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DEVELOPMENT AND QUALIFICATION OF GEMINI ESCAPE SYSTEM

by Hilary A. Ray, Jr., and Frederick T. Burns

Manned Spacecraft Center
Houston, Texas

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ABSTRACT

The development and qualification of the Gemini spacecraft escape system emphasized the center-of-gravity/thrust-vector relationship. Both men and anthropomorphic dummies were used to qualify the Gemini flight crew ejection seat for escape from pad aborts to an altitude of 45 000 feet at velocities in excess of 1600 feet per second and dynamic pressures of more than 750 pounds per square foot.

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SUMMARY

This report presents a summary of the development and qualification of the escape system incorporated in the Gemini spacecraft. This system provides a positive means of crew escape over a wide range of conditions. Escape can be effected from conditions of pad aborts at zero velocity to altitudes in excess of 40 000 feet at velocities in excess of 1600 feet per second.

Significant tests and results are presented in the report sections on development and qualification testing.

INTRODUCTION

The crew escape requirements for space vehicles are greatly complicated by the wide regions of altitude and velocities encountered during a mission. Altitudes from essentially zero at zero velocity to several hundred miles and extremely high Mach numbers must be considered.

The envelope in which the Gemini ejection-seat system is the prime escape method was established as 100 feet at zero velocity (pad aborts) to 15 000 feet at a Mach number of 0.75. Operational procedures, using the main recovery system, provide escape during the remainder of the launch phase as well as during the reentry portions of the mission. The seat system becomes the backup during these periods.

The ejection-seat concept was selected for the Gemini spacecraft after careful consideration of weights, launch vehicle performance reliability, and total system integration required to provide escape, both prime and backup, over the complete flight region.

SYMBOLS

C_A	axial force coefficient
C_D	drag coefficient
C_ℓ	rolling moment coefficient
C_m	pitching moment coefficient
C_N	normal force coefficient
C_n	yawing moment coefficient
C_Y	side force coefficient
D_o	nominal diameter
e_θ	eccentricity of pitch
g	acceleration constant, ft/sec^2
$\dot{g}_e$	rate of onset, g/sec (effective)
g_I	acceleration at given point in time
g_{max}	maximum acceleration
l_{ref}	reference length, ft
M	Mach number
q	dynamic pressure, lb/ft^2
S_{ref}	reference area, ft^2
t	time, sec
t_e	effective time, sec
$t_{s.o.}$	time of strip-off

u, v, w free stream velocities

V velocity, ft/sec

$V_{s.o.}$ velocity at strip-off

x, y, z Cartesian coordinate axes

α, β angles

SYSTEM DESCRIPTION

General

The ejection seat is designed for the dual purpose of providing restraint for the mission and a means of escape in the event of an abort. The seat could be divided into a relatively large number of subsystems, many of them operating in series. For purposes of this discussion, however, the seat system is divided into the hatch-actuator system, the seat assembly, the ballute system, the personnel-parachute system, survival equipment, and the sequence of events.

Hatch-Actuator System

Each seat is ejected from the spacecraft through a hinged hatch which is pyrotechnically opened. The hatch actuator is fired by the manual activation of an initiator by either crewmember. The major components of the system (fig. 1) are eight mild-detonating-fuse (MDF) interconnects, two MDF crossovers, two manual-firing mechanisms, and two hatch actuators. The interconnects consist of four rigid MDF assemblies and four flexible MDF assemblies that connect the firing mechanisms to the hatch actuators. The two crossovers are rigid MDF assemblies that cross-connect the two initiation system firing mechanisms. The firing mechanism is attached to the spacecraft structure near the crewman's feet. The hatch-actuator assembly unlocks, opens, and mechanically restrains the hatch in the open position. The assembly primarily consists of the breech-end cap, breech, cylinder, stretcher assembly, end cap (base), and rod assembly (fig. 2).

The breech-end-cap assembly contains the locking mechanism which mechanically restrains the hatch in the open position, provides for installation of the seat rocket-catapult ballistic hose, and provides for installation of the breech assembly. It is thread mounted to the top of the cylinder. Two MDF interconnects from the initiation system are attached to the breech adjacent to the firing pins. The stretcher assembly consists of the piston and stretch link, and it is located inside the cylinder. One end of the stretch link is attached to a web inside the piston. The other end is attached to the rod-end assembly. The rod-end assembly connects the stretcher assembly to the hatch. The end cap contains a latch piston that actuates the egress-hatch unlock mechanism. The hatch and actuator are designed to function under the maximum aerodynamic forces which the spacecraft will experience up to an altitude of 70 000 feet.

Seat Assembly

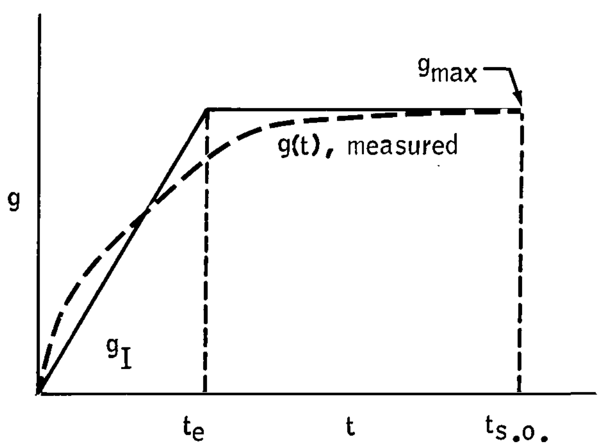
Structure. - An aircraft-type design is used in the seat structure to provide a good weight-to-strength ratio (fig. 3). The major portion of the structure is made from titanium and aluminum. The seat-back structure is designed around the rocket-catapult such that the center of gravity of the man is a minimum distance from the catapult force vector. Side panels are provided for support of the arms and to give structural integrity between the seat pan and back.

The seat is attached to the spacecraft with a torque box rail assembly. It slides on the rail assembly through six slotted titanium blocks on the seat back. The seat assembly in the spacecraft is designed for the loads shown in figure 4.

Rocket-catapult. - The rocket-catapult (ROCAT) is designed to provide the required impulse to propel the seat-man away from the spacecraft. Since a launch vehicle failure on the launch pad presents the most critical escape trajectory requirements, it was used as the criterion for ROCAT design. Half-scale tests on launch vehicle explosions and other available data were used to calculate the maximum fireball radius which could be expected. Heat flux radiation effects were included and a required ground separation distance for the seat was determined. The results of the fireball radius study are shown in figure 5.

The ROCAT is designed to meet the ground separation distance requirement, and yet it does not exceed the accepted limits on accelerations and rate of onset $\dot{g}_e$. The curves used for catapult design are shown in figure 6. The following method is used to define the effective $\dot{g}_e$.

Using a seat-man weight of 360 pounds, a record of acceleration g versus time t is measured.



If it is assumed that g_I does approximate g(t), then

$$\int_0^{t_{s.o.}} g_I \, dt = \int_0^{t_{s.o.}} g(t) \, dt = \frac{V_{s.o.}}{g} \qquad (1)$$

where $t_{s.o.}$ = time of catapult strip-off and $V_{s.o.}$ = velocity at strip-off.

Integration of equation (1) gives

$$\frac{1}{2} g_{max}\left(t_e\right) + g_{max}\left(t_{s.o.} - t_e\right) = \frac{V_{s.o.}}{g} \qquad (2)$$

Solving for t_e,

$$t_e = 2\left(t_{s.o.} - \frac{V_{s.o.}}{g_{max}g}\right) \tag{3}$$

By definition,

$$\dot{g}_e = \frac{g_{max}}{t_e} \tag{4}$$

or substituting equation (3) into equation (4) and simplifying,

$$\dot{g}_e = \frac{\left(g_{max}\right)^2}{2\left[\left(g_{max}\right)\left(t_{s.o.}\right) - \frac{V_{s.o.}}{g}\right]} \tag{5}$$

where $\frac{V_{s.o.}}{g} = \int_0^{t_{s.o.}} g(t)\,dt$.

Restraint. - The restraint system is designed to closely control the movement of the man under aerodynamic and ejection loads. Stability during free flight as well as desired trajectories can be obtained when the dynamic center-of-gravity (c.g.) thrust-vector relationship is accurately known. Since the thrust vector is fixed, the problem resolves to one of maintaining the c.g. shift to a minimum under dynamic conditions. The c.g. shift was determined by calculations and tests. Ballast was used to position the static c.g. such that the dynamic shift would move it into the desired location (fig. 7).

The allowable pitch eccentricity e_θ was determined by the required ground separation distance and by a minimum parachute opening altitude (fig. 8).

When the man is properly restrained and the c.g. is accurately located, the only remaining factors are outside forces. The largest influence on the thrust-vector aim point is the initial pitch rate or tipoff rate at the end of the rails. Tipoff at seat-rail separation exists since the seat is free to rotate about the lower slide blocks. The initial rate was found to be approximately 1.25 rad/sec with the occupant's head moving forward. This initial pitch rate is compensated for by aiming the thrust vector a predetermined distance below the dynamic center of gravity.

The center-of-gravity shift is minimized with several different restraints. These restraints include contoured fiber-glass cushions, foot stirrups, elbow guards, leg straps, lap belt, and shoulder straps. The head rest is also in a V-block shape to restrict movement of the head to the side. All restraints are removed automatically in the proper sequence and are discussed in the section "Sequence of Events."

Backboard. - The backboard is a structural member which is used to mount various pieces of necessary equipment. Mounted on the backboard are the parachute, the ballute, the survival kit, the contours, and the related pyrotechnics. The shoulder straps are at the top of the backboard and are connected to an inertia reel mounted on the lower back of the structure. The reel is a two-position reel which, by use of a control, can be put into a manual lock or on automatic. When manual lock is utilized, the straps can be reeled in but cannot be extended. On the automatic cycle, the straps will automatically lock when they are extended at a rate such as to produce at least 2g and no more than 3g. The inertia reel straps extend to 19 inches with the tension on the straps shown in figure 9. The backboard is structurally designed to withstand the load shown in figure 4.

Egress kit. - The egress kit (fig. 10) is located on the seat pan and provides oxygen for breathing and pressurization in the event of ejection at altitude. The tank portion of the kit is machined from an aluminum billet and forms a mounting surface for the egress-kit contoured cushion. Other components of the assembly are the connecting lines, the shutoff valve, the relief valve, the regulator, the pressure gage, and the composite disconnects.

The tank is pressurized to 1800 psig with gaseous oxygen. The oxygen flows from the container through a pressure regulator, where the pressure is reduced to 40 psia. It then flows through a shutoff valve and a flow restrictor, which allows a flow of 0.0366 ± 0.0024 pound per minute, and finally through a check valve to the suit. After leaving the suit, the oxygen flows through the shutoff and relief valve, which dumps the oxygen overboard. This valve controls the suit pressure to $3.5^{+0.4}_{-0.0}$ psia, if ejection occurs at an altitude above 35 000 feet, and controls from 0 to 5 inches water gage below 35 000 feet. The egress-kit oxygen is activated with lanyards which are pulled on seat motion at ejection.

Ballute

Purpose. - The ballute (fig. 11) is a balloon-shaped device which is used to stabilize the man between seat-separation and 7500 feet altitude. It is fabricated from a coated nylon fabric and is inflated by ram air through four reed-type vents located around the periphery. The ballute is designed to (1) eliminate any tumbling motion which the crewman has attained at separation and prevent any subsequent tumbling, and (2) limit sustained flat-spin average rates to not more than 45 rpm.

Components. - The ballute assembly consists of the ballute, the riser, the bridle, the ballute container, the saddle, and the pyrotechnic deploy and release device.

The ballute has a nominal diameter of 48 inches. The shape is basically a cone on the bottom portion with a spherical top. A burble fence is located near the top and creates turbulence, thus increasing the drag coefficient. The riser and bridle are made as an integral part of the inflated portion. The riser is 8 inches long and the bridle, formed by two 1-inch-wide nylon straps, is 60 inches long. The bridle is attached to the backboard assembly near the shoulders of the man. A saddle is connected to the bridle attach point on the backboard and runs beneath the crewman's buttocks. The saddle performs the function of more evenly distributing the shock loads on inflation.

An aneroid-controlled pyrotechnic device deploys the ballute after a 5-second delay for ejections above 7500 feet. This sequence is discussed in more detail in the section on sequence of events.

Loads. - A typical load curve for a maximum-dynamic-pressure condition on the ballute is shown in figure 12.

The ultimate loads are 1.5 times the limit load, except for the bridle-riser which is capable of ultimate loads 2.0 times the limit load. These limit loads represent the peak Mach number M condition which is $M = 1.92$ and dynamic pressure q of 180 lb/ft^2.

Function. - As stated previously, the primary purpose of the ballute is to limit the tumbling and spinning of the crewman to an acceptable rate. Figure 13 shows rates of rotation and the times for which they are acceptable. The design maximum for this system of 45 rpm is well within the accepted limits.

Personnel Parachute

Nomenclature. - The Gemini personnel parachute is a standard 28-foot-diameter flat circular C-9 canopy currently being used by the armed services. A ribless-guide-surface pilot parachute is incorporated into the system to facilitate main parachute deployment. The personnel harness is a single strap of Dacron webbing formed into a double "figure 8." Since each harness is individually fitted to the crewman, the only adjustable strap is the chest strap. The parachute-to-harness attachment is accomplished with quick disconnects. Figure 14 illustrates the basic components of the Gemini personnel-parachute system.

Operation. - The Gemini personnel-parachute system has a significant advantage over current systems in that the Gemini system has a positive and rapid canopy deployment. This is accomplished by a pyrotechnic-actuated drogue gun. The deployment is explained in detail in the section on sequence of events. Rapid parachute deployment is a vital requirement for an off-the-pad ejection. Figure 15 gives the opening times versus dynamic pressure obtained during simulated off-the-pad ejections and low-speed helicopter tests.

Design landings. - Table I gives the design parameters of limit, proof, and ultimate loads for basic system components at critical conditions.

The ballute provides sufficient drag to maintain the man in a feet-down attitude during descent. Although the crewman's rate of descent is decreased by only approximately 30 ft/sec on the ballute, the reduction is enough to prevent him from assuming a position which is conducive to spin.

Survival Equipment

Survival equipment is stored in two containers on the backboard assembly. One container is mounted on the left front of the backboard and the other on the rear. Both containers are fabricated from nylon and held closed with a daisy-chain-loop arrangement. All of the survival items, with the exception of the liferaft, are enclosed in two inner containers, or rucksacks, which are zipper operated. Each item is attached to the inside of the rucksack with a short line. Both of the rucksacks and the liferaft are connected to an 18-foot nylon lanyard which is attached to the crewman's harness. The components of the packs are designed to sustain the crewman for a 48-hour period.

The survival equipment in the backpack includes a liferaft, a CO_2 inflation cylinder, a sea anchor, a sea-dye marker, a radio/ beacon, an MK-2 desalter kit, a medical kit, sunglasses, two medical injectors, and a compress. Also contained in the backpack is a combination light which contains a flashlight, a strobe light, a fishing line, fish hooks, sewing needles, thread, a compass, fire starter, fire fuel, a whistle, and a signal mirror. The survival equipment in the frontpack consists of a machete and a water container with 4 pounds of water.

The total weight of the survival items and containers is approximately 25 pounds. The containers are designed to withstand aerodynamic and acceleration loads of ejection. All equipment is automatically deployed on the 18-foot lanyard during the ejection sequence.

Sequence of Events

Initiation. - The hatch-actuator initiation system is activated when either crewmember pulls the ejection control handle located between his knees. A pull force of about 40 pounds is required. Approximately 1/2-inch travel of the lanyard connecting the ejection control to the firing mechanism will energize and release the dual firing pins (fig. 16). The firing pins strike the dual percussion primers, causing the booster charge to detonate. The interconnecting MDF propagates the detonation wave at a velocity of 24 000 feet per second to the firing pins of the hatch actuators. The crossover MDF insures initiation of both hatch actuators.

Hatch actuation. - The shock wave propagated by the MDF interconnects causes the two firing pins of the breech assembly to sever shear pins and strike the primers of two percussion-fired cartridges. The cartridges ignite and generate hot gas which ignites the main propellant charge of the breech. The propellant charge produces a large volume of high-pressure gas which is exhausted into the area between the piston of the stretcher assembly and the cylinder. Orifices in the lower end of the piston wall admit the gas pressure to the base of the stretcher assembly. The gas pressure is ported through a drilled passage to the latch piston, which extends and unlocks the hatch through a bellcrank-pushrod mechanism. At the same time, the gas pressure acts on the base of the stretcher assembly and starts moving it through its stroke. Immediately prior to the stretcher assembly reaching full extension, gas pressure is exhausted through a port to the catapult ballistic hose (fig. 17). As the stretcher assembly reaches full extension, the lock pin of the locking mechanism engages the piston and holds the hatch open. The entire sequence from ejection control handle pull to hatch full open requires just over 0.3 second.

Catapult action. - The seat-ejection cycle is initiated when the gas pressure is received through the ballistic hose from the hatch actuator. A pressure of 500 psi shears the retaining pins on the dual firing pins (fig. 18) and causes them to strike dual percussion primers. The primers ignite the relay and main charges which produce a hot, high-pressure gas. The gas pressure releases the motor-lock housing by displacing the lock ring against the spring. With the motor-lock housing released, the gas pressure propels the rocket motor, and thus the seat, through the length of the catapult housing.

Prior to complete ejection from the catapult housing, the lock ring of the motor-lock housing makes contact with a stop which severs its four shear pins. The tang locks of the motor-lock-housing cam open and release the rocket motor. Separation of the rocket motor from the motor-lock housing allows the hot gas from the catapult main charge to enter the rocket motor through the nozzle. The hot gas fires the igniters, thus igniting the rocket motor. Dual igniters are installed in the rocket to provide redundancy.

Harness release. - The harness-release actuator is mounted on the seat structure (fig. 19) and serves to release the man from the seat and to initiate the firing mechanism of the separator thruster assembly. The firing mechanism of the harness-release assembly is initiated by lanyard pull when the seat rises on the ejection rails. The firing pin is cocked and released to strike the cartridge. The cartridge has a 1.08-second time delay so that the crewman is maintained in the seat until after rocket burnout. This time delay also allows the crewman to remain restrained in the seat while dynamic pressure is decaying for high-q ejections. At the end of the 1.08-second time delay, the cartridge fires and retracts the unlatch rod. The rod movement actuates the mechanical linkage (fig. 20) and releases the crewman from the seat. As the unlatch rod approaches the end of its travel, a port is exposed that vents gas pressure into the separator ballistic hose.

Seat-man separation. - The separator assembly is composed of a thruster assembly and nylon straps (fig. 21). The thruster supplies a stroke of adequate length and power to the webbed strap to forcibly separate the seat and the man. The high-pressure gas from the harness-release actuator is transmitted through the ballistic hose to the thruster-firing mechanism. Gas pressure causes the firing pin to sever its shear pin and strike the primer of the cartridge. The cartridge ignites, generates gas pressure, and shears the pin holding the thruster piston. As the thruster piston extends, the strap is pulled taut effecting seat-man separation.

Stabilization. - Deployment and release of the ballute is accomplished with an aneroid-controlled pyrotechnic device (figs. 22 and 23). As the crewman leaves the seat on seat-man separation, two lanyards are pulled and the firing pins are released.

Since the ballute is not deployed below 7500 feet altitude, the sequence of events must be described under two separate circumstances.

Sequence above 7500 feet: When initiated above 7500 feet, the release mechanism firing pin is restrained from moving into the primer by the aneroid. During the same time interval, the deploy firing pin is released and fires a 5-second time delay charge. The time delay of 5 seconds is used in order to allow the dynamic pressure to decay and thus reduce opening loads. At the end of the 5-second delay, the main cartridge fires generating gas pressure which is ported to the deploy-cutter assembly through a ballistic hose. This pressure drives a cutter into the cable holding the ballute container closed and allows a 250-pound spring beneath the ballute to push it from the pack. Once out of the container, the ballute inflates from ram air pressure entering the four vents. As the crewman reaches 7500 feet pressure altitude, the aneroid releases the firing pin on the cutter charge. The cutter-cartridge firing is instantaneous, and gas pressure is released through a ballistic hose to a guillotine assembly on the ballute riser. When the bridle is cut, the ballute is free from the man.

Sequence below 7500 feet: The operation is much the same when the separation occurs below 7500 feet. However, when the lanyards are pulled below 7500 feet, the aneroid does not restrain the release firing pin, and the instantaneous cartridge is fired. The gas pressure proceeds as in the higher altitude sequence and cuts the ballute riser. The pressure also acts on a small sequencing piston (fig. 22) and moves it over to block the deploy port. Since the deploy cartridge is delayed 5 seconds, it does not fire until after the port is blocked. With the port blocked, the gas pressure is unable to proceed to the deploy cutter and the ballute remains in the pack.

Parachute deployment. - At seat separation, an additional lanyard between the backboard and seat is pulled. This lanyard is attached to the firing pin of the parachute drogue gun (fig. 24). Pulling the lanyard shears a retaining pin which allows the firing pin to move into the primer. This device is also controlled by an aneroid and is preset to a pressure altitude of 5700 feet. When the aneroid altitude is reached, the primer is fired and initiates a 2.3-second time delay. At the end of the time delay, the main charge fires, generates gas pressure, and propels a 10-ounce slug away from the crewman. Before firing, the slug is retained in the drogue-gun barrel with a shear pin. The barrel is canted 20° outboard of the axis of the man's spine.

A nylon strap and a three-pronged wire pin are attached to the slug. The wire pin is pulled and opens the parachute pack. The nylon strap, attached to the top of the drogue parachute, pulls the drogue parachute and approximately one-third of the main canopy from the pack. The drogue parachute inflates and extracts the remainder of the main canopy.

A second firing pin and primer are included on the drogue gun and are designed for manual operation. This system is for use in the event of a primary-firing-pin-mechanism malfunction.

Equipment jettison. - High-pressure gas from the drogue-gun main charge is used to initiate the equipment jettison sequence. Gas pressure from the drogue-gun main cartridge causes the firing pin of the backboard firing mechanism to sever its shear pin and strike the primer of the time delay cartridge. After a time delay of 5 seconds, the cartridge propagates a detonation wave through a mild detonating fuse (MDF) interconnect (fig. 25) to a manifold assembly. Simultaneously, the detonation wave is propagated by three MDF interconnects to the restraint-strap cutter, lap-belt disconnect, and the jetelox release. The restraint-strap cutter is a flexible linear-shaped charge which cuts the inertia reel straps. The lap-belt disconnect frees the lap belt and the jetelox release disconnects the oxygen hoses and wire cable from the egress kit.

After the three MDF interconnects have fired, the backboard and egress kit are free to fall away from the man. The only remaining connection between the man and equipment is the survival-kit lanyard. The nylon lanyard is snapped on a small D-ring on the left side of the parachute harness. As the backboard drops away, the lanyard pulls open first the back survival kit and then the one on the front of the backboard. The rucksacks and liferaft are hanging below the man on the nylon lanyard as the backboard and egress kit fall free.

Summary. - The preceding sequences are summarized in table II. The times given are nominal times, and the sequences start with the actuation of the ejection-control handle.

DEVELOPMENT TESTING

Wind Tunnel

Seat configuration. - Wind-tunnel testing on the seat-man configuration was conducted in an intermittent-pressure blowdown-type facility with a Mach-number range of 0.5 to 5.8 and a 4- by 4-foot test section. Both the transonic and supersonic test sections were used.

The purpose of the tests was to obtain aerodynamic characteristics of the seat-man combination in various attitudes that might occur following ejection. These data were used in the trajectory calculations and in the determination of flight characteristics. Prior to these tests, only a limited amount of aerodynamic data of a similar configuration existed, and the assigned escape altitudes and velocities necessitated a complete definition of aerodynamic forces and moments.

Both a 20-percent scale model and a 10-percent model were used in the tests. The testing was done in three series. The 20-percent model was used in the free-stream tests while the 10-percent model was used in rocket-exhaust effects and proximity tests.

The series I (20-percent) model was preset to various pitch angles on the mounting sting; the model was then pitched to obtain various angles of attack. Sideslip data were obtained by rolling the entire sting-balance assembly 90°. The series II model was preset at various angles in the yaw plane and then pitched through selected angles of attack. Similarly, the sting-model assembly was rolled 90° to obtain additional sideslip data.

The 10-percent model was used to determine the effects due to the proximity of the spacecraft (hatches open) and due to the jet of the seat-sustainer rocket. Listed below are the escape positions at which the model was tested. These positions are also shown in figure 26. The body axes and angular nomenclature are defined in figure 27.

(1) Rail-seat separation

(2) Hatch-seat clearance point, that is, the position at which the bottom of the man's feet are tangent to the edge of the open hatch

(3) Midpoint between the above positions

Series III testing was necessary because several modifications were made on the seat after the initial testing was completed. These changes were:

(1) The foot position of the man was raised and the seat was shortened vertically.

(2) The armrests were lowered and the armrest angle reduced.

(3) A seat-man separator was added.

(4) The flat-plate area between the man's lower leg was relieved.

(5) A larger headrest was added.

This series of tests was made using a limited number of points. It was found that the previous curves could be faired to reflect the changes found on the series III testing. The only significant change due to seat modification was in the pitching-moment coefficient C_m. All other coefficients were affected very little.

The testing was made through a Mach number range of 0.5 to 3.5. A seat-back reference area of 7 square feet was used. Figure 28 is presented to show a typical variation in the coefficients determined by this testing.

Ballute. - A series of wind-tunnel tests was conducted to determine the opening characteristics and drag coefficients of the ballute. Also, the ballute-man stability parameters were investigated. The following paragraphs summarize these tests.

Low-speed tests (one-fourth and one-sixth scale): Three degrees-of-freedom, free-spinning ballutes of various sizes from 18 to 48 inches were used. The ballutes were constructed of heavy-rubberized nonporous material. The length of the riser lines varied from 12 to 36 inches. Deployment dynamic pressures varied from 27 to 67 lb/ft^2. No drag data were acquired, and data were obtained by motion picture coverage only. The ballutes inflated in all cases. The 36-inch ballute on a 12-inch riser adequately stopped the spinning of the dummy and brought it to a stable feet-first attitude.

Initial supersonic test (one-fourth scale): A one-degree-of-freedom, 18-inch ballute with a 15-inch riser was used. The drag on the ballute was not sufficient to bring the dummy to a feet-first attitude.

Second supersonic test (one-fourth and one-sixth scale): Solid ballutes and nonporous-inflatable models with rigid and three-degree-of-freedom mounts were used. Adequate inflation and drag characteristics were exhibited supersonically. Drag coefficients ranged from 0.9 at 1.75 to 0.7 at 2.25. The 36-inch ballute on 15- to 18-inch risers stopped the spin of the dummy and maintained a stable feet-first attitude.

First supersonic test (full scale): A single-degree-of-freedom mount was used in these tests, and the tests involved the first use of porous ballutes. The ballutes did not inflate satisfactorily; only two in the series inflated sufficiently to obtain drag coefficients (drag low: 0.36 prone and 0.14 standing). The ballutes were coated with a protective spray to reduce porosity. These tests were not successful.

Second supersonic test (full scale): The test equipment included a rigid-mounted dummy, porous 36-inch ballutes, and a 25-1/4 inch riser. Flapper valves, screens, and wire reinforcing were added to the inlets. Four of seven deployments were subsonic. The subsonic deployments in all attitudes tested were satisfactory except for one in which the dummy was positioned 90° to the stream. The subsonic drag coefficient, as predicted, was about 0.85 prone and was 0.46 with the dummy 45° to the stream. Two of three supersonic deployments were satisfactory. The one that did not deploy did not have the wire-reinforced inlet. The supersonic drag coefficients were about 0.45 for the prone position.

Additional low-speed tests developed the porous-fabric ballute with the inlet screens and flapper valves. All the ballutes inflated, with drag coefficients varying from 0.88 to 0.33 for the prone and standing dummy. The dummy was rigid when placed in either the prone or standing position.

Figure 29 presents drag coefficients versus Mach number as obtained from the wind-tunnel tests.

Static Tests

These tests were made to check one or more events in the ejection sequence and to verify design changes. No attempt is made to include in this section all of the bench firings and individual component tests. Only the major system static tests are listed.

Separation tests. - Many tests of this type were completed during the development testing period. The tests consisted of suspending a seat system containing an anthropomorphic dummy and of actuating the seat-man separator. Separation tests were made to verify that modifications to the system would not jeopardize a clean separation of man and seat. The tests were also made to check sequences which are actuated on separation.

Rocket-catapult tests. - Certain static rocket firings were made that were beyond the normal ejection-seat rocket development. This was necessary because this seat is designed to operate at altitudes and velocities above the present operational systems.

Early ejection tests resulted in structural failure in the thrust-pad area on the bottom of the seat. Design modifications were made in the seat, and a static rocket test was initiated to verify the modifications. A dummy was mounted (fig. 30) to a concrete pad between track rails. As the catapult was fired, the reactive force propelled the sled down the track allowing the rocket motor to fire with the force vector in the direction shown. The corrective measures proved to be successful.

Other static firings were made in an altitude chamber to determine the thrust-vector variation and rocket-plume effect at altitude. The rocket motor was fired at test-cell altitudes of 70 000, 72 000, and 73 000 feet. Six component data (normal, axial, and side force; yawing, pitching, and rolling moment) were recorded, and temperatures at different areas around the flame bucket were measured with temperature-sensitive paint.

The tests showed the thrust-eccentricity angle to vary, on the average, less than 1° from the results of similar tests near sea level. The forces, when compared to the total thrust, were also negligible. Altitude influence on rocket plume did not cause any detrimental effects on the seat.

A series of three free-flight trajectory tests was made. The tests were made to investigate the trajectory of the seat-man system. In order to simplify the test equipment requirements, the ejections were made from ground level and no attempt was made to separate the dummy from the seat. The seats were instrumented to give pitch and roll rates and accelerations in three planes. All of the seats had been used in previous tests.

Test 1 was made to obtain the optimum trajectory. This test was made to investigate the effects of several design modifications. Tests 2 and 3 were made to determine the results on trajectory and rates of firing a seat with the predicted maximum allowable eccentricities. Data from the tests are shown in the following table.

Test	Date	System weight, lb	Eccentricity, in.	Landing point, ft
1	April 19, 1963	405	--	711 ft down range 50 ft right of ℄
2	September 17, 1963	403	Pitch = -1.3 Lateral = 0	490 ft down range 17 ft left of ℄
3	September 18, 1963	363	Pitch = -0.4 Lateral = +0.6	550 ft down range 230 ft left of ℄

Harness tests. - Structural load and comfort tests were conducted on the personnel-parachute harness. The structural tests were made using a torso dummy for static pull and dynamic drop tests. On the pull tests, the harness was mounted on the dummy which was secured to the bottom of the static-testing machine. The harness risers were subjected to 2330 pounds and elongation was measured. There was no significant elongation noted. The torso dummy was then put on a tower and dropped various distances to produce the desired forces.

Early in the dynamic drop tests, a Navy-type canopy release was used. Two times during the drops, this type of fitting released on first-impact rebound. Failure analysis indicated that a combination of acceleration on the cover and eccentric loading on the locking bar caused the release. An Air Force version of the same fitting was found to have design characteristics which corrected the problem, and this version was integrated into the system. The following table summarizes the dynamic drop tests for the 300-pound torso dummy.

Drop test	Fall distance, ft	Peak force, lb
1	15.0	8 000
2	13.5	7 400
3	11.5	--
4	11.5	6 700
5	15.0	10 000
6	32.0	12 500
7	11.5	6 000
8	13.0	--
9	16.0	10 600

The comfort tests were made with live jump subjects. These tests were conducted to verify the comfort of the Gemini-configuration harness under opening loads. Full equipment and pressure suits were used on the drops. The tests were made on the same tower with the expected nominal opening loads. The tests showed that there should be no significant problems. Listed in the following table are the results of the tests.

Drop test	Subject	Gross weight, lb	Fall distance, ft	Peak force, lb
1	Human	261	2	870
2	Human	261	3	1027
3	Human	261	4	1400
4	Human	261	5	1420
5	Human	272	4	1400
6	Human	272	6	1720
7	Human	272	7	1740

Air Drops

Air drops were used throughout the development program to test modification and to verify functioning of systems. Configurations of equipment on the drops varied with test requirements and equipment availability. Some of the earlier drops were made with weights though the majority used anthropomorphic dummies. Live subjects were used in a series of ballute tests.

Parachute drops. - The first series of air drops was accomplished in 1962. These tests used weights with the parachute pack attached. Two different systems were tested in parallel at velocities of 60, 90, and 120 knots. The A system consisted of a standard C-9 canopy, a 42-inch D_o spring pilot parachute, a pyrotechnic automatic opener, and a rectangular daisy-chain pack with B5-type pilot parachute flaps. The B system was very similar in that it consisted of a C-9 canopy, a 42-inch D_o vane pilot parachute, and a rectangular daisy-chain pack; however, the daisy chain was locked by a steel pin and attached to a drogue gun.

The test results showed that the deployment time on the A system did vary with attitude while the drogue-gun-deployed B system was consistent regardless of attitude. This and the results of the early tower tests with the A system resulted in a decision to proceed with a drogue-gun-deployed parachute. A summary of the drop tests is shown in table III.

A second series of 14 air drops was completed in May 1963. These drops were performed to functionally test a new parachute-pack configuration utilizing a new drogue gun, risers, ribless-guide drogue parachute, and new retaining pin. Five of the drops were made from a helicopter and a two-engine aircraft. Anthropomorphic dummies were used as test subjects. The dummies were suspended on a cable 200 feet below the helicopter to avoid the downwash. A roller conveyor was used in the aircraft to launch the subject. Lanyards attached to the aircraft and to the cable were used to actuate the drogue gun.

The remaining nine tests verified the system at the low-q and design-limit air loads. Table IV summarizes the results of the 14 tests.

Parachute pocket tests. - These tests were conducted to investigate the effect of installing deflation pockets on the personnel recovery parachute. These pockets are a series of 1.1-ounce nylon panels sewn across the radial seams on alternate gores around the exterior of the canopy skirt with the open pockets facing the apex of the parachute. The pockets trap water and automatically collapse the chute on water impact.

Parachute opening times are of particular interest during pad aborts due to the limited time available for parachute deployment. In order to simulate the pad-abort dynamic-pressure conditions, the test dummies were suspended from an H-37 helicopter.

Eight tests were conducted and data obtained were compared to data previously obtained from tests conducted under similar test conditions but without pockets on the parachute. Figure 31 gives opening times with and without the pockets.

Figure 31 illustrates the increased opening time with the parachute pockets. This deployment-time increase of 0.75 second prevented the pockets from being used on the personnel-recovery system, as this increased time would allow full inflation to occur outside of the boundary conditions defined in the preceding section.

The increase in deployment times can be attributed to one or more of the following:

(1) Tighter pack, due to increased canopy mass, would result in slower canopy deployment from bag.

(2) Increased mass of canopy with fixed energies of drogue slug would result in slower deployment.

(3) Pockets trap air as canopy goes to line stretch resulting in longer time to line stretch.

(4) Increased mass of skirt area slows parachute inflation.

Seat system. - In August 1962, a complete seat system was dropped from an aircraft flying 90 knots indicated airspeed at an altitude of 1000 feet. This test was accomplished to verify operation of the seat-man separator and parachute system prior to simulated off-the-pad ejection test number 6. A 75-percentile dummy was used in the test, and all pyrotechnics were activated by lanyard pull on exit from the aircraft. All systems functioned as designed in this test.

Ballute tests. - Early wind-tunnel tests had shown that a 36-inch-diameter ballute on an 18-inch single riser would adequately stabilize a man. Data from similar stabilization tests indicated that the 18-inch single riser might be inadequate. A live-subject and dummy-test program was outlined for the purpose of determining the stabilizing characteristics of the 36-inch ballute. The program was such that configurations and procedures could be altered at the test site in order to meet the requirements.

In order to test the ballute, a special harness and ballute release were used. The ballute was folded and held against the jumper's back until he left the aircraft. The release enabled him to jettison the ballute at his option. No other Gemini equipment was used in the tests, and jumps were made using a 35-foot HALO parachute.

The initial tests showed that previous experience, not wind-tunnel data, provided better information. The rotation on the 36-inch ballute and 18-inch single riser was not extremely high, but it disoriented and confused the jumpers. Three jumps were made with each one resulting in early release of the ballute by the jumper. On the next two jumps, a 15-foot dual bridle and a 5-foot dual bridle were used. Each dual bridle converged to a single riser just below the ballute. Each produced lower rotation, but it was decided to proceed with the 5-foot dual bridle in order to minimize entanglement and stowage problems.

Several tests were completed with the 36-inch ballute and 5-foot bridle. Results showed a reduction in rotation, but not of sufficient magnitude. The next changes were to increase the ballute diameter to 42 inches and finally to 48 inches. Some tests with the 48-inch diameter ballute and 5-foot dual bridle produced no rotation while other tests produced rotations within acceptable limits. Results of the ballute tests are given in table V.

Body Slump Tests

A series of 27 tests on human subjects and 13 tests on dummies was to determine, under applied acceleration and by photographic means, the extent of displacement of specific points on the body surface of the human subjects. The dummy tests were made to provide comparative data between dummy and human subjects. A Gemini seat with contours was mounted on a tower inclined 20° from vertical. The seat was mounted tilted back 34° (fig. 32) and mounted on the tower with a movable carriage. A summary of the results is given in table VI.

Two 1500-frame-per-second (black and white) motion picture cameras were positioned to obtain photographs of the test subjects from the right side and front during the initial acceleration loads. Accelerometers were mounted on the seat to provide acceleration and onset data. A braking system stopped the man-seat as it moved up the tower.

Simulated Pad Ejection Tests

Twelve development ejection tests were made to simulate a pad-abort situation. These simulated off-the-pad ejection (SOPE) tests were made with complete seat systems from a 150-foot tower. Eight of the tests were single ejections and four were dual. Rail-box assemblies were mounted to a fixture on top of the tower. Data were obtained with telemetry in some cases and photographically on all tests.

Simulated pad test 1. - Simulated pad test 1, a single ejection, was completed on July 2, 1962. The dummy did not separate from the seat because of failure of the seat-man separator strap. The expected trajectory was not obtained and the rocket blast burned through the seat structure. The trajectory appeared smooth, with pitch and roll limited to incomplete cycles.

Simulated pad test 2. - Simulated pad test 2, a single ejection, was made on July 17, 1962, with a modified separator strap. The seat pitched forward 1-1/2 revolutions prior to separation. After separation, the pilot parachute deployed but wrapped around the dummy. The main parachute was never deployed.

Simulated pad test 3. - Simulated pad test 3, also a single ejection, utilized a drogue-gun-deployed parachute and was made on July 25, 1962. The dummy was modified to minimize slump, and thus reduce seat pitch rotation. On firing, the seat pitched up slightly and the seat-man separator fired on schedule. The more rigid dummy did not separate from the seat, and both seat and dummy impacted down range.

Simulated pad test 4. - Simulated pad test 4 was a single ejection on July 26, 1962, using a standard 75-percentile dummy. The seat had a very stable trajectory and separation occurred on schedule. However, the drogue gun did not fire and the parachute never deployed.

Simulated pad test 5. - Simulated pad test 5 was a single ejection made on August 3, 1962. The MA-6 lap-belt disconnect was removed, and provisions were made to release the lap belt at each end. A new heat-resistant shield was added in the flame-bucket area. The seat made one full revolution before separation. Again the drogue gun did not fire and the main parachute never deployed. A secondary drogue-gun lanyard of 550-pound nylon added after test number 4 also failed. Subsequent testing showed that the drogue-gun firing mechanism would bind when pulled at an angle.

Simulated pad test 6. - Simulated pad test 6, another single ejection, was made on September 12, 1962. The following changes were made prior to the test.

(1) A guide tube was added on the drogue-gun lanyard, and pull tests were completed to verify the correction.

(2) Tow tests were made on the pilot parachute.

(3) Drop tests from aircraft were made on the system.

During thrusting, the seat pitched down and rolled to the right approximately 90°. Seat-dummy separation occurred normally and the parachute was deployed at about 100 feet.

Simulated pad test 7. - Simulated pad test 7 on September 26, 1962, was the first dual ejection. A 75-percentile dummy was used in the command pilot's position, and a 15-percentile dummy was used in the pilot's position. It was concluded that both seat systems provided satisfactory emergency escape for the condition tested. Following simultaneous ejection, separation and recovery of the dummies occurred as programed. Some damage was incurred in the thrust-pad area of the seat.

Simulated pad test 8. - Simulated pad test 8 was made with a redesigned rocket which increased the thrust from 6000 pounds to a nominal 8300 pounds. The rocket burn time was reduced to 0.26 second. The test was a dual ejection made on February 7, 1963. Both seats developed an excessive pitch rate during rocket burn. Although seat-dummy separation functioned properly, only one parachute was deployed and a number of problems were uncovered. The problems uncovered on test number 8 are listed as follows:

(1) Excessive pitch rates

(2) Failure of ballutes to deploy and release

(3) Hangup of one parachute on ballute mechanism

(4) Burn-through of one ballistic fitting

A redesign program on the seat system was initiated immediately after this test.

Simulated pad test 9. - Simulated pad test 9 was made on May 15, 1963. The test was a single ejection with a 75-percentile dummy. The major changes incorporated after test number 8 are listed below.

(1) The basic seat structure was increased in strength.

(2) A new elbow restraint was added.

(3) The release mechanism was redesigned.

(4) The parachute and drogue gun were moved to the right side.

(5) A new pilot parachute was added.

(6) The backboard was redesigned.

(7) The drogue gun was canted out 20°, and a new aneroid-controlled ballute deploy and release mechanism were added.

(8) A new short tail-off rocket motor was used.

(9) A different thrust-vector c.g. relationship was used to correct tipoff effects.

There was no rotation during rocket firing on the test. All sequences occurred as programed with a full parachute being obtained at approximately tower height.

Simulated pad test 9A. - Simulated pad test 9A was performed on May 25, 1963, and was a single ejection. Simulated pad test 9 was originally scheduled as a dual ejection, but was changed to two single ejections after the seat redesign. As on ejection test number 9, there was no rotation on this test and all sequences occurred normally.

Simulated pad test 10. - Simulated pad test 10 was made on July 2, 1963, and was the first dual ejection after the major design changes. The center of gravity of one seat was intentionally displaced to verify predicted effects on trajectories. The thrust vector was aimed to provide eccentricity in both the lateral and pitch planes. The second seat was prepared such that the thrust vector had no eccentricity in either plane. Both trajectories on the test were very close to predictions and all sequences occurred normally. Pitch and yaw occurred in the test of the seat with excessive eccentricity, but the dummy was recovered normally.

Simulated pad test 11. - Simulated pad test 11 on July 16, 1963, was a dual ejection to further verify trajectories with a set of eccentricity parameters on the edge of the c. g. window. The dummy in the pilot's seat was set to have no lateral eccentricity and maximum pitch-up eccentricity. The dummy in the command pilot's seat was set for pitch down and yaw to his left. Both seats reacted as predicted and the dummies were recovered normally. Test number 11 completed the development phase of simulated off-the-pad ejections. A summary of all the development simulated pad tests is shown in table VII.

Track Vehicle Tests

Four ejection tests from a rocket-propelled track vehicle were completed during development testing. A test sled used in Project Mercury was modified for the tests with a boilerplate Gemini spacecraft mounted on the sled to provide realistic airflow.

Hatches on the sled were fixed open but did not include hatch actuators. The seats were initiated electrically from track-side electrical power supplies. Propulsion for the vehicle was provided by solid-propellant motors mounted on a pusher vehicle with the number of motors varying with velocity requirements. The vehicle was braked to a stop with a water brake after the ejection.

Instrumentation on the tests included telemetry mounted in the dummy test subjects, sled-mounted telemetry, and photography. The telemetry sensors detected accelerations, rates, and events. High-speed photography was used for tracking the seats and for recording onboard events.

Sled test number 1. - Sled test number 1 was made to verify drag calculations and structural integrity and no ejection was attempted. Two seats with dummies were mounted in the sled and telemetry transmission was checked during the run.

The test was completed on November 9, 1962. The solid-propellant motors were fired in four stages in order to maintain a low acceleration. When the third-stage motor ignited, the thrust bulkhead of the pusher vehicle failed, allowing the motor to penetrate the boilerplate spacecraft. The test vehicle was severely damaged, but remained on the track and was later repaired. Sufficient data were obtained to verify the drag calculations, although the vehicle did not reach maximum velocity. A new pusher vehicle was designed and manufactured.

Sled test number 2. - Sled test number 2 was a maximum-dynamic-pressure test at zero pitch and yaw. The test vehicle reached 893 ft/sec at seat ejection. The velocity was almost 100 ft/sec slower than target velocity, but the ejection was successful with both dummies being recovered on the dual ejection. The test was completed June 20, 1963.

Sled test numbers 3 and 3A. - Sled test numbers 3 and 3A were made to test the ejection seat for a 15° yawed condition. Target velocity was a Mach number of 0.70 with an overspeed tolerance of 25 ft/sec.

Test number 3 was run, but ejection was not made because a test-equipment abort wheel indicated that the velocity was out of tolerance. Evaluation showed that the velocity was marginal but within the acceptable limits. The test (number 3A) was made again on August 9, 1963, and all objectives were successfully met.

Sled test number 4. - Sled test number 4 was a test for ejection during descent after reentry. The test vehicle was configured with heat shield forward and with zero pitch and yaw. The Mach number was 0.33 with a dynamic pressure of 151.5 lb/ft^2. Both dummies were recovered and all phases of the test were successful.

Sled test number 5. - Sled test number 5 was actually a rerun of test number 2. This test was required because of the low velocity obtained on the initial run.

The sled reached a velocity of 910 ft/sec at ejection. Both dummies were successfully ejected and separated from the seat. One dummy was recovered on the parachute, but the second dummy had a low trajectory and contacted the ground prior to the time for drogue-gun fire. The test was not rescheduled because it would be run again in the qualification program.

QUALIFICATION TESTS

Sled Tests

Four tests were conducted between June 4, 1964, and December 11, 1964. These tests constituted the qualification of the ejection system during high dynamic pressures and during reentry conditions.

Sled test number 6. - Sled test number 6 verified the operation and structural integrity of the hatches and hatch actuators. All requirements were successfully met.

Sled test number 7. - Sled test number 7 was a dual ejection simulating a reentry or boost-phase abort. All test objectives were successfully met.

Sled test number 8. - Sled test number 8 has a dual ejection simulating high dynamic pressure during the boost-phase abort and reentry region. The right-side dummy (pilot) successfully met all objectives. The left-side dummy (command pilot) did not separate from the seat. The failure was due to a structural deficiency in the left armrest or side panel which caused this panel to separate from the seat. This failure caused the seat-man separator to malfunction, which prevented separation, and the seat and specimen impacted together. This structural deficiency was corrected and static tested satisfactorily prior to sled test number 9.

Sled test number 9. - Sled test number 9 was a high-dynamic-pressure boost-phase dual ejection. All test objectives were successfully met. Table VIII summarizes the results of the qualification series.

Simulated Off-The-Pad Ejections

Three dual simulated off-the-pad ejections (SOPE) were conducted between January 16, 1965, and March 6, 1965. These tests constituted the qualification of the ejection system in the off-the-pad abort region.

SOPE test number 12. - SOPE test number 12 was conducted on January 16, 1965. The left-hand dummy (command pilot) was successfully ejected and recovered 761 feet down range. However, the right-hand dummy (pilot) was not ejected because of premature ignition of the rocket catapult caused by blow-by in the hatch actuator. The actuator was redesigned and bench tested prior to SOPE test number 13.

SOPE test number 13. - SOPE test number 13 was conducted on February 12, 1965. The redesigned hatch actuator was incorporated. Both dummies were successfully recovered.

SOPE test number 14. - SOPE test number 14 was conducted on March 6, 1965. Both dummies were successfully recovered. Table IX shows specific data for each test.

Recovery and Survival System Aircraft Drop Tests

A series of 38 tests was conducted from January 11, 1965, to March 13, 1965. These tests were conducted to qualify system sequence, performance, and integrity under dynamic conditions simulating conditions following seat-man separation. All objectives were met.

Dummy tests. - A total of 20 dummy tests was conducted. Table X gives pertinent information as to drop conditions, anomalies, and the modifications made as a result of anomalies.

Human subject tests. - A total of 18 human subject tests was conducted. Table XI gives pertinent information on drop conditions, anomalies, and the modifications made as a result of anomalies.

Ground Qualification Tests

In conjunction with the development and qualification testing, a series of ground tests was conducted to qualify basic components and systems. These tests subjected particular components and complete systems to the most severe conditions of environment and loadings expected.

These tests had the added feature of positive control with respect to environment and structural loadings throughout these test programs. The following sections briefly outline the major ground tests.

Ballute loads on attachments and backboard assembly. - The test for ballute loads on attachments and backboard assembly was performed to structurally substantiate the backboard and its attachment to the crewman when subjected to the most severe loads applied by the ballute. All objectives were met.

Personnel-parachute system. - The test for the personnel-parachute system was conducted to demonstrate the ability of the parachute to function after exposure to various environmental extremes.

Ejection during reentry from abort. - The test for ejection during reentry from abort was conducted to structurally substantiate the ejection-seat assembly, which was subjected to the most severe inertial and air loads, when ejected during reentry aborts. No difficulty was encountered.

High-Altitude Ejection Tests

Purpose. - A demonstration and qualification test series was conducted utilizing an F-106B aircraft. Three tests were conducted at the following nominal conditions:

(1) Static ground ejection

(2) Ejection at a Mach number of 0.70 and 15 000-foot-pressure altitude

(3) Ejection at a Mach number of 1.75 and 40 000-foot-pressure altitude

Static ejection. - The static ejection was to prove the Gemini escape system compatibility with the F-106B aircraft. The test, conducted on October 15, 1964, proved system compatibility. Figure 33 shows a typical aircraft installation.

Subsonic ejection. - The subsonic ejection was conducted on January 12, 1965. All test objectives were met. Actual test conditions were Mach 0.65 at 15 700 feet pressure altitude and a dynamic pressure of 351 lb/ft^2. Figure 34 shows the pitch, yaw, and roll rates.

Supersonic ejection. - The supersonic ejection was conducted on January 12, 1965. All test objectives were met. Actual test conditions were Mach 1.72 at 40 000 feet pressure altitude and a dynamic pressure of 563 lb/ft^2. Figure 35 shows the pitch, yaw, and roll rates.

SIGNIFICANT RESULTS

The majority of the subsystems on the Gemini ejection seat are not innovations, but are refinements of existing types. There are, however, significant results of the extensive testing which should be pointed out for future use. Two of the most important features on the Gemini seat are the drogue-gun-deployed parachute and the thrust-vector control.

The drogue gun has consistently provided a fully inflated canopy in less than 2 seconds after activation. This is extremely important for the pad-abort condition. An equally important feature of this system is the pilot parachute which aids canopy extraction after the energy of the drogue slug has been depleted.

The other important feature on this seat is rigid control of the location of the thrust vector with respect to the dynamic c. g. of the seat-man combination. This control provides maximum range and optimum altitude on trajectories. It is gained through accurate location of the static c. g. with ballast, contours, and restraint of the feet with stirrups.

CONCLUSIONS AND RECOMMENDATIONS

The escape system described in this report is capable of providing safe escape from ground level and zero velocity to altitudes in excess of 45 000 feet and dynamic pressures of over 750 lb/ft^2. This system has been tested for the worst conditions in altitude and dynamic pressure using anthropomorphic dummies and, in certain areas, men. The tests were quite extensive and spanned a 3-year period. No phase of the escape system has been left to chance, and the Gemini ejection seat is qualified for flight-crew escape from the Gemini spacecraft from pad aborts to 45 000 feet.

It is recommended that in the development of future ejection systems, the c. g. to thrust-vector relationship continue to be emphasized. Though it is difficult to maintain control of this relationship in an operational system, ways and means of restraint and other methods of control should be explored.

Manned Spacecraft Center
National Aeronautics and Space Administration
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TABLE I. - DESIGN LOADS FOR RESTRAINT SYSTEM

Component	Condition	Limit load, lb	Proof load, lb	Ultimate load, lb
Canopy and suspension lines	Off-the-pad ejection	1500	None	2 250
	Launch and re-entry ejection	4550	None	5 000
Risers (total)	Off-the-pad ejection	1500	Not critical	3 000
	Launch and re-entry ejection	5330	Not critical	10 660
Risers (on one side)	Off-the-pad ejection	1050	Not critical	2 100 (50 percent in each strap)
Riser assembly on one side (transmitted to harness on one side)	Launch and re-entry ejection	3731	2330 (50 percent in each strap)	7 460 (50 percent in each strap)
Restraint straps (total with 65-35 percent distribution)	Crash landing	3130 (1950 and 1080)	2750 (1775 and 975)	4 120 (2 680 and 1 440)
Restraint strap (one only)	Ballute deploy	1713	Not critical	2 570
Harness (total)	Off-the-pad ejection	1500	Not critical	2 250
	Launch and re-entry ejection	5330	Not critical	8 000
Harness (load transmitted by one riser assembly)	Off-the-pad ejection	1050	Not critical	1 575
	Launch and re-entry ejection	3731	2330	5 600

TABLE II. - SUMMARY OF SEQUENCES FOR EJECTION AND RECOVERY FROM GEMINI SPACECRAFT

Elapsed time, sec	Time required for event, sec	Operation or action
0		Ejection handle pulled
	0.24	Hatch action
0.24		Hatch full open
	0.01	Time lag to catapult initiation
0.25		Catapult initiation
0.32		Initiation of 1.08-sec harness release delay
	0.14	Catapult-action time
0.39		Seat at end of rails and rocket ignition
	0.26	Rocket-action time
0.65		Rocket burnout
1.40		Initiation of harness release
	0.01	Harness release-action time
1.41		Initiation of separator delay
	0.05	Separator delay time
1.46		Initiation of separator
	0.04	Separator-action time
1.50		Man free from seat and initiation of: aneroid-controlled drogue gun, ballute-deployment time delay (5 sec), aneroid-controlled ballute release

TABLE II. - SUMMARY OF SEQUENCES FOR EJECTION AND RECOVERY FROM GEMINI SPACECRAFT - Concluded

Elapsed time, sec	Time required for event, sec	Operation or action
For ejection at 5700 ± 600 feet and below		
1.50		Separated from seat
	0	Ballute-release delay
1.50		Ballute release fired
	2.30	Drogue-gun delay
3.80		Drogue gun fired, initiation of 5-sec jettison delay
	2.0	Parachute inflation time
5.80		Full parachute
8.80		Equipment jettison
For ejection at 7500 ± 700 feet and above		
1.50		Separated from seat
	5.0	Ballute-deploy delay
6.50		Ballute deployed
Depends on altitude		Ballute release at 7500 ± 700 feet
	10.0	Free fall to 5700 ± 600 feet
		Aneroid drogue gun fired, and the remainder of the sequence is the same as the preceding

TABLE III. - DUMMY AIR DROPS (SERIES I)

Test	Date	System	Altitude, ft	Velocity, knots (a)	First full canopy, sec	Remarks
1	June 1962	A	1000	60	2.50	
2	June 1962	A	1000	60	--	Automatic-opener malfunction
3	June 1962	A	1000	60	--	Could not read time
4	June 1962	A	1000	120	1.80	
5	June 1962	A	1000	120	2.10	
6	June 1962	A	1000	90	2.05	
7	June 1962	A	1000	90	--	No deployment
8	June 1962	A	1000	120	1.60	
9	June 1962	A	1000	90	--	Could not read time
10	June 1962	A	1000	90	1.90	
11	June 1962	A	1000	90	2.05	
12	June 1962	A	1000	90	--	No deployment
13	June 1962	A	1000	90	--	
14	July 1962	B	1200	120	1.90	
15	July 1962	B	1200	120	2.00	
16	July 1962	B	1200	60	2.15	
17	July 1962	B	1200	90	2.10	
18	July 1962	B	1200	60	.85	
19	July 1962	B	1200	90	1.95	

[a]Indicated air speed.

TABLE IV. - DUMMY AIR DROPS (SERIES II)

Test	Date	Aircraft	Velocity, knots	Drop altitude, ft	Percentile dummy	Deploy time, sec
1	March 1963	Helicopter	35	1 000	15	--
2	Same	Helicopter	35	1 000	15	--
3	Same	Helicopter	35	1 000	75	--
4	Same	D-18	185	1 000	15	--
5	Same	D-18	185	1 000	75	--
6	April 1963	B-66	398	12 350	15	1.1
7	Same	B-66	426	12 300	15	1.0
8	Same	B-66	425	12 250	75	2.5
9	May 1963	H-21	55	3 000	75	1.9
10	Same	H-21	55	3 000	15	3.2
11	Same	H-21	55	3 000	15	2.3
12	Same	C-130	150	3 020	75	1.7
13	Same	C-130	153	3 020	15	2.1
14	Same	C-130	150	3 000	15	2.1

TABLE V. - LIVE-SUBJECT BALLUTE JUMPS

Subject (a)	Weight, lb	Ballute diameter, ft	Bridle type (b, c)	Riser length, in.	Jump altitude, ft	Ballute-release altitude, ft	Time on ballute, sec	Rate of descent, ft/sec	Maximum rotation, rpm (d)	Minimum rotation, rpm (d)
Human	244	3.0	S	26	12 600	11 000	13.6	160	50	18
Human	244	3.0	S	26	12 750	11 400	11.8	169	--	--
Human	223	3.0	S	26	12 600	8 700	26.4	165	--	--
Human	240	3.0	S	180	12 700	10 800	15.6	166	18	10
Human	245	3.0	D	26	12 900	11 600	11.3	156	37	37
Human	244	3.0	D	26	12 800	10 000	21.0	164	23	13
Dummy (15)	259	3.0	D	26	20 600	4 800	87.5	174	27	10
Dummy (15)	256	3.0	D	26	20 600	4 800	86.2	175	27	18
Dummy (75)	294	3.0	D	26	20 900	9 300	66.4	177	26	22
Dummy (15)	264	3.0	D	26	20 800	9 000	68.2	177	35	25
Human	240	3.5	D	12	12 800	7 300	38.6	155	16	6
Human	225	4.0	D	8	12 800	7 700	40.6	135	33	7
Human	259	3.5	D	12	13 200	6 600	44.6	157	32	7
Human	239	4.0	D	8	13 200	7 200	45.4	140	36	7
Human	256	3.5	D	12	15 200	9 000	41.0	157	42	2
Human	269	4.0	D	8	15 200	7 500	55.4	148	32	4
Human	240	3.5	D	12	20 700	7 600	81.2	158	39	17
Human	232	4.0	D	8	20 800	7 600	88.4	145	0	0
Human	240	3.5	D	12	26 000	14 000	72.0	165	62	55
Human	245	4.0	D	8	26 000	7 700	110.4	149	0	0
Human	257	4.0	D	8	30 000	8 300	131.0	150	0	0
Dummy (75)	290	3.5	D	12	31 000	5 000	134.2	165	38	0
Human	267	4.0	D	8	35 700	7 500	155.0	148	0	0
Dummy (75)	290	3.5	D	12	35 700	4 700	157.2	160	--	--

[a]Numbers in parentheses are percentile sizes of dummies.

[b]All dual bridles were 5.0 feet to confluence point with riser.

[c]S indicates single and D indicates dual.

[d]$t > 10$ seconds.

TABLE VI. - LIVE-SUBJECT BODY SLUMP TESTS

Test	Date	Subject	Nominal percentile	Peak acceleration, g	Onset, g/sec	Vertical shift, in.	Pitch eccentricity, in.
1	May 1963	Human	75	8.8	88	--	--
2	May 1963	Human	15	9.6	98	--	--
3	May 1963	Human	50	9.1	105	--	--
4	May 1963	Human	50	12.1	211	--	--
5	May 1963	Human	15	12.9	225	--	--
6	June 1963	Human	75	9.5	102	--	--
7	June 1963	Human	50	8.8	88	--	--
8	June 1963	Human	75	14.1	251	0.88	0.60
9	June 1963	Human	50	12.7	211	.80	.53
10	June 1963	Human	75	13.4	149	.83	.52
11	July 1963	Human	50	16.1	291	.87	.49
12	July 1963	Human	15	15.8	317	1.31	.82
13	July 1963	Human	75	14.9	277	.97	.65
14	July 1963	Human	75	12.0	107	1.10	.55
15	July 1963	Human	15	16.1	176	1.03	.68
16	July 1963	Human	75	18.4	218	.73	.55
17	July 1963	Human	50	19.3	236	1.05	.61
18	July 1963	Human	15	19.3	244	1.33	.81
19	July 1963	Human	75	19.2	237	.75	.57
20	July 1963	Human	50	18.8	235	.82	.48
21	July 1963	Human	15	19.6	254	1.27	.69
22	July 1963	Human	75	19.9	257	.98	.60
23	July 1963	Human	50	19.5	246	1.02	.60
24	July 1963	Human	50	19.7	256	1.00	.66
25	July 1963	Human	75	19.5	255	.91	.64
26	August 1963	Human	75	19.3	238	.90	.54
27	August 1963	Human	50	19.9	247	1.10	.59

TABLE VII. - SIMULATED PAD-EJECTION TESTS

Test	Date	Weight, lb	Pitch eccentricity, in.	Lateral eccentricity, in.	Landing point, ft	Maximum altitude above tower, ft	Remarks
1	July 2, 1962	373	+0.25	0	Unavailable	53	
2	July 17, 1962	357	+.25	0	492	185	
3	July 25, 1962	357	+.25	0	820	178	No separation
4	July 26, 1962	360	-.18	0	1190	285	
5	August 3, 1962	362	-.18	0	705	330	
6	September 12, 1962	348	-.18	0	350	125	24-knot wind
7	September 26, 1962	324	-.14	0	617	50	
		366	-.14	0	1116	215	
8	February 7, 1963	356	+.36	0	591	235	
		377	+.36	0	488	215	
9	May 15, 1963	413	-.30	0	538	150	
9A	May 25, 1963	376	-.27	0	696	135	
10	July 2, 1963	401	+.19	.18	517	155	
		341	+.01	0	632	225	
11	July 16, 1963	398	+.38	.20	302	192	20-knot wind
		374	-.55	0	630	135	

TABLE VIII. - QUALIFICATION SLED TESTS

Test	Date	Yaw, deg	Velocity at ejection, ft/sec	Dynamic pressure at ejection, lb/ft^2	Ejected weight, lb		Remarks
					Left	Right	
6	June 4, 1964	15	769	604	--	--	The test was made to verify proper functioning and structural integrity of the test vehicle hatches. No ejection was made. Ninety-eight percent of target dynamic pressure was obtained.
7	July 2, 1964	180	410	171	423	373	The test was successful and all systems functioned as designed.
8	November 5, 1964	0	948	952	431	379	The feet of the left dummy came out of the stirrups and caused a structural failure of the seat-side panel. Right-seat ejection was normal. The stirrups and side panel were modified prior to test 9.
9	December 11, 1964	15	760	623	434	384	The test was successful and all systems functioned as designed.

TABLE IX. - SIMULATED OFF-THE-PAD EJECTION QUALIFICATION TESTS

Test	Date	Seat position	Pitch eccentricity, in.	Ejected weight, lb	Landing point, ft	Maximum-altitude above tower, ft	Remarks
12	January 16, 1965	Left	-0.19	432	761		Test was satisfactory.
		Right	-0.19	376	---	---	O-rings in hatch actuator failed and seat contacted hatch. A design modification on actuator was made prior to test 13.
13	February 12, 1965	Left	-0.18	420	670		Test was satisfactory.
		Right	-0.18	375	707		Test was satisfactory.
14	March 6, 1965	Left	-0.19	430	535		Test was satisfactory.
		Right	-0.21	378	786		Test was satisfactory.

TABLE X. - DUMMY AIR DROPS (SERIES III)

USAF test number	Launch altitude, ft	Launch velocity, knots (a)	Subject size, percentile	Aircraft	Comments and anomalies	Modifications
0025	7 500	110	15	C-130	Test was satisfactory—no jetelox disconnect.	
0026	7 500	110	75	C-130	Test was satisfactory—no jetelox disconnect.	The jetelox disconnect was reworked to provide clean separation.
0030	5 700	110	75	C-130	Test was satisfactory.	
0029	8 000	110	15	C-130	Test was satisfactory.	
0028	30 000	110	75	C-130	Test was satisfactory—ballute deployment slow.	
0027	30 000	110	15	C-130	Test was satisfactory—ballute deployment slow.	The pin retention was changed in one ballute pack.
0072	44 800	208	15	B-66	Test was satisfactory.	
0071	43 000	212	75	B-66	Test was satisfactory.	
0277	30 000	130	75	C-130	Delayed ballute deployment.	
0406	15 000	110	75	C-130	Test was satisfactory.	

[a]Indicated air speed.

TABLE X. - DUMMY AIR DROPS (SERIES III) - Concluded

USAF test number	Launch altitude, ft	Launch velocity, knots (a)	Subject size, percentile	Aircraft	Comments and anomalies	Modifications
0477	15 000	131	75	C-130	Test was satisfactory.	
0478	15 000	130	15	C-130	Test was satisfactory.	
0496	15 000	130	75	C-130	Test was satisfactory.	
0497	15 000	130	75	C-130	Test was satisfactory.	
0501	12 400	470	75	B-66	Test was satisfactory.	
0502	12 500	325	15	B-66	Test was satisfactory.	
0533	23 000	150	75	B-66	The ballute did not deploy—the ballute pin was bent in installation. No jetelox release—jetelox pyrotechnics contained water.	Ballute-pin installation procedures were changed. Changes were made in pyrotechnic acceptance and installation procedures.
0534	28 000	150	15	B-66	Test was satisfactory.	
0498	23 000	130	75	C-130	Test was satisfactory.	
0499	23 000	130	15	C-130	Test was satisfactory.	

[a]Indicated air speed.

TABLE XI. - HUMAN-SUBJECT PARACHUTE JUMPS

USAF test number	Launch altitude, ft	Launch velocity, knots (a)	Subject	Remarks
0097	6 000	110	Human	The jumper had difficulty in pulling the manual arming lanyard. The drogue gun was fired with the manual T-handle at 3400 feet mean sea level. The reserve parachute deployed immediately after the main canopy, and the jumper descended with two canopies. The arming lanyard was modified prior to the next jump.
0098	5 700	110	Human	The drogue gun was armed and the parachute deployed in 1.5 seconds. The equipment did not jettison and the jumper landed with the backboard on. The malfunction was caused by the omission of dowel pins in the cutter.
0099	6 000	107	Human	The system worked properly, but as the jumper descended on the main canopy, the reserve parachute deployed. The reserve-parachute aneroid had not been deactivated.
0143	7 500	110	Human	Test was satisfactory.
0144	7 500	110	Human	Test was satisfactory.
0145	7 500	110	Human	The jumper was instructed to deploy the parachute with the manual T-handle. He had some difficulty in locating it because of the reserve parachute. The main parachute was deployed after about 12 seconds.
0146	7 500	110	Human	Test was satisfactory.
0147	7 500	110	Human	Test was satisfactory

[a]Indicated air speed.

TABLE XI. - HUMAN-SUBJECT PARACHUTE JUMPS - Concluded

USAF test number	Launch altitude, ft	Launch velocity, knots (a)	Subject	Remarks
0148	7 500	110	Human	The drogue gun was armed at 7500 feet. After a free fall of 16 seconds, the jumper deployed the reserve parachute. The main canopy deployed automatically 3 seconds later. The jumper had been unable to read the altitude during free fall, and this was first aneroid with a delayed firing.
0268	7 500	110	Human	Test was satisfactory.
0269	7 500	110	Human	The main canopy deployed normally. The reserve parachute deployed almost simultaneously. The jumper later jettisoned the main canopy and landed on the reserve parachute.
0270	7 500	110	Human	Test was satisfactory.
0347	15 000	130	Human	The ballute failed to deploy. The jumper deployed the main parachute after 34 seconds at 9200 feet. Modification to the aneroid design resulted from failure analysis.
0507	15 000	130	Human	Test was satisfactory.
0508	15 000	130	Human	Test was satisfactory.
0500	23 000	130	Human	The ballute did not deploy. The jumper deployed the main parachute after 56 seconds. Failure analysis resulted in a design change to the ballute release cutter.
0509	23 000	130	Human	Test was satisfactory.
0510	31 000	130	Human	Test was satisfactory.

[a]Indicated air speed.

NASA-S-66-12841 DEC 28

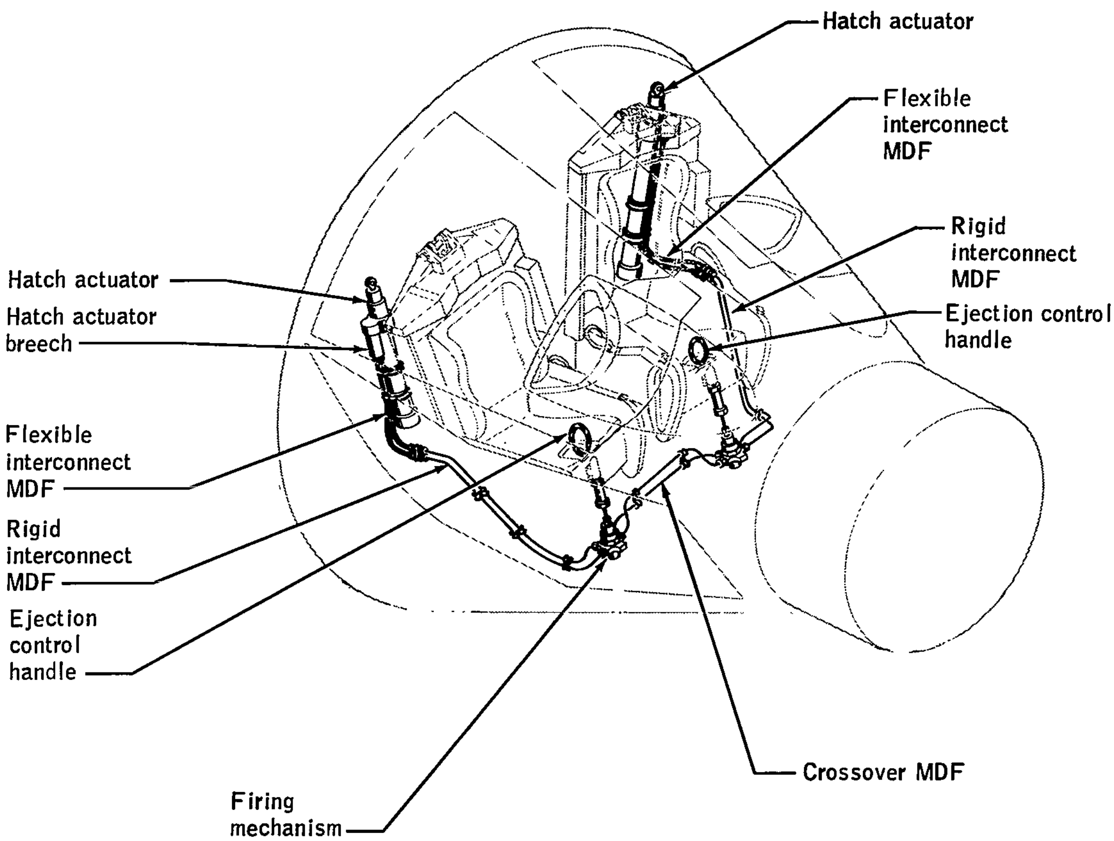

Figure 1. - Major components of hatch-actuator system.

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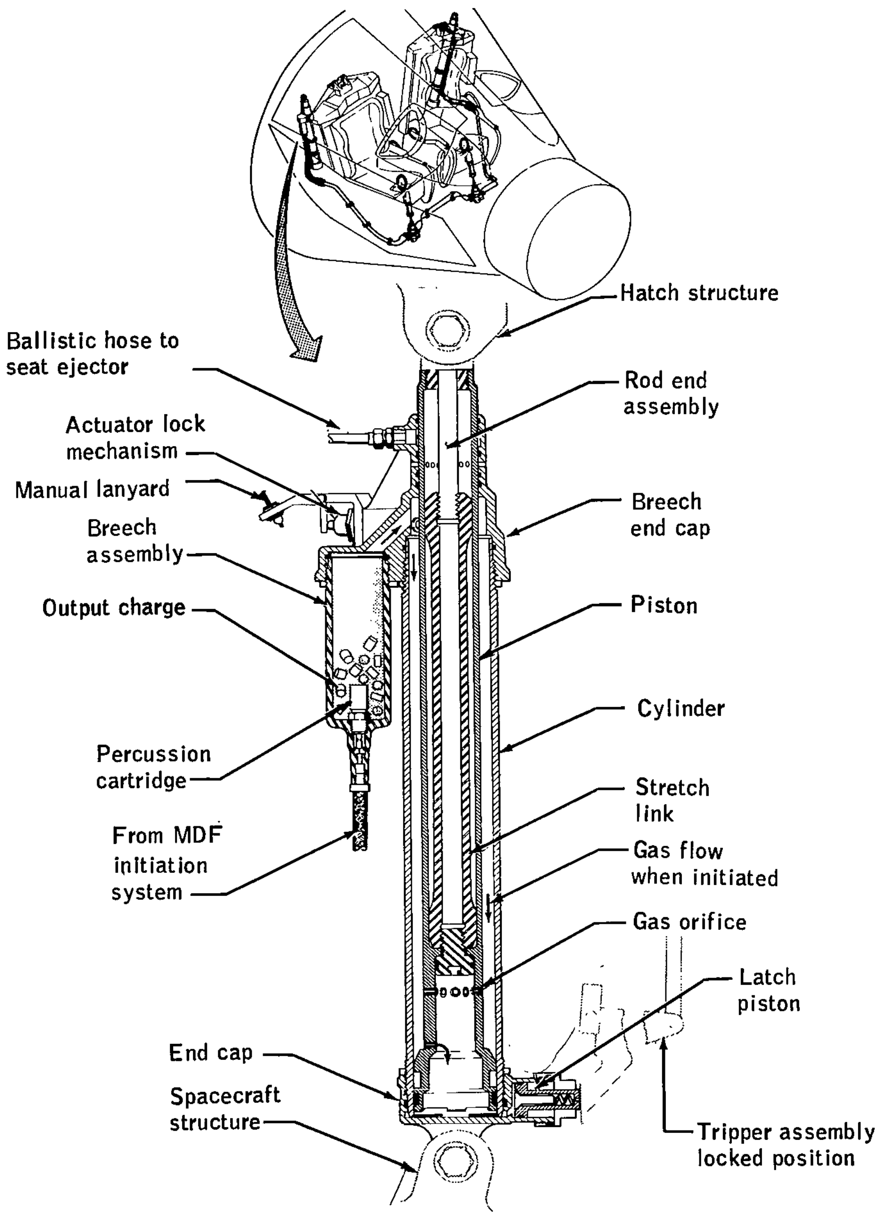
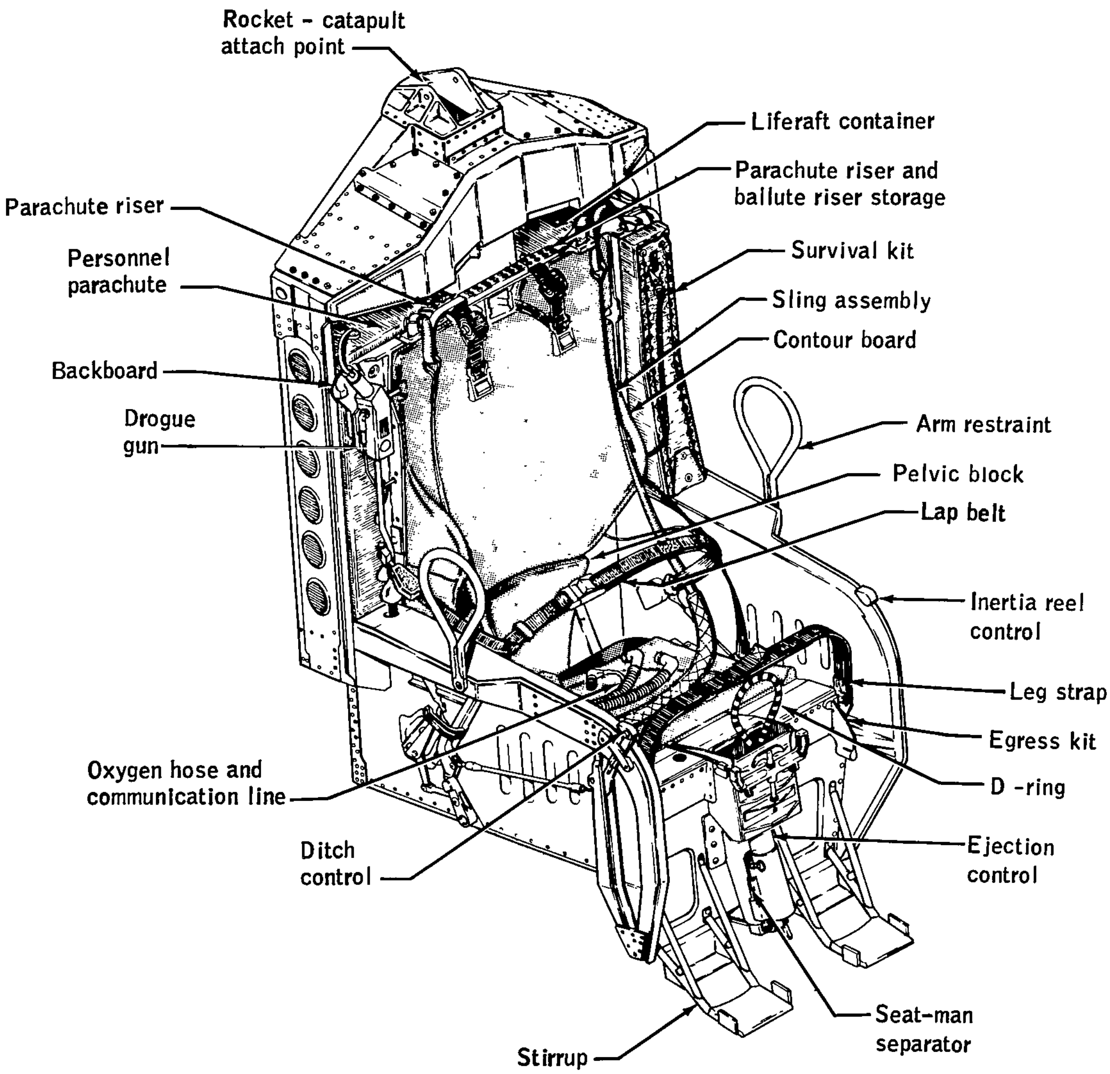


Figure 2. - Hatch-actuator assembly (before firing).

NASA-S-67-1999



Note:

Command pilot ejection seat illustrated. Harness release actuator is located on outboard side of seat.

Figure 3. - Gemini ejection-seat assembly.

NASA-S-66-12846 DEC 28

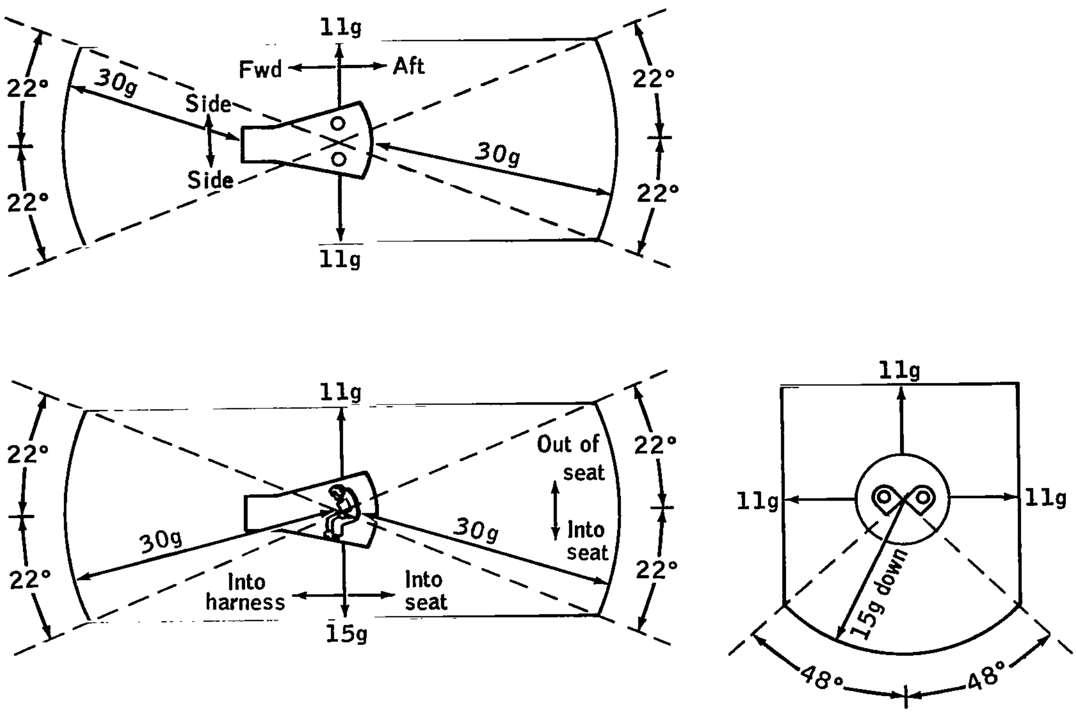


Figure 4. - Limit-load factors for design.

NASA-S-66-12833 DEC 28

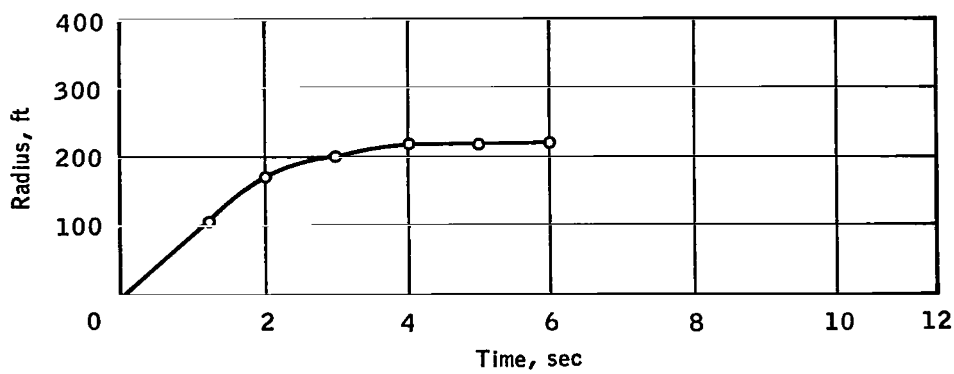
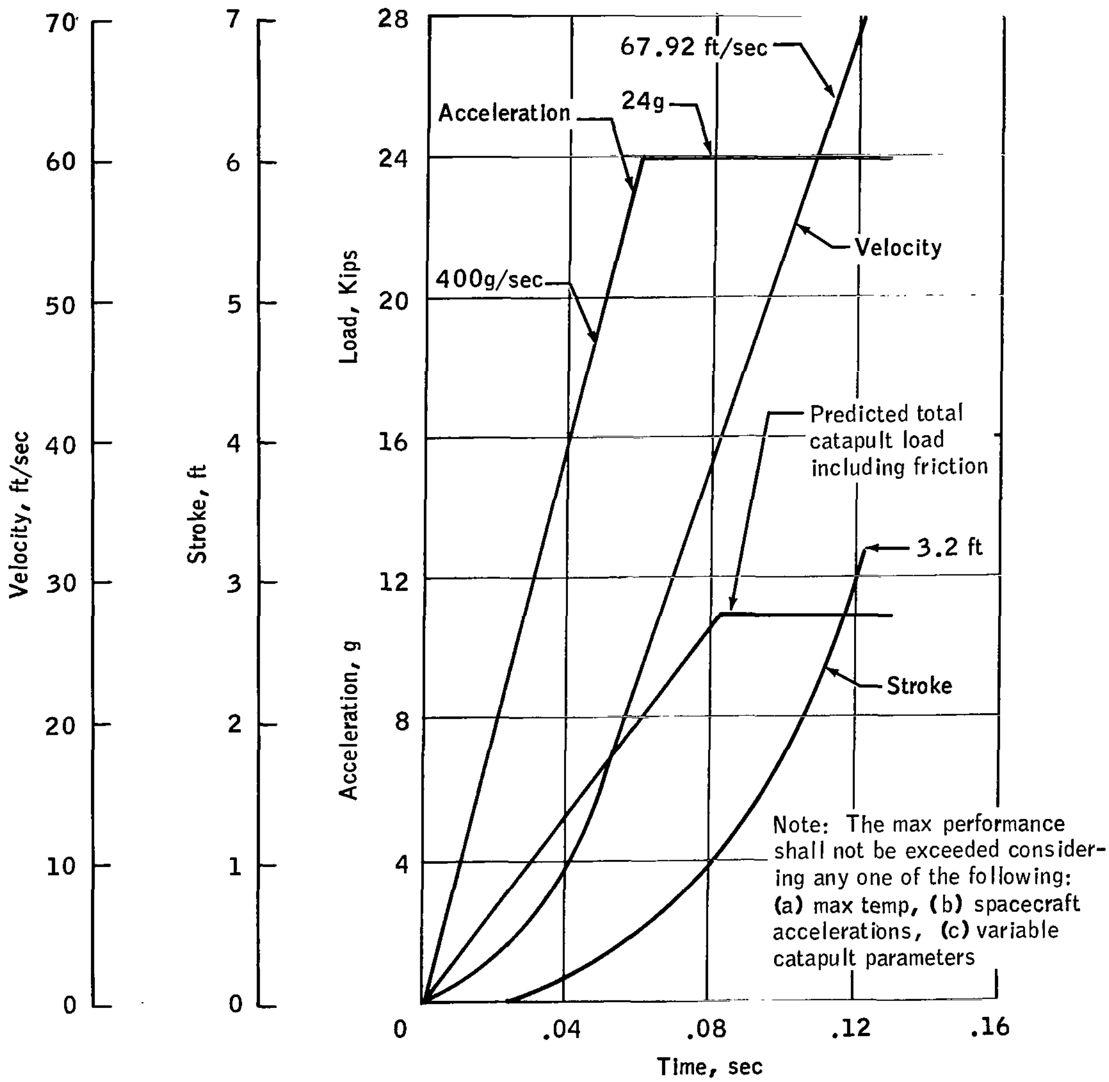


Figure 5. - Results of fireball radius study.

NASA-S-67-675



Note: Catapult load shown is based on a 375 lb man-seat mass.

Figure 6. - Catapult maximum performance (375-pound seat).

NASA-S-66-12842 DEC 28

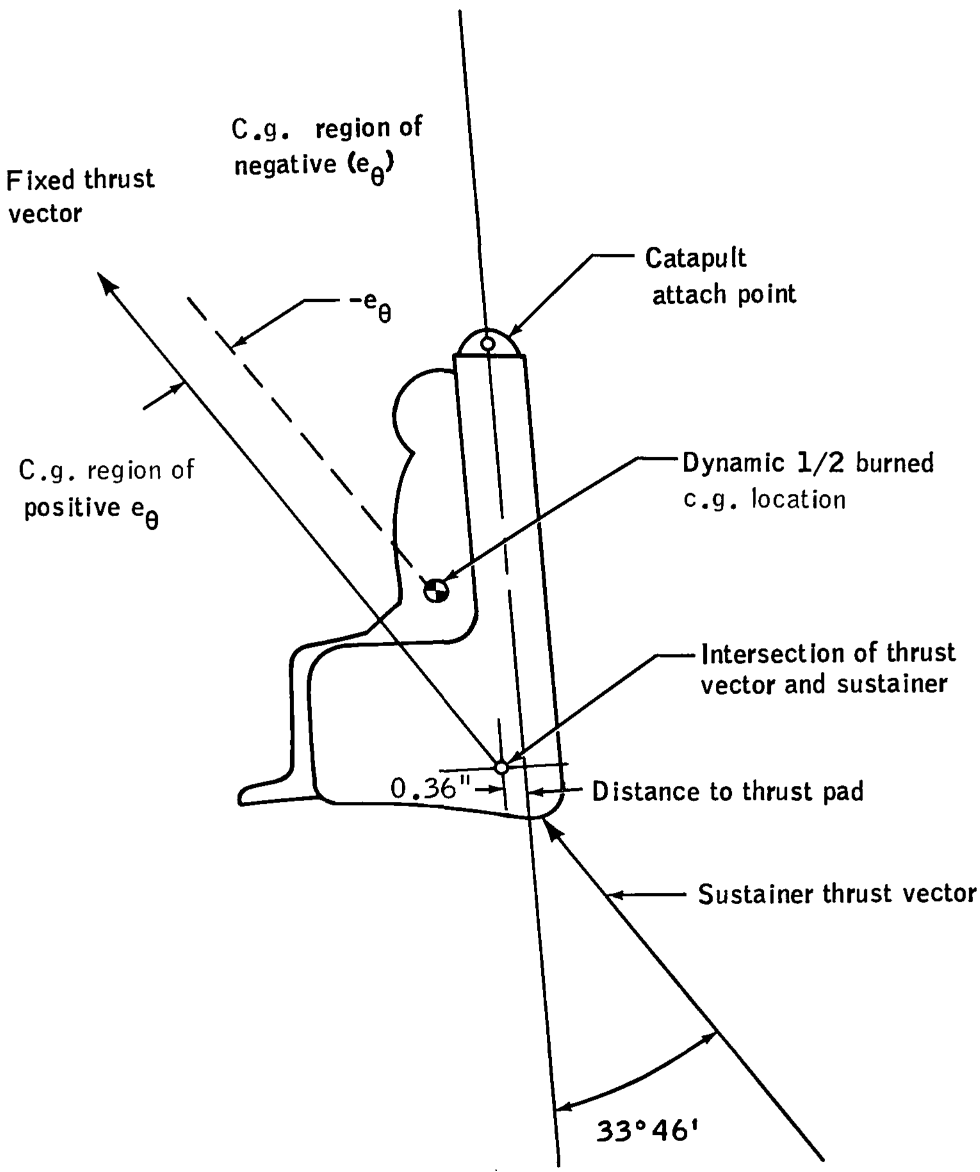


Figure 7.- Dynamic center-of-gravity thrust-vector relationship.

NASA-S-66-12845 DEC 28

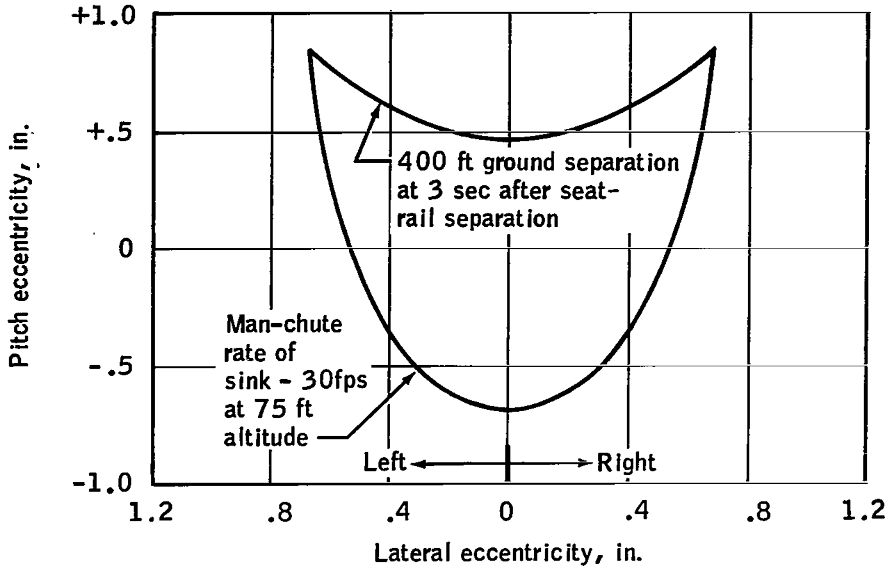


Figure 8. - Allowable pitch eccentricity.

NASA-S-66-12834 DEC 28

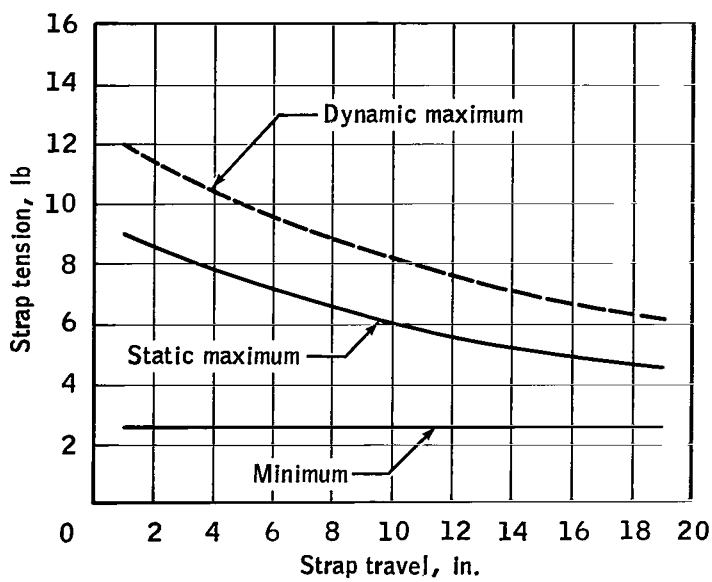


Figure 9. - Strap-tension load ranges.

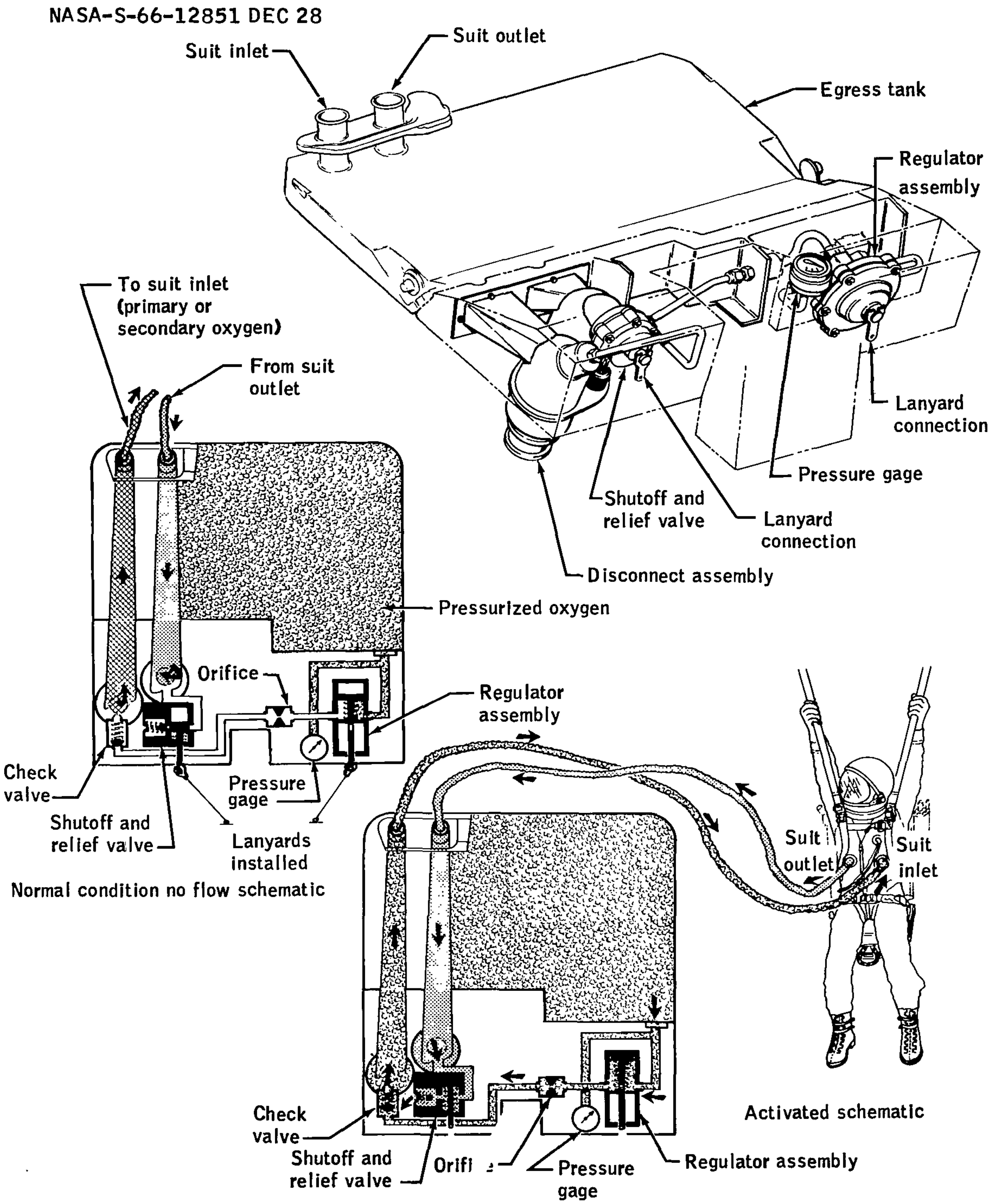


Figure 10. - The Gemini ejection-seat egress kit.

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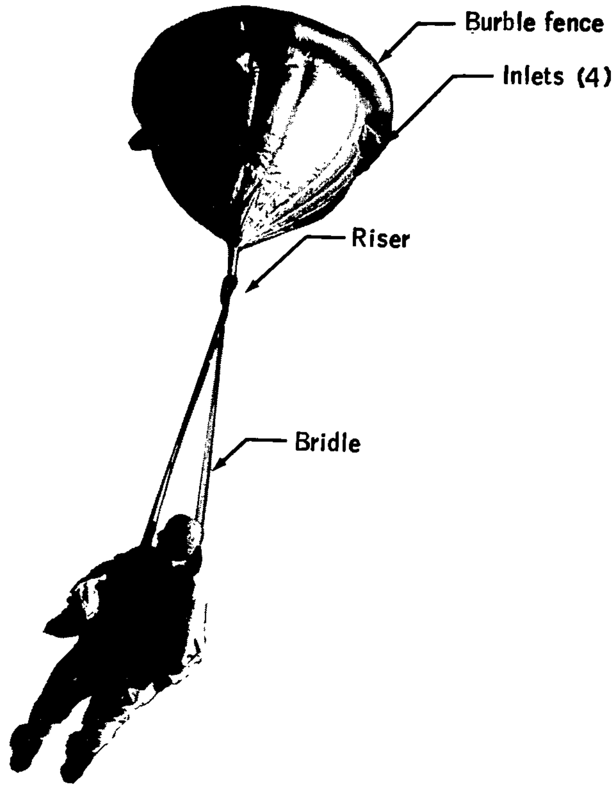

Figure 11. - Ballute.

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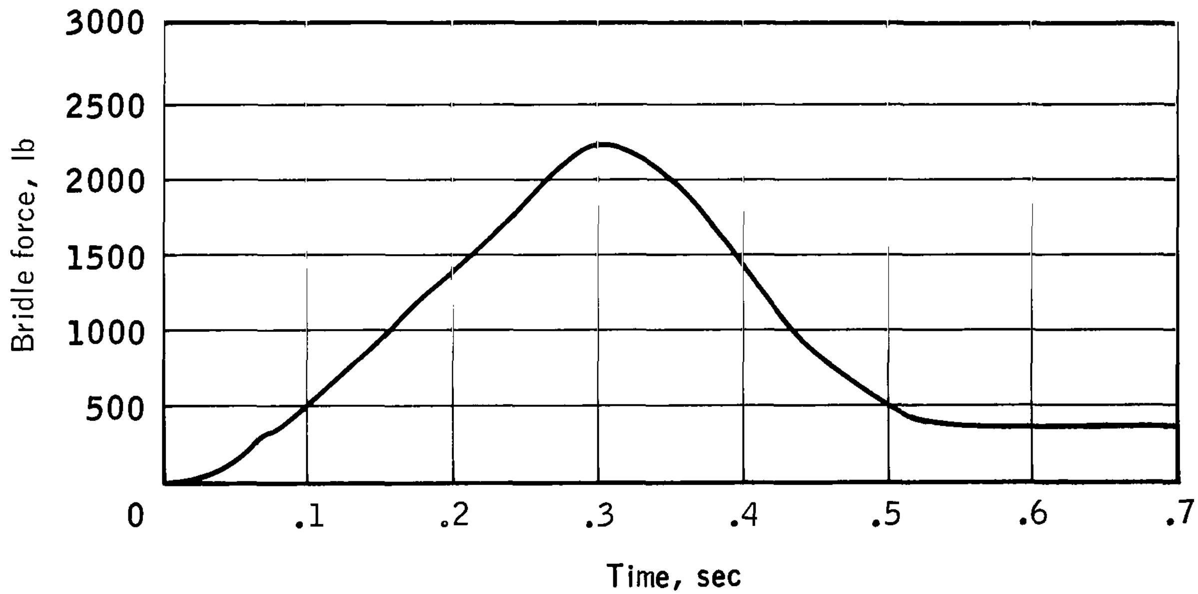

Figure 12. - Typical load curve for maximum dynamic-pressure condition.

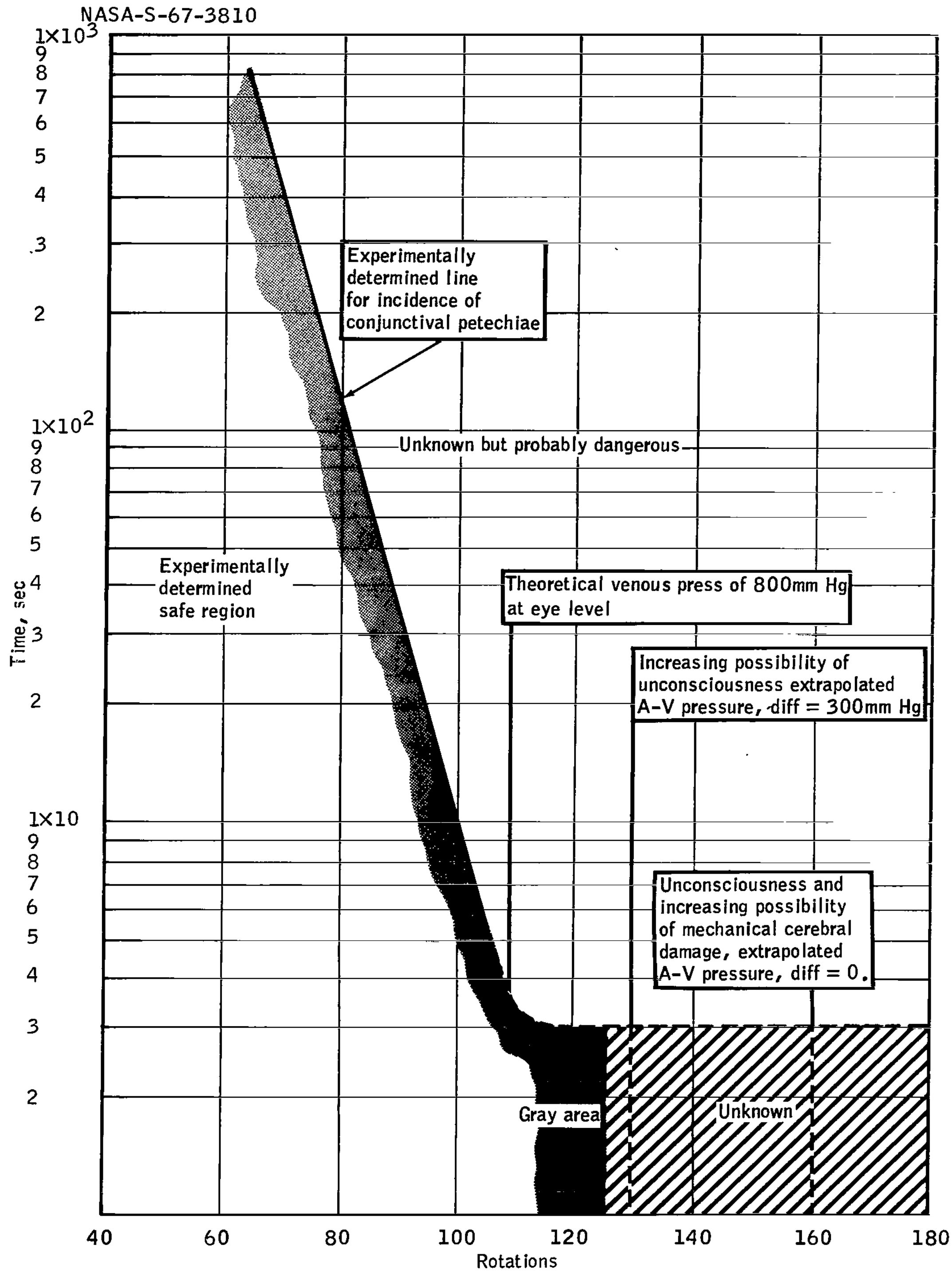

Figure 13. - Human reaction to simple tumbling, center of rotation at the heart.

NASA-S-66-12852 DEC 28

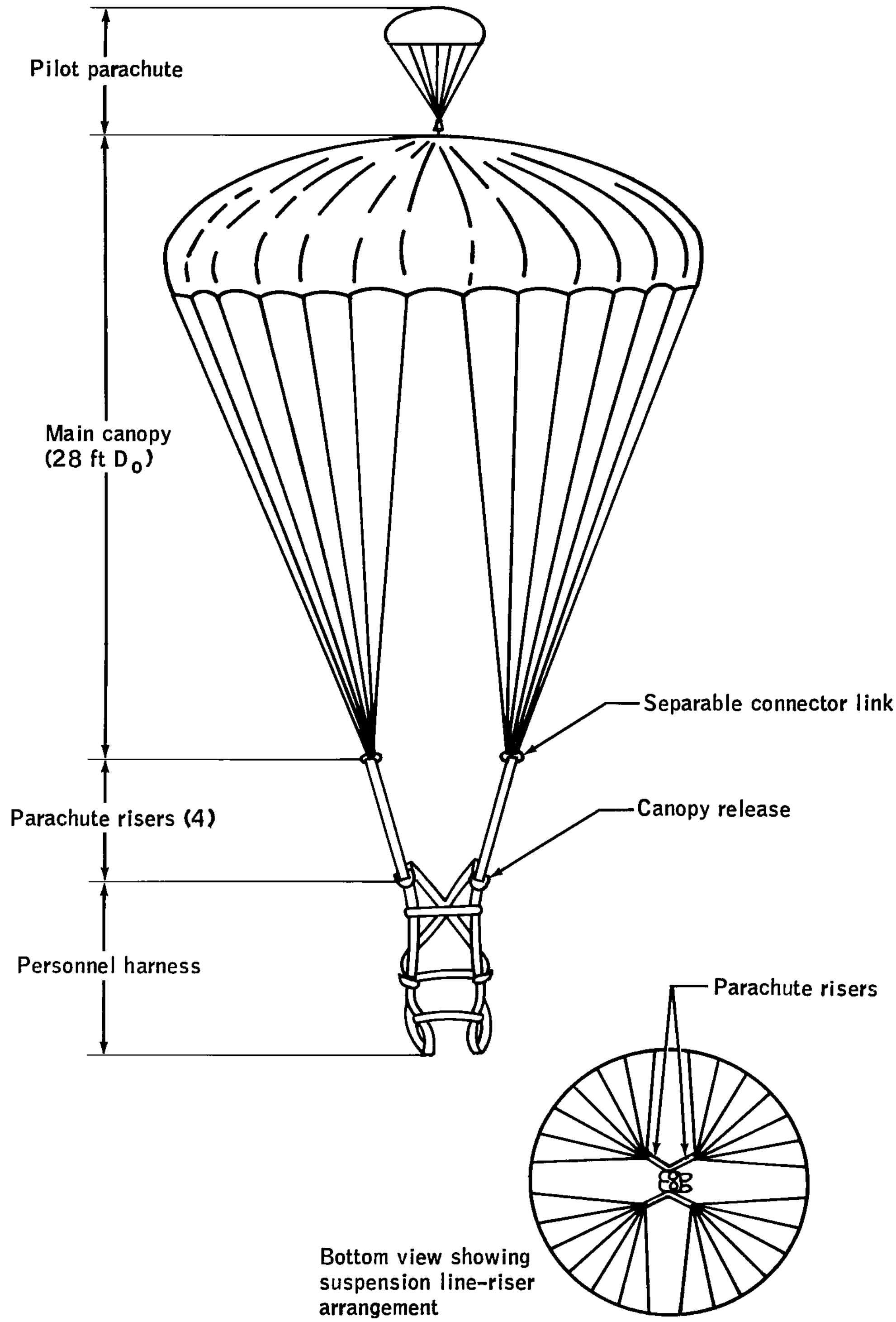

Figure 14. - Gemini personnel-parachute system (deployed).

NASA-S-66-12830 DEC 28

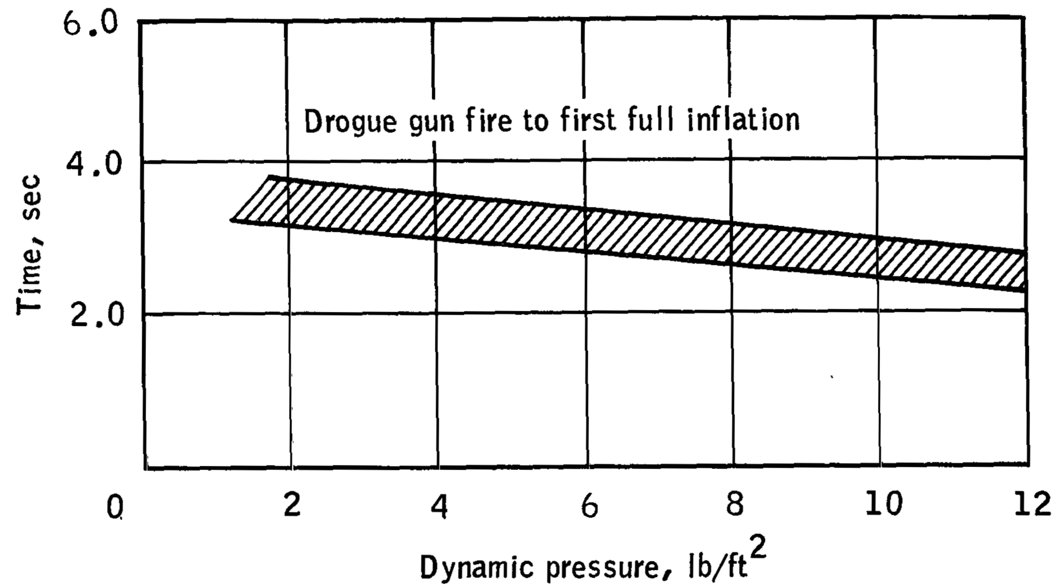

Figure 15. - Results of simulated ejections.

NASA-S-66-12854 DEC 28

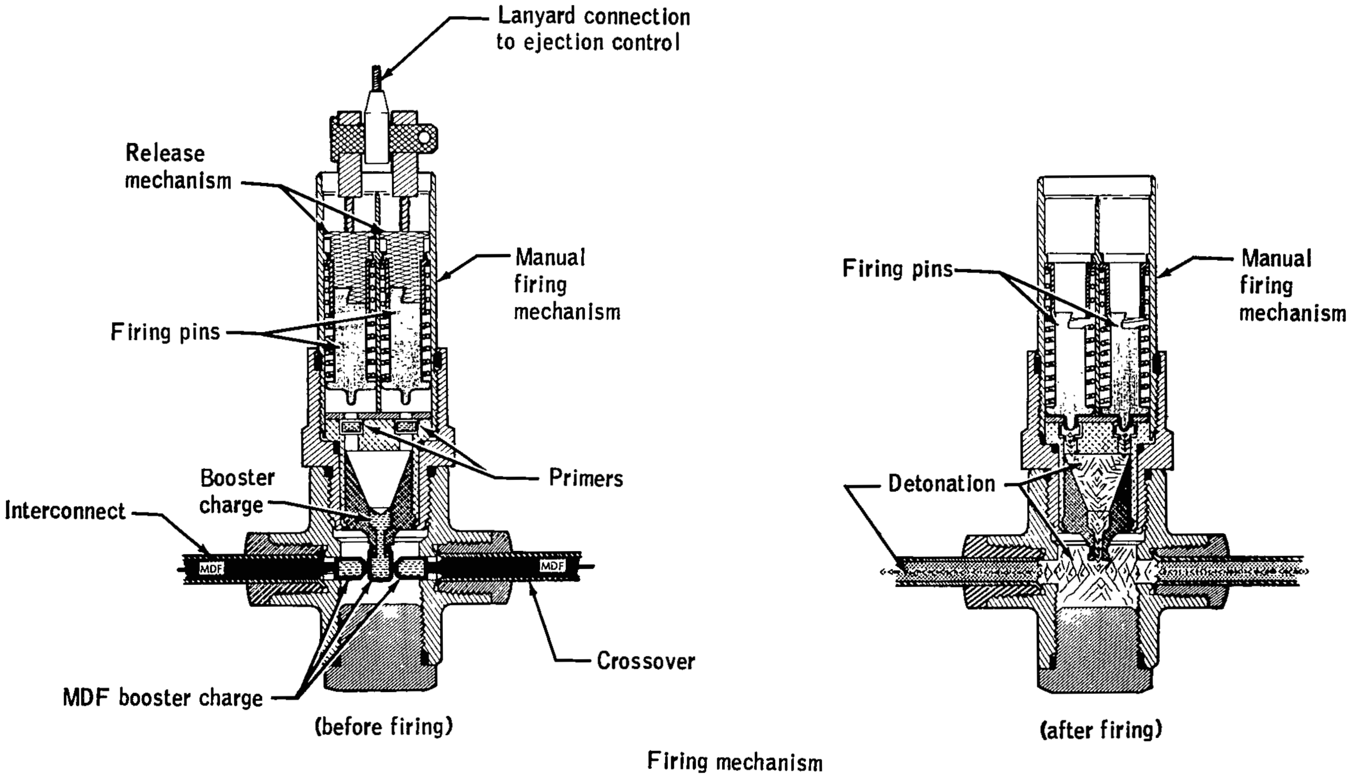

Figure 16. - Hatch-actuator initiation system.

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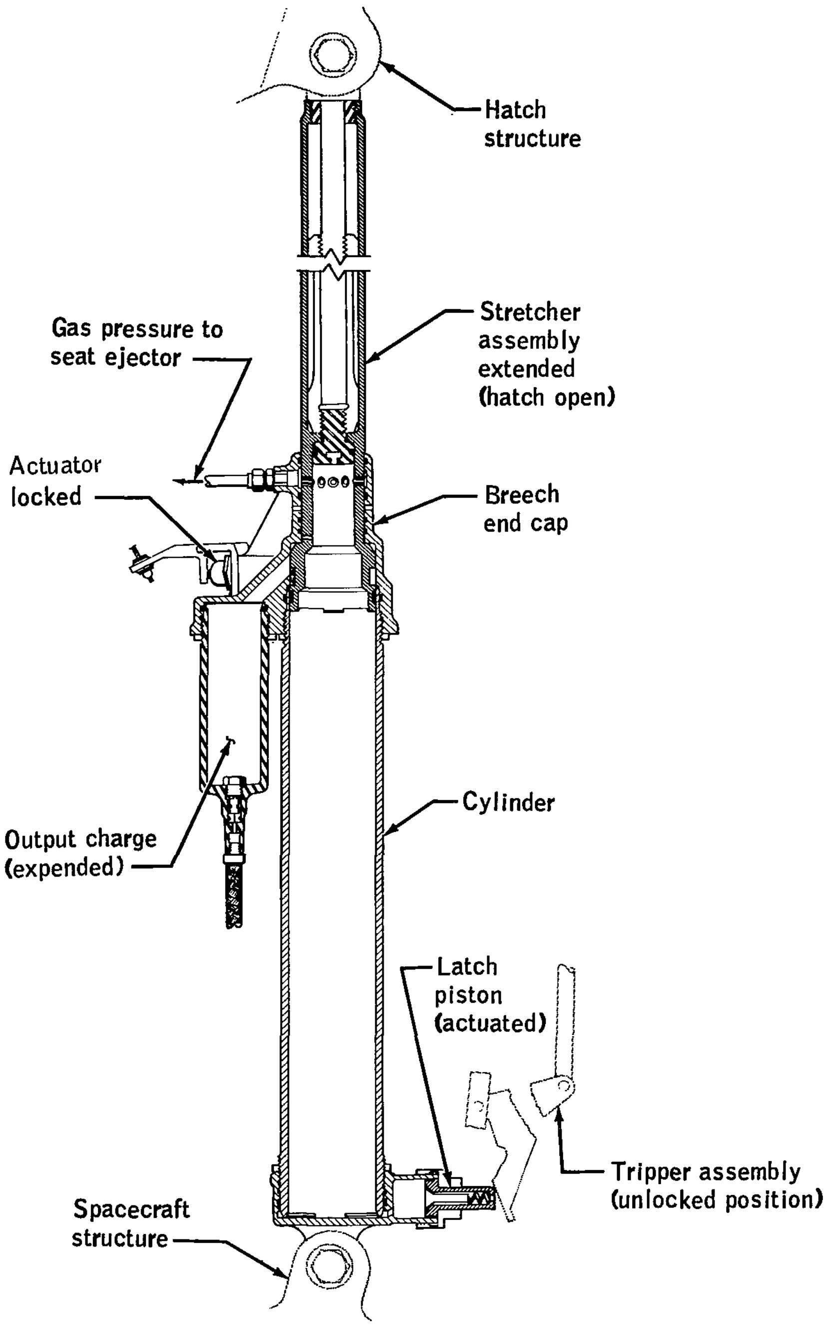

Figure 17. - Hatch-actuator assembly (after firing).

NASA-S-66-12849 DEC 28

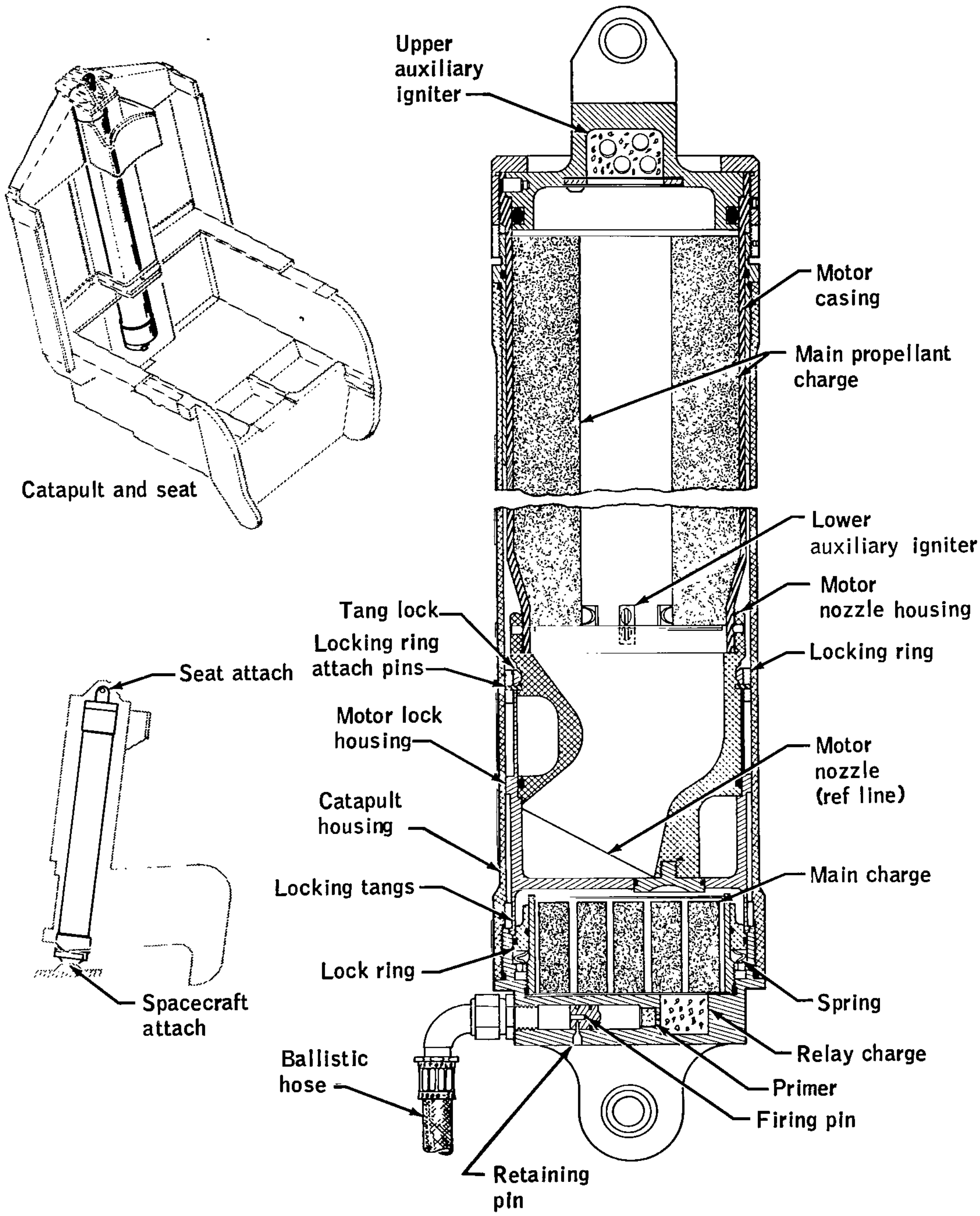

Figure 18.- Seat-ejector rocket catapult.

NASA-S-66-12832 DEC 28

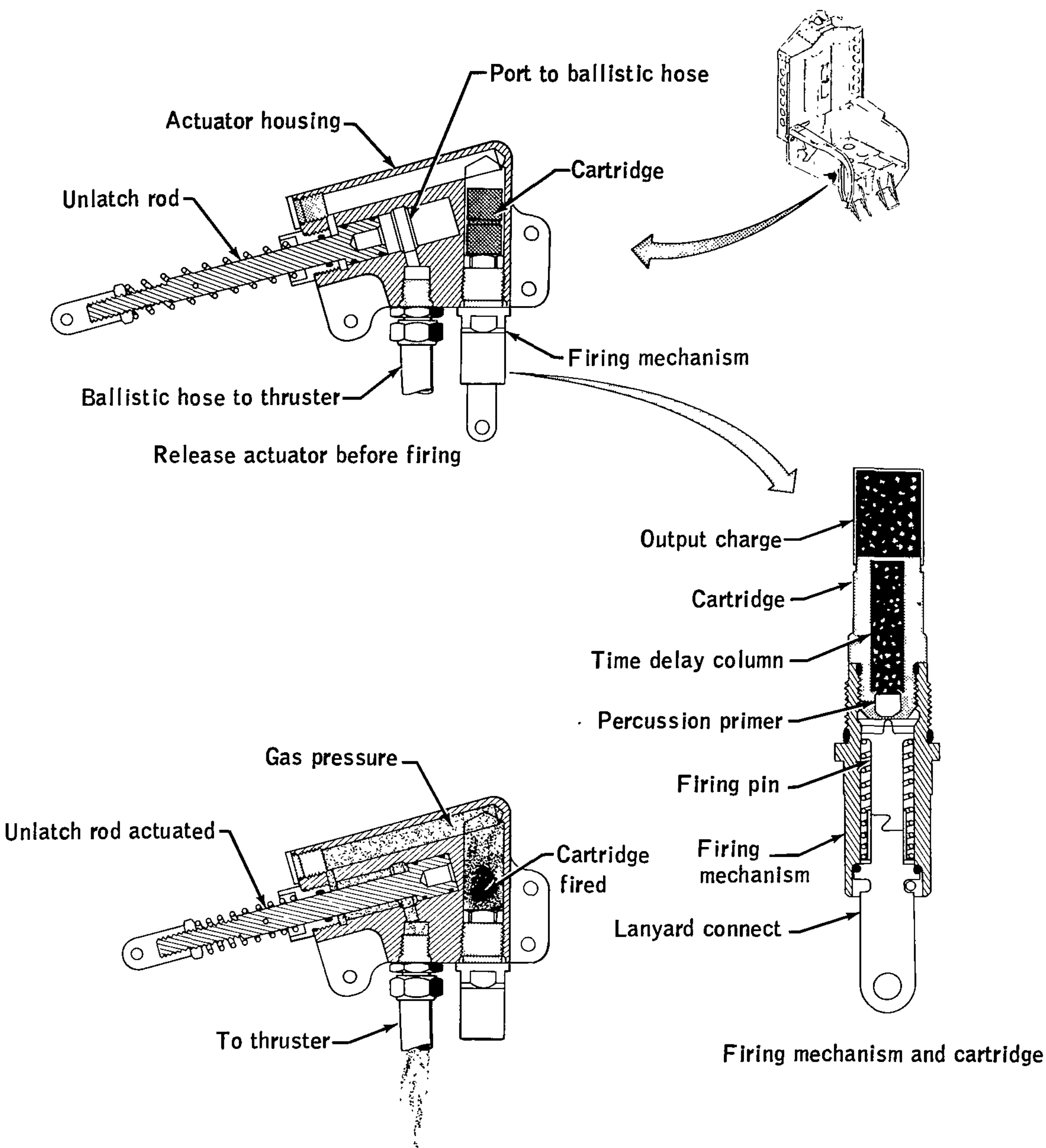

Figure 19. - Harness-release actuator assembly.

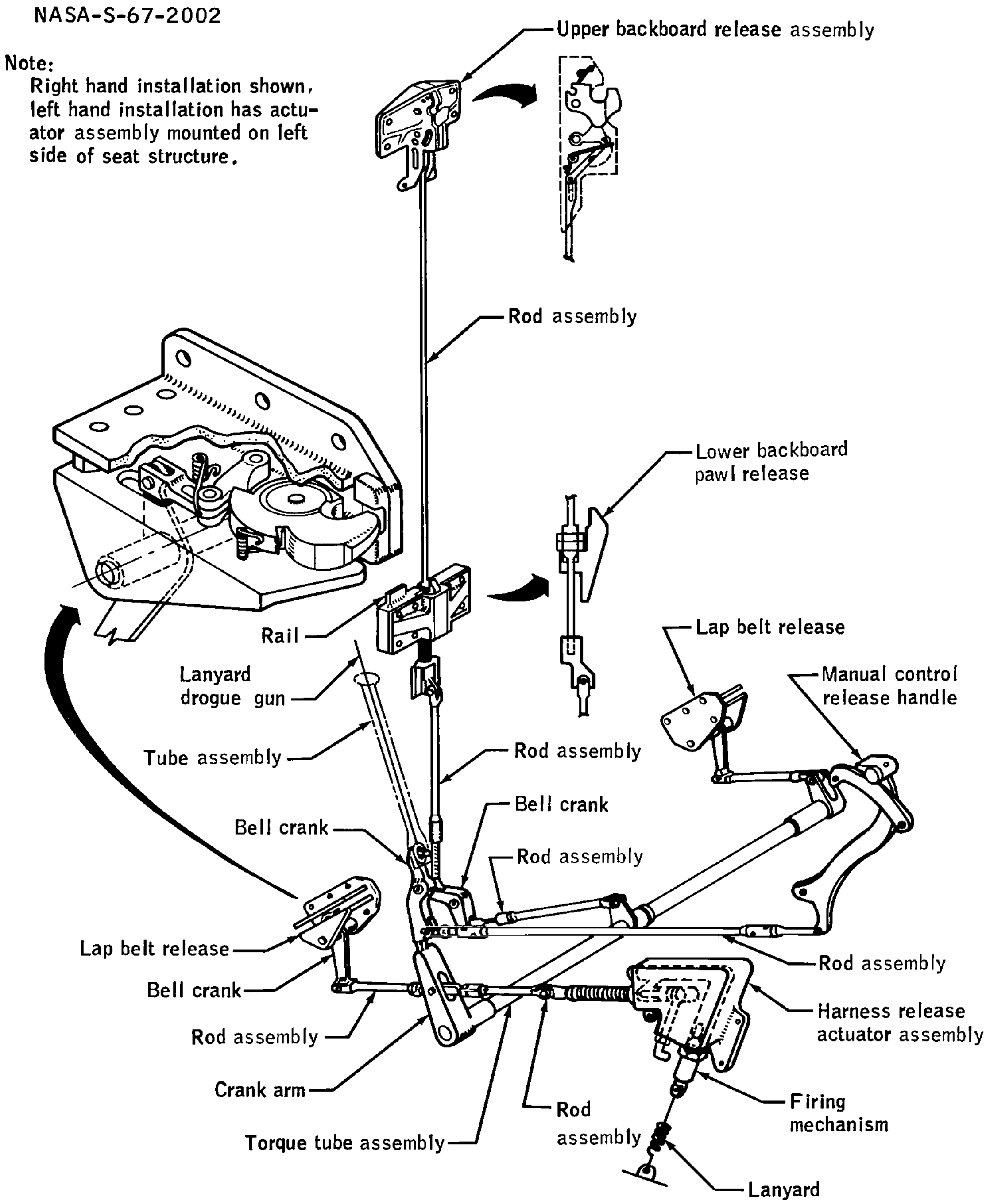

Figure 20. - Mechanical-linkage and release-installation integrated harness.

NASA-S-66-12855 DEC 28

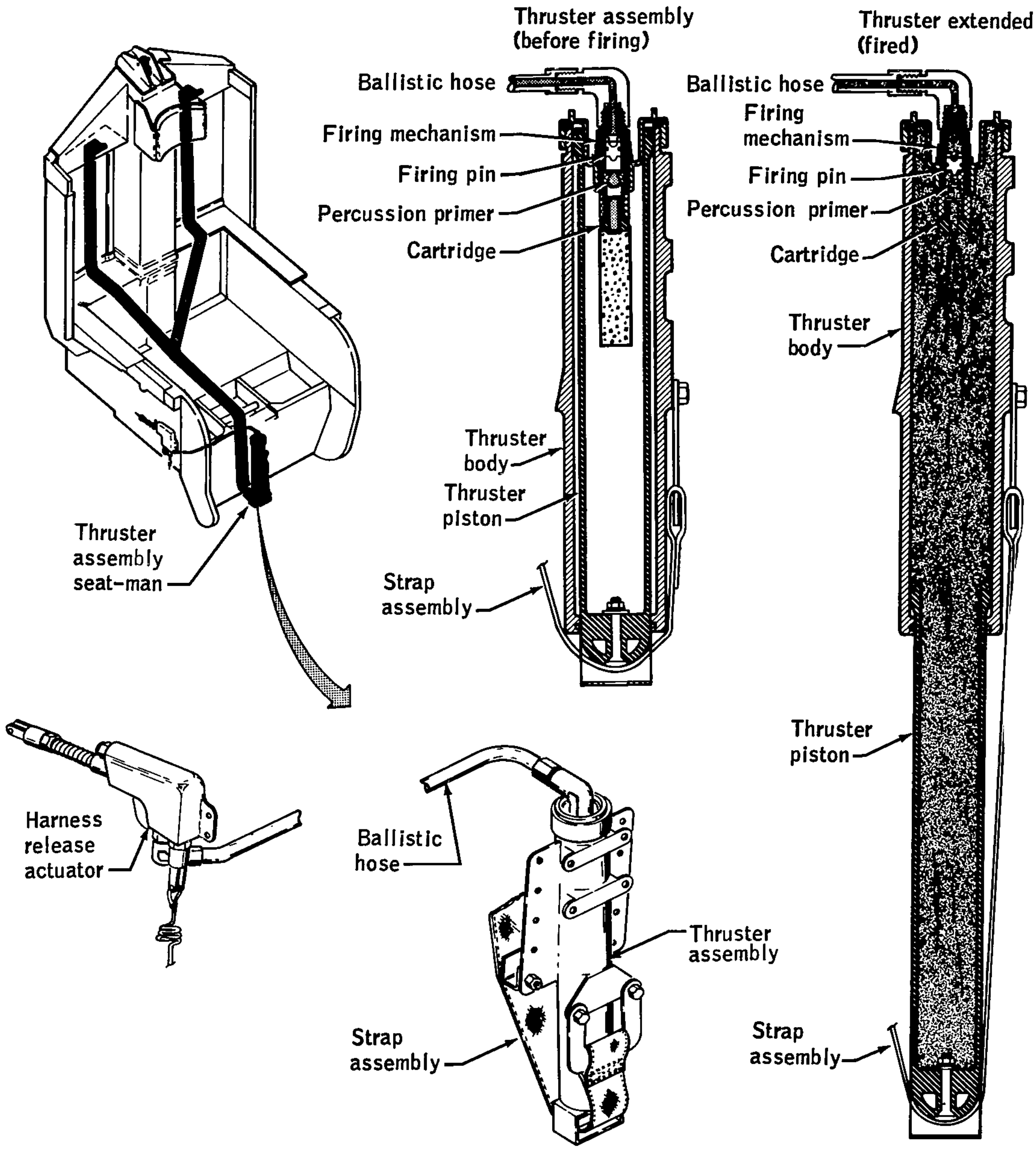

Figure 21. - Thruster assembly (seat-man separator).

NASA-S-66-12835 DEC 28

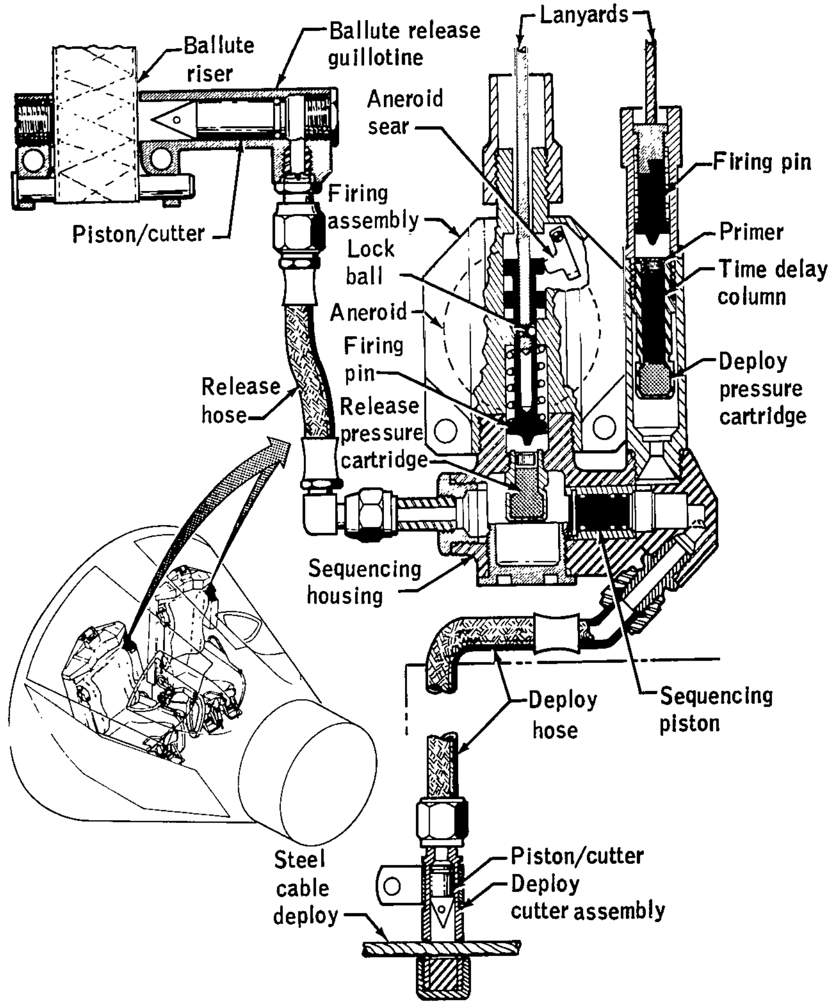

Figure 22. - Ballute deploy and release system.

NASA-S-66-12828 DEC 29

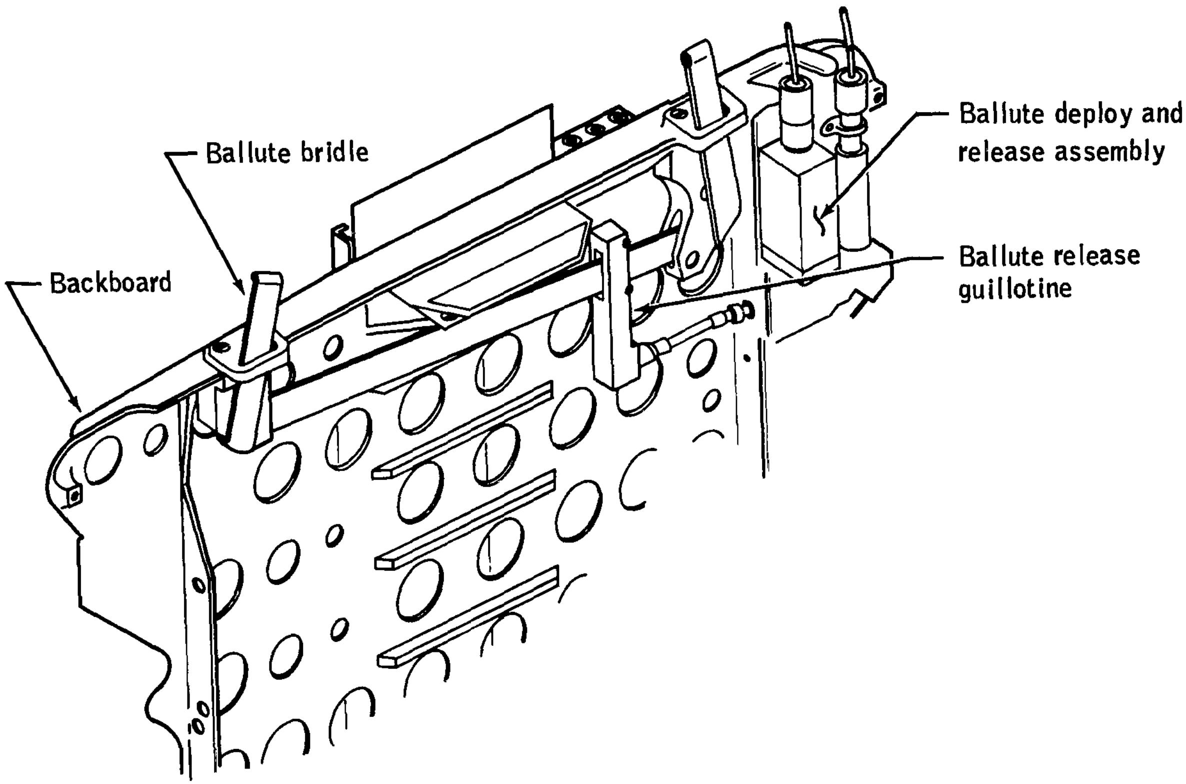

Figure 23. - Ballute deploy and release-assembly installation.

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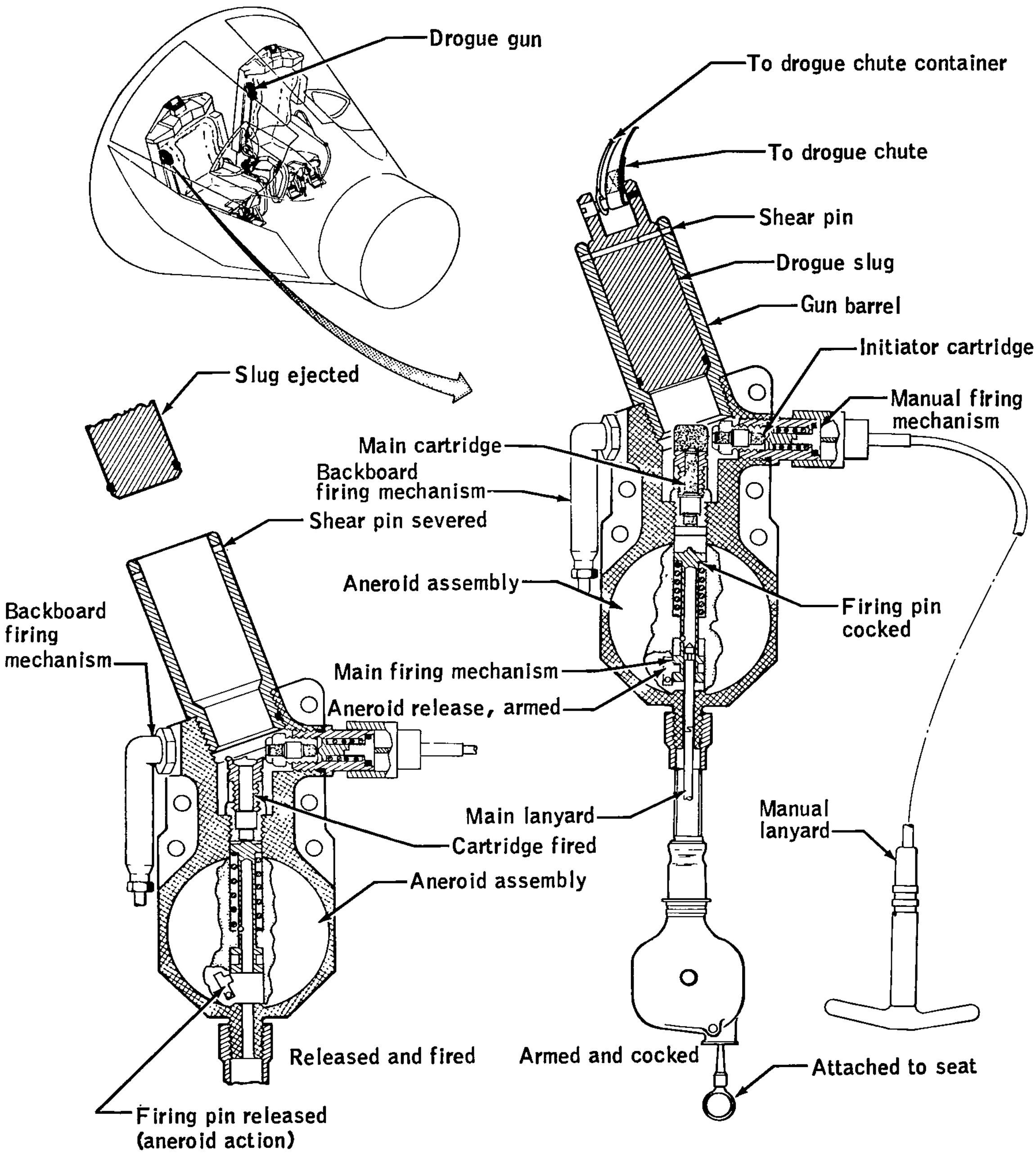


Figure 24. - Drogue gun.

NASA-S-67-2000

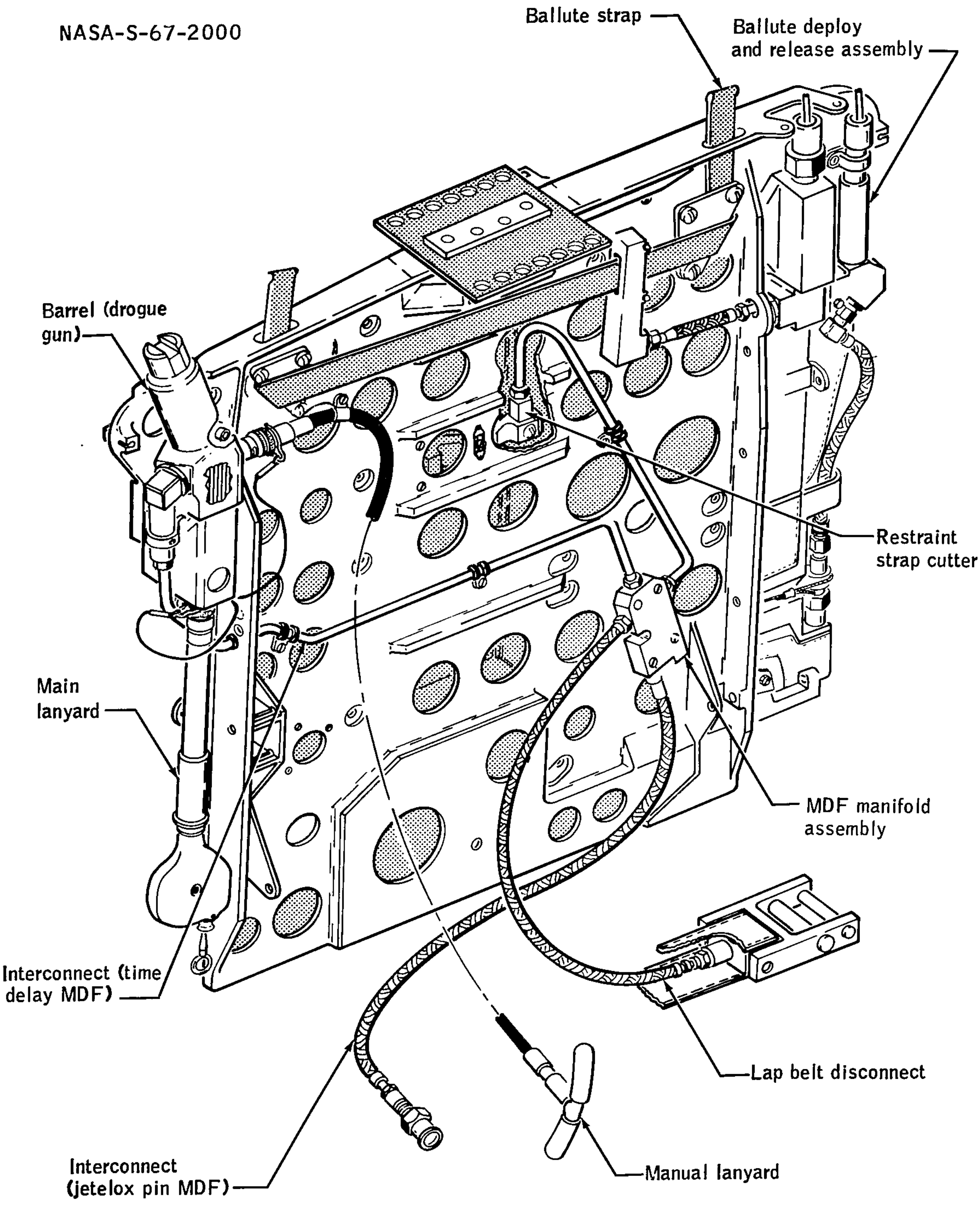


Figure 25. - Backboard-jettison system.

NASA-S-66-12840 DEC 28

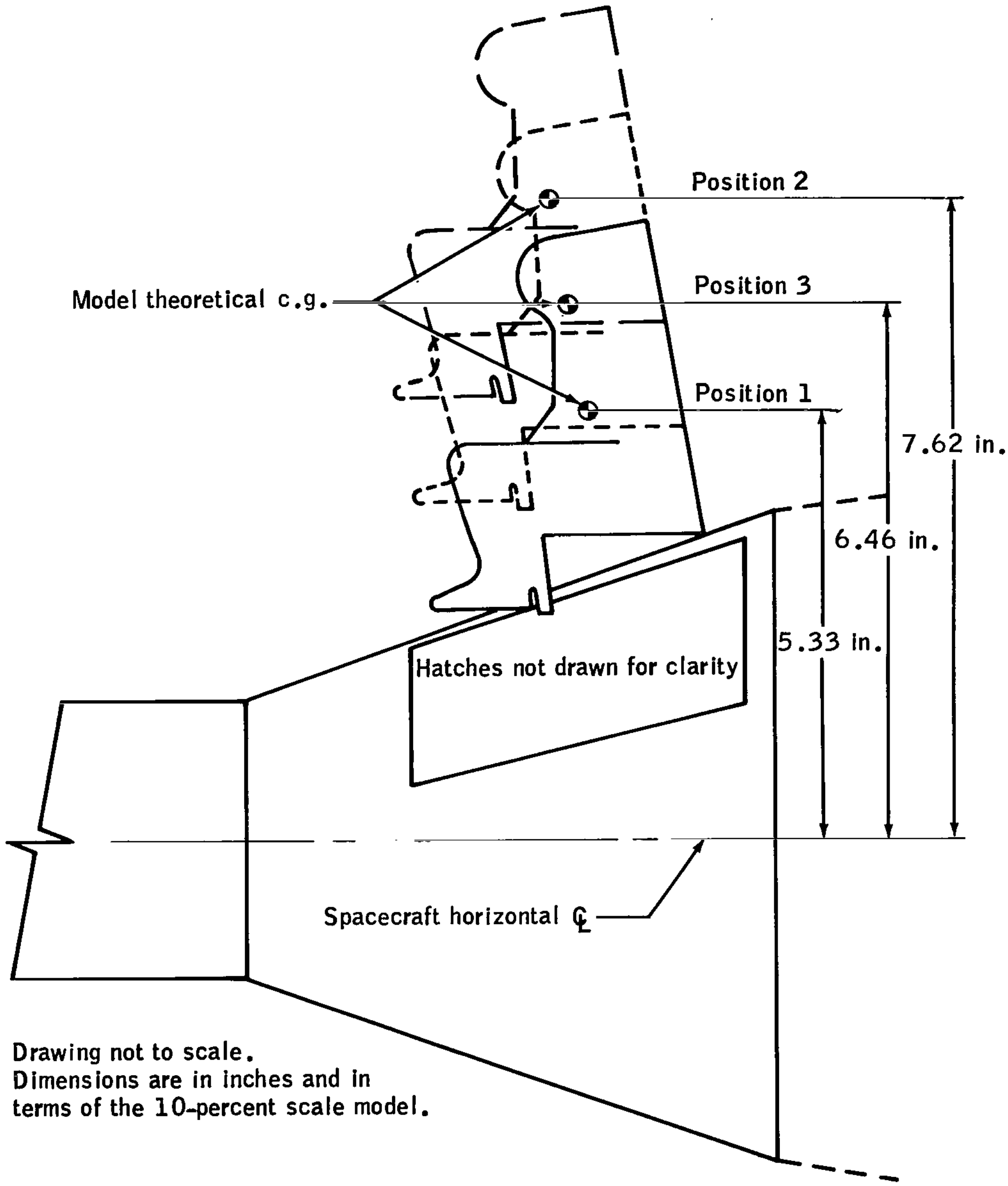


Figure 26. - Ten-percent ejection model shown in three escape positions.

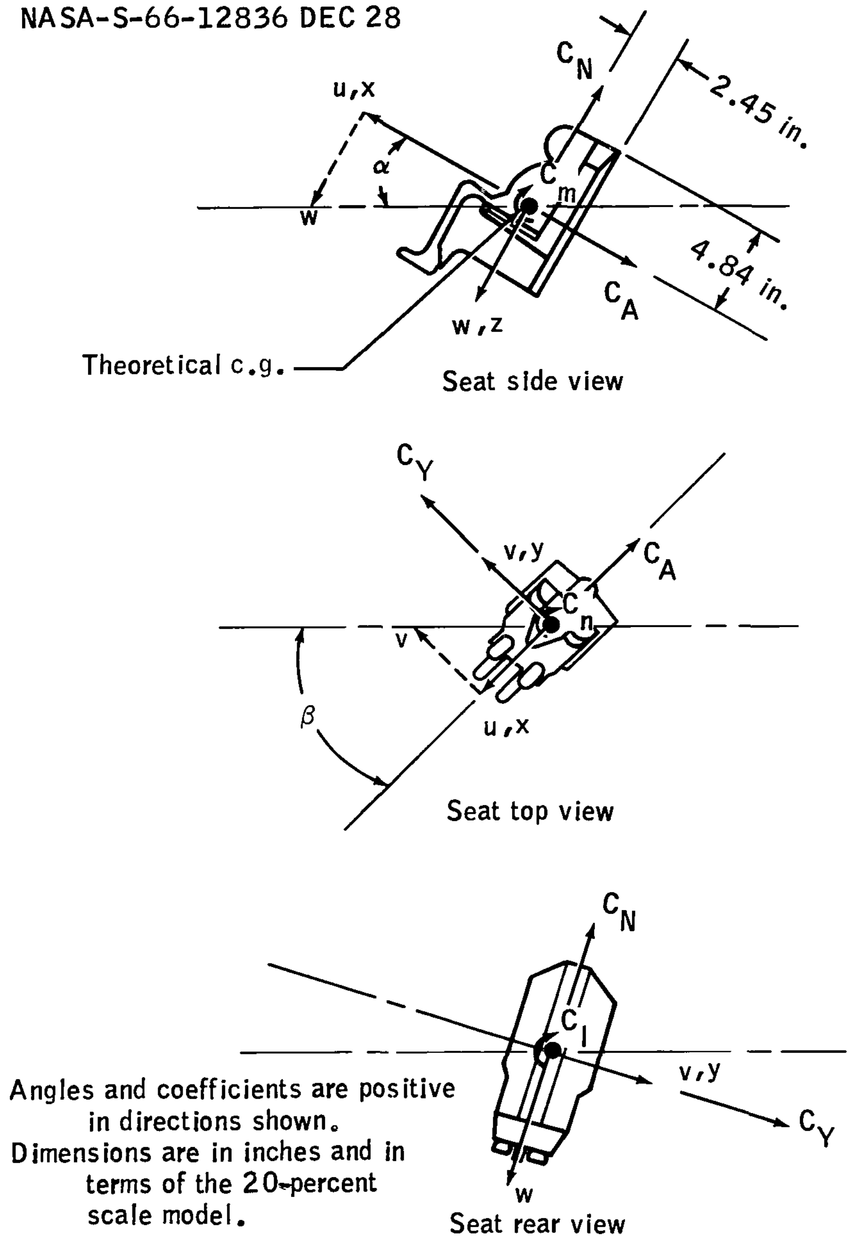


Figure 27. - Definition of body axes and angular nomenclature.

NASA-S-67-3809

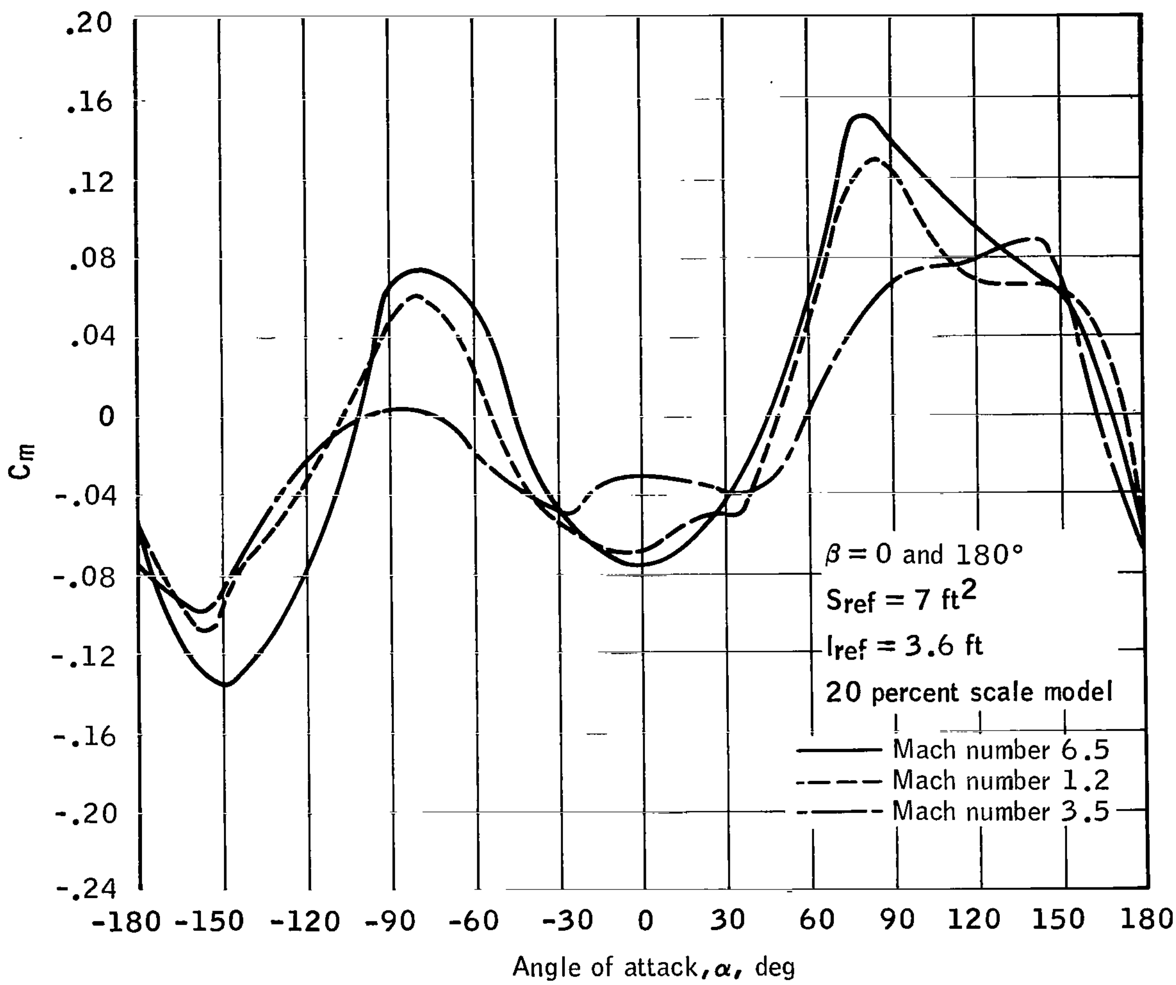
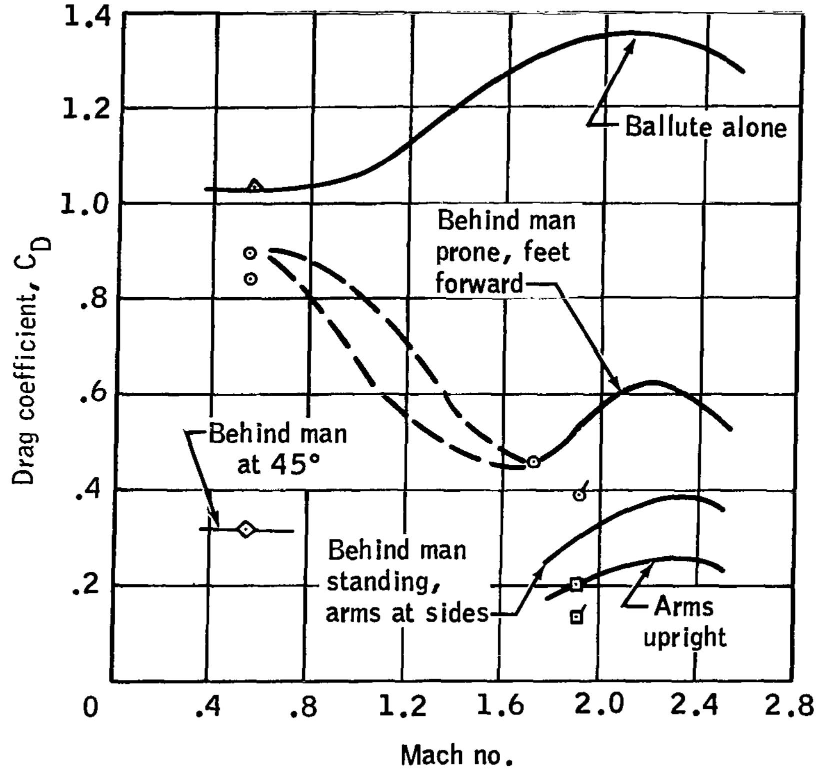


Figure 28. - Pitching-moment coefficient versus angle of attack.

NASA-S-67-3807

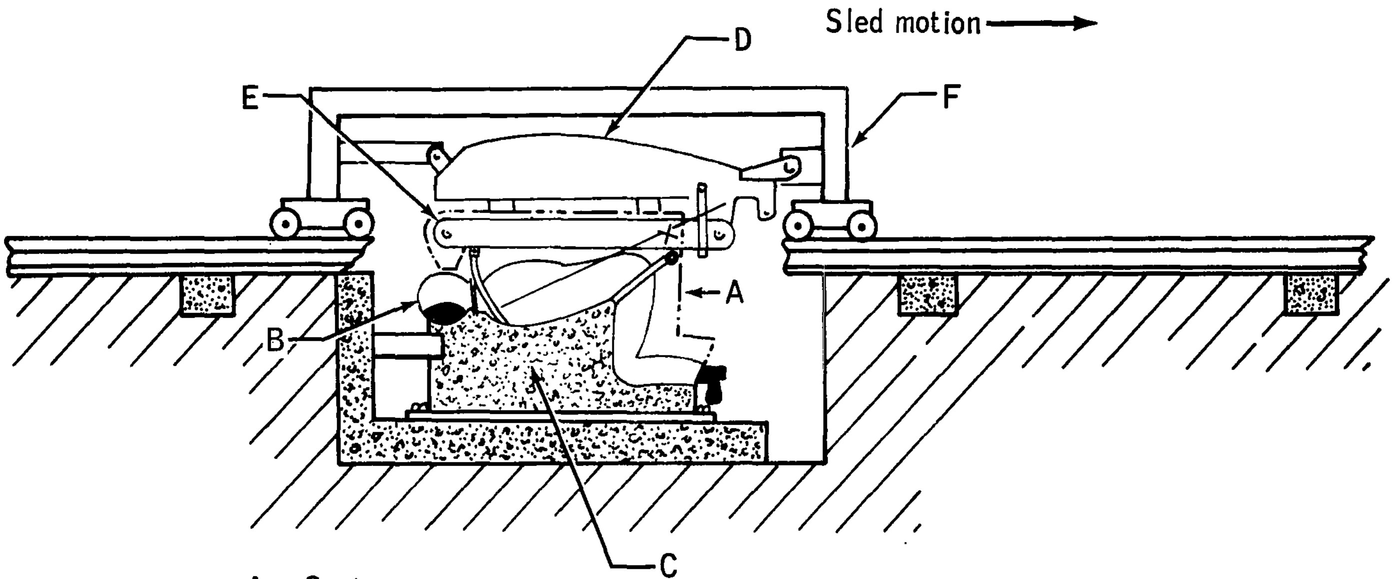


Full-scale 36-inch diameter ballute with 10 percent burble fence,
Dummy astronaut (arms up) with space suit, backpack, and seatpack

Plain symbols - series II test, 24 inch riser
Flagged symbols - series I test, 12 inches riser
△ Ballute alone
○ Man prone
◇ Man 45°
□ Man standing

Figure 29. - Results of wind-tunnel tests.

NASA-S-66-12843 DEC 28



A - Seat
B - Dummy
C - Support block and mounting for dummy
D - Fixed rail assembly
E - Rocket catapult
F - Test sled

Figure 30. - Static rocket-test configuration.

NASA-S-66-12853 DEC 28

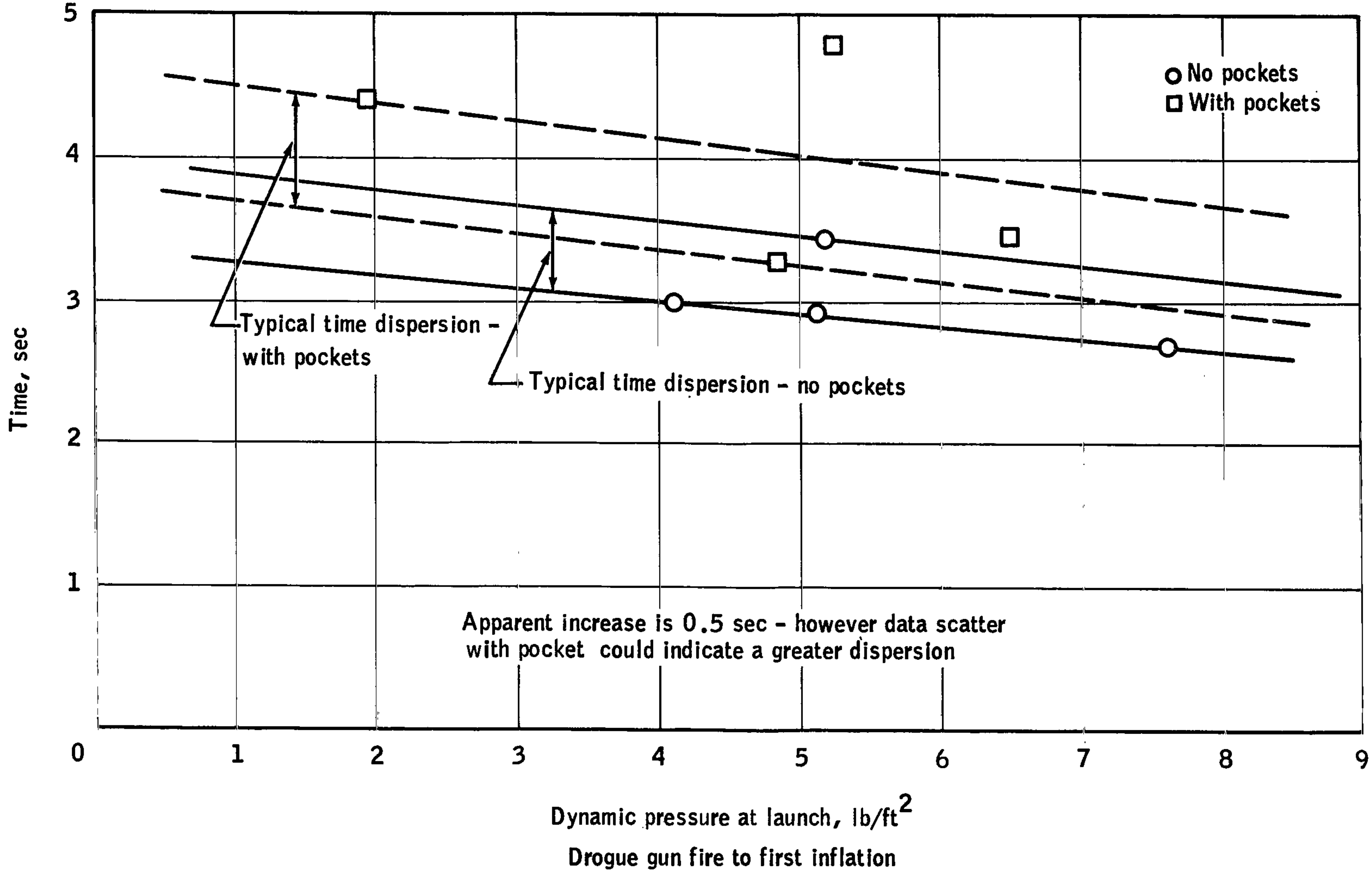


Figure 31.- Effect of parachute pockets on opening times.

NASA-S-66-12850 DEC 28

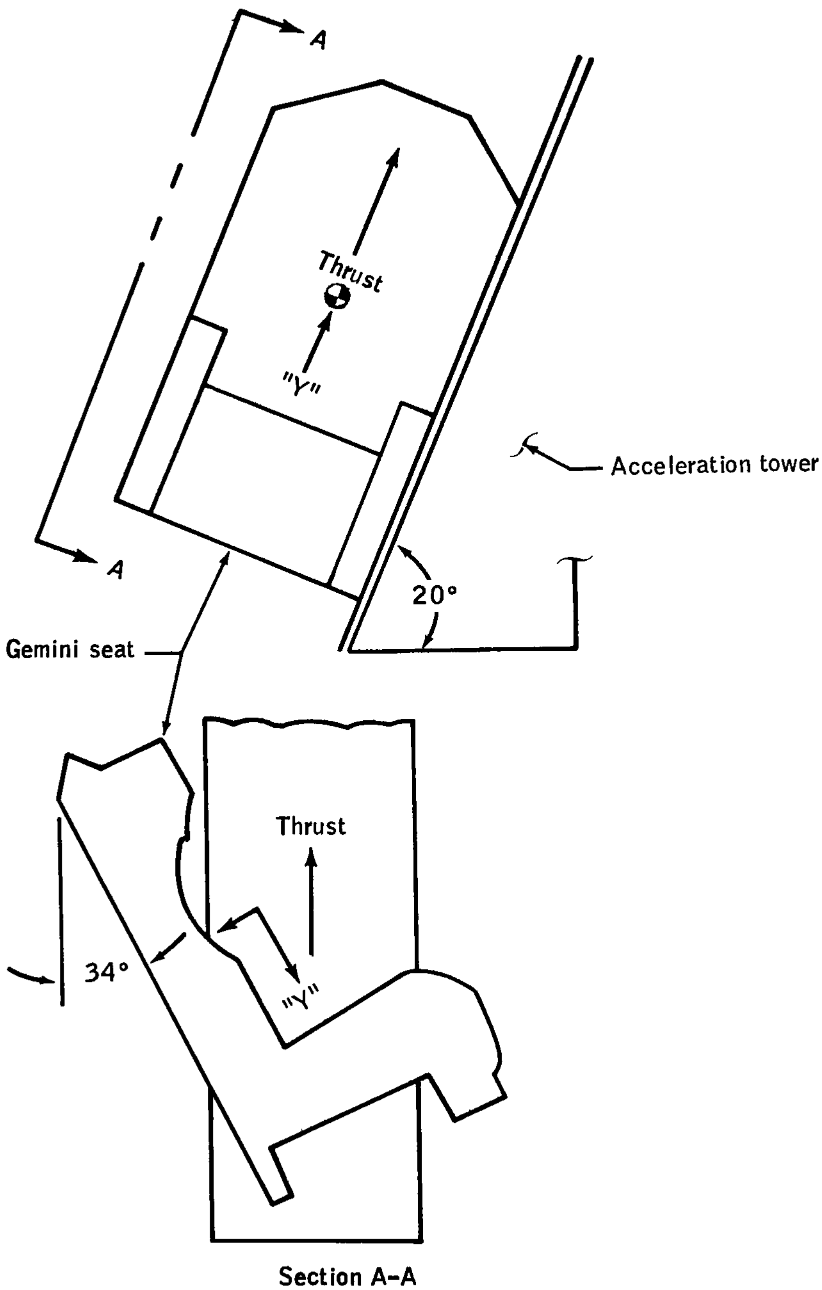


Figure 32. - Tower and seat angle.

Figure 33. - Typical aircraft installation of Gemini ejection seat.

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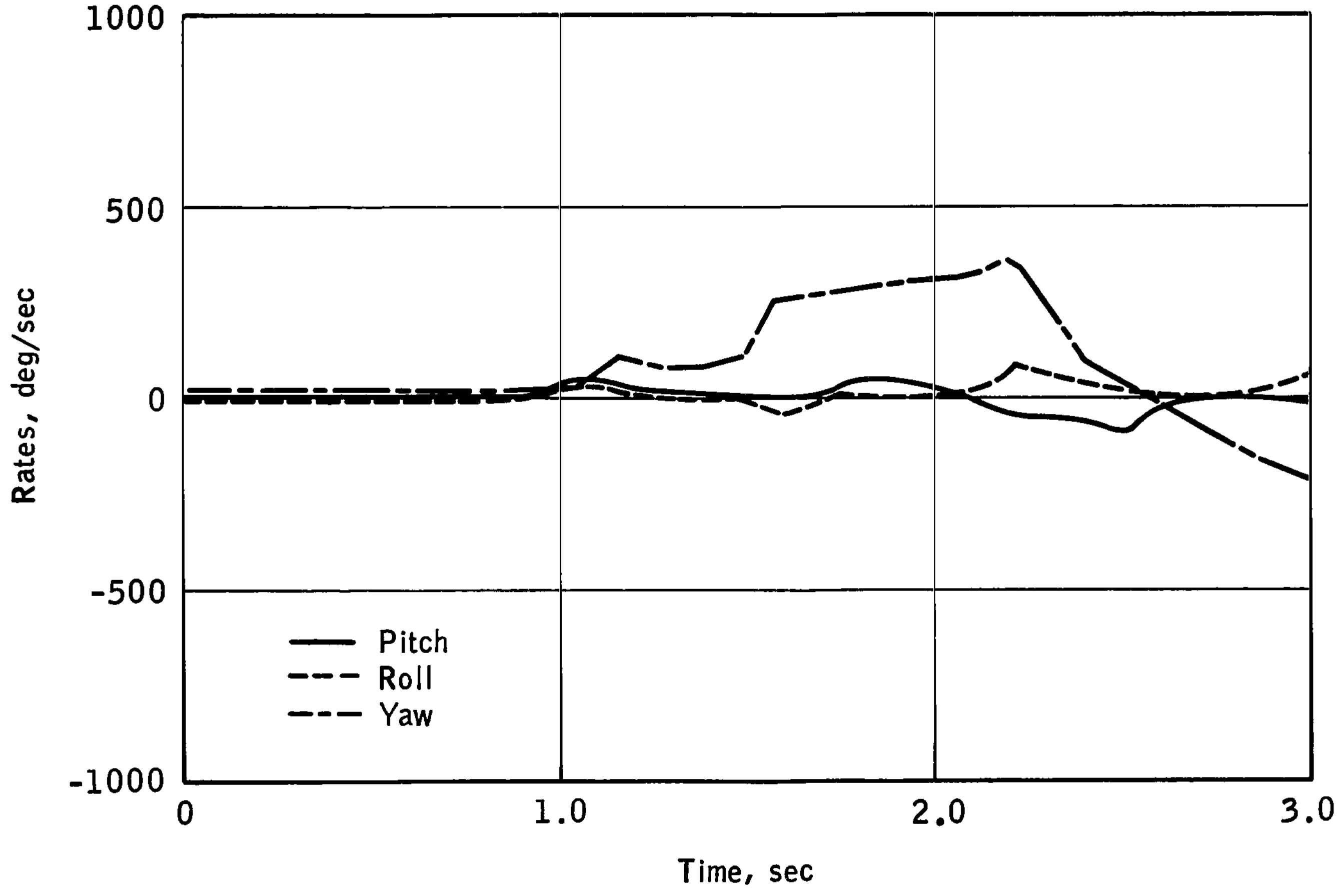
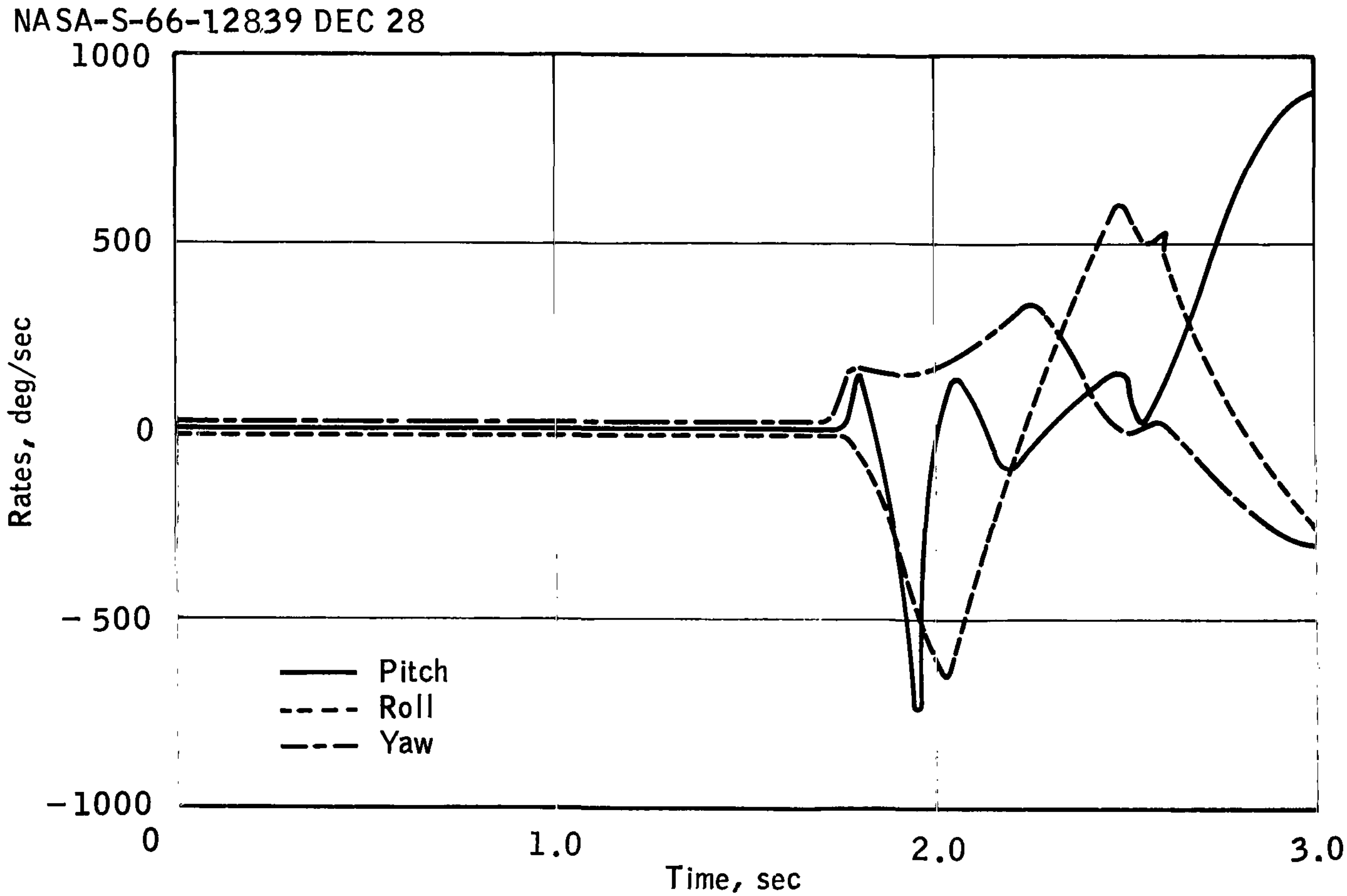


Note:

1. Launch Mach no. = 0.651
2. Launch altitude = 15,700 ft
3. Launch dynamic pressure = 3.51 lb/ft^2

Figure 34. - High-altitude subsonic ejection test.



Note:
1. Launch Mach no. = 1.72
2. Launch altitude = 40,046 ft
3. Launch dynamic pressure = 563 lb/ft^2

Figure 35. - High-altitude supersonic ejection test.

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