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The *Apollo* Command Module Side Access Hatch System

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The Apollo command module side access hatch system was redesigned on an expedited basis. This paper discusses the development of the redesign criteria and rationale and the redesign of the side access hatch system. A definition of the mechanisms and a description of the development testing required to qualify the system are included. This work was done under contract to NASA's Manned Spacecraft Center, Houston, Texas.

I. Introduction

After the accident with *Apollo* Spacecraft 012 at Kennedy Space Center, the command module side access hatch system was redesigned. Management at the Space Division of North American Rockwell Corporation realized the difficulty of designing and building a new hatch system in the time required by the revised *Apollo* Command Service Module Program schedule. A task force, staffed with management and design personnel from the engineering and manufacturing functions involved, worked seven days a week. NASA participated in the definition of criteria and the selection of the final redesign, which was turned over to the functional design groups for detailed design, analysis, and drawing release. North American Rockwell and NASA requested information from McDonnell Douglas Corporation on the definition of their mechanism and seals for the *Gemini* hatch; this information was immediately received.

A short description of the spacecraft is required to understand the design problems involved. The command module, which houses the astronauts, consists of three structures:

(1) An aluminum honeycomb inner structure, which serves as the pressurized crew compartment.

(2) A stainless steel heat shield covered with an ablative material. The heat shield is permanently attached to the inner structure by special fittings that allow relative motions between the structures due to thermal expansion and pressure variation.

(3) A lightweight boost protective cover, which covers and protects the heat shield during launch. The boost protective cover is attached to and jettisoned with the launch escape tower after second-stage booster ignition.

Spacecraft 012 had three hatches located in and latched to the three command module structures:

(1) The inner structure hatch was an inward-opening, completely removable, lightweight structure designed to react the applied loads with interlocking edge members on three sides and latches on the fourth. Cabin pressure was used to aid in sealing; the pressure differential had to be balanced before the hatch could be removed and stowed.

(2) The heat shield hatch was an outward-opening, removable structure with interlocking edge members and latches on four sides.

(3) The boost protective cover hatch was a removable lightweight structure of fiber glass and cork, which opened outward. Its latches could be opened from within the command module by manually striking a plunger which penetrated the heat shield hatch and contacted the boost protective cover latch mechanism. It could also be opened from the outside by the use of a special tool.

The basic procedure for egress was to:

(1) Equalize pressure across the inner structure hatch.

(2) Unlatch and remove the inner structure hatch and stow inside the command module.

(3) Strike the plunger to open the boost protective cover hatch latches.

(4) Unlatch the heat shield latches.

(5) Push the heat shield hatch and boost protective hatch outboard.

(6) Egress.

This hatch system was deemed acceptable for early *Apollo* spacecraft (designated Block I) because there was no firm requirement for extravehicular activity, and a 90-s egress time for the three astronauts was thought to be sufficient. Previous consideration for using a large explosive blowout panel for simultaneous exit for three astronauts was eliminated because of the danger of pyrotechnics inside the crew compartment.

The series of spacecraft designated Block II was designed for lunar orbit rendezvous and had an improved side access hatch system for extravehicular activity. The main difference between Block I and Block II was the heat shield hatch, which hinged outward for Block II and had latches with greater reach and pull-down capacity.

II. New Hatch Design Requirements

Because many of the Block II structures had been fabricated, systems installed, and heat shields assembled to the inner structures when the hatch redesign was started, management decided that:

(1) Major changes would be confined to the hatches, and rework to the inner structure and heat shield would be limited.

(2) The heat shield would not be removed for rework.

(3) No welding would be used for heat shield rework.

(4) Only readily available materials and machinery would be used.

(5) Excess strength margins would be used in structures, mechanisms and fasteners.

The normal engineering practice of designing for minimum weight was sacrificed for expediency and ruggedness. Furthermore, there was to be no planned future change point, which implied that the excess weight might never be eliminated.

The prime functional requirement was that the hatch would operate satisfactorily for normal usage, and the requirements for rapid emergency egress during manned command module checkout and prelaunch activities were changed drastically. Time allowed for opening the side hatch system was cut to 3 s and time for egress of three pressure-suited astronauts was reduced to 30 s.

A secondary functional requirement was for improved extravehicular activities characteristics including:

(1) Up to 20 min for the hatch to remain open for the most severe command module solar orientation.

(2) One-handed operation of mechanisms from either inside or outside.

(3) Inside operating handle motion: push open, pull closed.

(4) Outside operation: tool interface within interconnect to a lock pin.

(5) Emergency ingress for an unaided astronaut.

(6) An emergency (backup) method of hatch latching.

(7) A rapid pressure dump valve.

(8) No reduction in size of hatch opening; increased angle of hatch swing.

(9) Provision for replacing the hatch window with the Block I air lock to be used for scientific experiments on later flights.

(10) An operating force of 20 lb nominal.

Additional criteria were specified as the design progressed:

(1) One-hour opening of the hatch for extravehicular activity but not necessarily in worst solar orientation.

(2) Capability for the hatch to be left ajar for long-duration extravehicular activity.

(3) One hundred operating cycles without degradation to confirm repeat usage.

(4) Hatch damage acceptable in emergency use during test or prelaunch, under increased internal pressure, but damage to the command module structure not acceptable.

(5) No increase in the hatch leak rate.

III. Design Proposals

Some of the designs which were proposed but discarded are listed below to indicate the scope of redesigns attempted.

(1) A blowout panel design which was large enough for three astronauts to exit simultaneously was proposed. This was discarded because too much existing hardware would be changed, extravehicular activity would not be improved, and pyrotechnics inside the cabin would be dangerous.

(2) It was proposed to retain existing hatches, but incorporate small blowout panels. This was discarded for much the same reasons as above.

(3) It was proposed that the inner structure hatch and the boost protective cover hatch be mounted to, and supported by, the outward opening hinged heat shield hatch. When closed, the hatches would be individually latched to their respective structures. This proposal was discarded because of mechanical complexity and alignment problems.

(4) The inner structure hatch and heat shield hatch were proposed to be each hinged outward and latched independently. This was discarded because of mechanical complexity.

(5) Retention of the existing three-hatch system was proposed, with the addition to a power actuator for opening the heat shield hatch and an outward-opening door built within the confines of the inner structure hatch and operated by a quick-acting device. This was considered attractive because it did not change existing structure, but it had the disadvantages of extra mechanisms and reduced hatch opening. Moreover, the difficulty of handling and stowing the hatch by a pressure-suited astronaut counted heavily against this proposal.

IV. The Unified Hatch Concept

The concept proposed by North American Rockwell and approved by NASA is known as the unified hatch (Fig. 1). The design combines the functions of the heat shield hatch and the inner structure hatch into a single outward-opening hinged hatch with one set of mechanisms. The boost protective cover hatch was retained, but modified to be compatible with the unified hatch. The unified hatch provides the primary structure for pressure loads and the seal for the inner structure and supports the ablative material for thermal protection.

Two adapter frames are used, one attached to the inner structure and one attached to the heat shield, to provide structural continuity and transmit primary structure loads around the hatch. The frames reduced the hatch opening; however, NASA provided a new opening criterion. The reduction in the hatch egress path opening was offset by the minimum rework required to the existing structures.

The unified hatch is hinged and latched to the inner structure adapter frame; the heat shield and its adapter frame float relative to the hatch. The resulting gap between the hatch periphery and the heat shield adapter frame is blocked by a rubber thermal seal to prevent entry of thermal flow. This passive thermal design technology of thermal flow blockage was being proven at that time.

Although studies were made to eliminate the boost protective cover hatch, the decision was made to retain it with minor modification. Because the boost protective cover hatch represented another set of mechanisms, its elimination would have required drastic changes to the command module ablative material which were not possible because of schedule commitments.

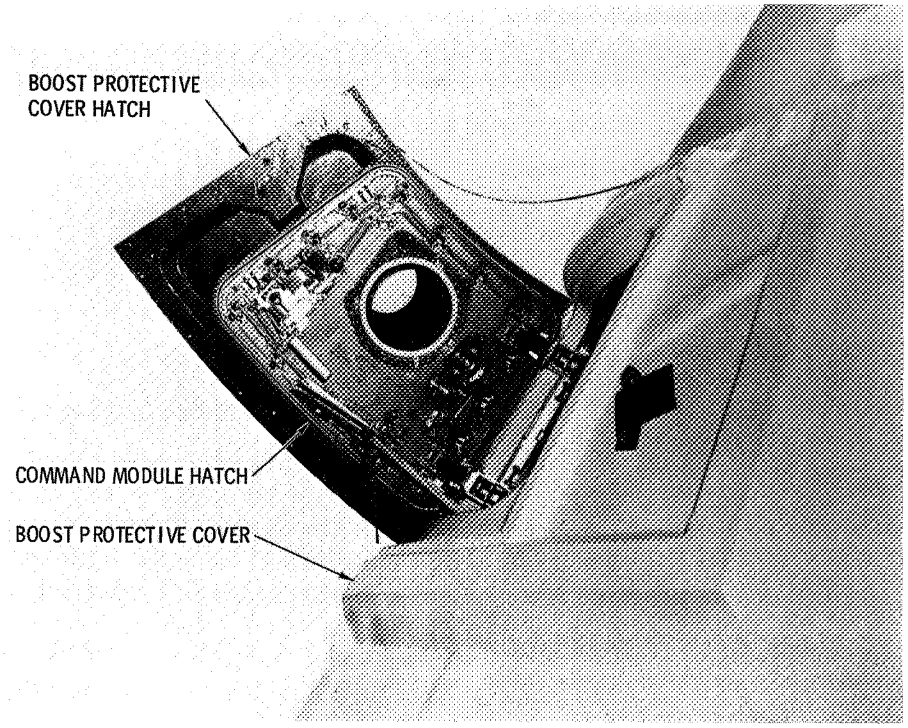

Fig. 1. Unified hatch in open position

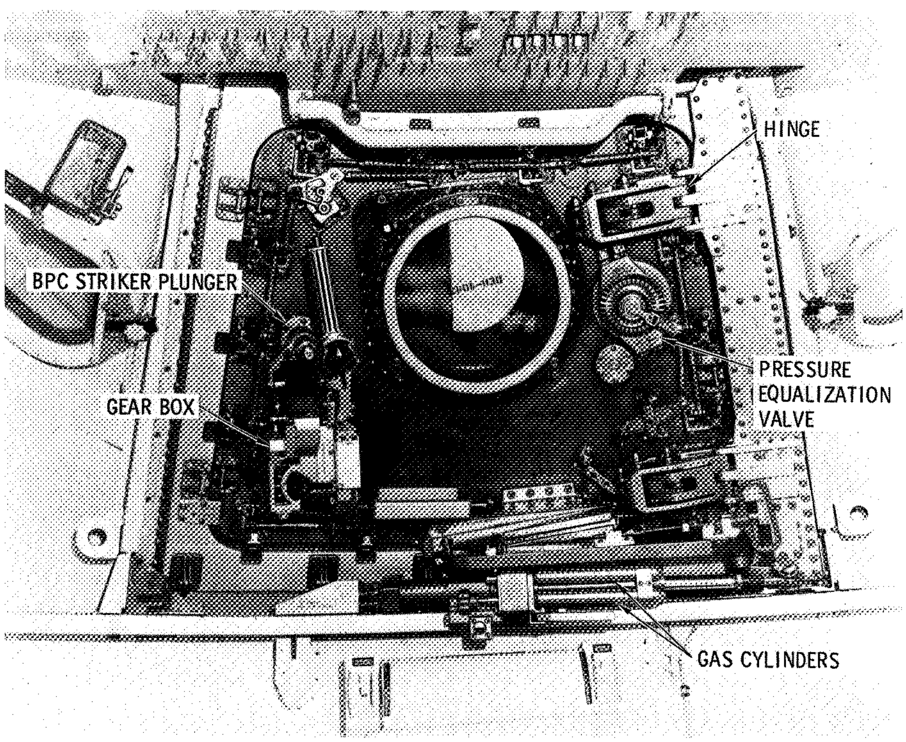

Fig. 2. Unified hatch from inside command module

V. Boost Protective Cover Mechanisms

The boost protective cover (BPC) hatch is slightly larger than the command module (CM) hatch and has a piano hinge along one vertical edge so that the two hatches swing open in the same direction. The other three edges are secured to the boost protective cover structure by latches which are linked to a central operating lever and are normally opened and closed by the ground crew outside the command module with a removable tool. For emergency egress, the boost protective cover hatch latches are released by the astronauts from inside the command module by means of a plunger (the boost protective cover striker plunger) that is automatically actuated when the astronaut performs the unlatching function for the unified hatch by operating the gear box handle. The boost protective cover hatch then remains resting against the command module hatch. An alternative emergency procedure is for the ground crew to pull on an external lanyard to open the boost protective cover latches and hatch.

VI. Unified Hatch Mechanisms

The command module unified hatch contains the following mechanical components (Fig. 2):

(1) Latches to retain the hatch in the closed position.

(2) Linkage to transmit motion to the latches.

(3) A manually operated gearbox to drive the linkage.

(4) A plunger mechanism to open the boost protective cover hatch latches (the boost protective cover striker plunger).

(5) A gas-powered piston/bell crank to push the hatch open and attenuate the travel (the counterbalance).

(6) A manually operated valve to equalize pressure across the hatch.

(7) A screwjack attachment for emergency hatch closure and retention.

A. Latches

The requirements of the command module hatch latches are:

(1) To hold the command module hatch closed and maintain the hatch pressure seal.

(2) To pull the hatch down when the hatch is within ½ in. of the mating surface. This allows hatch closure if the hatch is warped due to temperature differentials across the hatch structure.

(3) To cam the hatch open approximately ⅜ in. when the latches move to the open position.

These requirements are met by the use of the cone latch which has several features that make it advantageous to our hatch application (Fig. 3).

(1) It translates motion through 90 deg, thus permitting its drive linkage to be placed close to the hatch surface.

(2) Its mechanical advantage changes throughout its stroke so that the output force increases as the latch moves toward the latched position.

(3) Near the end of its closing stroke, the output lever passes over center, and cabin pressure then assists in holding the latches in the closed position.

(4) Cabin pressure forces do not feed back through the latch to the driving linkage, which can, therefore, be safetied with a comparatively light locking pin.

There are 15 latches spaced at approximately 5½-in. intervals around the periphery of the hatch. Each latch consists of a driving lever, a connecting lever, and a driven lever assembled in a housing secured to the inner surface of the hatch. Shims under the housings enable them to be rigged for equal distribution of seal squeeze load, and a gauging surface machined into each housing simplifies adjustment for correct amount of overcenter travel of the latch driving lever. The driven lever is shaped to form the pull-down dog and has an effective travel of ¾ in., which is more than sufficient to compensate for calculated hatch thermal warpage.

The latch driving linkage is a simple push–pull rod system with threaded adjustments for each latch.

B. Gearbox

The function of the gearbox is to open and close the command module hatch latches and to provide a drive for emergency opening of the boost protective cover hatch latches. It has two inputs and two outputs (Fig. 4).

(1) One manual input from the hatch exterior.

(2) One manual input from the hatch interior.

(3) One output to open and close the command module hatch latches via the driving linkage.

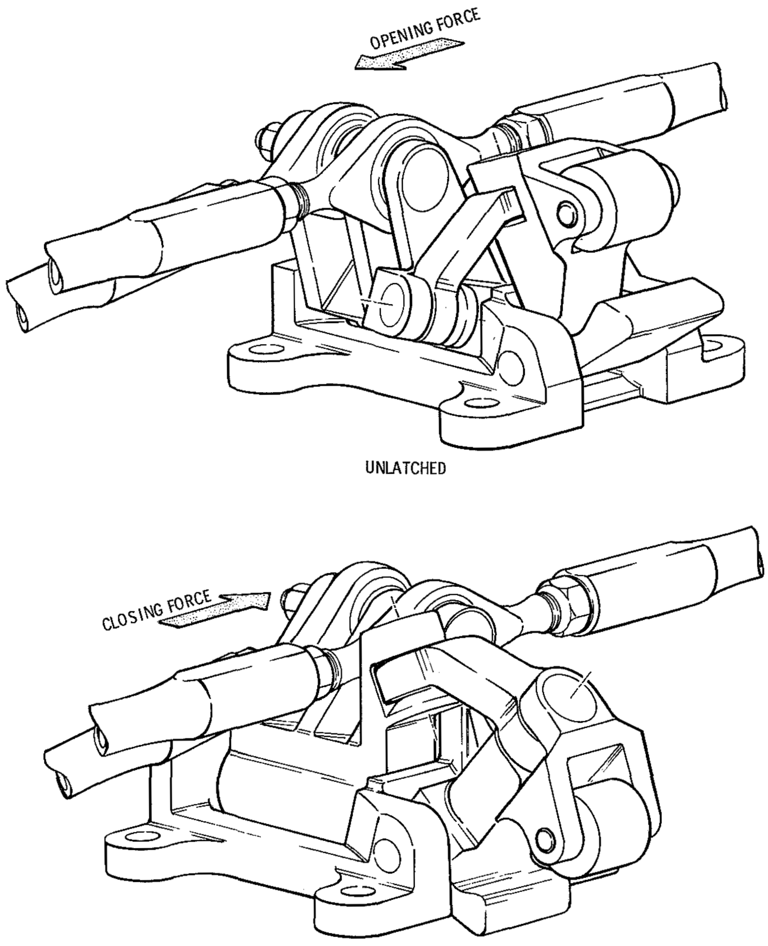

Fig. 3. Unified hatch latches

(4) The output to drive the boost protective cover hatch striker plunger to unlatch the boost protective cover hatch.

The exterior input is a socket in a recessed shaft, which penetrates the command module hatch and is rotated by a removable hand tool. It is used for ground operations, for checkout and test, for extravehicular activities, and for postlanding rescue. Because it is exposed to and must survive reentry heating, it is protected by a beryllium copper heat sink and is thermally insulated from the cabin interior by glass fabric spacers.

The interior input is a push–pull handle which moves normal to the command module hatch plane and is used by the astronauts during extravehicular activities and postlanding and emergency egress. The handle drives through pawls to a ratchet wheel splined to a gear train, which in turn drives the two gearbox outputs. Five oscillations of the handle are required to either open or close the command module latches. The motion of the ratchet wheel and output gear train relative to that of the push–pull handle is selected by two control knobs which engage and disengage the pawls.

One control knob is mounted on the handle and engages either one of two pawls which control the direction of advancing the ratchet wheel. The other selector knob is mounted on the gearbox housing and similarly engages pawls which prevent the ratchet wheel from backing off during the idling stroke of the push–pull handle. The arrangement of pawls is such that the handle push stroke is the working stroke for opening the latches and the pull stroke for closing them. A secondary set of pawls is staggered at half ratchet tooth spacing to reduce backlash between the handle and ratchet wheel

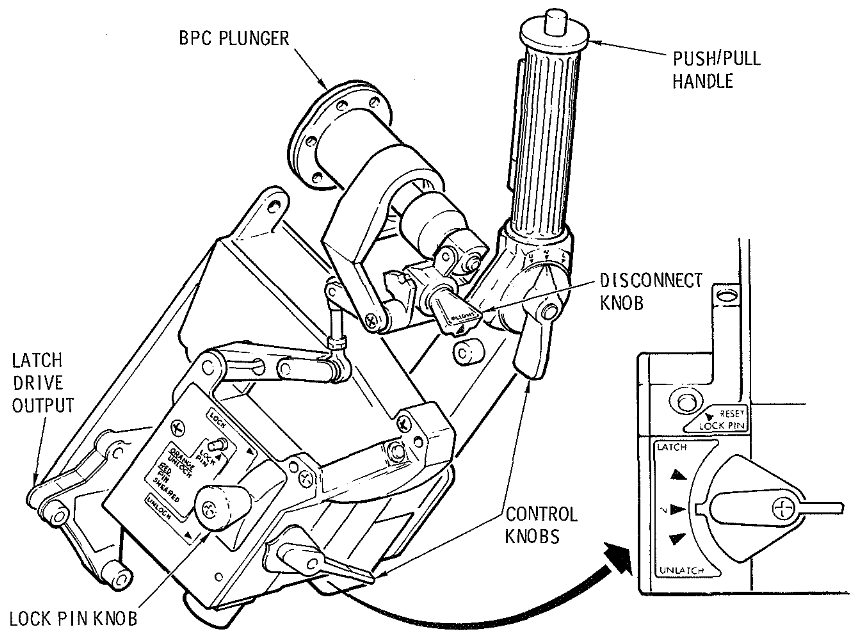

Fig. 4. Unified hatch gear box

and to provide a redundant safety feature. Immediately after the astronauts are locked inside the command module, the two selector knobs are set to the "open latches" position in readiness for an emergency egress.

The gearbox output for opening and closing the command module latches is a bellcrank driven by the gear train, the last gear of which is a 120-deg segment. The bellcrank has two quick-disconnect clevis joints, each driving half of the command module latch system, and an overcenter spring to retain it in either extreme of travel. The other gearbox output is a lever for operating the boost protective cover hatch latch release (the boost protective cover striker plunger). It is driven by a cam slot machined in the side of the 120-deg segment gear and is sequenced to open the boost protective cover hatch latches before the command module hatch latches have moved a significant amount (i.e., they are still in the overcenter locked position).

A safety locking pin is spring-loaded to lock into a matching hole in the segment gear at the end of the command module latch closing cycle and thus prevent accidental opening of the hatch because of vibration or human error. For normal (i.e., nonemergency) hatch opening, the locking pin is manually disengaged before the gearbox handle is operated. When the exterior input is used, this is accomplished by rotating the shaft 15 deg clockwise before rotating counterclockwise to unlatch the hatch. The locking pin is sized so that it will shear when a force greater than normal (35 versus 20) is applied to the push–pull handle, as, for example, in emergency egress.

C. Boost Protective Cover Mechanism

Because the boost protective cover is a separate structure and is jettisoned during boost, its hatch mechanism presents special problems. Before launch, it must be operable from outside the boost protective cover and from inside the command module for emergency egress; but after jettison, the command module hatch must present a smooth ablative surface. Also, for egress, it is required that the boost protective cover hatch latches open before the command module hatch latches so the two hatches can swing open together. These problems are solved by the boost protective cover striker plunger (Fig. 5), which is driven by the gearbox second output. The plunger penetrates the command module hatch and is capped by an ablative end piece which is flush with the hatch exterior surface. When activated by the gearbox, it moves outboard toward the latch mechanism of the boost protective cover hatch. Because the boost protective cover is a comparatively nonrigid structure and offers little resistance to a steady push, the plunger must apply its force very quickly. To accomplish this, the plunger contains a stack of Belleville spring washers

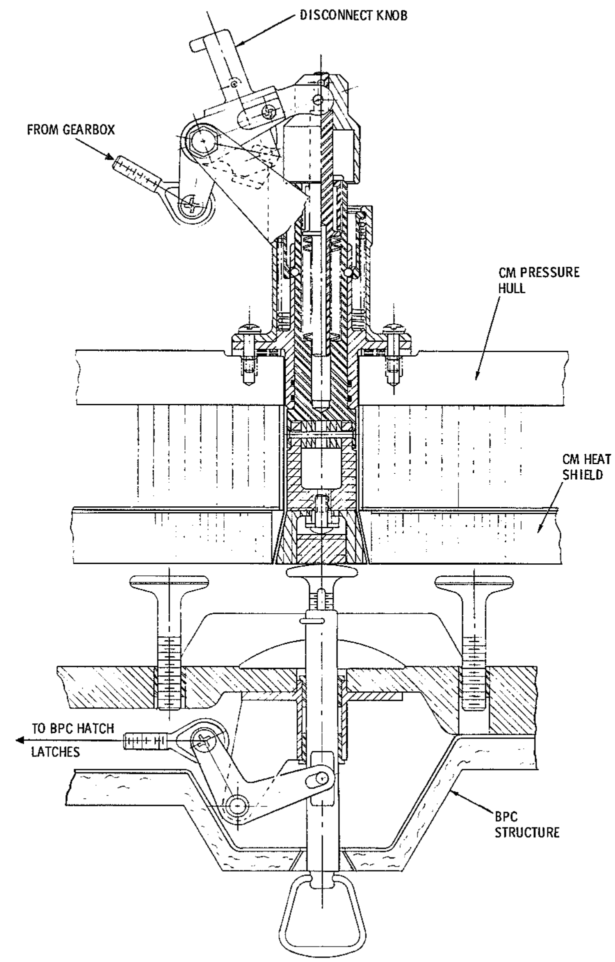

Fig. 5. Boost protective cover striker plunger

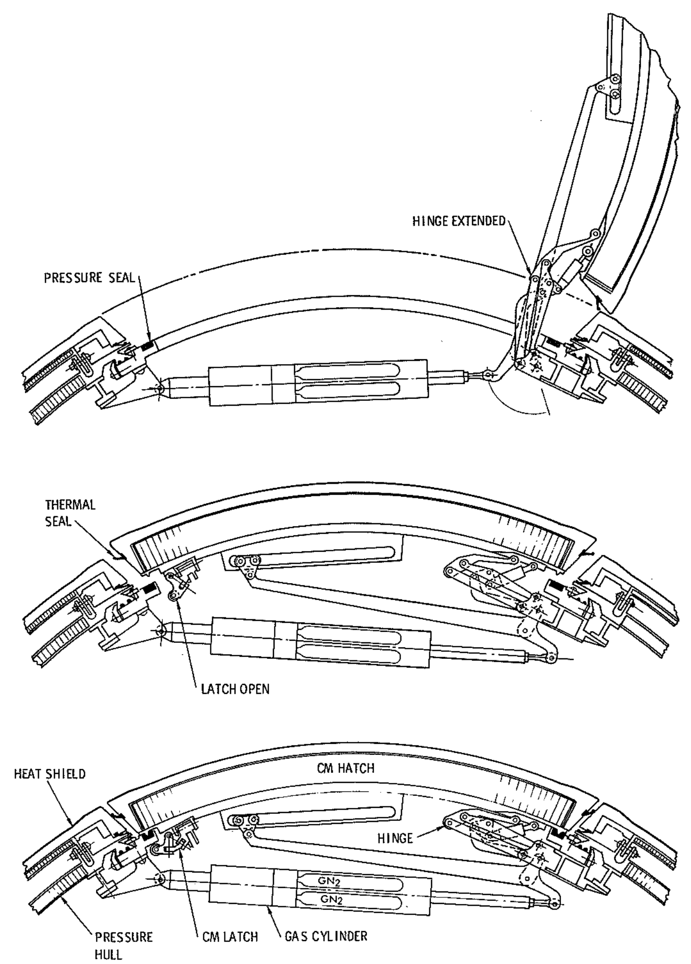

Fig. 6. Command module unified hatch

which are compressed at the beginning of the stroke and then released, the resulting hammer blow opening the boost protective cover hatch latches before the structure can deform. This action takes place during the first working stroke on the gearbox handle. During the remainder of the unlatching cycle, the command module hatch latches are opened and the boost protective cover striker plunger returns to its original position. Since it can serve no useful purpose after launch, the plunger is deactivated during orbit by turning a knob which disconnects it from the gearbox second output.

D. Hinges

The main problem associated with the command module hatch hinges is one that has plagued many mechanism designers. It is to hinge a thick, flush, closely fitting door, which, because of thermal and structural considerations, does not permit a hinge point to be located within its thickness. It is also desirable to design for minimum space usage in the cabin interior. The solution is a pair of collapsible linkage hinges mounted to the inner surface of the hatch (Fig. 6). The linkage unfolds and moves the hatch directly outboard before rotating, as the hinge point constantly changes. A spring-loaded bungee is incorporated to centralize the hatch in its opening when thermal warpage occurs.

E. Counterbalance

The function of the counterbalance (Fig. 7) is to push open the command module and boost protective cover hatches for emergency egress immediately after they are unlatched. Because the combined hatches weigh 350 lb, it is difficult, although not impossible, to open them without this assistance. The cylinder is powered by GN_2 contained in two sealed bottles at 5000 psi, one of which is punctured prior to launch, while the other is reserved for use during extravehicular and postlanding activities.

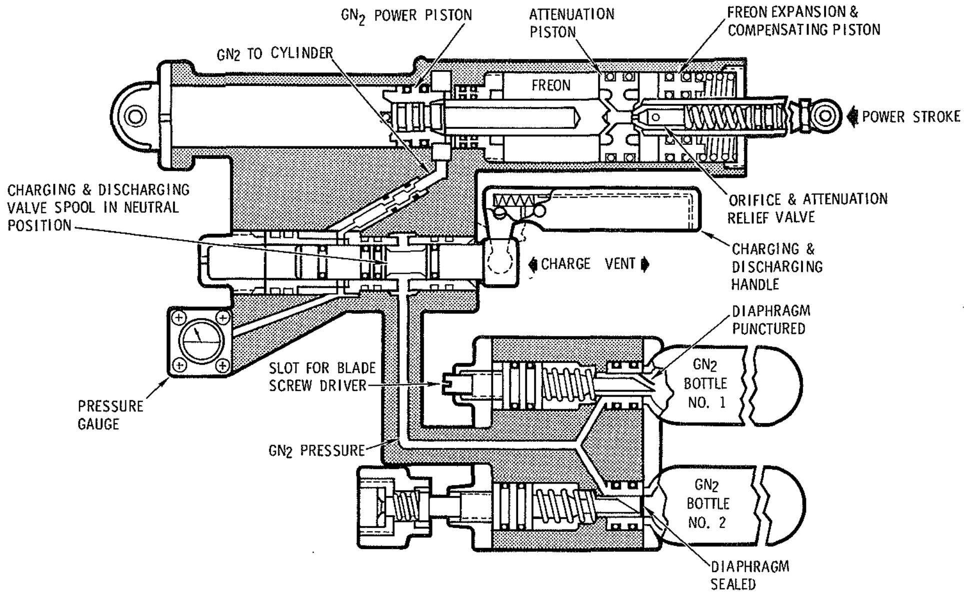

Fig. 7. GN_2 counterbalance schematic

A manually operated spool valve controls the GN_2 flow from the bottles to a power cylinder and piston. A control cylinder is mounted axially in line with the power cylinder and houses a piston and orifice to regulate the flow of Freon which controls the hatch opening velocity. The control cylinder also attenuates shock at the end of the hatch opening stroke. The counterbalance rotates a bellcrank which moves the hatch and engages a safety lock to hold it in the fully open position. The sequence of hatch operations at launch is:

(1) Pressurize the cylinder (ground crew).

(2) Board the spacecraft (flight crew).

(3) Force command module hatch closed against the cylinder pressure (ground crew).

(4) Close the command module hatch latches (flight crew).

(5) Set the gearbox control knobs to the "open latches" position (flight crew).

(6) Close and latch the boost protective cover hatch (ground crew).

The hatch system is then configured for emergency egress. The flight crew has only to operate the gearbox push–pull handle to:

(1) Shear the safety locking pin.

(2) Load and release the spring-loaded boost protective cover striker plunger to open the boost protective cover hatch latches.

(3) Release the command module hatch latches and allow the counterbalance to swing both hatches open approximately 100 deg.

(4) Lock the command module hatch in the open position.

The emergency egress procedure is for the right hand crewman to operate the gearbox (approximately 3 s) and to egress last.

Backup or redundant features were added to assure the safe return of the command module and crew even if primary mechanisms fail. The only mandatory requirement is to be able to hold the command module hatch closed during reentry, although other factors such as oxygen retention and flotation must be considered. To achieve redundancy, the command module latches are divided into four groups and are separable from each other and from the gearbox by quick-disconnect clevis pins so that latch failures can be localized. If the gearbox is inoperable, the disconnected latches can be manipulated by a hand wrench. Another difficulty which may arise is that during extravehicular activity the command module hatch thermally warps more than the latches can accommodate. To overcome this, a set of

three small screwjacks is provided to attach to the hatch and force it closed to provide structural integrity for reentry.

VII. Test Program

The test program was planned to support the accelerated design effort and to develop confidence in the hatch system using a step-by-step approach starting with simple ground tests and ending with a lunar-landing mission. A large amount of ground testing had to be performed to prove that the hatch system satisfied the design requirements (Table 1) before a flight could be attempted.

An existing wooden mockup of the command module was revised to include the new hatch design. Although the mechanisms were not functional, they enabled engineering to control the configuration and to evaluate handle and controls placement. Astronauts assisted with preliminary egress tests to verify hatch size opening and determine crew limitations in spacesuits. At the same time a component test program was started to develop and verify the performance of the hatch pressure seal, individual latches, a hinge, and the counterbalance.

To satisfy the requirements for a formal ground qualification test, five vehicles were used, designated 004B, 2TV-1, 2S2, 105, and 007A. Vehicle 004B is a Block I flight vehicle refurbished with a production unified

Table 1. General design requirements

Subject	Unmanned tests	Manned checkouts and prelaunch	Orbital, midcourse or extravehicular activity	Reentry or abort	Postlanding activity
Cabin pressure[a] (at hatch closing)	0–0.01 psi	0–0.01 psi	0–0.01 psi		0–0.01 psi
Hatch closing initiated from	Outside	Inside or outside	Inside		Inside or outside
Hatch closing energy supplied by	Ground crew	Ground crew or flight crew	Flight crew		Recovery crew or flight crew
Hatch closing time	5 min maximum	5 min maximum	5 min maximum normal[b]		5 min maximum[b]
Cabin pressure[a] (while hatch closed)	−1.75–6.2 psi[c]	−1.75–6.2 psi emergency 0–3.0 psi normal[c]	0–0.01 psi emergency 6.2 psi normal	−1.75–0.01 psi 8.3 psi normal	0.10–8.0 psi emergency[d] 0–8.0 psi normal (hydrostatic)
Cabin pressure[a] (at hatch opening)	0–0.10 psi	−1.75–6.2 psi emergency 0–0.10 psi normal[c]	0–0.01 psi		0–0.10 psi[e]
Hatch opening initiated from	Outside	Inside emergency Outside normal	Inside or outside[f]		Inside emergency Outside normal
Hatch opening energy supplied by	Ground crew	Ground crew Flight crew Counterbalance	Flight crew		Recovery crew Flight crew Counterbalance
Hatch opening time	2 min maximum	2 min maximum 3 s maximum emergency[g]	2 min maximum		2 min maximum 3 s maximum emergency[g]
Hatch maximum opened time	Indefinite	Indefinite	20 min (worst orientation)		Indefinite
Crewmen egress		5 min maximum 30 s maximum emergency[h]	5 min maximum		5 min maximum 30 s maximum emergency[h]

[a]Cabin pressures given are psi above external pressure.
[b]Heat shield thermal integrity only, effectively water-tight for limited flotation capability.
[c]Ground support equipment may be utilized at pressures above 3 psi.
[d]Hydrostatic water loads are ultimate; all other pressures are limit values.
[e]Command module in stable No. 1 position or No. 2 position apex down.
[f]Extravehicular activities operations—unaided outside crewman.
[g]Time required for crewmen to unlock hatch latches.
[h]Include crewmen disconnect, hatch opening, and egress for three active, unaided crewmen.

hatch and a portion of the boost protective cover including a complete boost protective cover hatch. This vehicle was used mainly to check out mechanism functions and was subjected to the following tests:

(1) Functional cycling of all mechanisms at room (ambient) temperatures between each of the environmental tests.

(2) Pressure seal leakage.

(3) Pressure and temperature differential: 9.75 psig, +180°F interior, −175°F exterior.

(4) Thermal reentry; +500°F for 10 min.

(5) Emergency opening of command module and boost protective cover hatches at maximum and minimum command module pressures.

(6) Simulated water landing: 10-psi water pressure pulse and maximum 11-g force in hatch opening direction.

(7) Hatch mechanism operational life cycles.

(8) Corrosive environment simulating command module cabin during flight: salt solution, oxygen, humidity, and temperature cycling.

(9) Ultimate load tests on gearbox, latches, linkage, and counterbalance fittings.

(10) Shock test to 70 *g*.

Vehicle 2TV-1 is a Block II command module assigned for use by NASA in its large thermal vacuum chamber at Houston. Many manned and unmanned test runs were performed to check various phases of a mission. The tests simulating solar heating of the open hatch during extravehicular activities demonstrated a greater change in shape and size than was anticipated, and consequently the rigging procedure was revised to obtain greater clearances in critical areas. Vehicles 2S2 and 105 are Block II command modules assigned for structural and vibration tests. Vehicle 007A is a command module used for postlanding flotation tests. The unified hatch was not tested separately but in conjunction with the remainder of the command module.

Two Block I vehicles were available for unmanned test flights. *Apollo 4* was flown in earth orbit but simulated a lunar mission reentry. The spacecraft had an old Block I hatch with simulated unified hatch thermal seal and gap in place of a window. *Apollo 6* was another simulated lunar mission but with a complete unified hatch. Successful completion of these two flights led to a manned earth orbit mission, *Apollo 7*, followed by *Apollo 8*, the first manned lunar orbit mission. During both of these flights, the unified hatch, and indeed the whole spacecraft, performed flawlessly.

At the time of writing, the spacecraft and its unified hatch are being readied for another flight, that of *Apollo 9*, which will demonstrate performance in extravehicular activity and crew transfer. This flight is a major milestone. It says "GO" for a lunar landing in this decade.