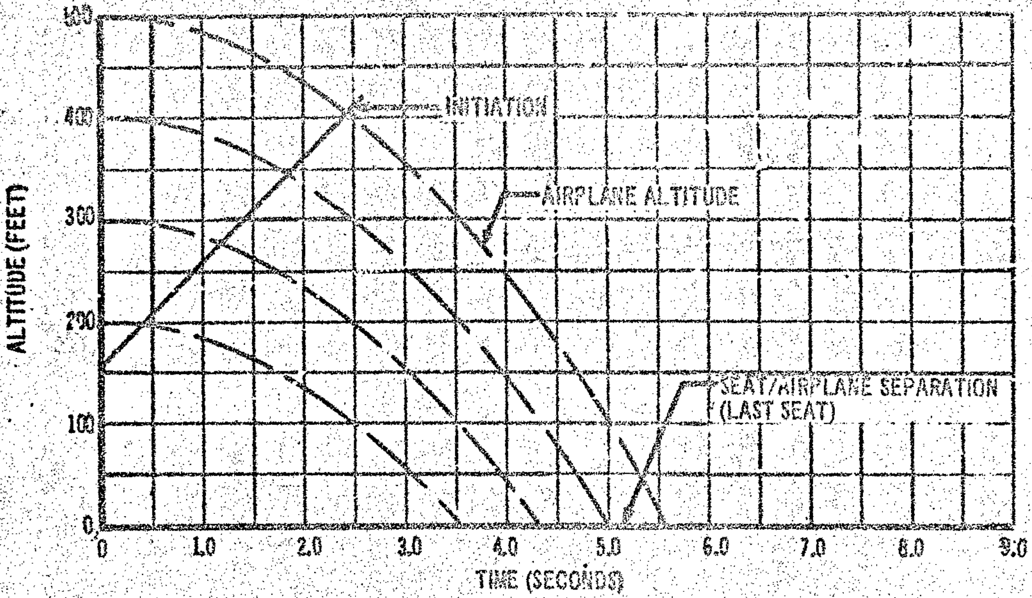


Figure 317. Four-Man Supersonic Dash Vehicle Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude Zero g Pushover

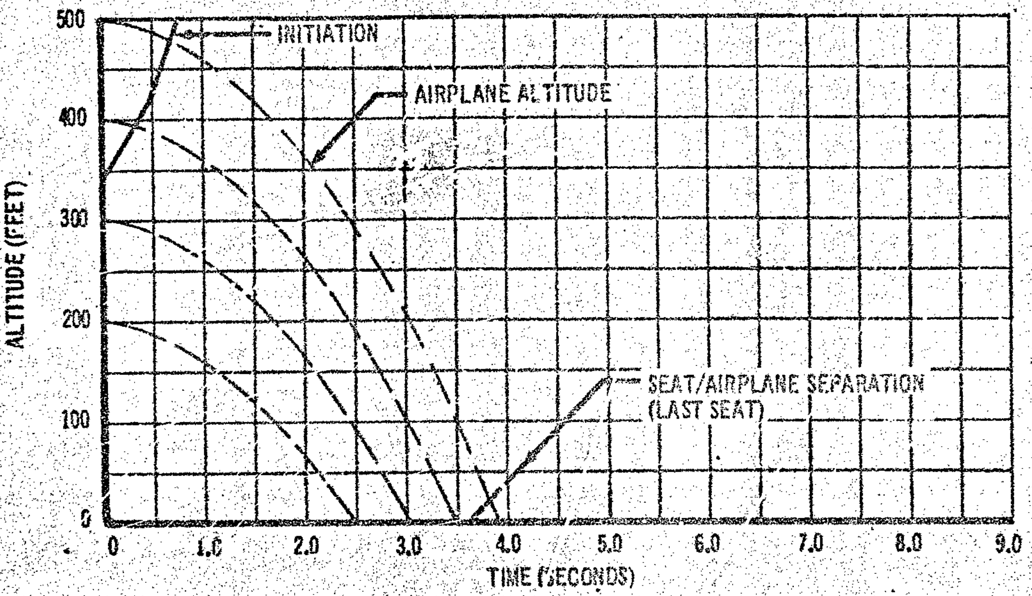


Figure 318. Four-Man Supersonic Dash Vehicle Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude −1.0 g Pushover

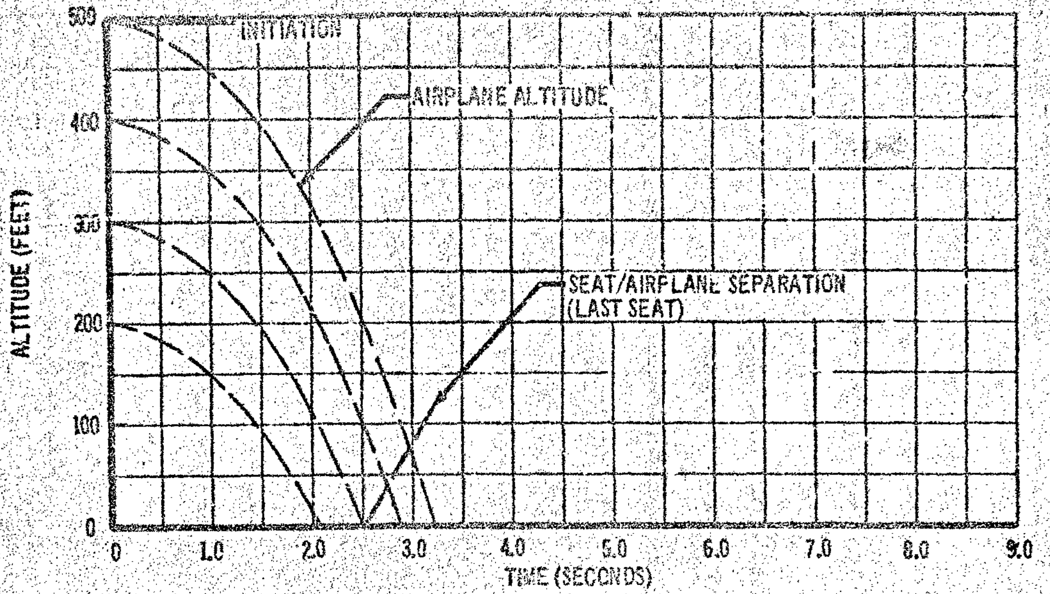


Figure 319. Four-Man Supersonic Dash Vehicle Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude –2.0 g Pushover

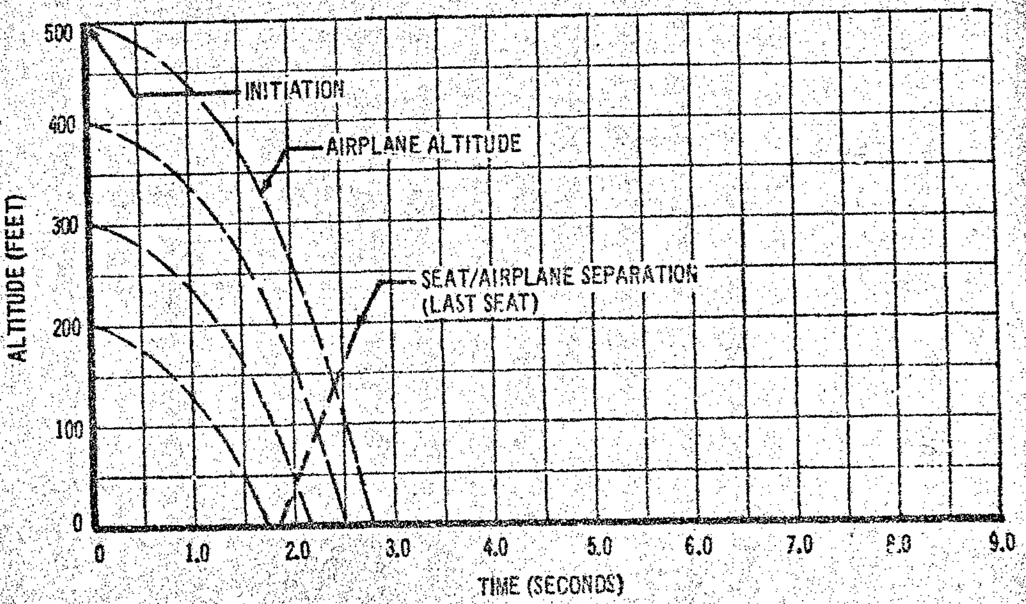


Figure 320. Four-Man Supersonic Dash Vehicle Mach 1.2 Encapsulated Ejection Seat Minimum Escape Altitude –3.0 g Pushover

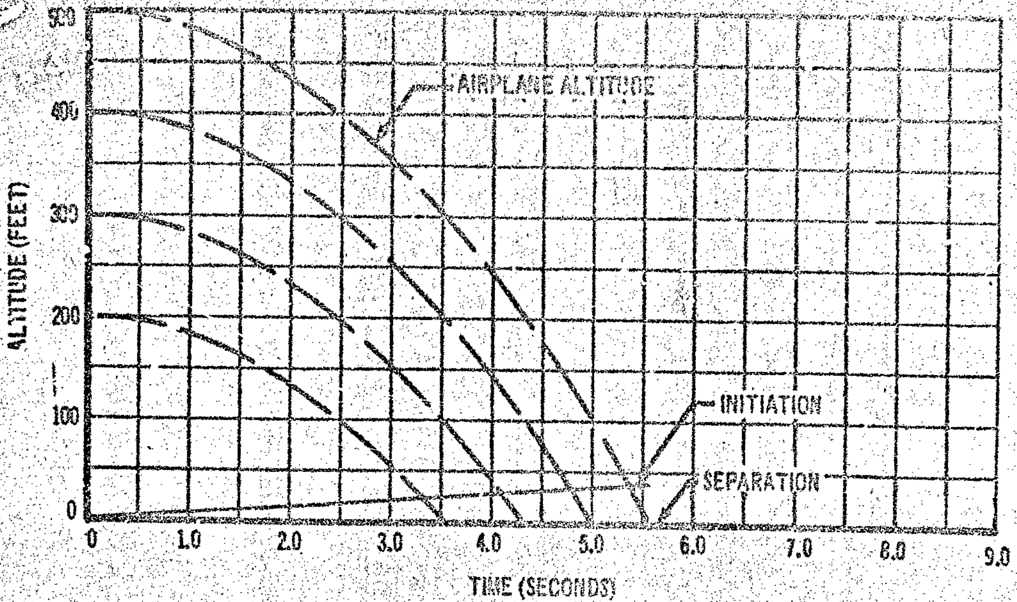


Figure 321. Four-Man Supersonic Dash Vehicle Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude Zero g Pushover

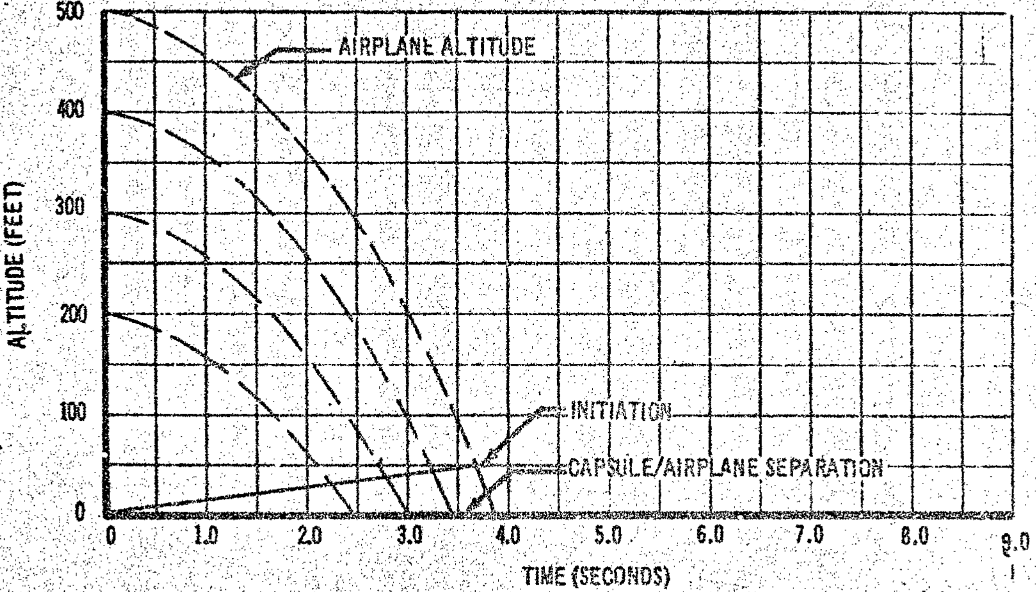


Figure 322. Four-Man Supersonic Dash Vehicle Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude –1.0 g Pushover

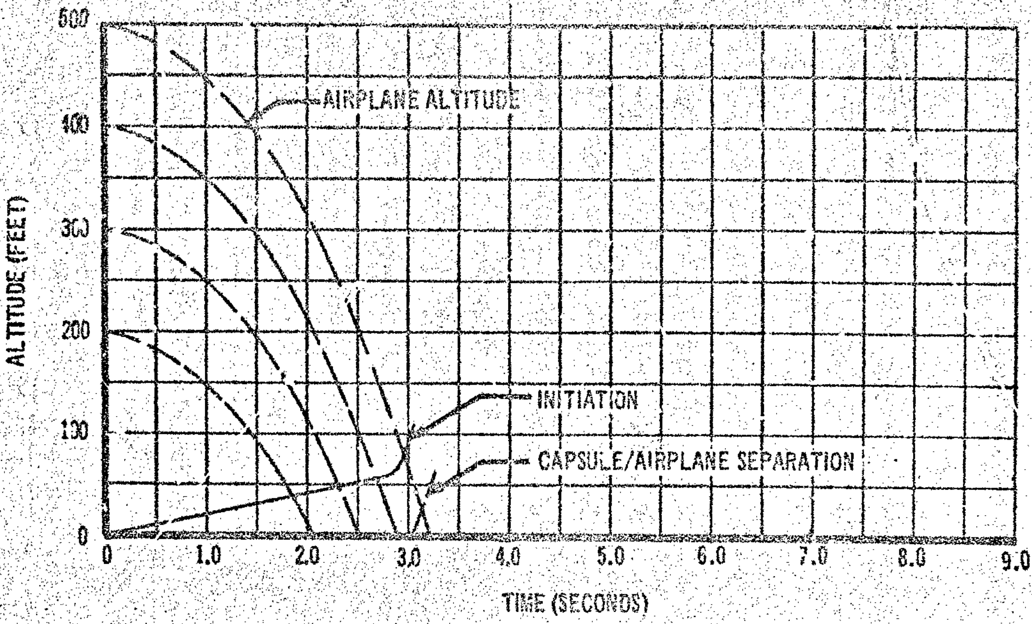


Figure 323. Four–Man Supersonic Dash Vehicle Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude –2.0 g Pushover

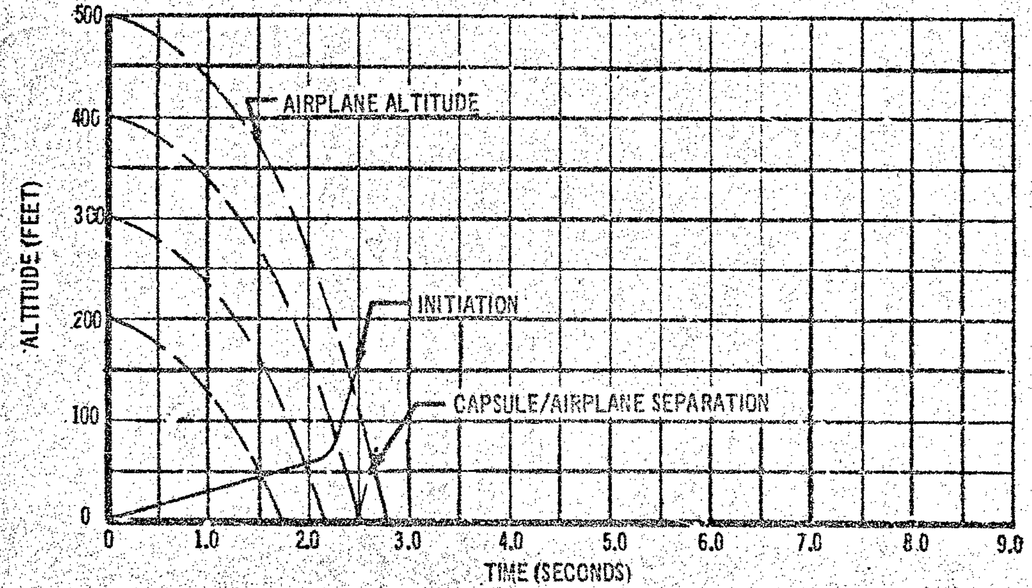


Figure 324. Four–Man Supersonic Dash Vehicle Mach 1.2 Cockpit Pod Capsule Minimum Escape Altitude –3.0 g Pushover

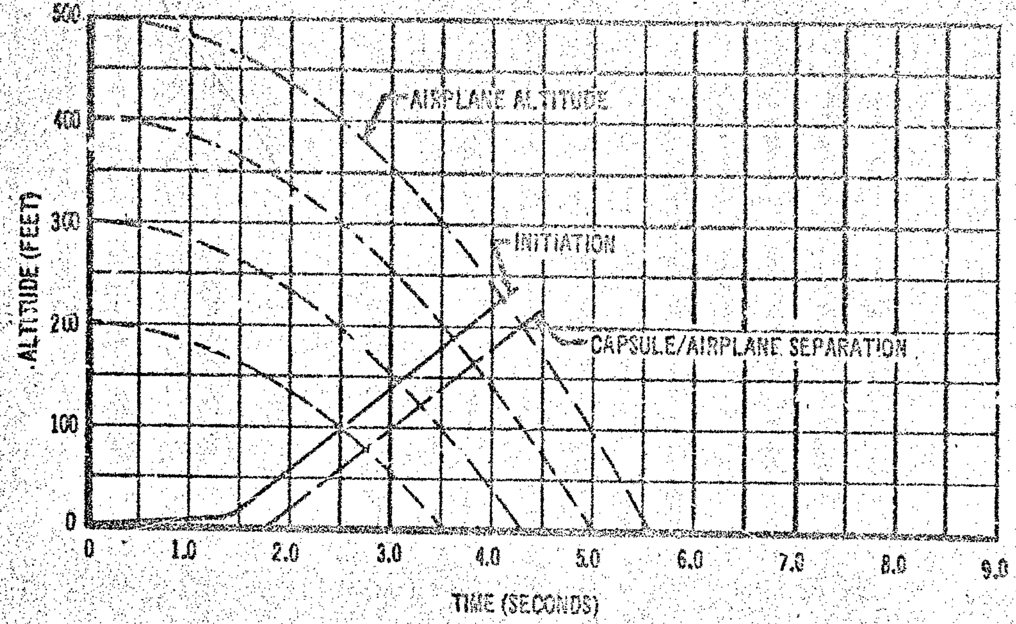


Figure 325. Four-Man Supersonic Dash Vehicle Mach 1.2 Separable Nose Capsule Minimum Escape Altitude Zero g Pushover

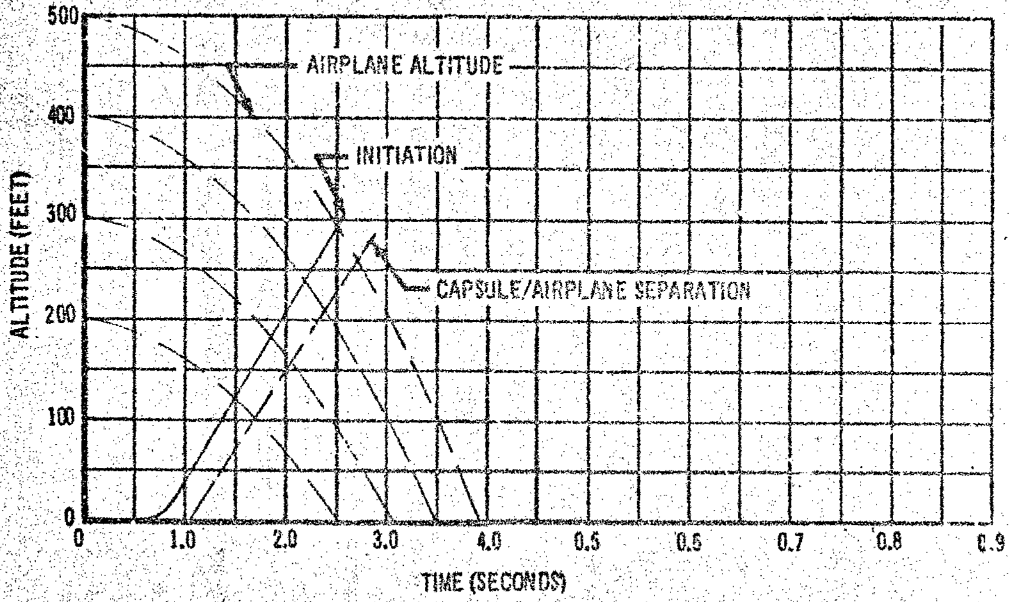


Figure 326. Four-Man Supersonic Dash Vehicle Mach 1.2 Separable Nose Capsule Minimum Escape Altitude -1.0 g Pushover

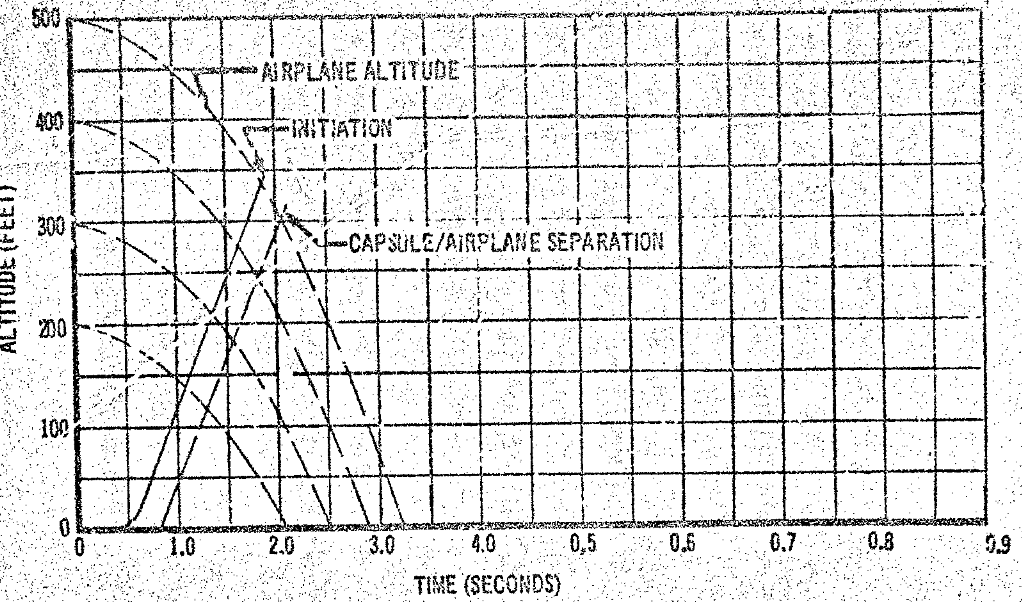


Figure 327. Four-Man Supersonic Dash Vehicle Mach 1.2 Separable Nose Capsule Minimum Escape Altitude –2.0 g Pushover

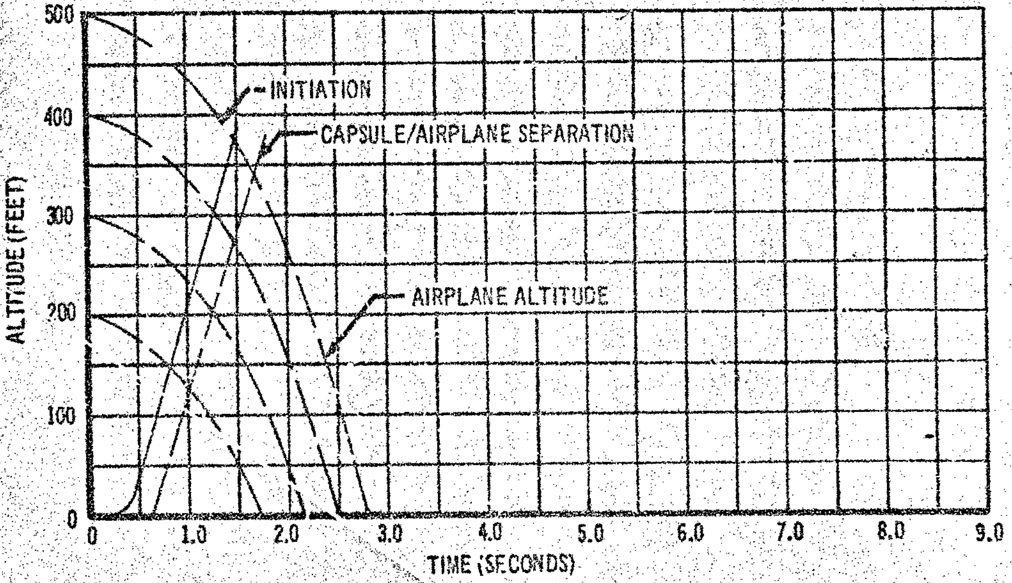


Figure 328. Four-Man Supersonic Dash Vehicle Mach 1.2 Separable Nose Capsule Minimum Escape Altitude –3.0 g Pushover

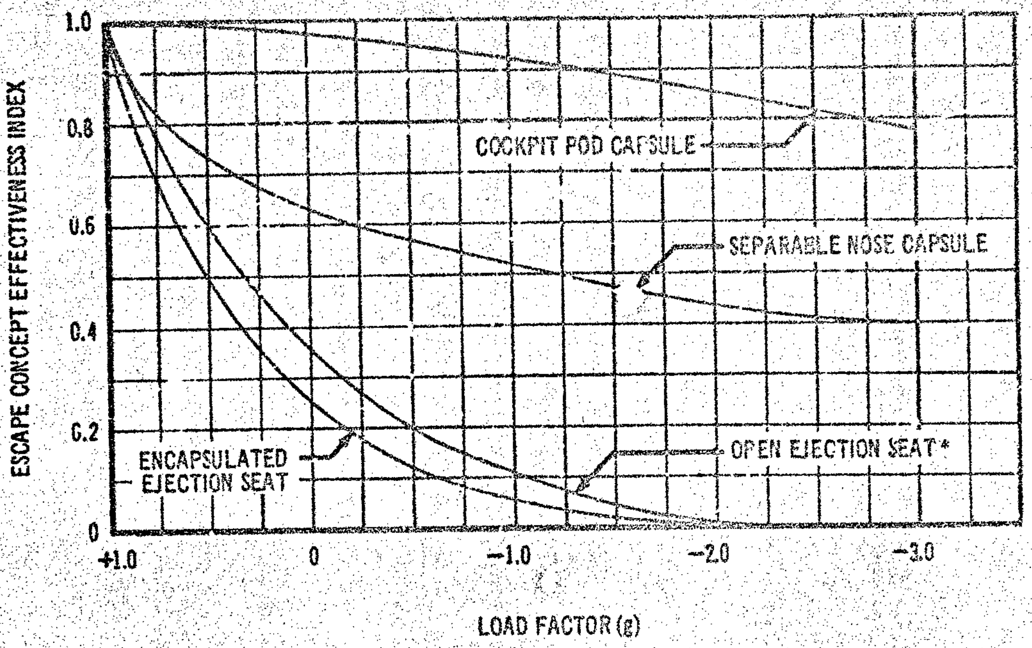


Figure 329. Four-Man Supersonic Dash Vehicle – Low Altitude Dash Escape Concept Effectiveness Index Versus Load Factor During Pushover, Mach 0.9

*DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEATS DUE TO HIGH SPEED

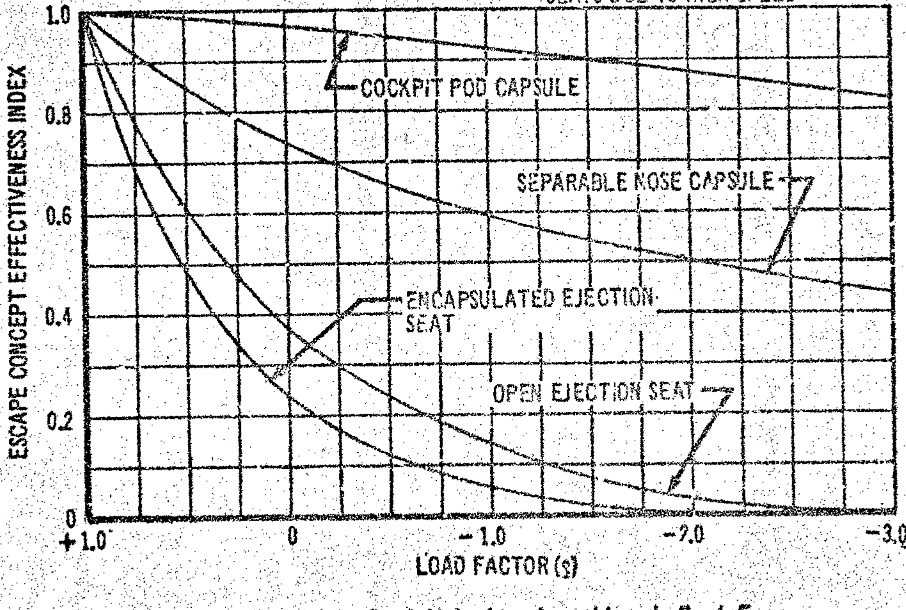


Figure 330. Four-Man Supersonic Dash Vehicle – Low Altitude Dash Escape Concept Effectiveness Index Versus Load Factor During Pushover, Mach 1.1

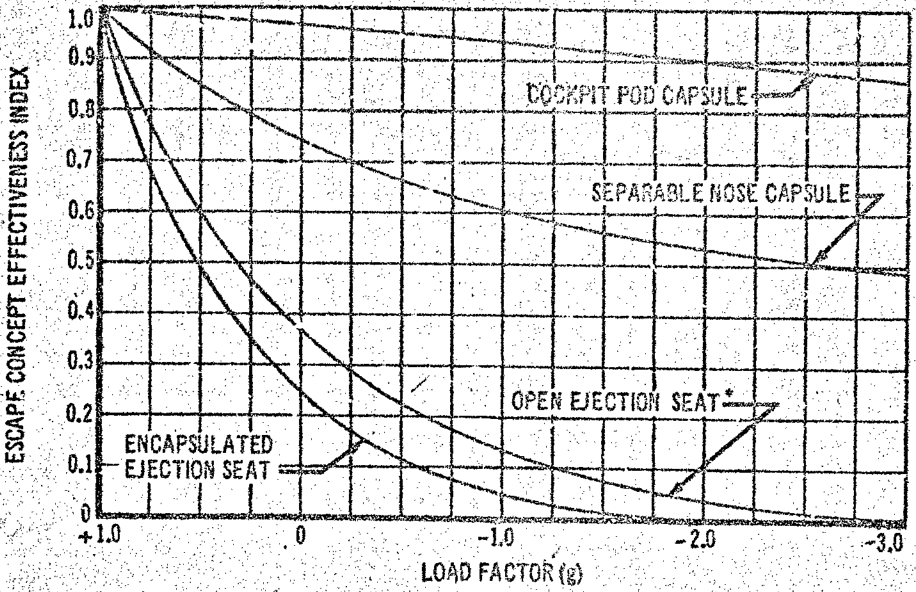


Figure 331. Four-Man Supersonic Dash Vehicle – Low Altitude Dash Escape Concept Effectiveness Index Versus Load Factor During Pushover; Mach 1.2

*DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEATS DUE TO HIGH SPEED

**CORRECTED FOR REDUCED HIGH SPEED CAPABILITY (0.175 SURVIVAL RATE, SEC. V.4)

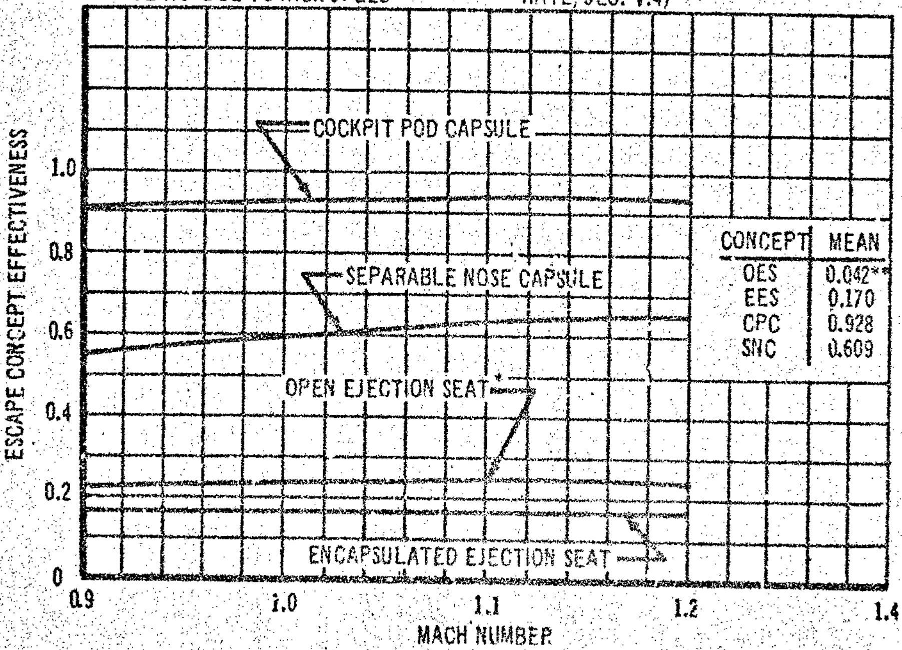


Figure 332. Four-Man Supersonic Dash Vehicle Escape Effectiveness Versus Mach Number During Pushover at Low Altitude Dash

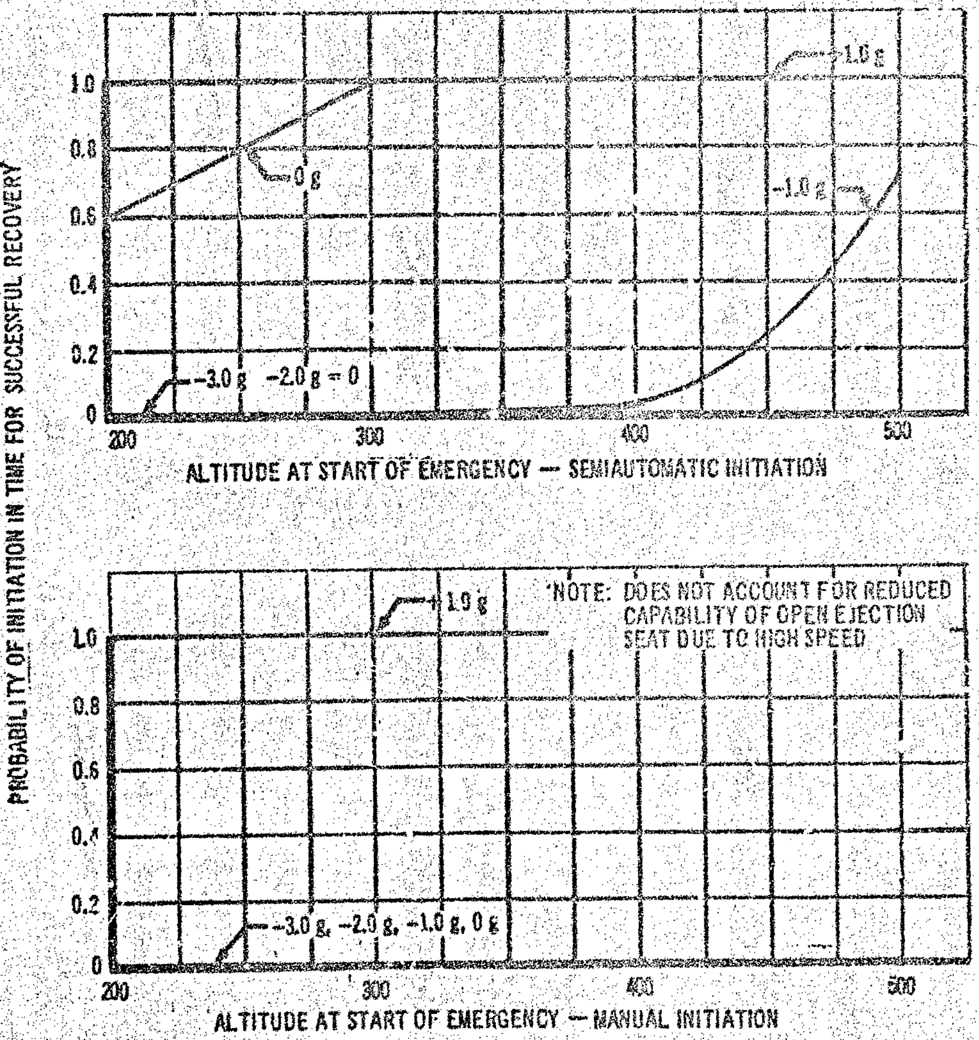
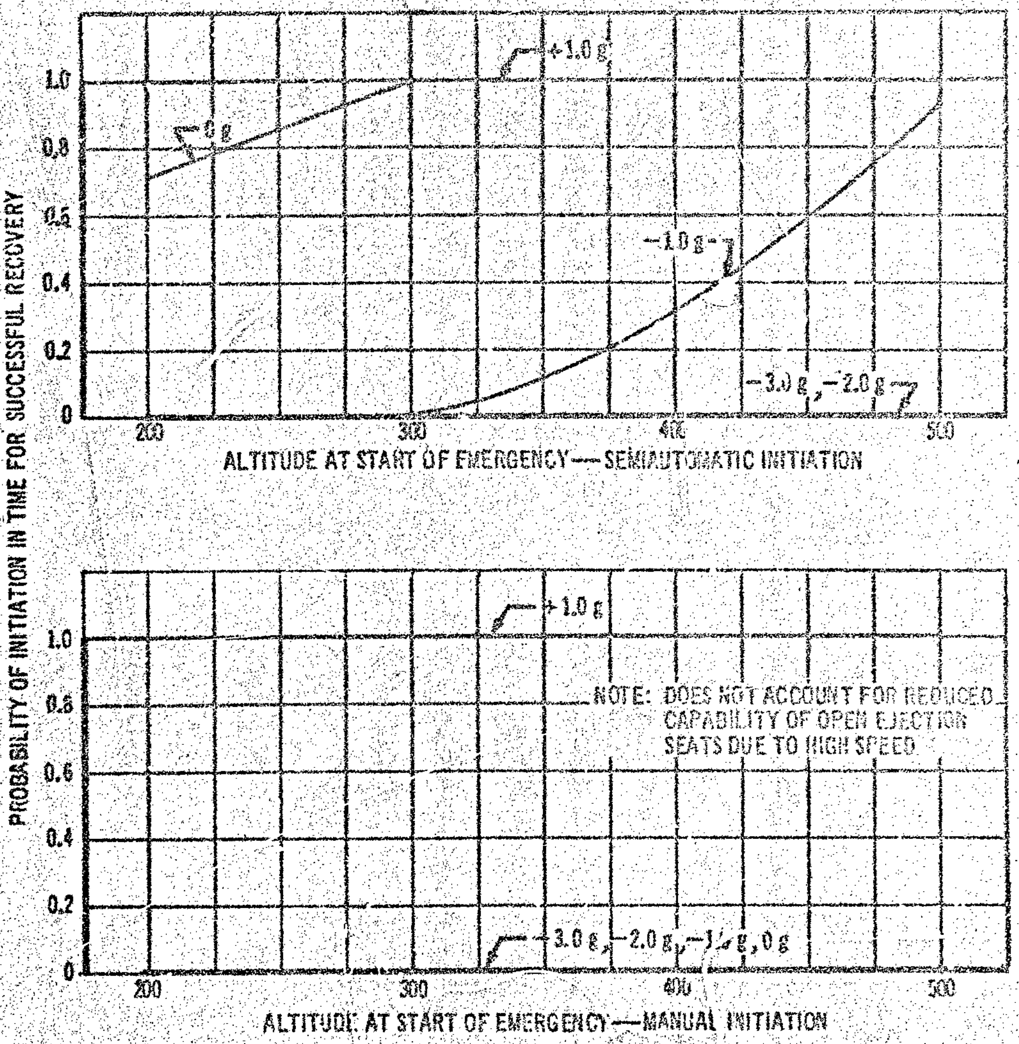


Figure 333. Probability of Successful Escape Versus Altitude Four-Man Vehicle Open Ejection Seats, Mach 0.9



NOTE: DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEATS DUE TO HIGH SPEED

Figure 334. Probability of Successful Escape Versus Altitude Four-Man Vehicle with Open Ejection Seats, Mach 1.1

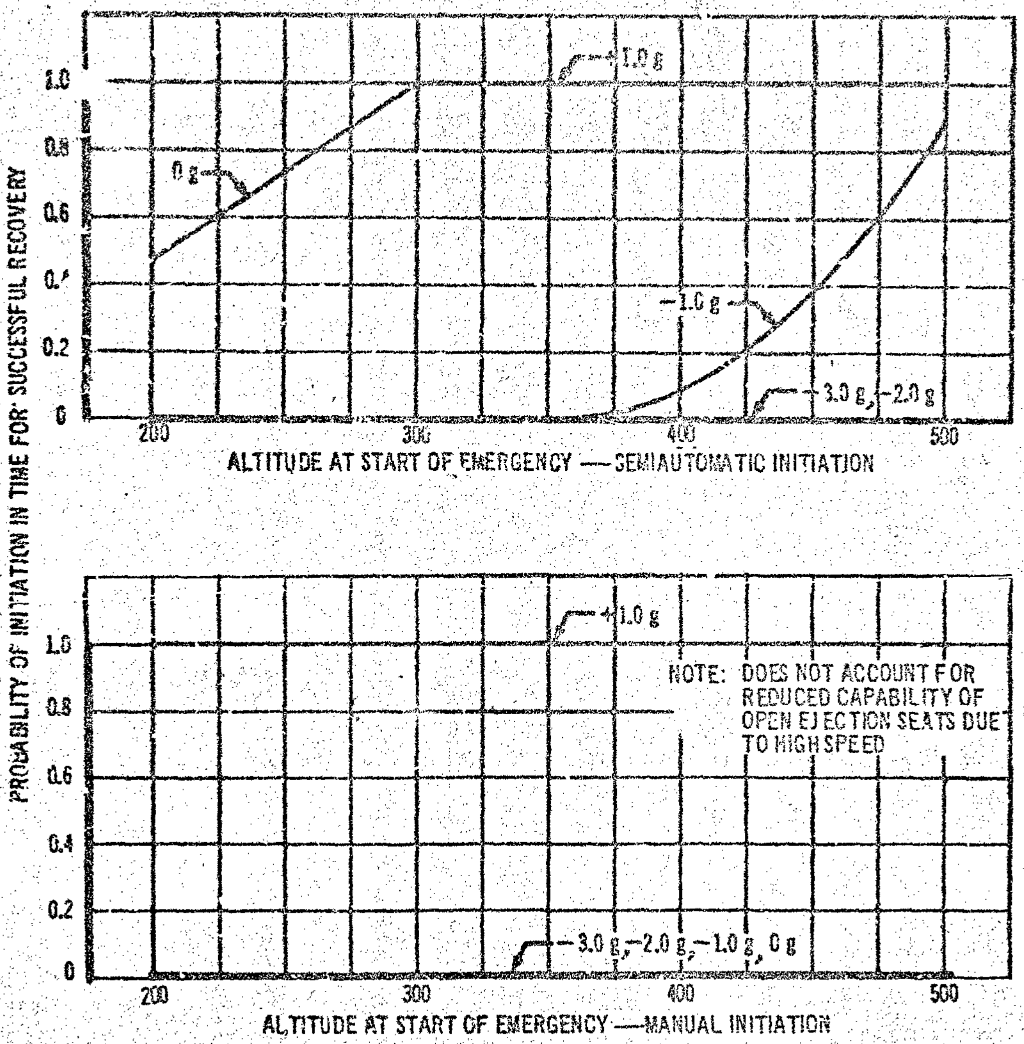


Figure 335. Probability of Successful Escape Versus Altitude Four-Man Vehicle with Open Ejection Seats, Mach 1.2

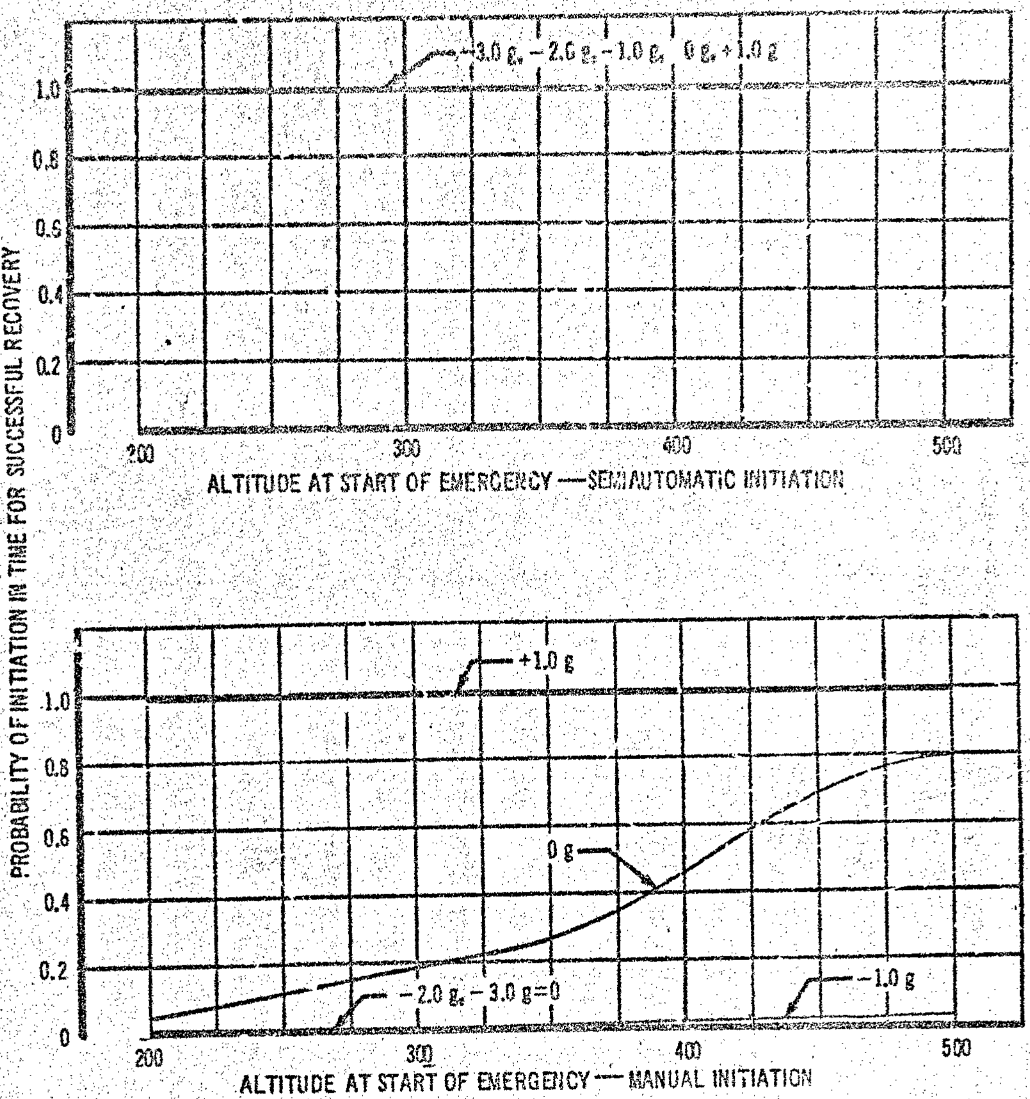


Figure 336. Probability of Successful Escape Versus Altitude Four-Man Vehicle, Cockpit Pod Capsule, Mach 0.9

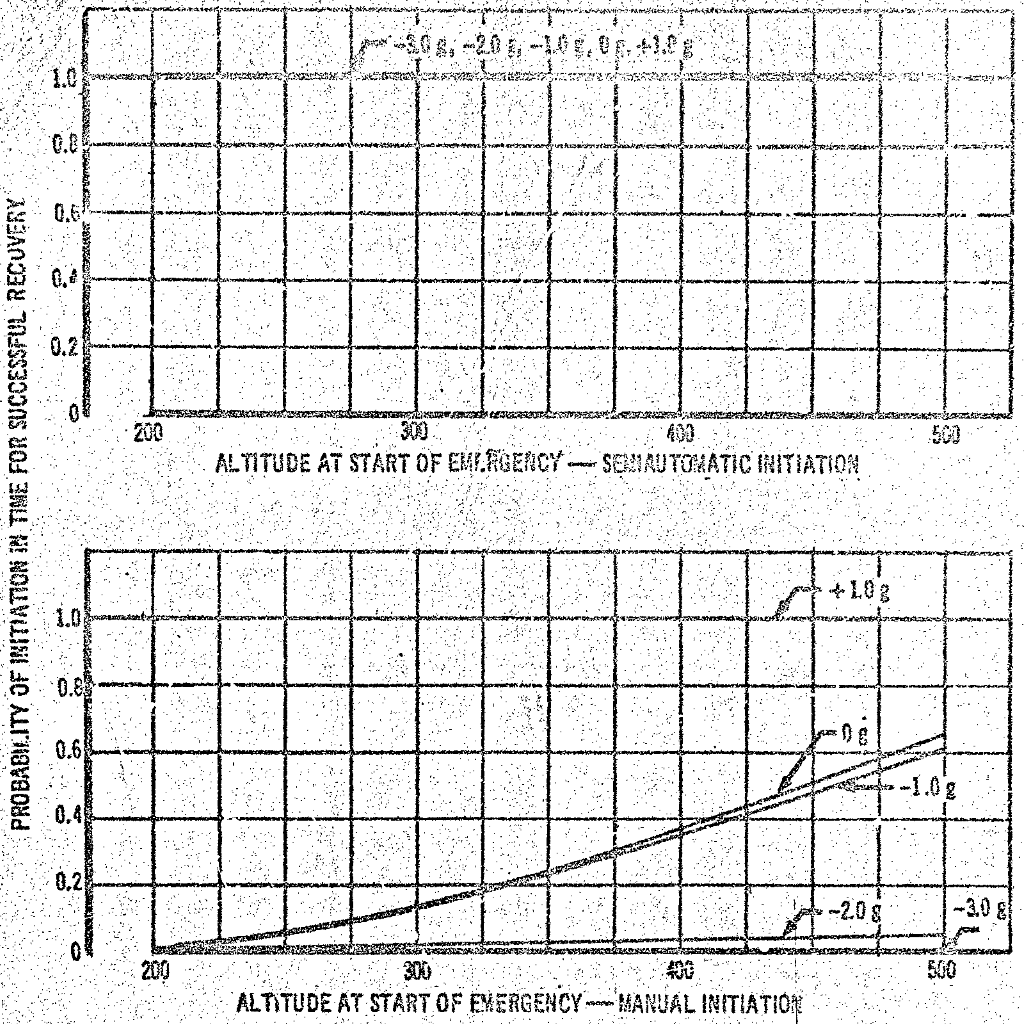


Figure 337. Probability of Successful Escape Versus Altitude Four-Man Vehicle, Cockpit Pod Capsule, Mach 1.1

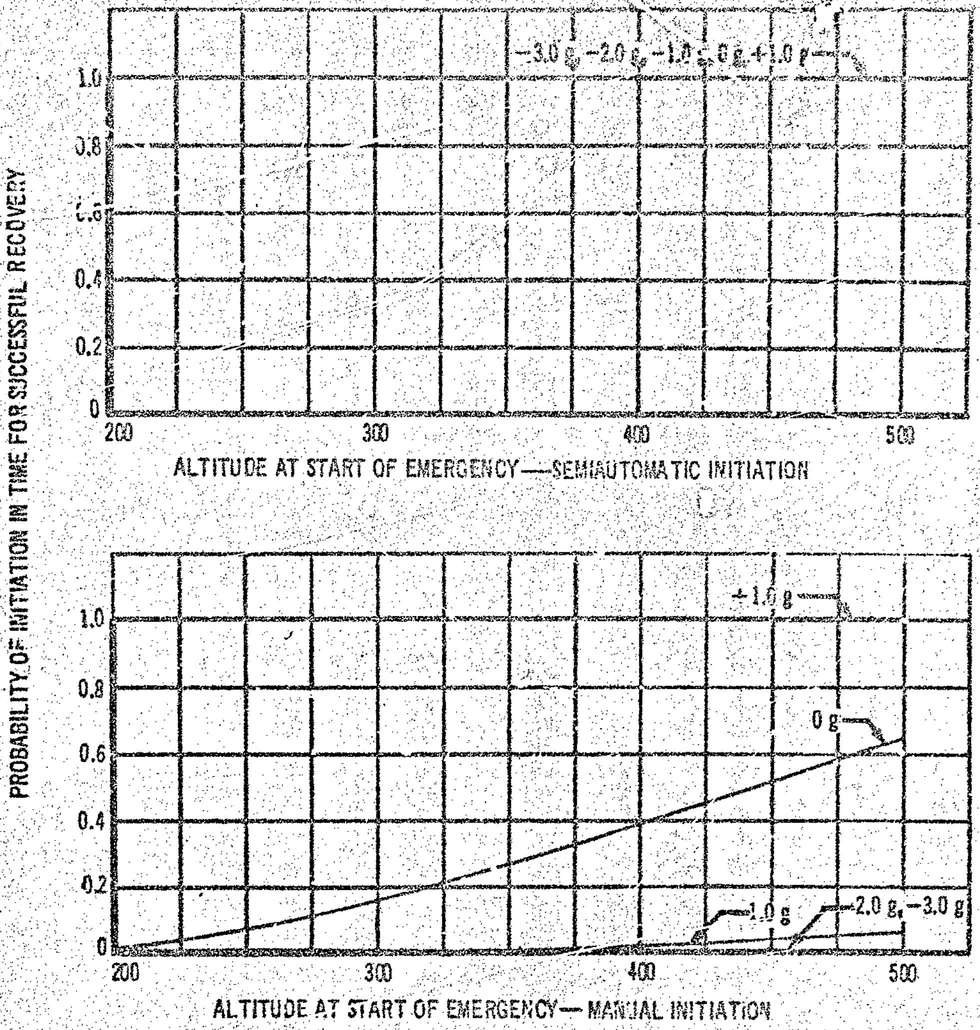


Figure 338. Probability of Successful Escape Versus Altitude Four-Man Vehicle, Cockpit Pod Capsule, Mach 1.2

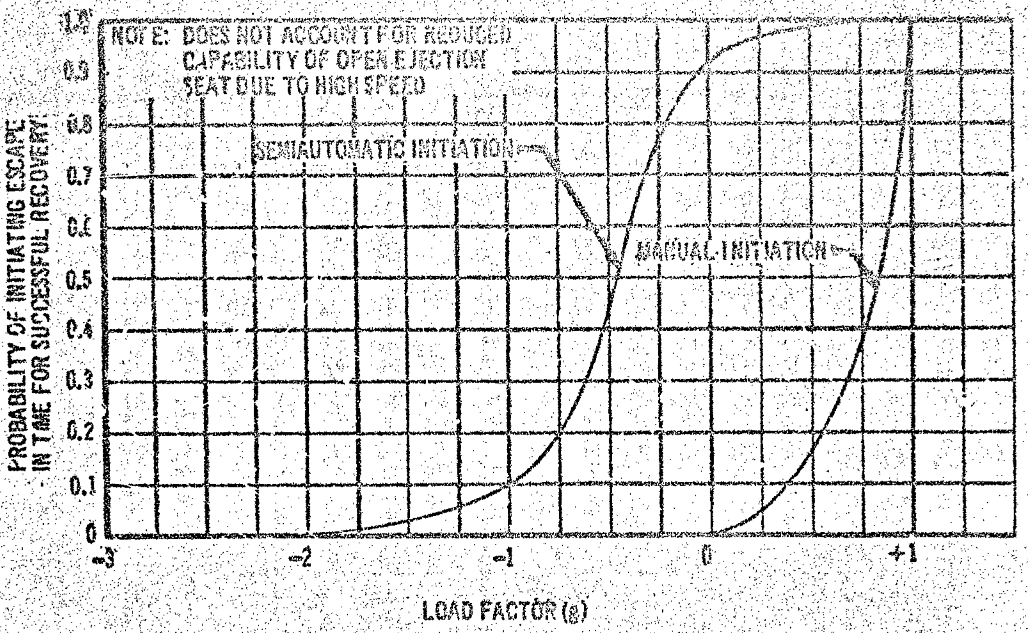


Figure 339. Four-Man Vehicle Open Ejection Seats Mach 0.9 Probability of Initiating Successful Escape Versus Pushover g

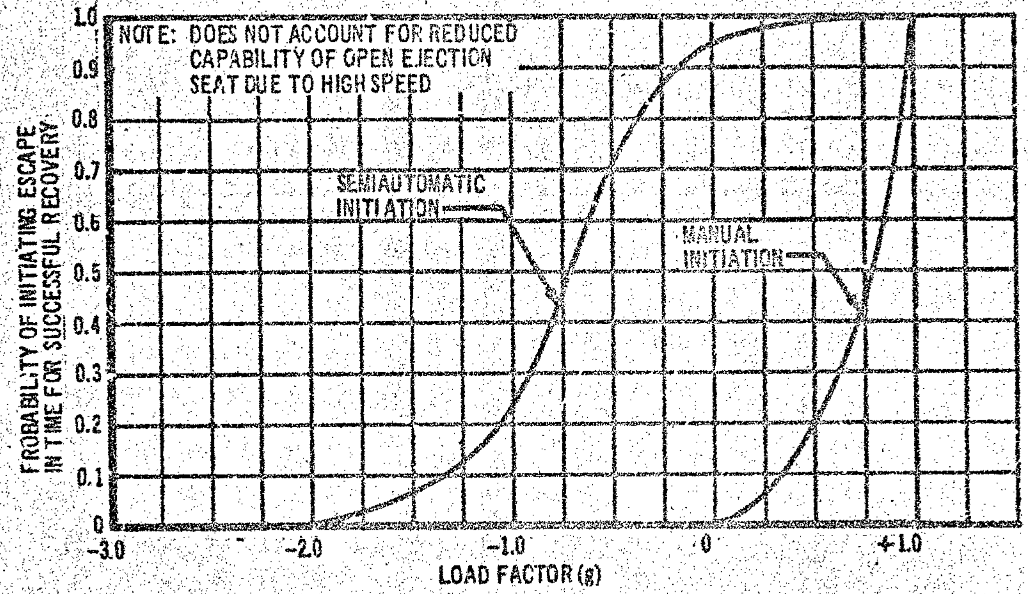


Figure 340. Four-Man Vehicle Open Ejection Seats Mach 1.1 Probability of Initiating Successful Escape Versus Pushover g

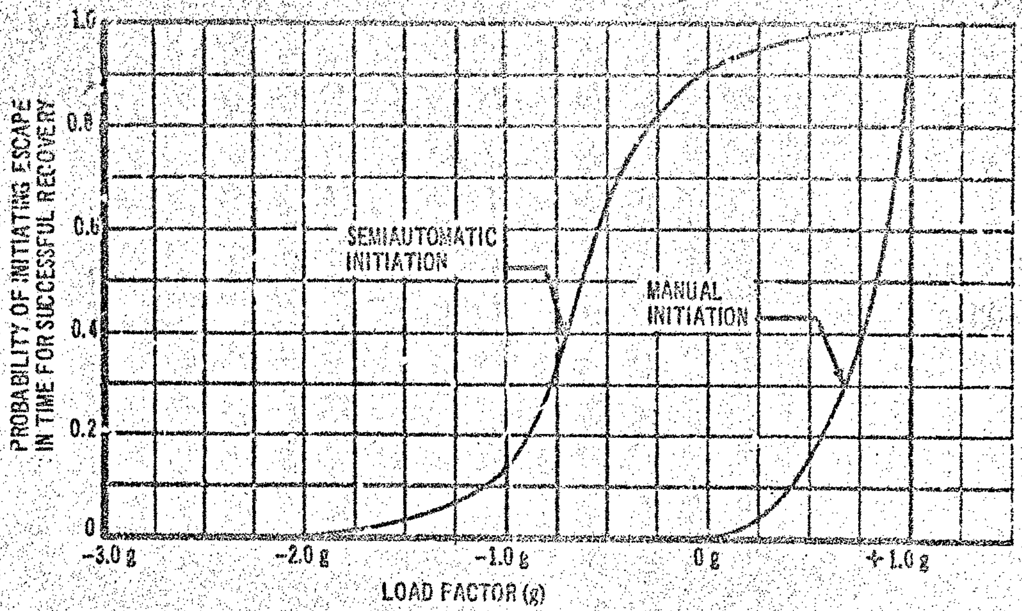


Figure 341. Four-Man Vehicle Open Ejection Seats Mach 1.2 Probability of Initiating Successful Escape Versus Pushover g

NOTE: DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEAT DUE TO HIGH SPEED

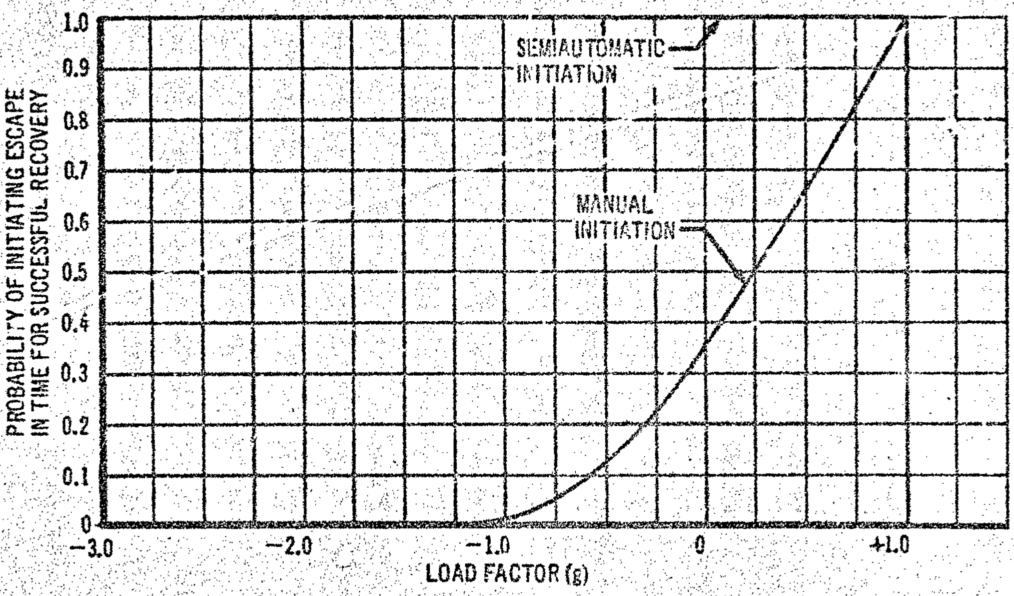


Figure 342. Four-Man Vehicle Cockpit Pod Capsule Mach 0.9 Probability of Initiating Successful Escape Versus Pushover g

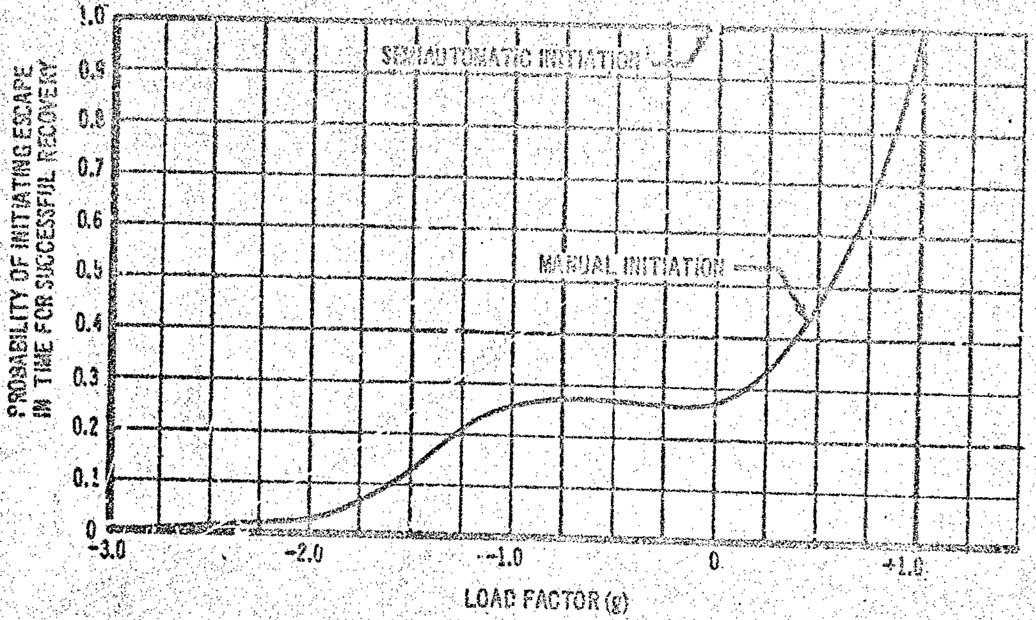


Figure 343. Four-Man Vehicle Cockpit Pod Capsule Mach 1.1 Probability of Initiating Successful Escape Versus Pushover g

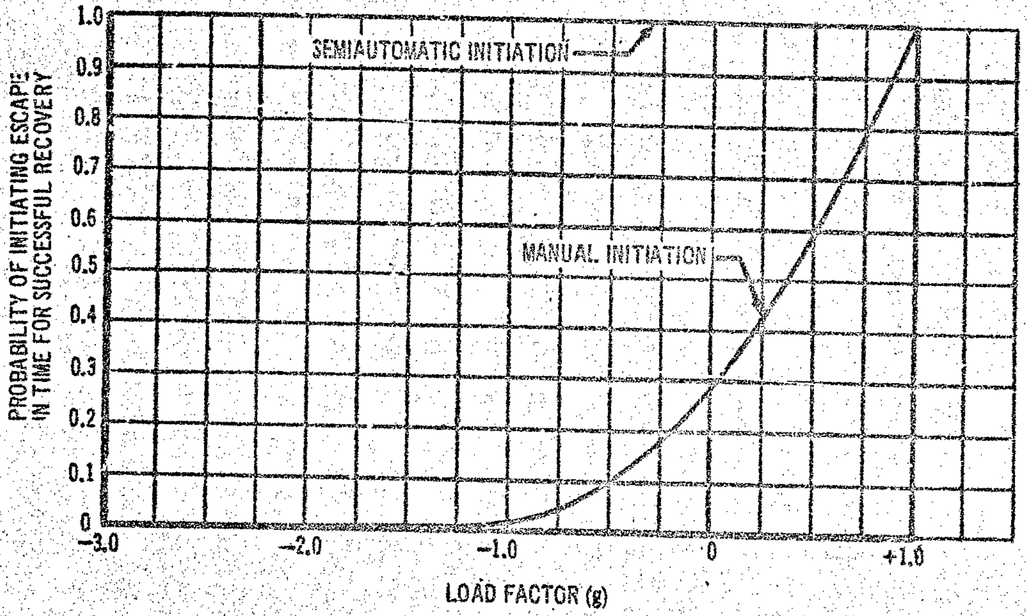


Figure 344. Four-Man Vehicle Cockpit Pod Capsule Mach 1.2 Probability of Initiating Successful Escape Versus Pushover g

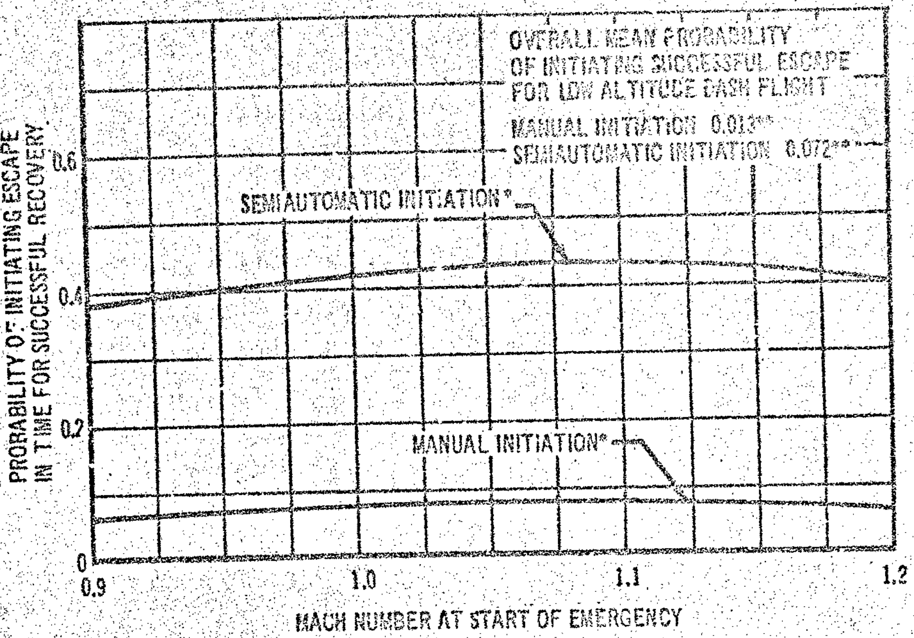


Figure 345. Four-Man Vehicle Open Ejection Seats, Probability of Successful Escape Versus Mach Number

*DOES NOT ACCOUNT FOR REDUCED CAPABILITY OF OPEN EJECTION SEATS DUE TO HIGH SPEED

**CORRECTED FOR REDUCED HIGH SPEED CAPABILITY (0.175 SURVIVAL RATE SECT V.4)

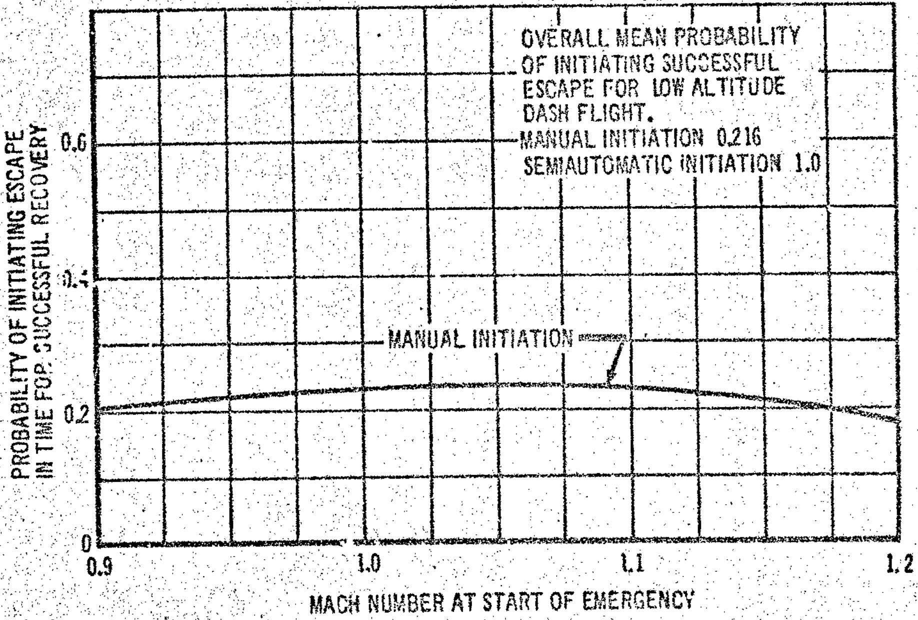


Figure 346. Four-Man Cockpit Pod Capsule Probability of Successful Escape Versus Mach Number

4. HIGH ALTITUDE AND HIGH SPEED

Successful escape with respect to equivalent airspeed or "q" depends on the ability of the escape system to protect the crewman from the effects of windblast, flailing, and intolerable g-forces during high speed escape. Relative to open ejection seats, reference 4 states that ejection at a "q" of 8.5 psi (600 knots EAS) is the threshold of fatal injury; however, in at least one case, there has been survival at 9.5 psi (640 knots EAS). Flailing seems to be the major contributing cause of high speed ejection fatalities; however, internal organ damage from crush type chest injuries, due to compression, was indicated as a possible cause of fatalities in extremely high-speed ejections. Further examination of the high speed ejection data reveals that at least four fatalities out of seven ejections were attributed to windblast effects. Based on these data, it was concluded that an open ejection seat with an improved restraint system would probably result in a 40 percent windblast fatality rate for ejections between 600 and 650 knots EAS. Further, the rapid onset of windblast injuries as speeds increase above 600 knots indicates that survival will be very unlikely at speeds above 650 knots.

In regard to g-force injuries, it is noted from the escape system performance computations (Section III) that g-forces for the open ejection seats exceed allowable human tolerance limits for ejections above 600 knots. However, windblast is more critical and is the governing factor.

For the encapsulated seat, cockpit pod capsule, and separable nose capsule concepts, the crewmen will be protected from the effects of windblast and the computed g-forces do not exceed allowable human tolerance limits for escape at the maximum equivalent airspeed capability of the vehicles. Table XIII lists the estimated probabilities of successful escape with airspeed for the various escape concepts. Table XIV lists the percentage of the high speed envelope (600 to 800 KEAS) for each vehicle and escape concept in which the crewman will be protected from fatal injury due to wind blast.

Table XIII. Escape Concept Capabilities with Respect to Airspeed

Equivalent Airspeed, Knots	Probability of Survival			
	Open Ejection Seat	Encapsulated Seat	Cockpit Pod Capsule	Separable Nose Capsule
0 to 599	1.0	1.0	1.0	1.0
600 to 649	0.6	1.0	1.0	1.0
650 to 699	0.10	1.0	1.0	1.0
700 to 800	0.0	1.0	1.0	1.0

Table XIV. Percentage of High Airspeed Envelope Protected by Various Escape Concepts

Escape Concept	Percentage of High Speed Envelope Protected (600 to 800 KEAS)	
	Two-man Subsonic VTOL Vehicle	Three-man Combined Capability Vehicle and Four-man Supersonic Dash Vehicle
Open Ejection Seat	Not applicable	17.5 percent
Encapsulated Ejection Seat Cockpit Pod Capsule, and Separable Nose Capsule	Not applicable	100 percent

The primary requirements for high altitude escape are pressurization protection, low temperature protection, provision for a breathable atmosphere, initial escape system stability, and free fall stability. Each of the escape concepts as defined in Section III have the potential of providing high-altitude and free-fall stability. However, due to rocket plume effects in a rarefied atmosphere, advanced development in this area is indicated.

Concerning pressurization, temperature, and breathing requirements, cockpit pod and separable nose capsule concepts provide the most efficient protection. The encapsulated ejection seat protects the crewman at high altitude, but additional subsystems required at these altitudes are complex and less reliable. Open ejection seats require the use of pressure suits for ejections above 50,000 feet; and although adequate protection is provided, a substantial degradation of crew comfort and efficiency results. For the two-man subsonic VTOL vehicle, for which the altitude envelope does not exceed 50,000 feet, pressurization will not be required. However, for the open ejection seat concept, oxygen mask and pressure breathing provisions will be required. Table XV lists the estimated relative high altitude escape capability of each escape concept with respect to the performance envelopes of each vehicle

Table XV. High Altitude Escape Index

Escape Concept	High Altitude Escape Index	
	Two-man Subsonic VTOL Vehicle	Three-man Combined Capability Vehicle and Four-man Supersonic Dash Vehicle
Open Ejection Seats	0.95	0.80
Encapsulated Ejection Seats	0.93	0.85
Cockpit Pod Capsule	1.0	1.0
Separable Nose Capsule	1.0	1.0

SECTION VI

ESCAPE CONCEPT TRADE DATA

The evaluation and selection of an appropriate escape concept for specific types of future advanced military aircraft involves the consideration of many individual and interrelated factors. The factors that must be considered include: inflight escape capability relative to vehicle performance and usage; survival capability after landing on land or water; escape system complexity, reliability, and maintainability; escape system weight penalty; development and manufacturing costs; the effect of the time required to develop and of developmental risk on the availability of the escape system; effect of the volume required to accommodate escape system components inside and outside the crew compartment on the overall airplane size and performance; effect of escape system cockpit layout requirements, vision, personal equipment, pressure suit and arctic clothing requirements, seating, and restraint requirements on shirtsleeve environment and crew comfort and efficiency; and the effect of escape system hatch requirements (cabin pressure integrity), crash landing protection provisions, additional crewmembers aboard (without escape systems), and of protective encumbrances on overall crew flight safety.

Examination of the relationships between the various factors reveals that all the pertinent considerations may be expressed in terms of seven major trade factors. Figure 347 lists the major factors along with the considerations of each.

The following pages of this section summarize data from the preceding sections of the report and provide additional data pertaining to each trade factor. For each trade factor the various escape concepts are rank-ordered with respect to its suitability to the two-man subsonic VTOL vehicle, the three-man combined capability vehicle, and the four-man supersonic low-altitude dash vehicle.

The method of rank-ordering is to rate the most suitable concept at 1.0. The remaining concepts are rated less than 1.0 and represent a percentage degradation of the best.

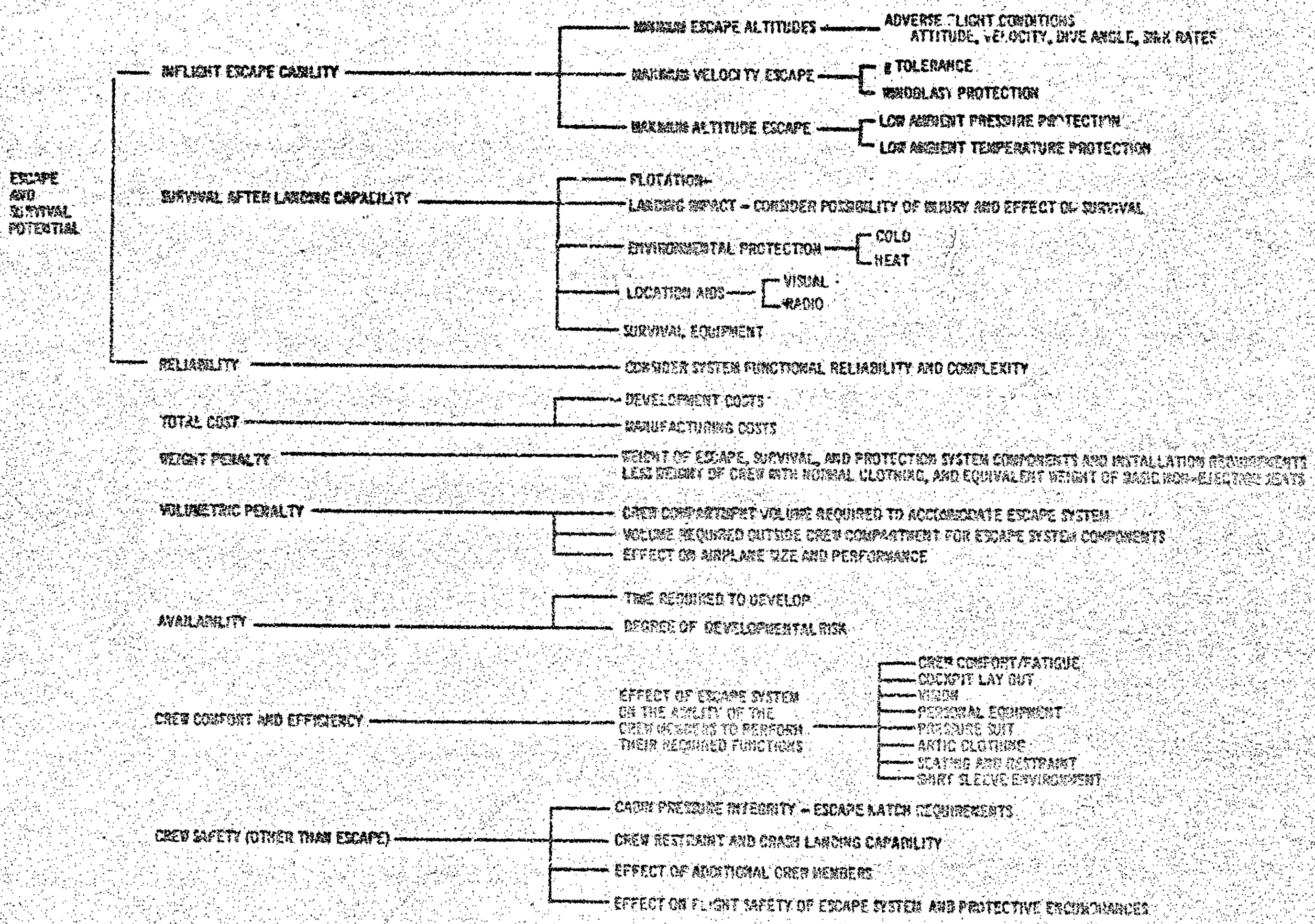


Figure 347. Escape Concept Evaluation Factors

1. ESCAPE AND SURVIVAL POTENTIAL

a. Inflight Escape Capability

Summarized in Table XVI are data from Section V pertaining to the effectiveness of the escape concepts to provide safe escape from disabled aircraft with respect to operations within certain critical flight regimes for each of the vehicle types considered. The flight regimes are VTOL hover and transition, conventional takeoff and landing, low-altitude dash, and high-speed and altitude. The escape concept effectiveness indexes are rank-ordered within each flight regime to provide a basis for evaluation and selection of the most suitable concept for specific vehicles.

b. Survival After Landing Capability

To protect the crewman following an inflight escape resulting in a survival situation on land or water, the escape system must keep the survivor afloat, protect him from environmental extremes, provide emergency rations and a means of obtaining food and water, provide equipment and clothing to maintain the survivor in good physical and mental condition, provide a means for assisting the survivor in taking evasive measures to prevent capture by the enemy, and provide communication and signalling devices to facilitate location and rescue. Further, the escape system should protect the crewman from injury that would tend to reduce his chance of survival during landing impact.

Review of USAF survival experience (1958 through 1963, Ref. 5) reveals that approximately 10 percent of the crewmen involved in known survival situations did not survive. Of these, approximately 77 percent of the fatalities occur following landings on water, 15 percent following landings on snow or ice, and 8 percent following landings on land. Due to the period of time covered, this data generally will be applicable to the open ejection seat escape concept. Cockpit pod and separable nose capsules will provide better protection against drowning (the major cause of water landing fatalities); better protection against exposure; will provide a greater quantity of survival equipment; will provide superior communication and location aids and are more readily visible, which will aid in search and rescue; will provide impact attenuation, reducing the chance of landing injuries; and will allow mutual assistance between crewmembers.

It is estimated that the capsule systems could prevent 90 percent of the water landing fatalities, 70 percent of the snow and ice landing fatalities, and 50 percent of the land landing fatalities associated with open ejection seat usage.

The encapsulated ejection seat provides better protection than the open seat, but is inferior to the capsule concepts. The estimated fatality rate for the encapsulated seat is 50 percent of the open ejection seat rate.

Table XVII presents estimated relative fatality rate comparisons for critical survival situations and rank-orders the escape concepts with respect to survival capability.

Table XVI. Escape Concept Effectiveness Index

		FLIGHT REGIMES									
VEHICLE	ESCAPE CONCEPT	VTOL TRANSITION		CONVENTIONAL TAKEOFF AND LANDING		LOW-ALTITUDE DASH		HIGH ALTITUDE		HIGH SPEED	
		INDEX	RANK	INDEX	RANK	INDEX	RANK	INDEX	RANK	INDEX	RANK
2-MAN SUBSONIC VTOL	OES	0.773	0.964	0.733	0.924			0.95	0.95		
	EES	0.589	0.734	0.442	0.556			0.98	0.98		
	CPC	0.759	0.945	0.794	1.0			1.0	1.0		
	SNC	0.802	1.0	0.787	0.993			1.0	1.0		
4-MAN SUPER SONIC DASH	OES			0.501	0.619	0.042	0.045	0.80	0.80	0.175	0.175
	EES			0.295	0.364	0.170	0.183	0.85	0.85	1.0	1.0
	CPC			0.810	1.0	0.923	1.0	1.0	1.0	1.0	1.0
	SNC			0.732	0.904	0.609	0.656	1.0	1.0	1.0	1.0
3-MAN COMBINED CAPABILITY	OES	0.687	0.755	0.590	0.670	0.058	0.062	0.80	0.80	0.175	0.175
	EES	0.512	0.562	0.356	0.404	0.226	0.241	0.85	0.85	1.0	1.0
	CPC	0.873	0.958	0.842	0.956	0.938	1.0	1.0	1.0	1.0	1.0
	SNC	0.911	1.0	0.880	1.0	0.794	0.846	1.0	1.0	1.0	1.0

Table XVII. Survival Capability

Escape Concept	Percent Fatalities for critical Survival Situations (100% Fatal for Open Ejection Seats)				Rank Order Rating
	Type of Surface				
	Water	Ice/Snow	Land	Total	
Open Ejection Seat	77.0	15.0	8.0	100.0	0.16
Encapsulated Ejection Seat	38.5	7.5	4.0	50.0	0.32
Cockpit Pod Capsule	7.7	4.5	4.0	16.2	1.0
Separable Nose Capsule	7.7	4.5	4.0	16.2	1.0

c. Escape Concept Reliability

The reliability of an escape system to function as designed is primarily dependent upon the integrity of the particular design, the extent of developmental and qualification testing to which the system is subjected, level of quality control during manufacture, level of maintenance applied, and simplicity and maintainability of the basic concept.

In evaluating the reliability of projected escape concepts it is presumed that equal effort and skill will be expended toward design, development, qualification, manufacturing, and maintenance. The relative reliability of escape concepts as opposed to specific system designs is, therefore, chiefly a function of concept simplicity and maintainability. To evaluate the relative simplicity or complexity of the various concepts, the number of essential functions required by each concept to complete the escape sequence was considered. The essential escape sequence functions were based on the concept definitions from Section III and are as follows:

Open Ejection Seat Concept

- Initiation
- Torso positioning
- Hatch jettison
- Rocket catapult ejection
- DART stabilization
- Drogue chute deployment
- Personnel harness release
- Recovery parachute deployment
- Seat-man separation
- Ejection sequencing functions

Encapsulated Ejection Seat

- Initiation (encapsulation system)
- Leg retraction
- Torso positioning
- Door closure
- Catapult firing trigger
- Hatch jettison
- Rocket catapult ejection
- Stabilization booms deployed
- Stabilization chute deployed
- Stabilization chute disreefed
- Recovery parachute deployed
- Recovery parachute disreefed
- Impact system deployed
- Ejection sequencing functions

Cockpit Pod and Separable Nose Capsules

- Initiation
- Crew restraint
- Stabilization booms deployed
- Stabilization chutes deployed
- Capsule/vehicle separation
- Rocket thrust
- Stabilization chutes disreefed
- Main parachutes deployed
- Main parachutes disreefed
- Capsule repositioning
- Impact system deployed

Comparison of the essential escape functions, complexity and maintainability of the open ejection seat and encapsulated ejection seat concepts indicate that the encapsulated ejection seat will be to some degree less reliable than the open ejection seat concept. The encapsulated seat concept requires the additional functions of leg retraction, encapsulation or door closure, catapult firing trigger actuation, stabilization boom deployment, stabilization and recovery parachute disreefing functions, and landing system deployment. Functions required by the open seat which are not required by the encapsulated seat are DART stabilization, personnel harness release, and seat-man separation. Torso positioning, required by both systems, is more complex for the encapsulated seat because the entire seat bucket probably will have to position forward of the clam shell body (B-70 type) to provide acceptable vision and access to flight controls and equipment during normal flight, and is retracted into the clam shell for ejection. The encapsulated ejection seat as defined in Section III requires two separate motions by the pilot to initiate escape. These are: 1) raising the handgrip which closes and pressurizes the clam shell (required for emergency pressurization when escape is not mandatory); and 2) squeezing the catapult trigger for actual ejection. This introduces an additional human element into the escape sequence and could result in a significant decrease in escape reliability. Further, due to the additional complexity of the encapsulated ejection seat concept, maintenance errors that would adversely affect system reliability are more likely.

Cockpit pod and separable nose capsule concepts require a greater number of generally more complex functions for escape than the open ejection seat concept. The capsule must be severed from the aircraft by a linear shaped charge system. Stabilization is more critical to successful escape, and reliable functioning of the two stabilization booms and parachutes is essential. Parachute reefing is required and the larger capsules require multiple main recovery parachutes (which detract from system reliability) as opposed to the single recovery parachute for ejection seat systems. Also, the capsule concepts require capsule repositioning and landing impact system deployment which are not required by the open ejection seat concept. Functions required by the ejection seat concept and not required by the capsule concepts are hatch jettisoning, DART stabilization, harness release, and seat-man separation. Also, ejection sequencing functions are required to prevent rocket-catapult blast injuries and to reduce the possibility of seat collisions or parachute entanglement.

Due to continual use and exposure of ejection seat systems to flight crews and ground personnel, these systems are more vulnerable to critical damage and harder to maintain than the capsule concepts. Also, reliable functioning of ejection seat systems is dependent on proper "hookup" by flight personnel. Capsule system components will not be exposed, and once installed will require minimal maintenance.

Although the capsule concepts are basically more complex than the open ejection seat concepts, they are considered slightly more reliable due to their higher degree of maintainability, and because ejection seats are vulnerable to damage, and depend more on flight personnal. Also, there is the possibility of parachute entanglement.

To provide a basis for estimating reliability of each escape concept, USAF ejection experience from January 1961 to December 1963 (Ref. 6) was studied. These data deal with ejection seat equipment failures during ejection that resulted in fatalities by violent contact with the ground. Table XVIII lists the numbers of personnel involved and causes of ground impact fatalities. Of 601 ejections, 100 were fatal and 73 of the fatalities were caused by violent contact with the ground.

Table XVIII. Factors Contributing to Ground Impact Fatalities

Ejection attempted outside performance envelope of system	30
Delayed decision to eject	18
Held onto seat actuating controls	3
Equipment failure/difficulty	9
Failed to use available equipment	8
Seat/chute entanglement	3
Miscellaneous	2
	73

The percentage of equipment failure is therefore $\frac{9}{601} = 1.5$ percent, and the probability of successful escape system operation is 0.985 for open ejection seats.

Based on the preceding discussions and comparisons of escape concept complexity and maintainability, the estimated reliability for cockpit pod and separable nose capsule escape concepts is 0.990, and for encapsulated ejection seats it is 0.975. Table XIX shows the rank-order rating for each concept.

Table XIX. Escape Concept Functional Reliability

Escape Concept	Functional Reliability	Rank-Order Rating
Open ejection seat	0.985	0.995
Encapsulated ejection seat	0.975	0.985
Cockpit pod capsule	0.990	1.0
Separable nose capsule	0.990	1.0

2. COST

The budgetary development costs listed in Table XX are based on 1966 dollars, 30 months' development time of the first flight article, use of existing test recording equipment, major test parts taken from production lines, and the assumption that each test program will be part of the airplane production program. The development and qualification programs used as a basis for these cost estimates are defined in Section IV.

Table XX. Development/Qualification Cost Summary

Vehicle	Concept	Dev/Qual Costs	Rank-Order Rating
Two-man subsonic VTOL	OES	2,144,936	1.00
	EES	10,151,258	0.211
	CPC	16,000,969	0.134
	SNC	17,058,278	0.126
Four-man supersonic dash	OES	3,609,429	1.0
	EES	11,678,412	0.309
	CPC	25,020,563	0.144
	SNC	27,921,134	0.130
Three-man combined capability	OES	2,615,338	1.0
	EES	10,640,801	0.245
	CPC	18,546,453	0.140
	SNC	20,075,743	0.130

3. WEIGHT PENALTY

Table XXI shows the comparison of escape system hardware weights from Section III. These weight penalties represent the weight of escape, survival, and protection system components and installation requirements, less weight of crew with normal clothing and equivalent weight of basic nonejection seats. The actual weight penalty incurred as a result of incorporating an escape system could be substantially more than just the escape system hardware weight because of the interrelation of airplane structural requirements and airplane mission degradation, which, in turn, would be reflected in cost increase.

As an example, it would be expected that the relatively heavy escape system hardware in the cockpit pod capsule would cause some degradation in mission performance. If this mission degradation is unacceptable, then additional fuel will be required. Carrying more fuel will necessitate larger fuel tanks (hence more structure and larger landing gear), increased thrust needed to meet takeoff requirement, etc., and, consequently, increased costs.

The escape system hardware weights in Table XXI, then, serve as baseline data to use as a guide in estimating the effect on aircraft performance, structure, and cost. The rank-order rating listed in Table XXI was obtained by ratioing, for a given vehicle, the weight of the lightest escape system to the other escape systems. This procedure results in the lightest weight system receiving a rank-order rating of 1.0 and the heavier systems receiving a rank-order rating between 0 and 1.0, with the heaviest system having the smallest rank-order rating.

Table XXI. Weight Penalty

	OES		EES		CPC		SNC	
	Lb	Rank-Order Rating	Lb	Rank-Order Rating	Lb	Rank-Order Rating	Lb	Rank-Order Rating
2-man Subsonic	392	1.0	1238	0.317	1589	0.246	2042	0.192
3-man Combined	588	1.0	1857	0.317	2809	0.209	3634	0.166
4-man DASH	784	1.0	2476	0.317	3674	0.220	6488	0.121

4. VOLUME PENALTY

Table XXII shows the volume penalties incurred by incorporating an escape system. These penalties result from vehicle enlargements required to accommodate the escape system. Defining volume penalty in this manner is considered to be more meaningful than merely summing the volumes of escape system components, because an increase in cockpit volume results in additional airplane wetted area and structure. This causes the weight and drag to increase, which, in turn, causes aircraft performance degradation and cost increase. Elimination of the performance degradation may be accomplished by providing more fuel, greater engine thrust, etc., which increases weight and cost.

The cost increase resulting from the volume penalty is similar to that resulting from the weight penalty. However, in one case the effect is the result of escape system weight, whereas, in the other case, the effect is the result of the cockpit volume increase required to accommodate the system (irrespective of the system weight).

Table XXII volumetric penalties are based on the four-man supersonic dash vehicle values for which a detailed study was made. The penalties for the two- and four-man vehicles were estimated from the four-man vehicle values.

The volume penalties for open ejection seats or encapsulated ejection seats in the three-man vehicle were estimated to be the same as the four-man vehicle. The reasoning behind this is: 1) the airplane fuselage cross-section at the pilots' station must be enlarged to accommodate the seats (this cross-sectional enlargement is not dependent upon whether or not additional seats are behind the pilots); and 2) the extra length required in the cockpit is attributed primarily to the side view dimensions of the seats, and, therefore, does not depend on whether or not a fourth man is positioned beside the third man. The volume penalties for the cockpit pod capsule or separable nose capsule for the three-man vehicle were estimated to be slightly less than for the four-man vehicle because for these escape systems the volume penalty depends primarily on rocket size, parachute sizes, boom dimensions, etc.

The volume penalties for open ejection seats or encapsulated ejection seats in the two-man vehicle were estimated to be approximately one-half of those for the three-man vehicle. This reasoning is based on: 1) the tandem seating arrangement results in a fuselage cross-sectional area increase at the pilots' station approximately one-half of that in a side-by-side arrangement; and 2) the extra length required in the tandem cockpit will be the same as for a three-man vehicle because the length increase is primarily dependent upon the side view dimensions of the seats, and not whether a man is sitting beside the pilot. The volume penalties for the cockpit pod capsule or separable nose capsule for the two-man vehicle were estimated to be somewhat less than for the three-man vehicle because for these escape systems the volume penalty is primarily dependent upon rocket size, parachute sizes, boom dimensions, etc.

The escape system volume penalties in Table XXII may be used as a baseline in aircraft design and in estimating the effect on aircraft performance, structure, and cost. Table XXII also shows the volumetric penalty rank-order rating for each escape concept for each vehicle.

Table XXII. Volume Penalty

	OES		EES		CPC		SNC	
	Ft^3	Rank-Order Rating	Ft^3	Rank-Order Rating	Ft^3	Rank-Order Rating	Ft^3	Rank-Order Rating
2-man Subsonic	75	1.0	200	0.375	150	0.500	175	0.429
3-man Combined	154	1.0	410	0.375	200	0.769	225	0.685
4-man DASH	154	1.0	410	0.375	219	0.703	250	0.615

5. AVAILABILITY

The overall effectiveness and usefulness of an escape system depends on whether the system is available, proven, and operational in time for use in the first prototype or production airplane for which the system is designed. The time required to design, develop, and qualify the escape system and the degree of developmental risk involved are factors which affect the availability of the escape concepts. It is presumed that any of the escape concepts can be developed to meet their particular designed performance as defined in Section III if unlimited time is available. The development risk factor, therefore, pertains to whether the system can be developed within the time schedule anticipated.

The time required for predevelopment, development, and qualification testing from Figures 109, 110 and 111 of Section IV are summarized for each escape concept in Table XXIII. The rank-order rating of the development time requirements is also shown.

Since open ejection seats currently available or under development will meet the limited design performance as defined, and since well established and proven testing techniques and procedures only are required, no development scheduling risk is considered to be involved. The open ejection seat concept is, therefore, assigned a development risk factor of 1.0.

Encapsulated ejection seat escape systems have been developed for the B-58 and B-70 aircraft. Also, studies and experimental test programs have been conducted by government and industry on this concept. Therefore, a sound basis exists for successful development of an encapsulated ejection seat system for advanced aircraft. However, additional capability, not available in present systems, is required. Also, system complexity imposes a slightly greater development time risk than for open ejection seats.

Cockpit pod and separable nose capsule escape concepts have been under study by government and industry for approximately twelve years, and several significant experimental test programs have been accomplished. Further, an operational cockpit pod type system has been successfully developed for the F-111 aircraft. The feasibility of developing these concepts for future aircraft has been demonstrated. However, development of these concepts for specific vehicles may present problems peculiar to the aircraft for which the system is developed.

The estimated developmental time risk factors are shown in Table XXIII.

To obtain the escape concept availability rank-order rating (also shown on the Table) the development time rank order is multiplied by the development risk factor.

Table XXIII. Escape Concept Availability

Escape Concept	Development Time Months	Development Time Rank-Ordered Rating	Development Risk Factor	Availability Rank-Order Rating
OES	21	1.0	1.0	1.0
EES	33	0.637	0.95	0.605
CPC	40	0.525	0.85	0.446
SNC	40	0.525	0.80	0.420

6. CREW COMFORT AND EFFICIENCY

The human engineering evaluation of the four escape systems for the two-, three-, and four-man vehicles placed prime emphasis on the following aspects of crew comfort and efficiency:

- Cockpit layout and design for crew effectiveness;
- Adequacy of external vision;
- Personal equipment integration and crew comfort;
- Seat design for comfort and efficiency;
- Windblast and deceleration forces;
- Ejection sequencing time.

A discussion of these factors, summarized in Table XXIV is presented below.

Cockpit Design — Crew compartment design is optimized in the cockpit pod capsule and separable nose capsule permitting maximum cockpit volume usable for efficient arrangements. In this escape system there is no seat ejection clearance required. Therefore, crewmembers and instrument panels and consoles may be arranged and integrated for maximum operational efficiency.

Encapsulated and open ejection seat systems compromise crew station design and result in impaired crew comfort and efficiency. Both systems impose restrictions on the efficient arrangement of flight equipment due to the requirements for removable hatches, fixed ejection rails, and seat clearance envelopes during ejection. Due to the bulk involved, these two systems restrict crew mobility.

Vision — The four escape systems (open seat, encapsulated seat, separable nose capsule, and cockpit pod capsule) under study do not differ significantly, with the possible exception of the encapsulated ejection seat, as to freedom of vision. In this case, vision to the sides and upward will be somewhat restricted if a B-58 type escape capsule is used. This is due to the retracted shell configuration. However, if a B-70 type capsule in which the seat occupant sits well forward of the capsule shell during normal operations is used, vision is comparable to the other two escape systems.

Table XXIV. Escape System Summary

Factors	Open Ejection Seat	Encapsulated Ejection Seat	Cockpit Pod Capsule Separable Nose Capsule
Cockpit Design	Design for comfort and efficiency is limited due to ejection envelope, removable hatches, ejection rails	Design for comfort and efficiency is limited due to ejection envelope and rails, removable hatches, restricted seat positioning	Design for comfort and efficiency is most flexible
External Vision	No comfort or efficiency degradation unless pressure suits (helmet, visors) are required	Restricted vision due to shell configuration	No efficiency or comfort degradation unless pressure suits (helmets, visors are required
Personal Equipment	Degraded comfort and efficiency; pressure suits, protective clothing, life vests, food, medical, oxygen requirements	Comfort and efficiency is good - essentially "shirt-sleeve" environment	Comfort and efficiency is excellent unless pressure suits are employed as back up for depressurization
Seat Design	Design for comfort and efficiency is limited due to ejection envelope requirement	Design for comfort and efficiency is least flexible due to ejection envelope and capsule shell restrictions	Design for comfort and efficiency is most flexible
Windblast & Deceleration	No protection from windblast, poor protection from g-forces (tumbling and deceleration)	Good protection from windblast, limited escape envelope due to g-forces (tumbling and deceleration)	Maximum protection from g-forces (tumbling and deceleration) and windblast
Ejection Sequence Time	Excessive time required between escape initiation and seat/airplane separation for crews of three or more.		Reduced time lapse from escape initiation to separation for crews of two or more.

If pressure suits are worn, vision to the sides and upward will be somewhat restricted. In addition, pilots wearing pressure suits, because of faceplate glare and interference, can encounter visual problems such as degradation in target acquisition and scope interpretation. Furthermore, high humidity can fog the face plate.

Personal Equipment — The cockpit pod capsule and separable nose capsule ejection systems provide a "shirt sleeve" environment in all cases except cabin depressurization above 50,000 feet. In this case, either an emergency pressurization system or pressure suit is required. The encapsulated ejection seats will provide secondary pressurization protection without the use of pressure suits. Thus, a "shirt sleeve" environment is essentially achieved. Open ejection seats require pressure suits if the escape envelope exceeds 50,000 feet and 1100Q (dynamic pressure) because, in this system, man is directly exposed to the environment during escape. Elimination of the pressure suit relieves the crewman of a primary encumbrance and permits greater crew comfort and efficiency, and less fatigue.

Protective clothing provides physiological protection at the expense of mobility, ease of control manipulation, visibility, and comfort. Pressure suits evoke small to quite large degradations, depending on the conditions and task requirements, in the crewman's performance. Gross tasks such as knob turning and lever pushing are little affected by the unpressurized suit. However, pressurization introduces cumbersomeness and fatigue. Performance of tasks of finer resolution show a dexterity decrement, the amount of which depends on whether the suit is inflated or not. F-106 pilots have reported that restricted mobility while wearing pressurized suits made it difficult to actuate fuel switches, armament recycle buttons, M-A-1 power switches, and manually tune the UHF radio. Pilots wearing pressure suits have also found that glare from the helmet visor and the effort required to turn their heads were factors contributing to fatigue and lower efficiency.

Examination of sweat patterns on pressure suits worn for three hours or longer has indicated that ventilation is generally not adequate. Because of the difficulty to urinate normally while wearing a pressure suit, urination in the suit is not uncommon. Because of this and extended use, the suits soon become odorous and untenable. To date, no competent cleaning procedure has been devised to overcome this problem.

Light-weight to heavy-weight antiexposure suits that are fully effective within established temperature limits are presently available. The degree of comfort, mobility, and performance provided by antiexposure suits is inversely proportional to the weight of the garment. Light to medium weight suits have been accepted by pilots, but the heavier suits have not been well received due to ventilation requirements, degradation of mobility and performance, etc.

Survival gear, such as life vests, oxygen equipment, food, medical supplies, etc., introduce serious problems by encumbering the airman's movements in open seat ejection systems. The encapsulated seat, the cockpit pod, and separable nose systems allow for the design of such survival gear and other protective provisions into the capsule or cockpit pod itself. The open seat, however, limits the placement of such awkward equipment to the man-seat complex.

Seats and Restraints — Design for comfort and efficiency is most flexible in the cockpit pod capsule and separable nose capsule ejection systems. This flexibility results from the lack of a restricting clearance envelope during escape, and it permits the incorporation of methods and devices (size, arm rests, reclining or rotary action, etc.) designed to alleviate fatigue and provide maximum comfort. In the open ejection seat and encapsulated seat systems flexibility is greatly limited because of the clearance envelope required during ejection. The encapsulated seat is further restricted because the seats must be placed within the capsule.

The restraining equipment for crewmen required by the open seat, encapsulated seat, cockpit pod, and separable nose systems are essentially the same.

Windblast and Deceleration Forces — Windblast presents no problems to crewmembers in the encapsulated seat, cockpit pod capsule, or separable nose capsule escape systems. However, in an open ejection seat, windblast can cause severe human injury. Open and encapsulated ejection seat systems are limited to approximately 500-600 KEAS (dynamic pressure of 1200 psf) and 700-800 KEAS (dynamic pressure of 1600 psf) respectively. This is due to tumbling or because deceleration forces approach human tolerance limits. Capsule-type systems provide better aerodynamic qualities and extend performance capabilities.

Ejection Sequence Time — The elapsed times from system initiation to seat or capsule/airplane clearance for the four escape concepts with two-, three-, and four-man crews are presented below.

CREW SIZE	Length of Time from Initiation to Clearance (SEC)			
	OES	EES	CPC	SNC
2	1.06	2.15	0.2	0.2
3	1.56	2.65	0.2	0.2
4	2.06	3.15	0.2	0.2

The period from initiation to clearance is considerably greater for open and encapsulated ejection seat systems than for cockpit pod or separable nose capsule systems. This is because they require sequenced ejection to prevent injury to the remaining crewmembers, collision between seats, and possible parachute entanglement.

Such extended time periods between initiation and clearance of the airplane not only affect system effectiveness, but also affect crewmember confidence in the system. This can lead to degradation of crewmember morale, which, in turn, will adversely affect the efficiency and effectiveness of their performance.

Table XXV presents the relative crew comfort and efficiency in an estimated rank-order rating for the two-, three-, and four-man vehicle.

Table XXV. Crew Comfort and Efficiency

Vehicle	Escape Concept	Rank-Order
2-man Subsonic VTOL	OES	0.75
	EES	0.81
	CPC	1.00
	SNC	0.95
3-man Combined Capability	OES	0.61
	EES	0.79
	CPC	0.95
	SNC	1.00
4-man Supersonic Dash	OES	0.55
	EES	0.75
	CPC	1.00
	SNC	1.00

The actual numerical scale for the rank-order was developed on the basis of 1.00 for the best and a fraction thereof for lower ratings.

7. CREW SAFETY (OTHER THAN ESCAPE)

The effect an escape system has on overall flight safety, other than the actual escape function, is a factor that should be considered in the evaluation and selection of an escape concept for advanced vehicles. Open and encapsulated ejection seat concepts require jettisonable hatches or canopies. Past experience shows that escape hatches or canopies are subject to inadvertent loss in flight, with the resulting rapid or explosive decompression. Thus a degradation of crew safety exists for these concepts as opposed to the higher degree of cabin pressure integrity obtainable with the capsule concepts.

When extra crewmembers who are not provided with adequate escape provisions are carried aboard an aircraft, another degradation in overall crew safety exists. This is apparent for the open and encapsulated seat concepts which provide escape systems only for the normal crew complement. Not only will the extra crewmembers who are not provided with an adequate means of emergency escape generally be lost if inflight escape is required, but their presence in the aircraft has a demoralizing affect on the normal crew, often resulting in delayed and ineffective use of the ejection seats. For the cockpit pod and separable nose concepts, extra crewmembers will be saved with the capsule and crew safety will not be impaired. Also, for the two-man vehicle no degradation was assumed, since this type of vehicle will not be designed to accommodate extra crewmembers.

Another form of flight safety degradation exists when pressure suits must be worn. The use of a restrictive pressure suit results in lowered pilot proficiency rendering the vehicle more vulnerable to accident. This factor is apparent only in the three- and four-man vehicles with open ejection seats. The two-man open ejection seat vehicle will not require the use of pressure suits, since its flight envelope does not exceed 50,000 feet.

With the open ejection seat concept, environmental clothing will be required during flights over arctic regions. This will result in a flight safety degradation for the same reason as the pressure suit requirement. For the other concepts, environmental clothing will be carried within the seat or capsule.

When open ejection seats or encapsulated ejection seats are used, a further degradation in crew safety exists because of impaired pilot proficiency and vision, and because of the vulnerability of these systems to inadvertent actuation.

The effect of the escape system concept on the crash landing and ditching capability of the vehicle is another consideration, other than inflight escape, relevent to crew safety. All of the concepts will provide adequate restraint to protect the crew during crash landing; however, due to the flotation capabilities of the cockpit pod and separable nose capsule concepts, these concepts will provide additional survival capability following a ditching at sea.

Table XXVI summarizes the factors pertaining to crew flight safety and indicates by a minus sign (-) the escape concepts for which a relative degradation in crew safety exists. The table also shows the estimated rank-order rating for crew safety for each concept and vehicle.

Table XXVI. Crew Flight Safety

		OES	EES	CPC	SNC
Escape Hatch Required		Yes (-)	Yes (-)	No	No
Extra Crewmembers Escape Potential	Two-Man Vehicle	Not Appl	Not Appl	Not Appl	Not Appl
	Three- & Four-Man Vehicle	No (-)	No (-)	Yes	Yes
Pressure Suit Required	Two-Man Vehicle	Not Appl	Not Appl	Not Appl	Not Appl
	Three- & Four-Man Vehicle	Yes (-)	No	No	No
Environmental Clothing Required		Yes (-)	No	No	No
Ejection Seats or Encapsulated Seats Required		Yes (-)	Yes (-)	No	No
Ditching Flotation Capability		No (-)	No (-)	Yes	Yes

Crew Flight Safety Rank Order Rating		
Escape Concept	Two-Man Vehicle	Three- & Four-Man Vehicles
OES	0.88	0.80
EES	0.92	0.88
CPC	1.00	1.00
SNC	1.00	1.00

SECTION VII

ESCAPE CONCEPT TRADE DATA SUMMARY AND EVALUATION

The preceding sections of this report contain data pertaining to crew escape performance requirements, design criteria, escape concept performance evaluation, automatic detection and initiation evaluations, test requirements, survival capability, cost, weight, volume, escape concept availability, crew comfort and efficiency, and crew safety. These data were developed for use as a basis or guide in the selection, design, and evaluation of escape concepts for advanced VTOL and low-altitude dash vehicles.

Tables XXVII, XXVIII and XXIX summarize the rank-order ratings of the escape concepts for each trade factor for the representative two-man subsonic VTOL vehicle, the three-man combined capability vehicle, and the four-man supersonic low-altitude dash vehicle. The rank-order ratings are on the basis of the best concept with respect to each trade factor being given a rating 1.0; the remaining concepts are then rated as a percentage degradation from the best or most suitable concept.

These data may be used as a guide in the selection of the most suitable escape concept for specific advanced vehicles. However, the relative importance of the various trade factors must be taken into account.

The relative importance of the various trade factors is to a great extent dependent upon the specific aircraft configuration, operations and mission requirements relating to type and length of missions, and the proportion of flight time that the vehicle will be expected to be exposed to various hazardous flight regimes, monetary procurement policies relating to the vehicle at the time of procurement, and procurement lead time available. Also, the significance of escape system weight and volume requirements, that primarily manifest themselves in terms of vehicle cost and gross weight growth and/or vehicle performance degradation, is dependent on procurement policies and the particular vehicle requirement at the time of procurement. However, even though cost, weight and development time may be high, an escape concept should be provided that will assure an escape capability throughout the vehicle performance envelope.

Although an actual selection of the most suitable escape concept for the general types of vehicles studied is not practical without applying the relative importance or weighting factors to each of the trade factors considered, certain valid observations pertaining to the results of this study are possible.

For all three of the representative vehicles studied, the cockpit pod and separable nose capsule concepts provide superior inflight escape capability in all the flight regimes considered, superior survival after-landing capability, superior crew comfort and efficiency, and superior crew safety.

The open ejection seat concept provides a decided advantage over the other concepts with respect to cost, weight, volumetric penalty, and availability.

The encapsulated ejection seat displays the least escape potential relative to the other concepts for VTOL transition, conventional takeoff and landing, and low-altitude dash flight regimes. However, the encapsulated seat shows

Table XXVII. Escape Concept Trade Data Summary for Two-Man Subsonic VTOL Vehicle

Trade Factor	Rank-Order Rating				Best Concept
	Open Ejection Seat	Encapsulated Ejection Seat	Cockpit Pod Capsule	Separable Nose Capsule	
Escape and survival potential					
VTOL transition	0.96	0.73	0.95	1.0	SNC
Conventional takeoff and landing	0.92	0.56	1.0	0.99	CPC
Low altitude dash	----	----	----	----	----
High altitude	0.95	0.98	1.0	1.0	CPC and SNC
High speed					
Survival after landing	0.16	0.32	1.0	1.0	CPC and SNC
Reliability	0.99	0.98	1.0	1.0	CPC and SNC
Total cost	1.0	0.21	0.13	0.13	OES
Weight penalty	1.0	0.32	0.25	0.19	OES
Volumetric penalty	1.0	0.38	0.50	0.43	OES
Availability	1.0	0.61	0.45	0.42	OES
Crew comfort and efficiency	0.75	0.81	1.0	0.95	CPC
Crew safety (other than escape)	0.88	0.92	1.0	1.0	CPC and SNC

Table XXVIII. Escape Concept Trade Data Summary for Three-Man Combined Capability Vehicle

Trade Factor	Rank-Order Rating				Best Concept
	Open Ejection Seat	Encapsulated Ejection Seat	Cockpit Pod Capsule	Separable Nose Capsule	
Escape and survival potential					
VTOL transition	0.76	0.56	0.96	1.0	SNC
Conventional takeoff and landing	0.67	0.40	0.96	1.0	SNC
Low altitude dash	0.06	0.24	1.0	0.85	CPC
High altitude	0.80	0.85	1.0	1.0	CPC and SNC
High speed	0.17	1.0	1.0	1.0	EES, CPC and SNC
Survival after landing	0.16	0.32	1.0	1.0	CPC and SNC
Reliability	0.99	0.98	1.0	1.0	CPC and SNC
Total cost	1.0	0.25	0.14	0.13	OES
Weight penalty	1.0	0.32	0.21	0.17	OES
Volumetric penalty	1.0	0.38	0.77	0.69	OES
Availability	1.0	0.61	0.45	0.42	OES
Crew comfort and efficiency	0.61	0.79	0.95	1.0	SNC
Crew safety (other than escape)	0.80	0.88	1.0	1.0	CPC and SNC

Table XXIX. Escape Concept Trade Data Summary for Four-Man Supersonic Dash Vehicle

Trade Factor	Rank-Order Rating				Best Concept
	Open Ejection Seat	Encapsulated Ejection Seat	Cockpit Pod Capsule	Separable Nose Capsule	
Escape and survival potential					
VTOL transition	----	----	----	----	----
Conventional takeoff and landing	0.62	0.36	1.0	0.90	CPC
Low altitude dash	0.04	0.18	1.0	0.66	CPC
High altitude	0.80	0.85	1.0	1.0	CPC and SNC
High speed	0.17	1.0	1.0	1.0	EES, CPC and SNC
Survival after landing	0.16	0.32	1.0	1.0	CPC and SNC
Reliability	0.99	0.98	1.0	1.0	CPC and SNC
Total cost	1.0	0.31	0.14	0.13	OES
Weight penalty	1.0	0.32	0.22	0.12	OES
Volumetric penalty	1.0	0.38	0.70	0.62	OES
Availability	1.0	0.61	0.45	0.42	OES
Crew comfort and efficiency	0.55	0.75	1.0	1.0	CPC and SNC
Crew safety (other than escape)	0.80	0.88	1.0	1.0	CPC and SNC

slightly better survival after-landing capability and provides better high-speed and high-altitude capability for the three- and four-man vehicles than the open ejection seat concept. Crew comfort and efficiency factors for the encapsulated seat are also better than the open seat concept. The encapsulated seat provides a cost, weight, and availability advantage over the capsule concepts, but is inferior to the open ejection seat for these factors.

A more detailed comparison of the inflight escape potentials of the capsule concepts with the open ejection seat concept reveals that for the four-man low-altitude dash vehicle and the three-man combined capability vehicle the capsule concepts have a decided advantage. However, for the two-man subsonic VTOL vehicle, the inflight escape potentials of the concepts are more nearly equal. The open ejection seat showing essentially equal to the capsule concepts for VTOL transition flight, and only slightly lower in other flight regimes. This better showing for the ejection seat concept when used with the VTOL vehicle is partly due to the speed and altitude envelope of the vehicle being more compatible with the open ejection seat capability, and partly due to the fewer number of seats requiring less sequencing time for ejection.

Table XXX summarizes the results of the investigation to evaluate the need for, or benefits of, automatic emergency detection and escape initiation from Sections V 1c, 2c, and 3c. The values in the table indicate the derived probabilities of escape initiation in time for successful escape for manual and for semiautomatic initiation.

It should be recognized that the data for the VTOL hover and transition flight regime are for the two-man subsonic VTOL vehicle, while the data for the conventional takeoff and landing and low-altitude dash flight regimes are for the four-man supersonic dash vehicle. The data, therefore, are not directly comparable. Also, the data for the VTOL hover and transition flight regime are based on engine failure emergency flight conditions, while the data for the other flight regimes are based on the range of possible nose-over g and speed emergency flight conditions.

As shown in the table, successful escape will be initiated in less than one-half of the VTOL engine failure situations analyzed if manual detection and initiation are relied upon. With semiautomatic detection and initiation, where the emergency situation is automatically sensed, escape decision logic is computerized, and the pilot is conditioned to respond to the escape signal with full confidence. The analysis indicates that near 100 percent successful escape could be anticipated for the VTOL engine failure situations.

For the conventional takeoff and landing, and the low-altitude dash emergency conditions analyzed, manual initiation will not result in an acceptable expected survival rate. The low-altitude dash flight regime presents an especially critical area for manual escape initiation when open ejection seats are used. The presentation of this data should, however, be qualified, since, for the analysis, successful escape was considered to include recovery of the entire crew. Therefore, for the open ejection seats, escape was not considered successful unless the last of the four crew members (ejected in sequence) could be successfully recovered, even though part of the crew may have been saved.

Table XXX. Automatic Detection and Initiation Evaluation

VTOL Hover and Transition Flight Regime
Two-Man Subsonic VTOL Vehicle

Escape Concept	Probability of Successful Escape Initiation	
	Manual	Semiautomatic
Open Ejection Seats	0.484	1.000
Cockpit Pod Capsule	0.445	0.975

Conventional Takeoff and Landing Flight Regime
Four-Man Supersonic Dash Vehicle

Escape Concept	Probability of Successful Escape Initiation	
	Manual	Semiautomatic
Open Ejection Seats	0.197	0.720
Cockpit Pod Capsule	0.288	1.000

Low-Altitude Dash Flight Regime
Four-Man Supersonic Dash Vehicle

Escape Concept	Probability of Successful Escape Initiation	
	Manual	Semiautomatic
Open Ejection Seats	0.013	0.072
Cockpit Pod Capsule	0.216	1.000

The results of this analysis indicate the need for some form of automatic or semiautomatic emergency detection and escape initiation for all the critical flight areas studied. Special consideration should be given to the use of fully automatic detection and initiation systems for large multiplace (4 crewmembers) vehicles employing the open or encapsulated ejection seat concepts.

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13. ABSTRACT

This report covers the results of a study to define crew escape requirements and criteria for selection, evaluation, and design of crew escape systems for VTOL and low-altitude dash vehicles. Escape concept performance, survival, pressurization, restraint, crew comfort and efficiency, and development and qualification testing requirements are defined. Representative open ejection seat, encapsulated ejection seat, cockpit pod, and separable nose capsule escape concepts and vehicle configurations are defined. Escape concept performance capabilities with respect to altitude, speed, and descent angle are presented and results of analyses of escape concept effectiveness for VTOL hover and transition, conventional takeoff and landing, low-altitude dash, and high-speed and high-altitude flight regimes are presented. Also, the results of an investigation of automatic emergency detection and escape initiation are presented. Escape concept trade data relative to escape and survival potential, reliability, cost, weight, volumetric penalty, availability, crew comfort and efficiency, and crew safety were developed and are presented in a form useful as a guide in the selection, evaluation and design of escape concepts for advanced VTOL and low-altitude dash vehicles.

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