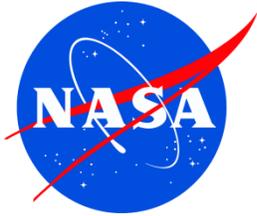


NASA/TP-2010-216131



Worldwide Spacecraft Crew Hatch History

*OSMA Assessments Team
Johnson Space Center, Houston*

National Aeronautics and
Space Administration

Johnson Space Center
Houston, TX 77058

August 2010

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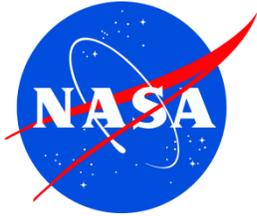
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Space Administration

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Summary, Purpose, and Background

The Johnson Space Center (JSC) Flight Safety Office has developed this compilation of historical information on spacecraft crew hatches to assist the Safety Tech Authority in the evaluation and analysis of worldwide spacecraft crew hatch design and performance.

The document was prepared by SAIC's [Science Applications International Corporation's] Gary Johnson, former NASA JSC Safety & Mission Assurance (S&MA) Associate Director for Technical. Mr. Johnson's previous experience brings expert knowledge to assess the relevancy of the data presented. He has experience with six of the NASA spacecraft programs that are covered in this document: Apollo, Skylab, Apollo-Soyuz Test Project (ASTP), space shuttle, International Space Station (ISS), and the Shuttle/Mir Program. Mr. Johnson is also intimately familiar with the JSC Design and Procedures Standard, JPR [JSC Procedural Requirements] 8080.5, having been one of its original developers.

Observations and Findings

The observations and findings are presented first by country and are then organized within each country section by program in chronological order of emergence. A host of reference sources used to augment the personal observations and comments of the author are listed in the reference section of this document. Careful attention to the selection and inclusion of photographs, drawings, and diagrams is used to give visual association and clarity to the topic areas examined.

Recommendations and Conclusions

Recommendations and conclusions are beyond the scope of this report.

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Acronyms

ASTP	Apollo-Soyuz Test Project
ATV	Automated Transfer Vehicle
CSM	command and service module
DM	docking module
ESA	European Space Agency
EV	extravehicular
EVA	extravehicular activity
FGB	Functional Cargo Block
HTV	H-2 Transfer Vehicle
ISS	International Space Station
JPR	JSC Procedural Requirements
KhSC	Khrunichev State Research and Production Space Center
JAXA	Japan Aerospace Exploration Agency
JSC	Johnson Space Center
LM	lunar module
MDA	multiple docking adapter
MLM	Multipurpose Laboratory Module
MOL	Manned Orbiting Laboratory
MPLM	multi-purpose logistics module
MR-2	Mercury Redstone 2
MRM 1	Mini-Research Module 1
MRM 2	Mini-Research Module 2
OM	orbital module
PLM	permanent logistics module
PMA	pressurized mating adapter
psi	pounds per square inch
RCS	Reaction Control System
RSCE	S.P. Korolev Rocket & Space Corporation Energia
S&MA	Safety and Mission Assurance
SAIC	Science Applications International Corporation
SM	service module
TMA	transportation modified anthropometric
USOS	U.S. Orbital Segment

1.0 History of United States Spacecraft Crew Hatches

1.1 Mercury

Project Mercury, the first U.S. human spacecraft program, successfully completed nine piloted missions. One event on the Mercury Redstone 2 (MR-2) mission occurred shortly after landing: the entrance hatch pyrotechnic device fired, which caused the hatch to be jettisoned. Astronaut Virgil I. “Gus” Grissom, who was piloting MR-2, was able to quickly exit the spacecraft and swim away. The recovery helicopter picked up Astronaut Grissom, but the Mercury capsule sank. The cause of the accident was not determined; it was reported by Astronaut Grissom that the initiator cap and safety pin were removed after landing, but the plunger was not depressed.

1.1.1 Entrance hatch

“An entrance hatch [figs. 1 and 2] is located on the right side of the afterbody conical section as viewed from the crew member station. Entrance hatch construction, similar to the conical section construction, consists of an inner and outer (beaded) skin seam welded together and reinforced with hat stringers.

“An explosive charge, molded in the hatch sill, is provided to quickly release the hatch and enable the astronaut to egress rapidly. An explosive charge initiator, located in the upper aft corner of the hatch, is linked to an internal release control initiator.

“Prior to launch, the hatch is bolted and sealed into position with bolts, and two corrugated shingles are installed over the hatch. The bolts are inserted through the entrance hatch sill, which incorporates the explosive charge, [then] threaded into the spacecraft sill. A magnesium gasket, with inlaid rubber, forms the hatch seal when the hatch is bolted into position.

“Two hatch shingles are attached to the hatch stringers, but in no manner are they attached to spacecraft shingles. (This enables the hatch to separate cleanly, upon ignition of [the] hatch explosive charge.)

“Following impact, the astronaut removes the initiator cap from the [internal release control] initiator, and the safety pin from the initiator plunger. By depressing the initiator plunger, the initiator’s two spring-loaded firing pins strike the explosive charge percussion caps and detonate the explosive charge. This action explodes the hatch from the spacecraft.

“An exterior hatch release control is provided to enable ground personnel to explode the hatch in the event the astronaut is unable to do so. Hatch retention springs, secured by pip pins, are incorporated on the inner side of the entrance hatch to prevent injury to ground personnel in the event the initiator plunger is accidentally depressed.

“Two pressure valves, located in the hatch enable pressurization and purging of the spacecraft during ground checkout operations.”¹



MCDONNELL

SEDR 104-18

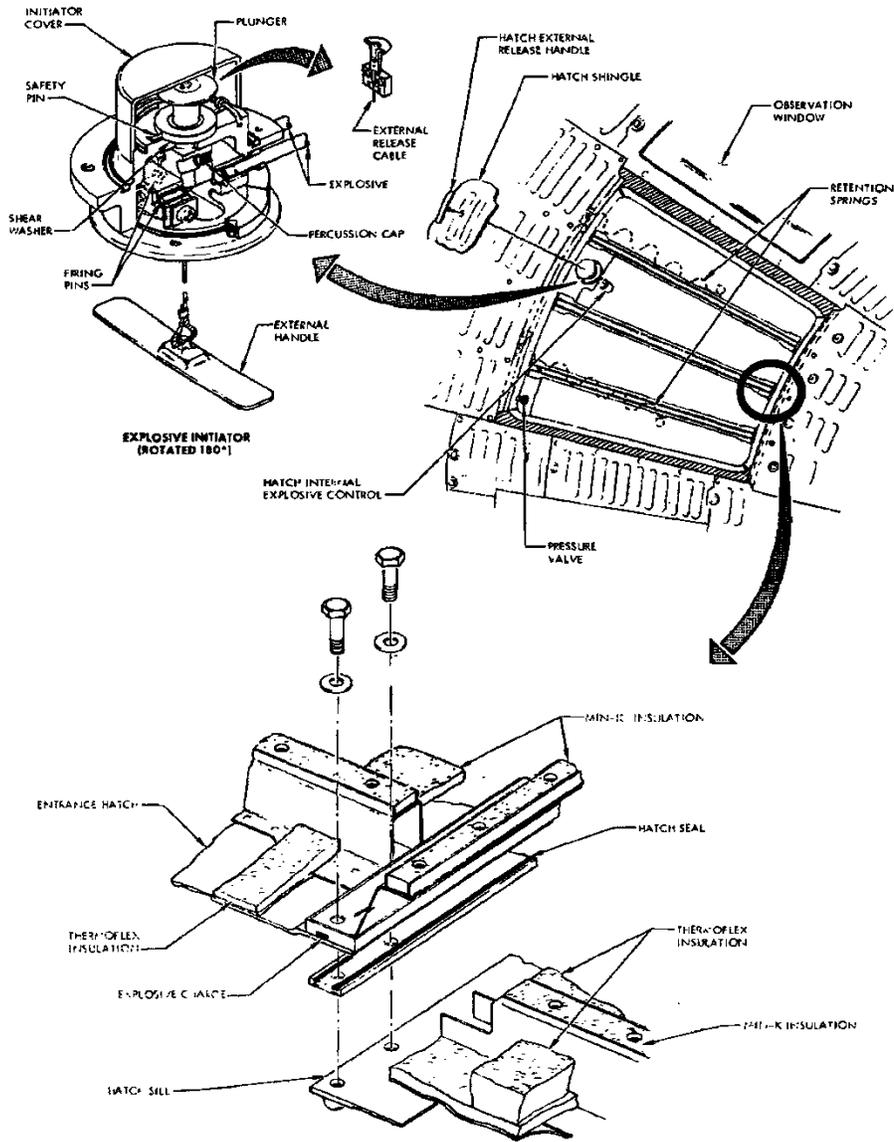
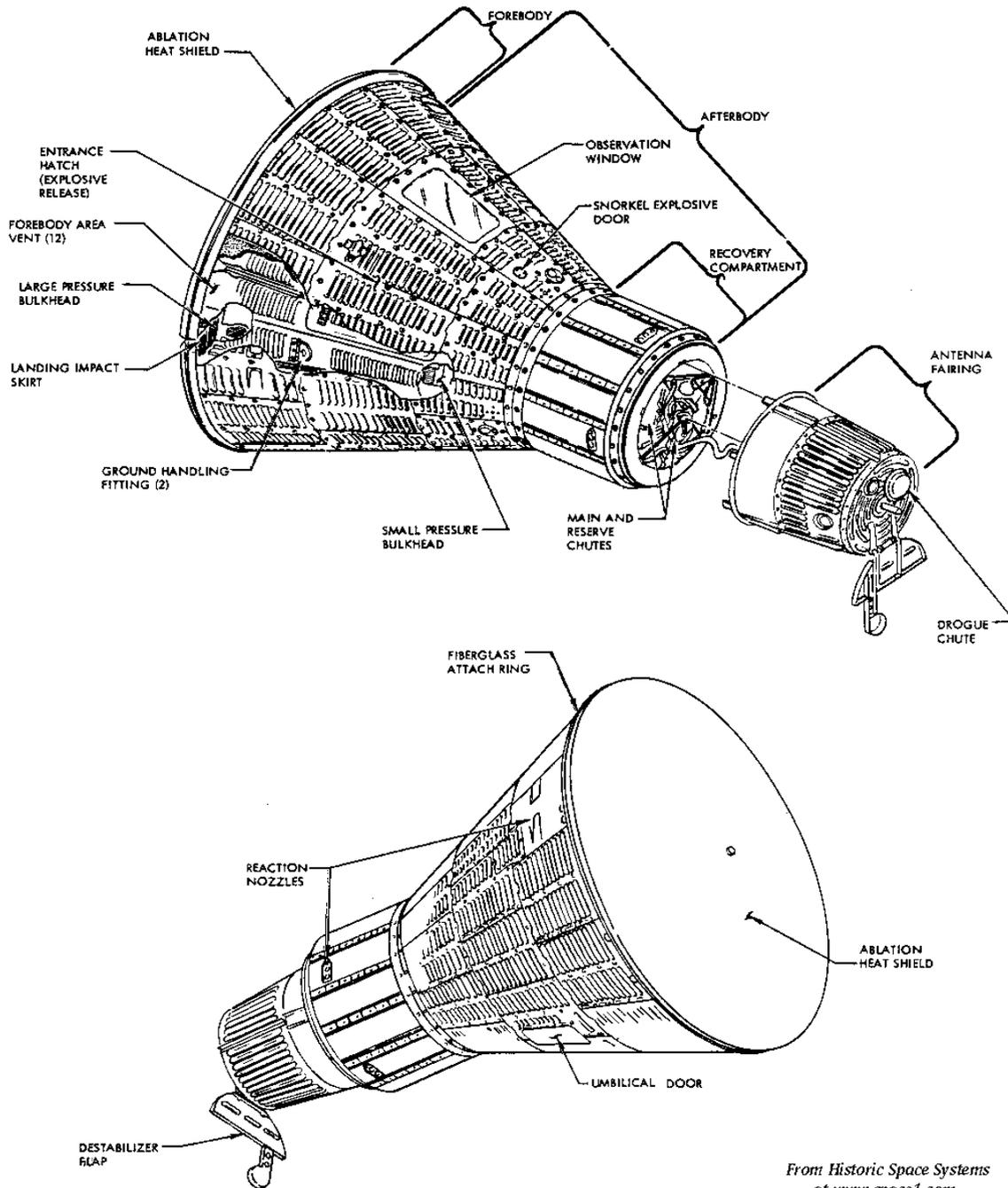


Figure 1. Entrance hatch.



*From Historic Space Systems
at www.space1.com*

Figure 2. Entrance hatch (exterior).

1.1.2 Escape hatch

“A sealed escape hatch [fig. 3], internally actuated, is provided in the small pressure bulkhead to enable the astronaut’s exit following spacecraft landing. The dish-shaped escape hatch is constructed of a beaded aluminum skin [that is] spot welded to an inner skin, that is reinforced with structural ‘Z’ shaped members.

“The hatch outer flanged edge fits into the small pressure bulkhead sill and is held in place with a retaining ring. By raising the hatch handle, the retainer ring is expanded, which wedges the retainer ring between the bulkhead sill and the hatch flanged edge. This forces the hatch flange aft to provide a sealing action.”¹



SEDR 104-18

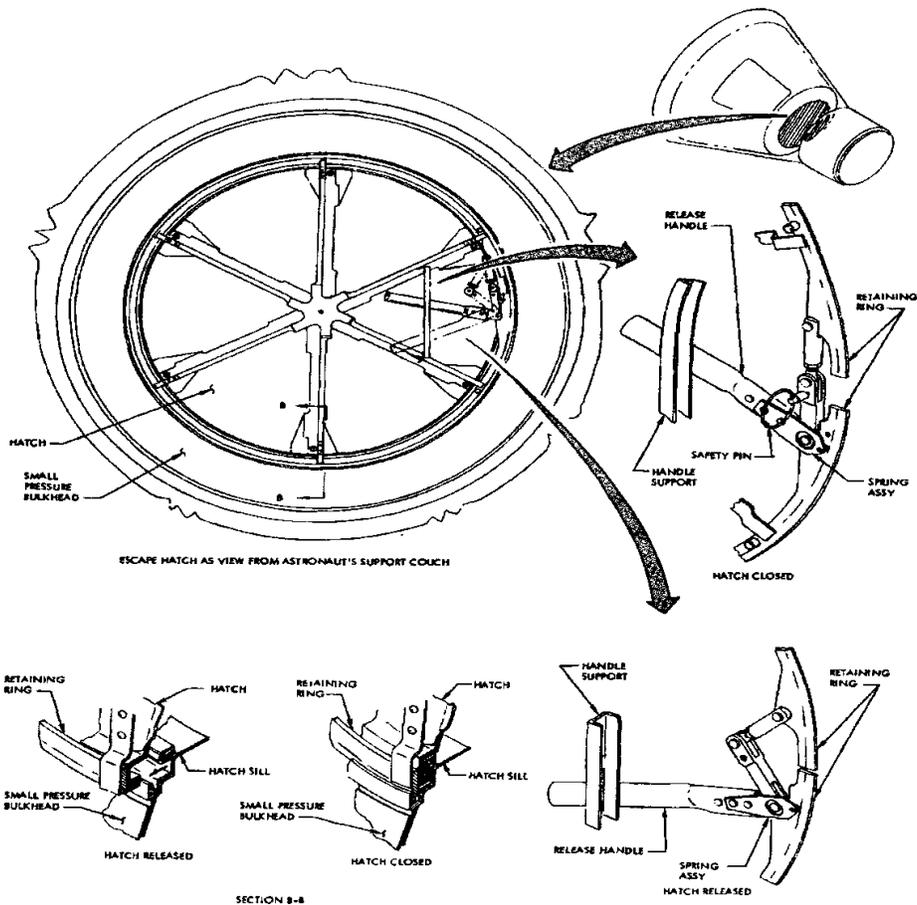


Figure 3. Sealed escape hatch.

1.2 Gemini

The Gemini Program was the second U.S. human spacecraft program. It was designed for rendezvous, docking, and extravehicular activity (EVA). The Gemini Program successfully completed 10 piloted missions. The crew consisted of a Command Pilot and Pilot. Design modifications included separate outward opening ingress and egress hatches.

1.2.1 Hatches

“Two large structural hatches, [fig. 4], are incorporated for sealing the cabin ingress or egress openings. The hatches are symmetrically spaced on the top side of the cabin section. Each hatch is manually operated by means of a handle and a mechanical latching mechanism; the hatches are hinged on the outboard side. In an emergency, the hatches are opened in a

three sequence operation employing pyrotechnic actuators. When initiated, the pyrotechnic actuators simultaneously unlock and open the mechanical latches, open the hatches and supply hot gases to ignite the ejection seat rocket catapults.

“An external hatch linkage fitting is incorporated to allow a recovery hatch handle to be inserted for opening the hatches from the outside. The recovery hatch handle is stowed on the main parachute adapter assembly; the assembly is located on the forward face of the RCS [Reaction Control System] section.

“A hatch curtain, [fig. 5], is stowed along the hinge of each hatch. After water landing, when the hatches are open, the curtains are [engaged] to help prevent water from entering the cabin.”²

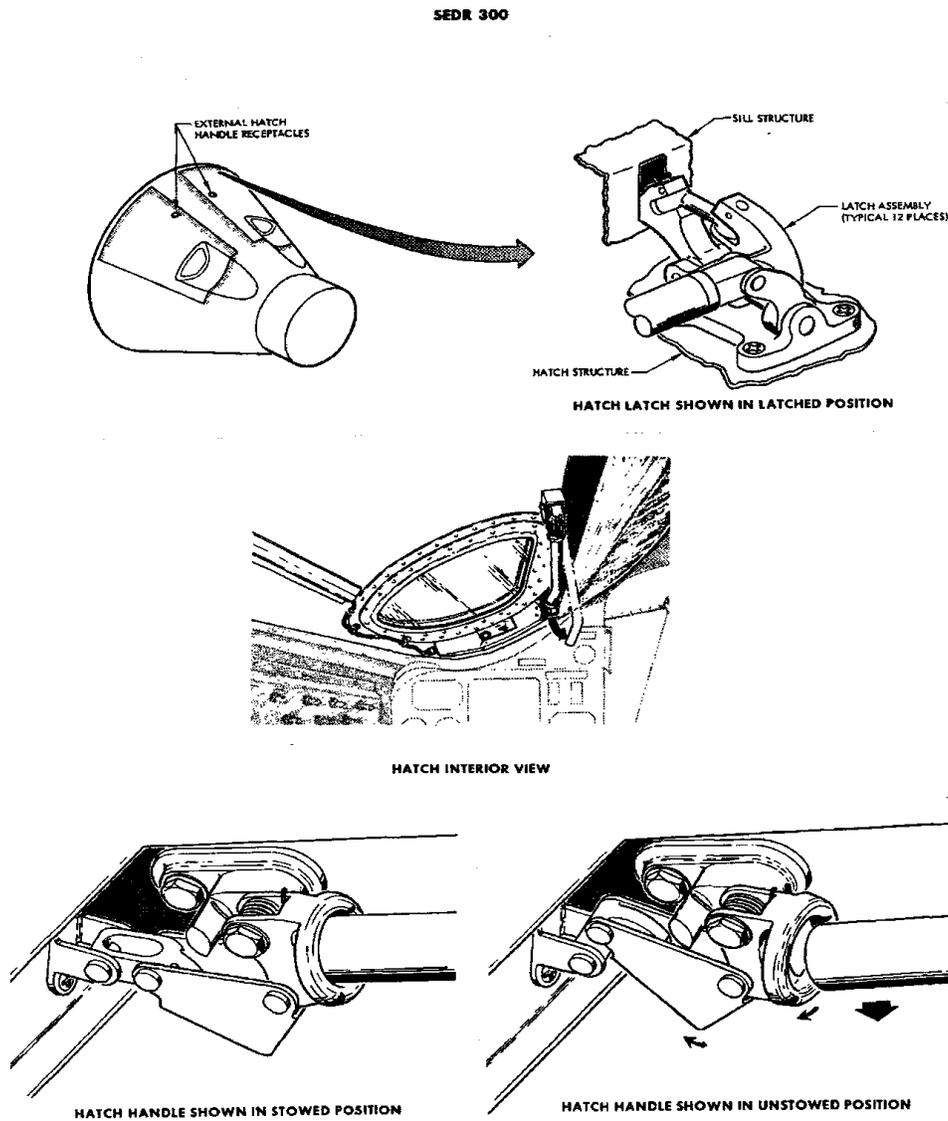


Figure 4. Structural hatches.

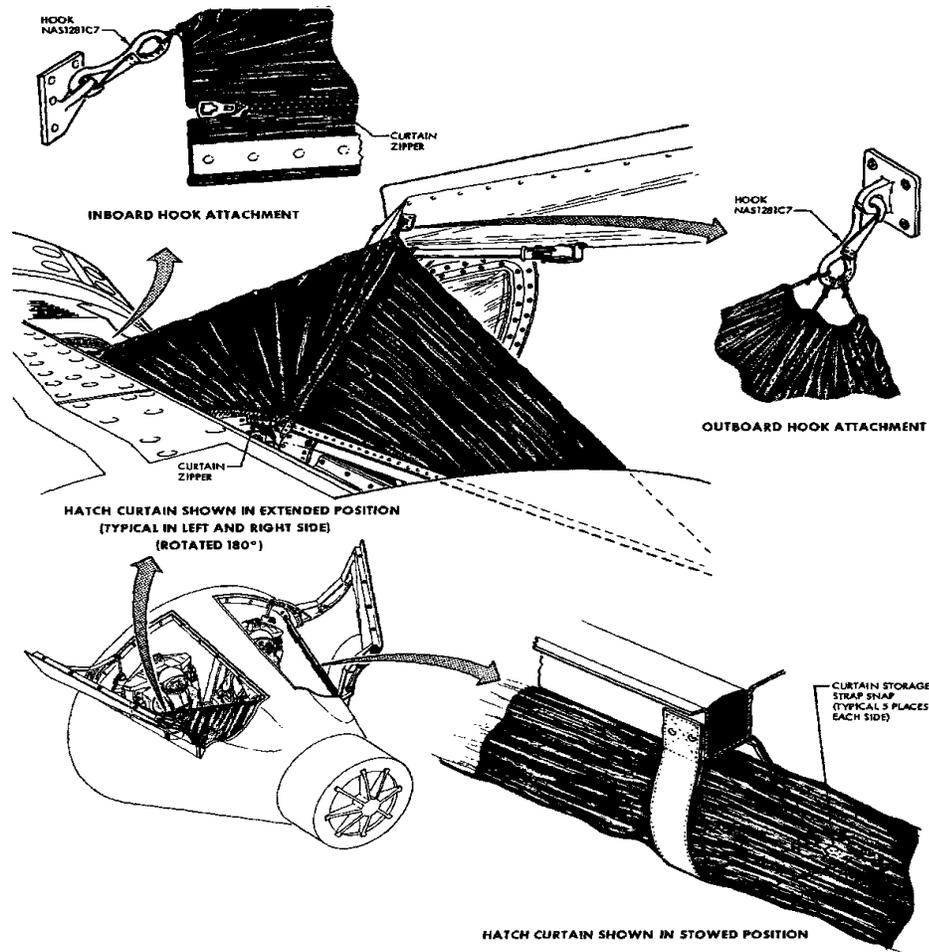


Figure 5. Hatch curtain.

1.2.2 Gemini B/Manned Orbiting Laboratory

The United States Air Force developed a Manned Orbiting Laboratory (MOL) with a modified Gemini spacecraft, Gemini B (Blue). The Gemini B was not designed to fly separately. It was launched with the crew aboard and attached to the MOL. After reaching orbit, the crew shut down the capsule systems to put them into a hibernation mode. The crew then crawled through an 0.635-m-diameter hatch in the heat shield, which led to a tunnel that accessed the MOL. After 30 days of operations, the crew returned to the Gemini B, separated from the MOL, and reentered the atmosphere. Gemini B had only 14 hours of hovering capability for autonomous operations after separation from the MOL.³

As with the original Gemini spacecraft, the two crew ingress/egress hatches were outward opening. The cabin atmosphere was changed to helium-oxygen in place of pure oxygen.

There was one crewless spacecraft flight to test the hatch in the heat shield, after which the Gemini B/MOL program was cancelled.

Figure 6 shows the heat shield hatch location. Figure 7 shows the heat shield hatch exterior, and figure 8 is a diagram contrasting the differences in the Gemini B structure with that of the Gemini.⁴

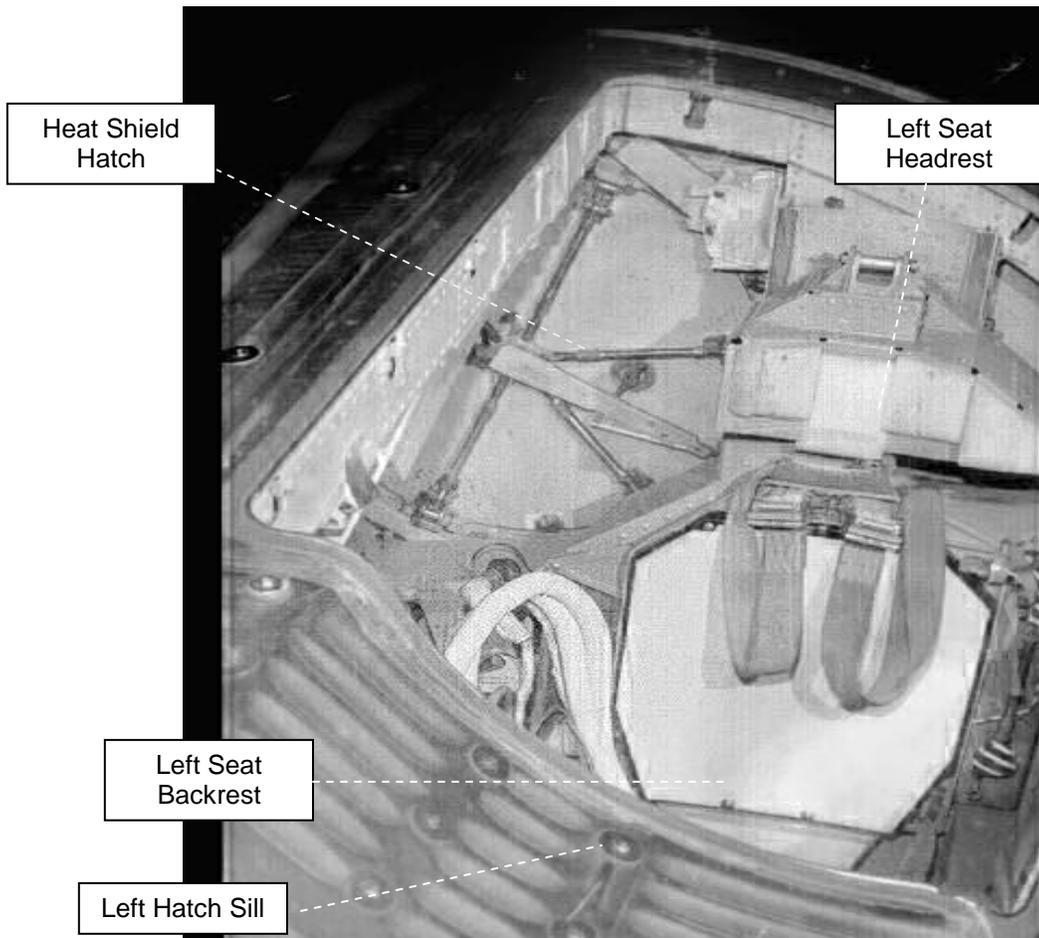


Figure 6. Gemini B heat shield hatch.

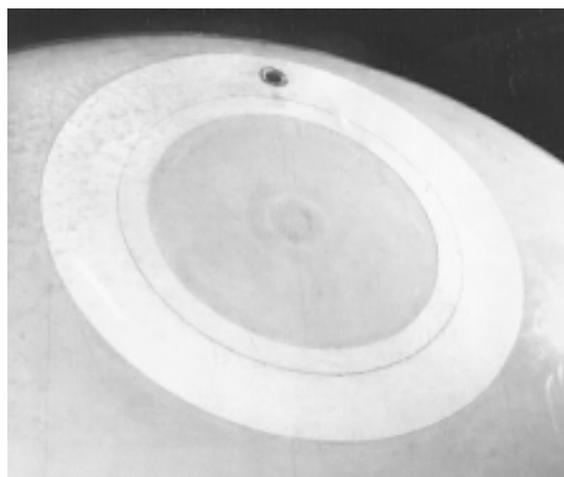


Figure 7. Gemini B heat shield hatch exterior.

1.3 Apollo

Apollo spacecraft for the crew consisted of the command and service module (CSM) and a lunar module (LM). The LM was configured with a Commander, a Command Module (CM) Pilot, and an LM Pilot. The Apollo Block 1 spacecraft was designed to orbit the Earth; the Block 2 spacecraft was designed for the lunar mission.

1.3.1 Block 1 command module side hatch

“The original hatch [fig. 9] consisted of three doors: an inner structure (main) hatch; a middle heat shield hatch; and a lightweight outer hatch hinged to the Boost Protective Cover, which was jettisoned with the escape system shortly after launch. The inner and middle hatches had to be manually unlocked and removed to egress. The hinged outer hatch was unlocked by striking a plunger through the middle hatch that unlocked the outer hatch latches. Under good conditions the crew could unlock the doors, remove them, and egress in 60 to 90 seconds.”⁵

1.3.2 Block 2 command module side hatch

After the Apollo fire, “the crew egress requirements were drastically changed.”⁵ The timeline was improved to ensure the crew could open the hatch in 3 seconds and egress within 30 seconds. Other design requirements were dictated by schedule constraints such as: modifications to the existing spacecraft structure were to be minimal and welding to the spacecraft structure would not be permitted.

“The selected design combined the inner and middle hatches into a ‘unified’ hatch [fig. 10]. The outer hatch, part of the Boost Protective Cover, was only slightly modified.

“The unified hatch mounted 15 latches linked together around the hatch perimeter. The latches applied enough force from inside the hatchway to seal the hatch. A ratchet handle allowed the crew to open or close the latches in five strokes of the handle. The handle also triggered a striker plunger to unlock the outer hatch latches (while the Boost Protective Cover was still attached).

“A counterbalance improved the opening time in emergency situations. Once the latches were unlocked, a cylinder was pressurized with gaseous nitrogen that activated a piston to force the combined 350 pound hatch open, and lock it into position. The total weight added by the new design was 253 pounds.”⁵

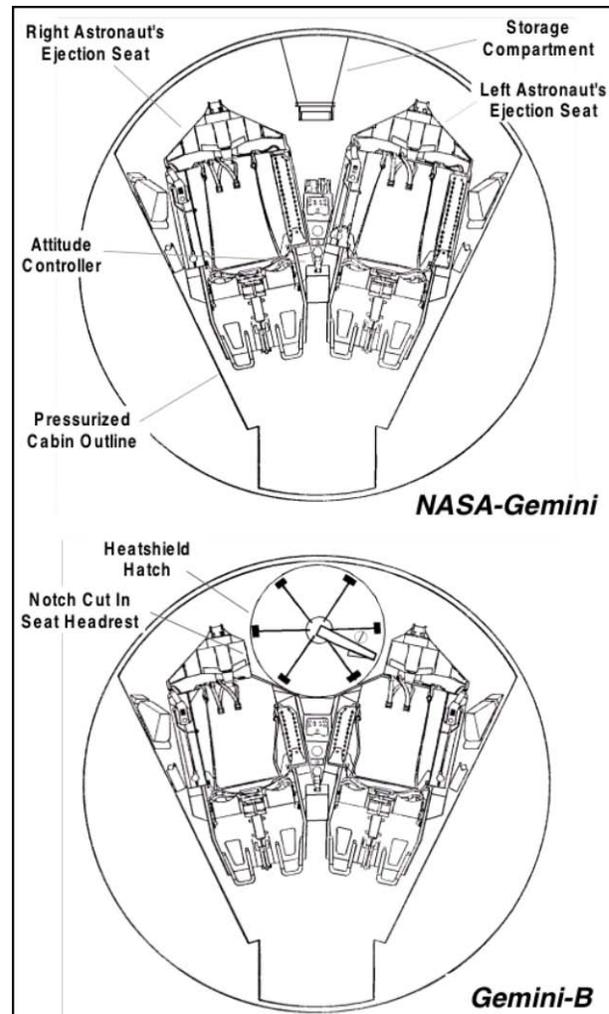


Figure 8. Differences in Gemini and Gemini B.

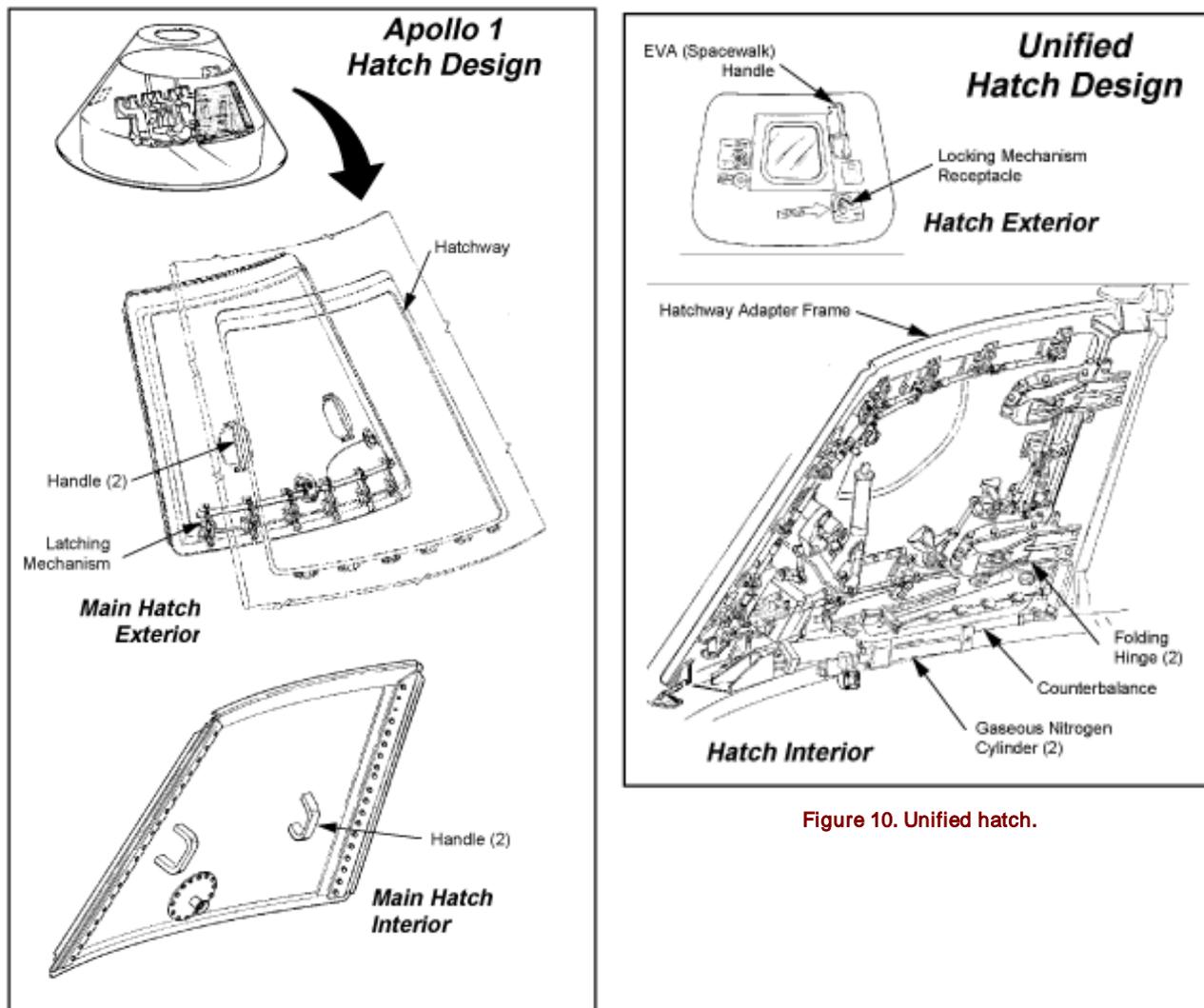


Figure 10. Unified hatch.

Figure 9. Block 1 command module side hatch.

1.3.3 Block 2 command module docking/transfer hatch

The forward docking hatch was mounted at the top of the docking tunnel. It was 30 in. (760 mm) in diameter, weighed 80 lbs. (36 kg), and was constructed from two machined rings that were weld-joined to a brazed honeycomb panel. The exterior side was covered with 0.5 in. (12.70 mm) of insulation and a layer of aluminum foil. It was latched in six places and operated by a pump handle. At the center was a pressure equalization valve, used to equalize the pressure in the tunnel and LM before the hatch was removed.

1.3.4 Lunar module

The LM forward hatch opened inward to the right, thereby permitting the Commander to exit first. The overhead hatch opened inward to facilitate the transfer to and from the CM. Both the LM forward hatch and the overhead hatch were pressure sealing. Figures 11 and 12 are drawings of the LM forward and aft cabins.⁶

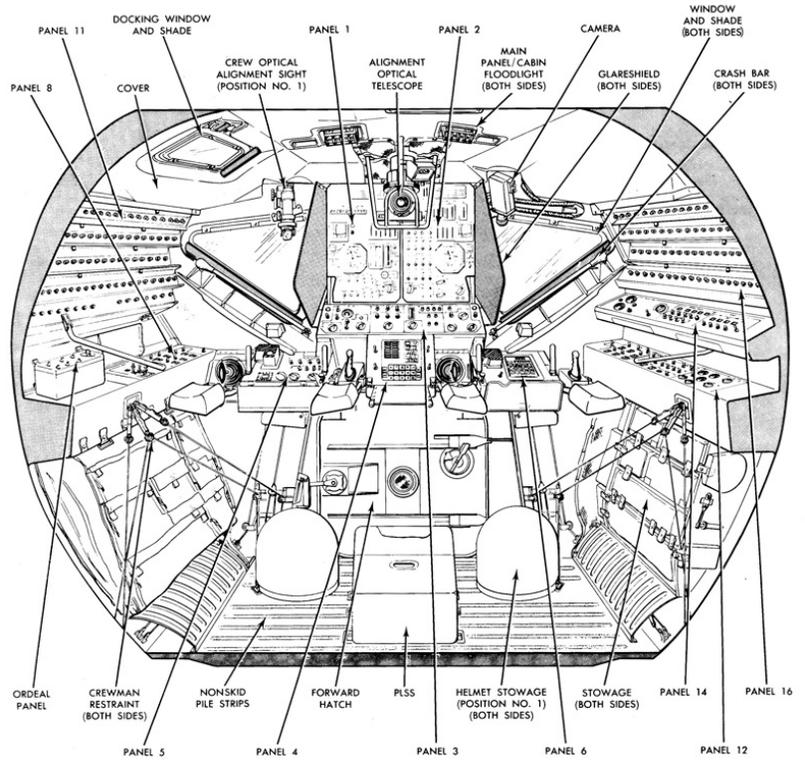


Figure 11. Apollo lunar module forward cabin.

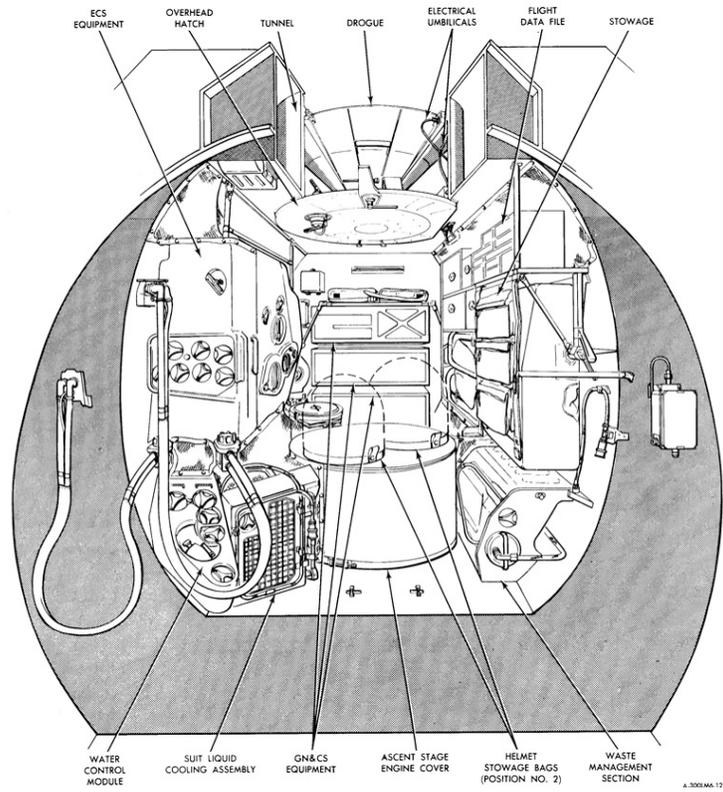


Figure 12. Apollo lunar module aft cabin.

1.4 Skylab

The Skylab Program deployed the first U.S. space station. The Apollo CSM was modified for transporting the crew to and from the Skylab; and the Saturn V third stage; the S-IVB, was changed to become the orbital workshop. Skylab also contained four new compartments: the airlock module; the Apollo telescope mount, the multiple docking adapter (MDA), and the Saturn instrument unit (fig. 13)⁷.



Figure 13. Astronaut Joe Kerwin is shown in the hatch between the multiple docking adapter and the Apollo spacecraft.

1.4.1 Skylab command module

The Skylab CM crew hatches (side and docking/transfer) were the same as the Apollo Block 2 CM.

1.4.2 Skylab hatches

The EVA hatch in the airlock module, which was a hatch from the Gemini Program, opened outward. The crew transfer hatches in the orbital workshop, MDA, and airlock were inward-opening and pressure-sealing hatches.

1.5 Apollo-Soyuz Test Project

The Apollo-Soyuz Test Project (ASTP) involved the U.S. and the U.S.S.R. in a joint mission to dock the Apollo CSM with the Russian Soyuz and to develop a compatible docking system.

The crew atmosphere differed for each of the vehicles, which required a module to allow the crew to transfer between them. The crew atmosphere for Apollo was 5 pounds per square inch (psi) pure oxygen; and, for Soyuz, the cabin atmosphere was air at a pressure of 1 atmosphere. The U.S. docking module (DM) was designed and developed to provide for crew transfer.

1.5.1 Apollo-Soyuz Test Project command module

The ASTP CM crew hatches (side and docking/transfer) were the same as those of the Apollo Block 2 CM.

1.5.2 Apollo-Soyuz Test Project docking module

The DM (figs. 14 and 15) contained crew hatches for docking and crew transfer (CSM/DM docking and DM/Soyuz docking). The modified CM forward hatch was used for the DM crew transfer hatches. Both DM hatches opened inward and were pressure sealing.⁸

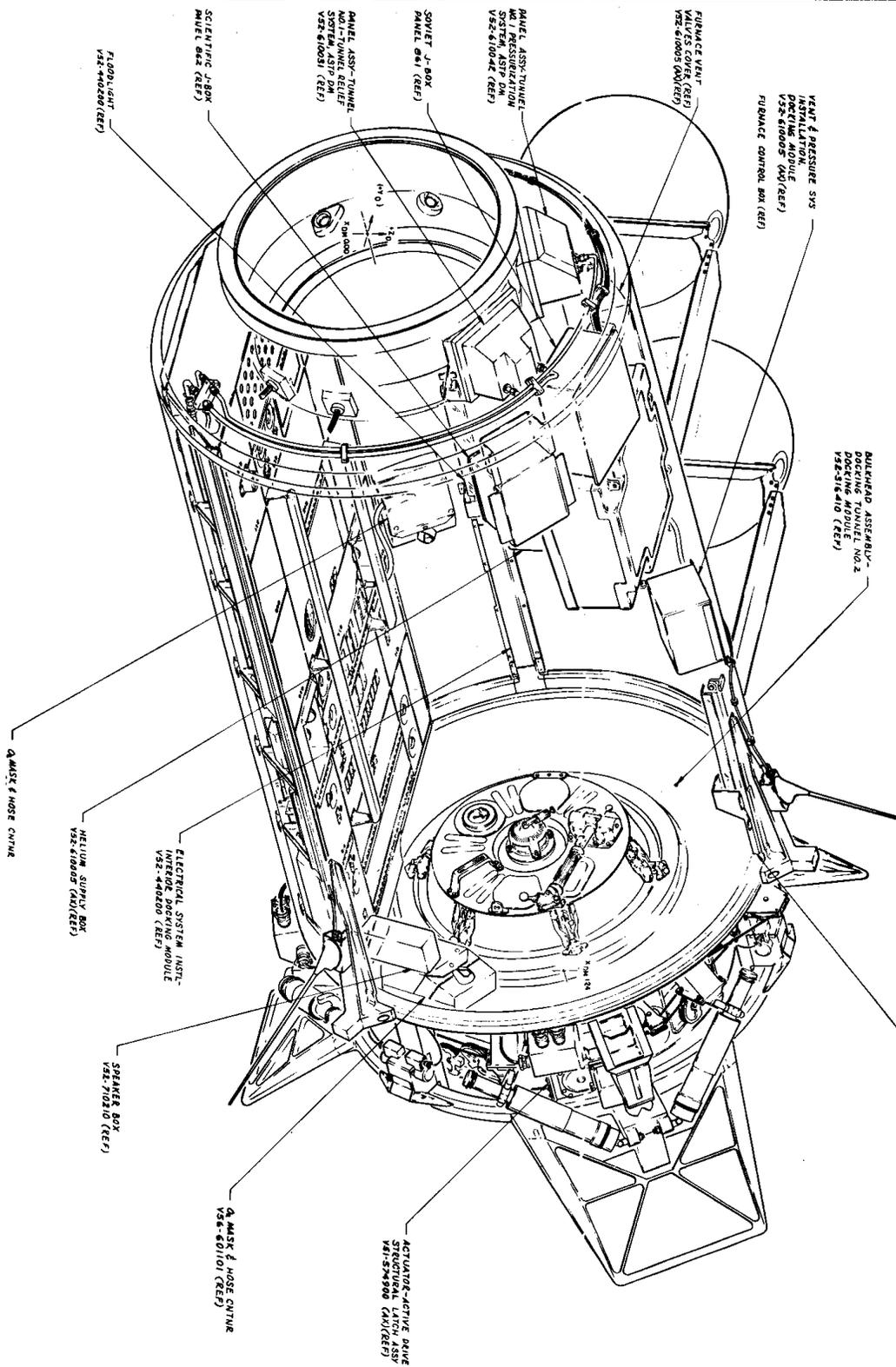


Figure 14. Apollo-Soyuz Test Project docking module (image 1).

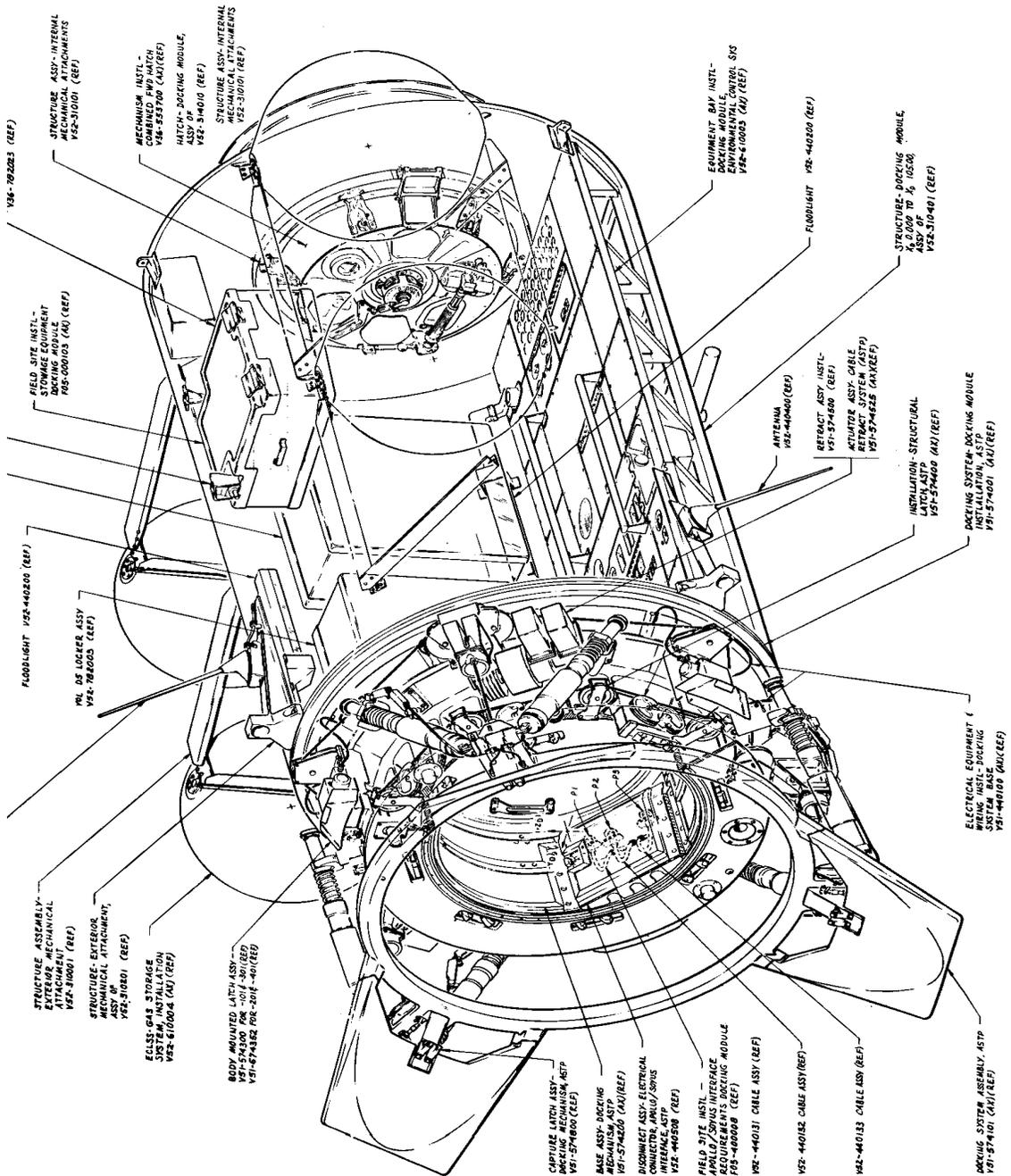


Figure 15. Apollo-Soyuz Test Project docking module (image 2).

1.6 Space Shuttle Orbiter

1.6.1 Orbiter side hatch

The side hatch for crew ingress/egress opens outward and is equipped with pyrotechnic jettison to enable crew egress in an emergency.

1.6.2 Side hatch structure

The side hatch (fig. 16) in the middeck is used for normal crew ingress/egress and may be operated from within the crew cabin middeck or externally. It is attached to the crew cabin tunnel by hinges, a torque tube, and support fittings. The hatch opens outwardly 90° down with the orbiter horizontal or 90° sideways with the orbiter vertical. It is 40 in. in diameter and has a 10-in. clear-view window in the center of the hatch.⁹

The side hatch has a pressure seal that is compressed by the side hatch latch mechanisms when the hatch is locked closed. A thermal barrier is constructed of INCONEL® (Special Metals Corporation, New Hartford, N.Y.) wire mesh spring. A ceramic fiber braided sleeve is installed between the reusable surface insulation tiles on the forward fuselage and the side hatch. The total weight of the side hatch is 294 lbs.⁹

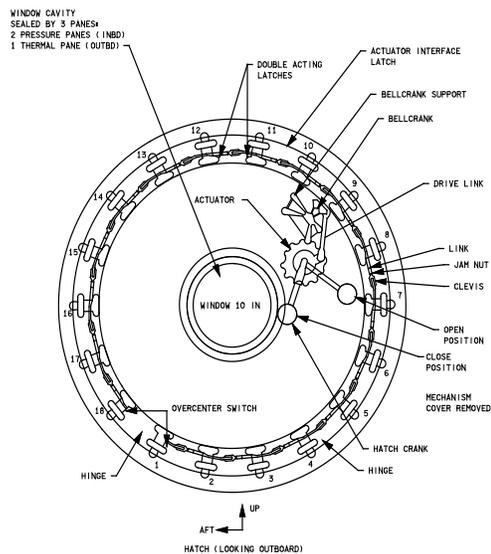


Figure 16. Side hatch assembly.

1.6.3 External airlock hatches (airlock, extravehicular activity, and docking)

Three pressure-sealing hatches are mounted on the airlock. They are designated as an inner hatch, an extravehicular (EV) hatch (fig. 17), and a docking hatch (fig. 18). The inner hatch is located on the exterior of the external airlock opening into the middeck. The inner hatch isolates the airlock from the crew cabin. The inner hatch is hinged to be pulled first into the middeck and rotated down until it rests with the low-pressure (outer) side facing the airlock floor. The hatch has a hold-open hook that snaps into place over a flange when the hatch is fully open.⁹

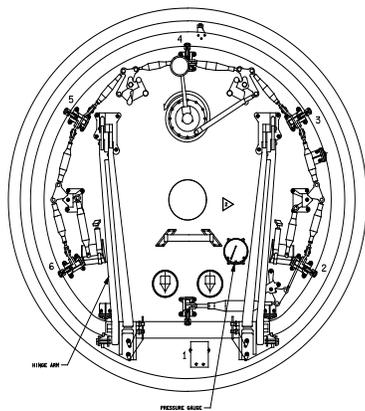


Figure 17. Typical extravehicular, B hatch assembly.

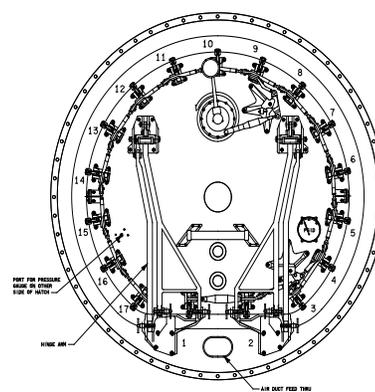


Figure 18. Typical docking, D hatch assembly.

The EV hatch isolates the airlock from the unpressurized payload bay when the hatch is closed and permits the EVA crew members to exit from the airlock to the payload bay when the hatch is open. The EV hatch of the external airlock opens in the same manner as the inner hatch. The external airlock's third hatch is an additional upper, outer hatch used for docking operations. The docking hatch, located on the top of the external airlock (toward the payload bay doors), is hinged to be pulled into the external airlock and then rotated until the low-pressure side rests against the airlock wall facing toward the nose of the orbiter. Each hatch has interconnected latches with gearbox and actuator, a window, a hinge mechanism with hold-open device, a differential pressure gauge on each side, and two equalization valves. The external airlock hatches also have hold-open protection and deployable struts for support against the airlock structure. External airlock repressurization is controlled from the middeck or inside the external airlock. It is performed by equalizing the external airlock and cabin pressure with the airlock-hatch-mounted equalization valves on the inner hatch. Depressurization of the external airlock is controlled from inside the external airlock. The external airlock is depressurized by venting its pressure overboard. The three D-shaped airlock hatches are installed to open toward the primary pressure source, the orbiter crew cabin, to achieve pressure-assist sealing when closed. Each hatch opening is 40 in. in diameter; yet, with one side flat, the minimum dimension is 36 in.⁹

Each external airlock hatch has dual-pressure seals to maintain the external airlock's pressure integrity. One seal is mounted on the external airlock hatch and the other seal on the external airlock structure. A leak check quick disconnect is installed between the hatch and the airlock pressure seals to verify hatch pressure integrity before flight. Each airlock hatch has the following design characteristics:

- Capable of being fully locked/unlocked from either side
- Designed for 2,000 open/close cycles
- One-handed operation by astronaut in pressure suit
- Capable of opening against 0.2 psi maximum
- Latches capable of withstanding 20 g's in the +X direction
- Actuator handle load of 30 lbs. maximum⁹

The gearbox with latch mechanisms on each hatch allows the flight crew to open or close the hatch during transfers and EVA operations. The gearbox and the latches are mounted on the low-pressure side of each hatch, with a gearbox handle installed on both sides to permit operation from either side of the hatch. Some of the latches on each hatch are double-acting with cam surfaces that force the sealing surfaces apart when the latches are opened, thereby acting as crew-assist devices. To latch or unlatch the hatch, the gearbox handle must be rotated 440°. The hatch actuator/gearbox is used to provide the mechanical advantage to open and close the latches. The hatch actuator lock lever requires a force of 8 to 10 lbs. through an angle of 180° to unlatch the actuator. A minimum rotation of 440° with a maximum force of 30 lbs. applied to the actuator handle is required to operate the latches to their fully unlatched positions. The hinge mechanism for each hatch permits a minimum opening sweep into the airlock or the crew cabin middeck.⁹



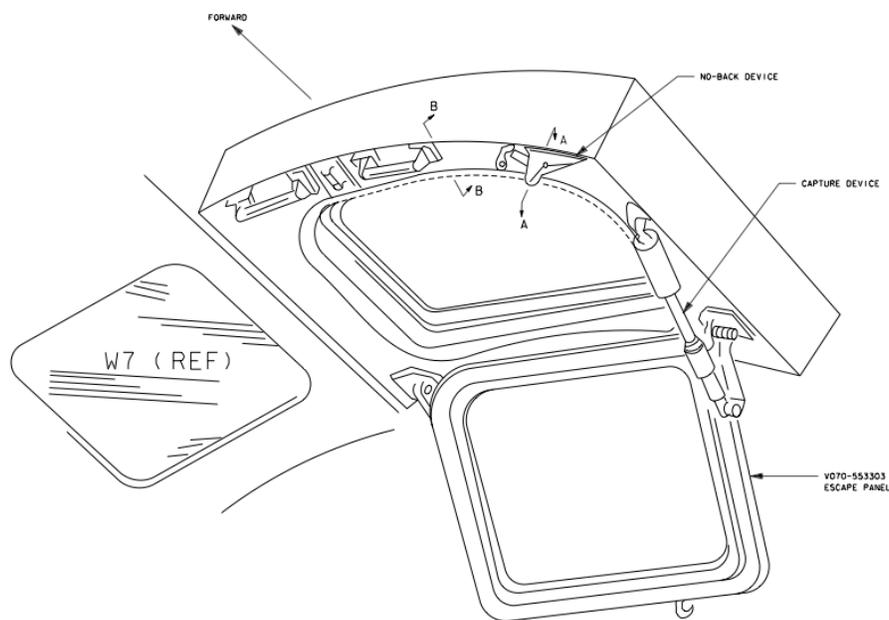
During the STS-80 mission, November 1996, a loose screw in the gearbox was the cause for the jammed hatch that led to the cancellation of two EVAs on *Columbia* (fig. 19).

Figure 19. Jammed hatch from loose screw.

1.6.4 Overhead escape panel

The portside flight deck overhead window 8 (fig. 20) provides the flight crew with a secondary emergency egress route in the event an egress through the side hatch is not possible. The overhead window consists of three panes of glass: two panes are attached to the crew compartment, and one pane is attached to the upper forward fuselage. The overhead window jettison system consists primarily of expanding tube assemblies, mild detonating fuses, frangible bolts, and associated initiators. Pulling the ring handle, located forward of the flight deck center console (C3), activates the overhead window jettison system. When initiated, the outer pane is jettisoned upward and aft. A time delay in the pyrotechnic firing circuit delays the initiation of the opening of the inner pane 0.3 sec after the outer pane is jettisoned. The inner window pane rotates downward and aft into the crew compartment aft flight deck on hinges located at the aft portion of the window frame. A capture device attenuates the opening rate and holds the window in position. This overhead window jettison system can also be initiated by ground personnel from outside the orbiter on the starboard side of the forward fuselage.⁹

Crew members use the Mission Specialist 2 (Seat 4) to climb up through the window. Seven emergency ground descent devices (SKY GENIES[®] [Descent Control, Inc., Fort Smith, Ark.]) are stowed on the overhead aft flight deck outboard of each overhead window, one for each flight crew member. The emergency ground descent device enables crew members to lower themselves to the ground over the starboard side of the orbiter.⁹



INNER WINDOW OPERATION

- WHEN CABIN TO ATMOSPHERE $\Delta P \leq 0.25$ PSID, THE WINDOW OPENS AND THE CAPTURE DEVICE HOLDS THE WINDOW FULL OPEN FOR EGRESS.
- WHEN CABIN TO ATMOSPHERE $\Delta P > 0.25$ PSID, AND ≤ 0.44 PSID, THE WINDOW OPENS AND THE NO-BACK DEVICE ENGAGES TO PREVENT SUBSEQUENT WINDOW CLOSING DURING CABIN PRESSURE EQUALIZATION.
- WHEN CABIN TO ATMOSPHERE $\Delta P > 0.44$ PSID, THE WINDOW WILL NOT OPEN FAR ENOUGH TO ENGAGE THE NO-BACK DEVICE. THE PRYBAR MUST BE USED TO PRY THE WINDOW OPEN TO ENGAGE THE NO-BACK DEVICE AND ALLOW CABIN PRESSURE EQUALIZATION.
- AFTER CABIN PRESSURE EQUALIZATION, THE WINDOW WEIGHT (150 LB) WILL OPEN THE WINDOW.

Figure 20. Overhead escape panel.

1.7 International Space Station

1.7.1 Russian segment

The Russian segment of the International Space Station (ISS) consists of the Functional Cargo Block (FCB), also known as Zarya; it is the first ISS module launched and developed by the Khrunichev Space Research and Production Space Center (KhSC) (Moscow, Russia). The Russian service module (SM) Zvezda was the first ISS module containing crew equipment and accommodations to enable working and living on the ISS; it was developed by the S.P. Korolev Rocket & Space Corporation Energia (RSC) (Moscow, Russia). The Russian segment also has the docking compartment and airlock named Pirs (fig. 21).¹⁰

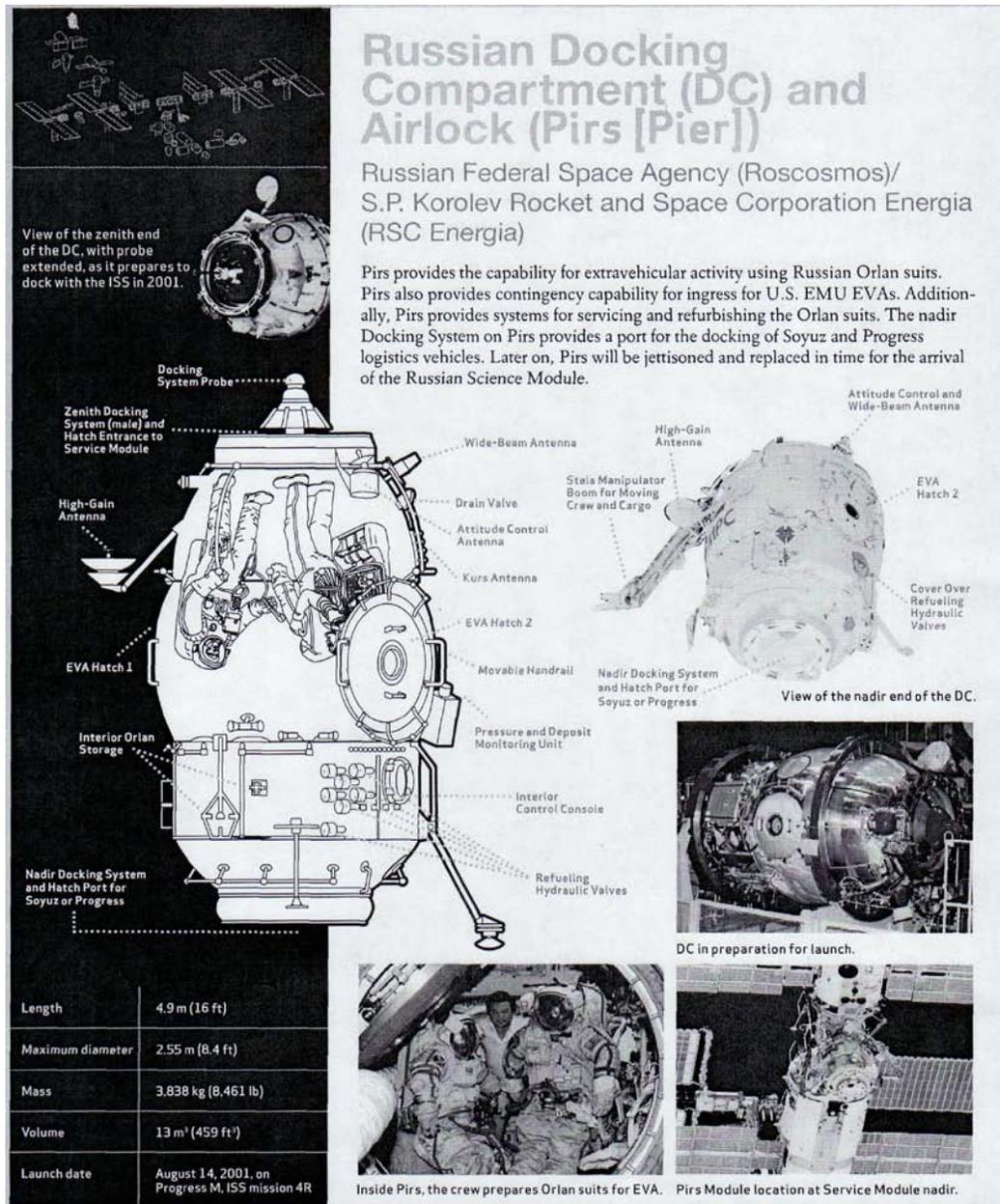


Figure 21. Russian docking compartment and airlock.

Several modules are to be launched in future. Mini-Research Module 2 (MRM 2) is to be carried on a Progress flight and docked to the Russian SM, Zvezda; the MRM 2 is very similar to Pirs. Mini-Research Module 1 (MRM 1) is a docking cargo module built from the pressurized hull of the cancelled solar power platform; it is docked to the FGB (Zarya) with two docking ports. The final module to be launched is the Multipurpose Laboratory Module (MLM). A modified KhSC-built FGB 2, it will also be docked to the Russian SM, Zvezda. The MLM will be used for experiments, docking, and cargo. All of the Russian segment docking, transfer, and EVA hatches are inward opening and pressure sealed.

Requirements for the FGB hatch device from the *Specification of Technical Requirement for the FGB*, [SSP 50128] are as follows:

“Paragraph 3.2.4.4. The hatch and seals must be accessible for inspection, maintenance, and repair by crew members.

“Paragraph 3.3.6.1.20.2. The design must permit isolation of FGB pressurized compartments within 3 minutes, including the closing of hatches.

“Paragraph 3.3.6.1.20.8. The hatch design must provide for hatch opening and closing from either side by a single crew member.”¹¹

“The hatch device consists of the hatch cover with a double-barrier rubber seal to ensure reliable sealing, a sealing mechanism, and telemetering microswitches to signal the closed position of the hatch device.”¹¹

“The main characteristic of the hatch device are the hatch inside diameter at 800mm; the hatch cover opening angle at 105°; sealing mechanism opening time at 2 seconds; cover withdrawal time at 5 seconds; weight at 25 kg; and operating life cycle at 300 cycles.”¹¹

“To ensure reliable operation, when the hatch is open the rubber seals are covered by a protective guard ring. The hatch cover can be opened and closed from either side by a single crew member.”¹¹

“The hatch cover design, the crosspieces, the sealing mechanism, and the microswitches are prototypes of analogous assemblies of the internal hatch device of the Kvant-2 module.”¹¹

“The design of the double-barrier rubber seal is analogous to the design of the seal of the exit hatch of the Kvant-2 module, whose operation has been tested in space during many EVA's by crew members.”¹¹

1.7.2 U.S. segment

The first U.S. ISS module launched with the attached pressurized mating adapter (PMA) was the Node 1; named Unity, Node 1 was equipped with the common berthing mechanism and was docked to the FGB (Zarya). The U.S. Laboratory, named Destiny, expanded the crew operating workspace and was berthed to Unity. The U.S./Joint airlock, known as Quest (fig. 22),¹² was berthed to Unity. The U.S. ISS module Node 2, called Harmony, was berthed to Destiny.

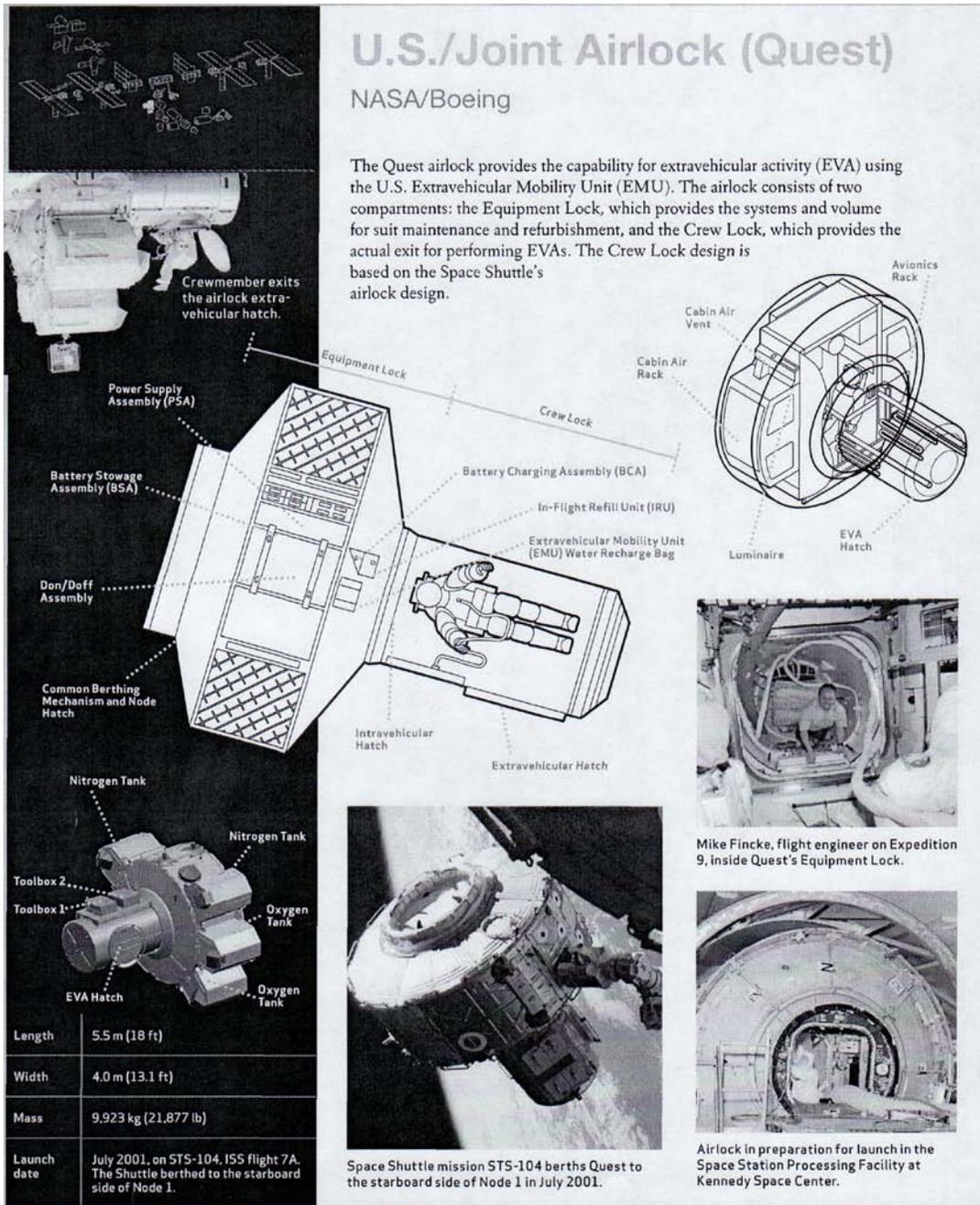


Figure 22. U.S./Joint airlock (Quest).

The European Laboratory, developed by the European Space Agency (ESA) and named Columbus (fig. 23), is considered a part of the U.S. segment and was developed by the International Partners. The Columbus module was launched on the space shuttle and berthed to Harmony.



S122E008911

Figure 23. Columbus module (interior).

the European multi-purpose logistics module (MPLM) Raffaello.

All U.S. segment berthing and transfer hatches, referred to as the U.S. Orbital Segment (USOS) standard hatch, are inward opening and pressure sealed. See figures 25 and 26 for drawings of the outer and inner hatch assemblies.¹³

The Japanese Experiment Logistics Module developed by Japan Aerospace Exploration Agency (JAXA), Kibo (fig. 24), is included in the U.S. segment; it was launched on the space shuttle and berthed to Harmony. The Japanese Kibo pressurized module was launched on the space shuttle and temporarily berthed to Node 2 (Harmony); its permanent home is on the Japanese laboratory, Kibo.

A future scheduled launch is planned for Node 3, Tranquility; Node 3 will have the cupola attached and be berthed to Unity. The final U.S. Segment module scheduled for launch will be the permanent logistics module (PLM), which is planned to be



Figure 24. Kibo pressurized module.

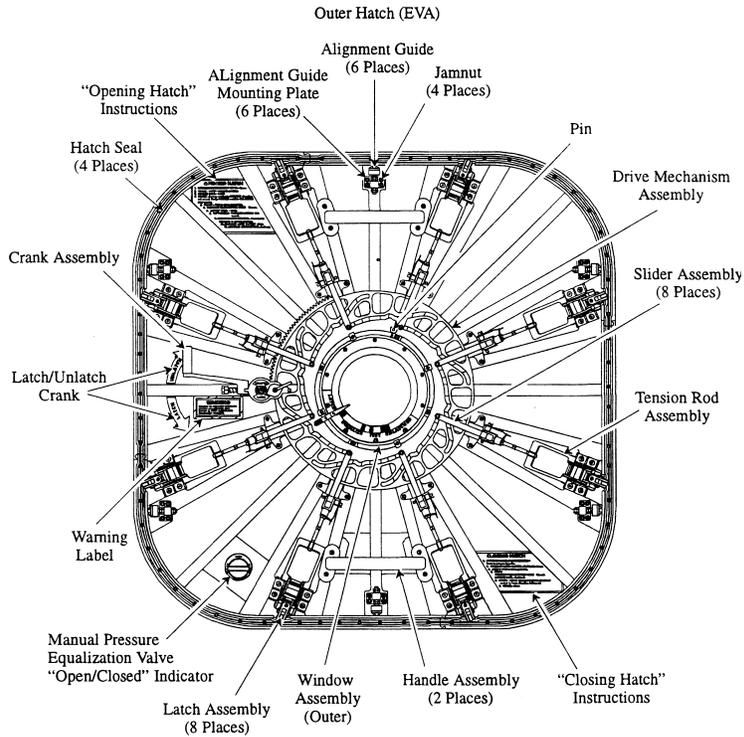


Figure 25. Outer hatch assembly.

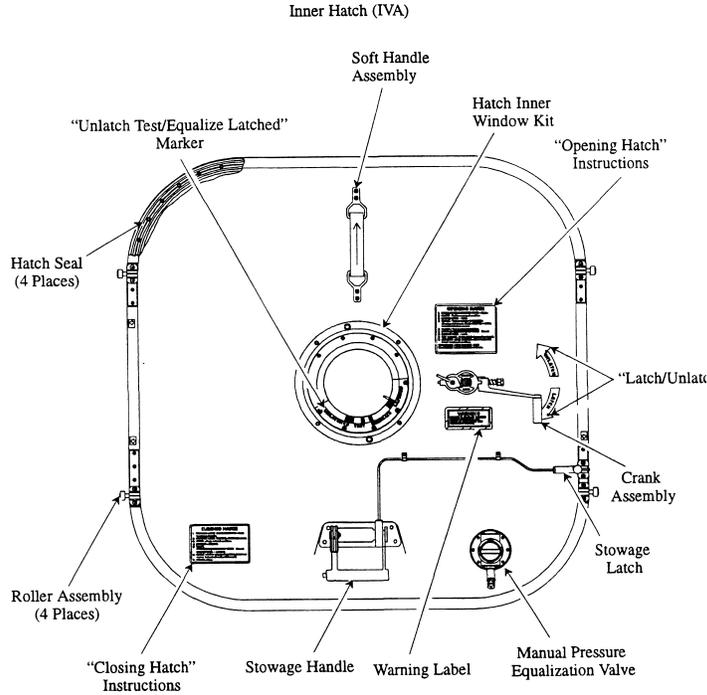


Figure 26. Inner hatch assembly.

1.7.3 Automated Transfer Vehicle European

The Automated Transfer Vehicle (ATV) (fig. 27) is an ISS logistics and resupply vehicle manufactured by ESA. It is launched on the European Arian and automatically docks to the Russian SM (Zvezda) aft docking port. The docking and transfer hatch is the same as the Russian docking and transfer hatch, using the same hatch tool for opening and closing. The hatch is inward opening and pressure sealed.



Figure 27. Automated Transfer Vehicle.

1.7.4 H-2 Transfer Vehicle Japanese cargo vehicle

The H-2 Transfer Vehicle (HTV) (fig. 28)¹⁴ is launched on the Japanese H-2B [rocket] and berthed to the U.S. Harmony module. The HTV uses the USOS standard berthing and crew transfer hatch, and is inward opening and pressure sealing.

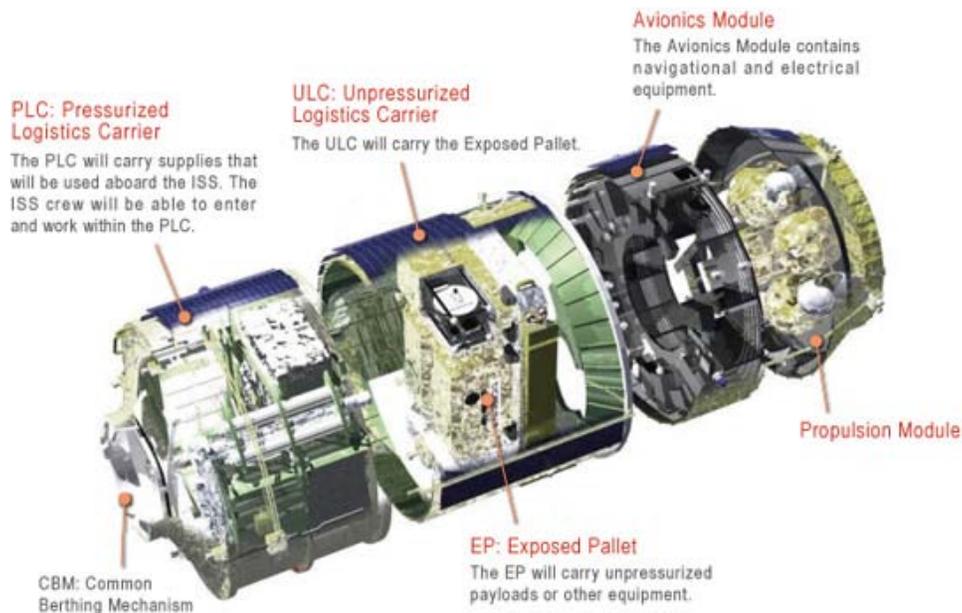


Figure 28. H-2 Transfer Vehicle.

2.0 History of Russian Spacecraft Crew Hatches



Figure 29. Vostok.

2.1 Vostok

Vostok (fig. 29) was the first spacecraft to launch a human to orbit. It had one entry hatch that was pyrotechnically jettisoned when the crew member ejected before landing.

2.2 Voskhod

Voskhod was a modification of Vostok that allowed a crew of three or two for EVA. The ejection seat was removed and the entry hatch was converted to an inward-opening and pressure-sealed hatch. For the EVA mission, an external inflatable airlock was attached over the Vostok entry hatch. The airlock, called Volga, and the EVA hatch opened inward and was pressure sealed. During the Voskhod mission, two EVA crew members had trouble closing the EVA hatch.

2.3 Soyuz

The Soyuz spacecraft (fig. 30) was built after the Voskhod and was part of the Russian Lunar Program. The Soyuz TMA [transportation modified anthropometric] is the present version used for ISS. It contains upgraded avionics, software, and increased size to accommodate larger number of crew members. The descent module crew ingress/egress hatch is inward opening and

pressure sealed; the hatch is also the transfer path to the attached orbital module (OM). The OM also has a docking/transfer hatch and a crew entry/exit hatch that serves as an EVA hatch. Both crew hatches are inward opening and pressure sealed. The transfer hatch is opened and closed manually with a removable crank handle. An outward-opening fairing hatch is used to enter or exit the Soyuz OM when the Soyuz is on the launch vehicle.

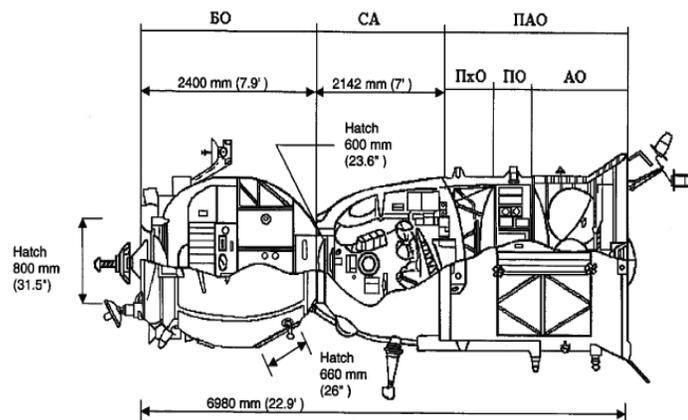


Figure 30. The Soyuz spacecraft.

BO – Orbital Module	ПхО – Intermediate Compartment
CA – Descent Module	ПЮ – Instrumentation Compartment
ПАО – Instrumentation/Propulsion Module	АО – Propulsion Compartment

2.4 Progress

Progress is an uncrewed expendable resupply spacecraft. It was derived from Soyuz to resupply the ISS, and was originally used to resupply the Salyut and Mir space stations. The docking and transfer hatch, the same as that of the Soyuz, is inward opening and pressure sealed.

2.5 Almaz

The Almaz (fig. 31), also referred to as TKS, was a military space station project built by what is now called KhSC; it consisted of a TKS-FGB and a crewed transport spacecraft called TKS-VA (fig. 32)¹⁵. The TKS-VA, developed during the U.S. Gemini B/MOL program, had a crew transfer hatch located in the descent capsule heat shield (fig. 33).¹⁶ The heat shield hatch and the crew ingress/egress side hatch opened outward. Only uncrewed TKS-VA test flights were made. The Salyut 2 mission was the first launch of military space station Almaz TKS. It was given the designation Salyut 2 to conceal its true nature, as it was not really a part of the same program as the other Salyut stations. This mission used the Soyuz crew spacecraft as the TKS-VA was still in development.

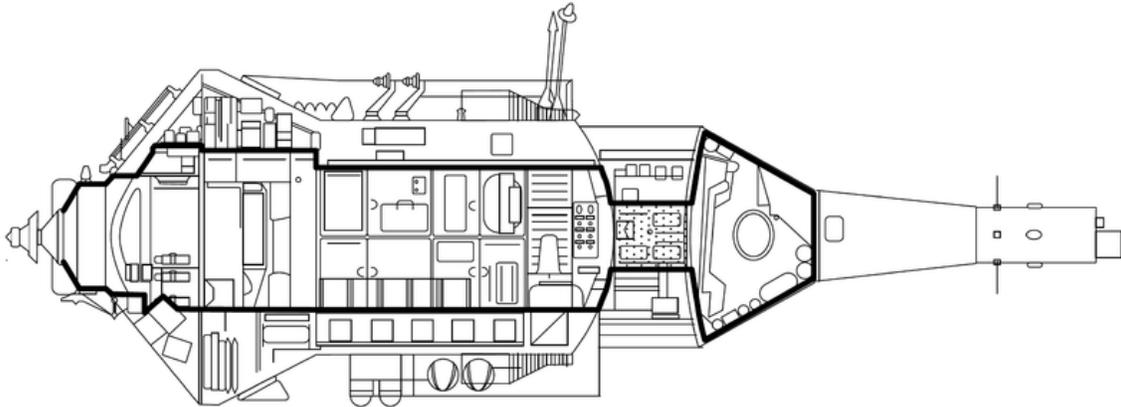


Figure 31. Almaz TKS-FGB.



Figure 32. Almaz TKS-VA.

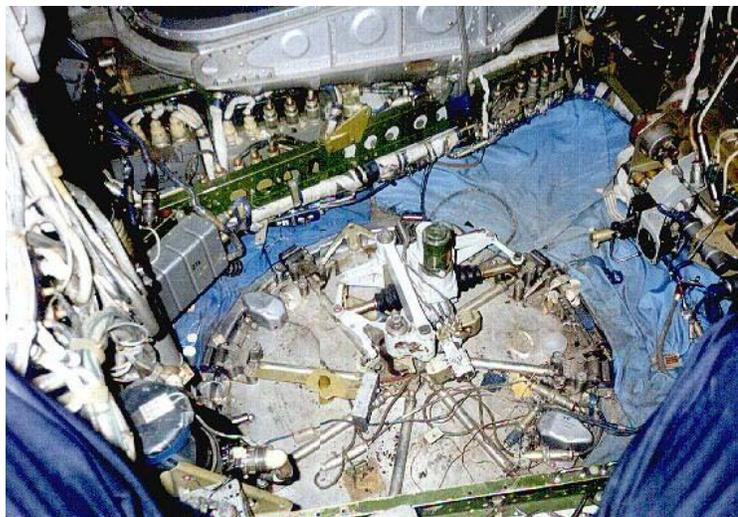


Figure 33. Almaz TKS heat shield hatch.

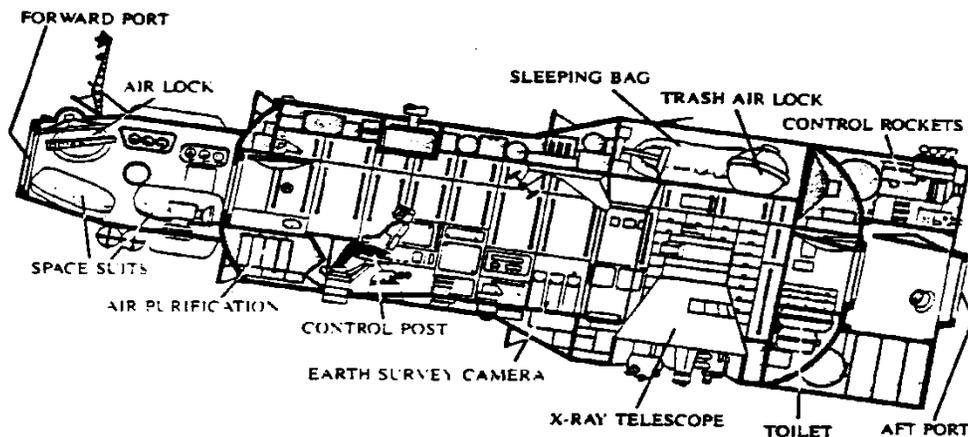
2.6 Salyut

The Salyut (fig. 34),¹⁷ the first space station program undertaken by the Soviet Union, consisted of a series of nine single-module space stations launched over a period of 11 years from 1971 to 1982. Salyut, which was developed by what is now called RSCE, was based on the design of a military station module, the Almaz. It initially had one docking port used for crew ingress and egress; the hatch was inward opening and pressure sealed. The Salyut was later modified to have two docking ports, but was equipped with the same type of inward opening and pressure sealed hatch.

SOVIET SPACE STATION ANALOGS, Ed. II
Mir 1.0

1.1 GENERAL LAYOUT AND DESIGN OF SPACECRAFT SYSTEM

A. Basic Characteristics of Salyut*:



-Length:	13-15 m
-Width:	4 m
-Volume:	90-100 m ³ usable volume
-Weight:	18,900 kg
-Diameter (maximum):	4.15 m
-Largest room:	Working compartment, 40 m ²
-Solar generator:	
--Surface area	60 m ²
--Power	4 KW (increased during flights to 8 KW)
-PSAI	14.7
-Accessible orbits:	
--Altitude	300-400 km
--Inclination	51.6°
--Span	17 m

*Sources vary slightly with regard to the basic characteristics of the Salyut.

Figure 34. Salyut.

2.7 Mir

The improved model of the Salyut DOS-17K space station with one aft docking port and five ports in a spherical compartment at the forward end of the station became the core module of Mir (fig. 35),¹⁸ sometimes called Base Block.¹⁹

Kvant 1 was originally designed for Salyut 7 with gyro dynes added, and the Kvant 2 module followed. It was based on the Almaz TKS transport spacecraft, which had an airlock for EVA. Kristall was later designed for payloads, experiments, and a docking system for Buran, which was used by the space shuttle orbiter. Spektr followed and was outfitted for scientific research; the DM was added for the orbiter to dock to, and the last module added was the Priroda.

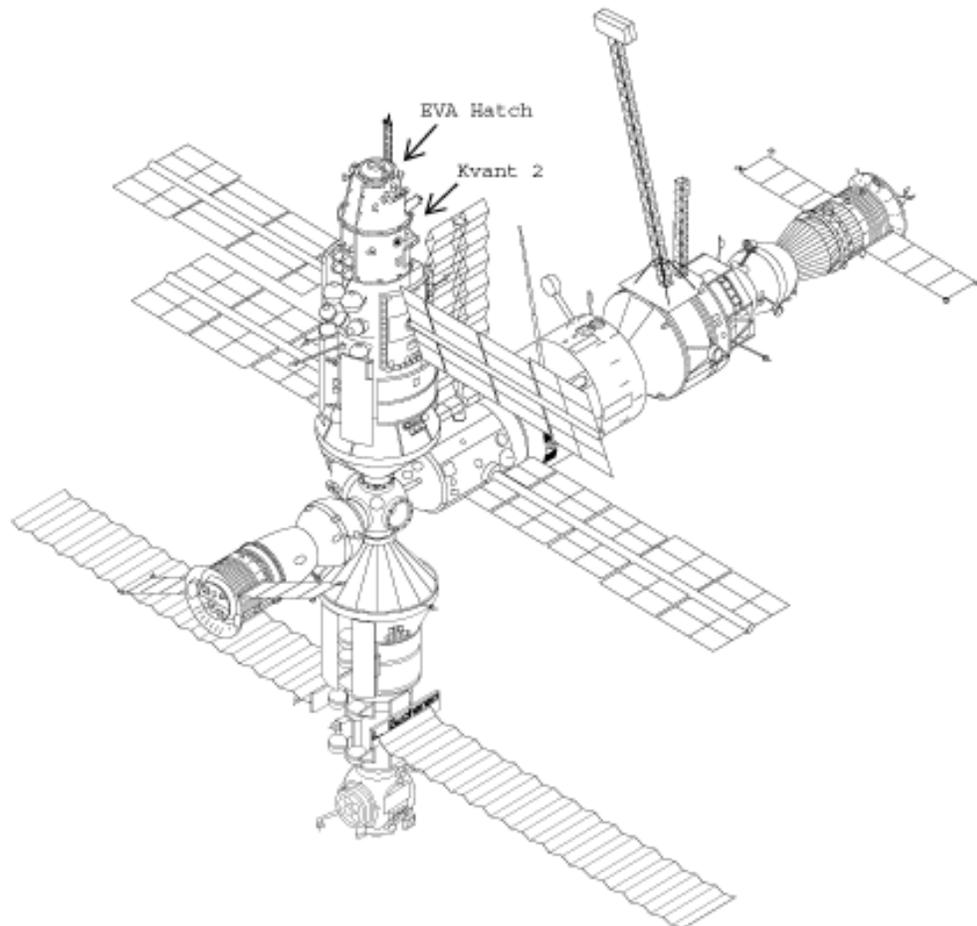


Figure 35. Mir.¹⁸

All docking and transfer hatches were inward opening and pressure sealed. The EVA hatch on Kvant 2 was an outward-opening hatch that became damaged and was unable to seal in 1990 during an EVA. It was opened when the internal airlock still had some pressure, resulting in the rapid opening that bent the hatch hinges.

2.8 Buran

The Buran (fig. 36),²⁰ designed by RSCE and built by NPO Molniya, was the first Russian spacecraft capable of multiple trips to space as it was equipped to carry and return payloads. It was developed based on the U.S. space shuttle, and, in fact, the design specifications enabled Russia to reduce the development cycle time. The shuttle's aerodynamic shape had been selected by NASA and the U.S. Air Force only after iterative analysis of different configurations from 1968 to 1972. The Russian government decree authorizing development of the Energia-Buran system was issued on February 12, 1976. The launch vehicle booster for Buran was called Energia. The only orbital launch of Buran, on November 15, 1988, required that Buran perform an automatic landing as it did not have a crew on board.

The Energia booster for Buran used liquid propellant engines instead of the solid rocket motors used on the shuttle. All of the rocket engines were on the Energia booster for the launch phase of the mission. Improvements were made to the U.S. space shuttle design that included tying the forward RCS with the aft RCS and Orbital Maneuvering System propellant. The Buran was designed for automatic capability and could accommodate heavier payloads. Maximum payload for the Buran was 30,000 lbs. as compared to 25,000 lbs. for the shuttle orbiter.

The crew ingress/egress hatch, as on the space shuttle orbiter, was located on the side of Buran. However, the hatches were an inward-opening pressure-sealing hatch and an outward opening outer hatch with thermal protection, as compared to the one unified hatch for the shuttle orbiter. The Buran, as is the U.S./space shuttle, was also fitted with an airlock hatch that opened inward and was pressure sealing to permit EVA.²⁰

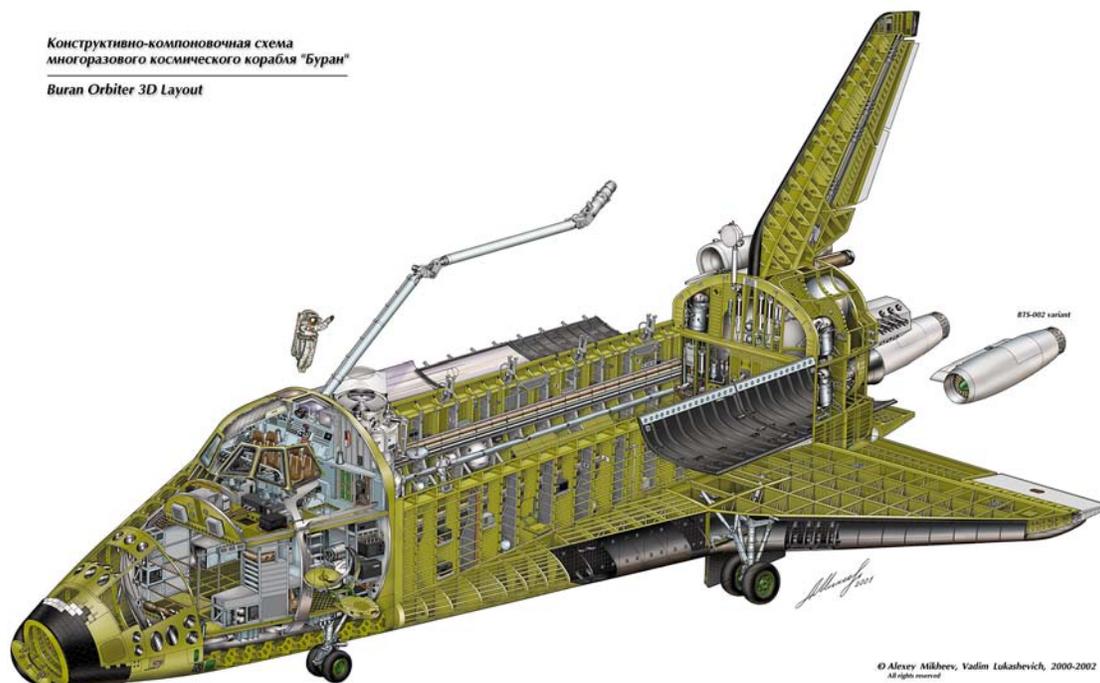


Figure 36. Buran (three-dimensional layout).

3.0 History of Chinese Shenzhou Spacecraft Crew Hatches

The Shenzhou spacecraft closely resembles Soyuz, although it is substantially larger and, unlike the Soyuz, features a powered orbital module capable of autonomous flight. Like Soyuz, Shenzhou (fig. 37)²¹ consists of three modules: a forward orbital module, a reentry capsule in the middle, and an aft SM. The reentry module has a crew of three, but is 13% larger than the Soyuz reentry capsule. The orbital module has an 80-cm-diameter EVA hatch, and photographs from the Shenzhou 7 mission show this hatch to be inward opening and pressure sealing. On that mission, the hatch opening was harder than expected.²² At the base of the orbital module is a 70-cm-diameter hatch providing access to the reentry vehicle; this compares to 60 cm with no hatch on the Soyuz orbital module base. The Soyuz 60-cm hatch was located on the reentry module compared to the 70-cm hatch on the Shenzhou reentry module. It appears that the Shenzhou hatches would all be inward opening and pressure sealing like the Soyuz. The fairing crew hatch for Shenzhou would be outward opening like the Soyuz.



Figure 37. Shenzhou.

4.0 NASA Johnson Space Center Design and Procedural Standards

Two design standard requirements for crew hatches are included in the NASA Johnson Space Center (JSC) Design and Procedural Standard, JPR [JSC Procedural Requirements] 8080.5, dated March 8, 2005. These are Standard Number MS-4, Crew Hatches, and Standard Number MS-8, Penetration of Inhabited Spacecraft Compartments. See Appendix B for details on each Standard.

5.0 Future Human Spacecraft

The future design of human spacecraft crew hatches will require a trade study to weigh the risk of designing an inward-opening hatch as compared to an outward-opening hatch. A rigorous risk analysis of conditions or hazards that can potentially create a need for emergency crew egress or emergency ingress of ground personnel for the pre-launch and post-landing time periods must be performed. To mitigate the crew safety hazard, a single unified (pressure seal and thermal protection) hatch for quick outward opening is preferred; reference the Apollo CM and shuttle orbiter crew ingress/egress hatch. This would be compared to a risk analysis of long mission time exposure to space vacuum in which the crew safety hazard is cabin depressurization/loss of cabin atmosphere due to crew hatch seal leakage or failure. To mitigate the crew safety hazard related to depressurization, an inward-opening and pressure-sealing hatch is preferred, as cabin pressure tends to seal the hatch vs. an outward opening where cabin pressure tends to open the hatch. This may result in an inward-opening pressure-sealing hatch and an outward-opening thermal protection hatch, as the Russians designed for Buran.

An earlier look at the performance history of spacecraft hatches has shown that when the crew hatch is also the EVA hatch, an inward-opening pressure-sealing hatch is preferred. A relevant example can be found with the problem in the Mir Kvant 2 EVA outward-opening hatch, also described in Section 2.7 of this document.

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Appendix A: Matrix for Worldwide Spacecraft Crew Hatches

Spacecraft Crew Hatches 9/25/2009	Type			Direction of opening		Comment
	Ingress/Egress	Transfer/Docking	EVA	Inward	Outward	
Mercury						Failure on MR-2
Entrance Hatch	X				X-Pyro	
Escape Hatch		X		X		
Vostok						
Entrance Hatch	X				X-Pyro	
Gemini						Gemini 4 EVA difficulty opening & closing hatch
Ingress/Egress Hatch	X		X		X-Man & Pyro	
Gemini B/MOL Heatshield		X			X	
Voskhod						Voskhod 2 difficulty sealing the EVA hatch
Entrance Hatch	X		X	X		
Volga-Airlock Hatch			X	X		
Apollo						Apollo 1 Unable to egress
Block I CM Side Hatch	X			X-Inner	X-TPS & Cover	
Block 1 CM Docking		X		X		
Block II CM Side hatch	X		X		X-TPS & Cover	
Block II CM Docking		X		X		
LM docking	X	X		X		
LM forward	X		X	X		
Skylab						
Airlock(Gemini hatch)			X		X	
Docking hatch	X	X		X		
ISS						
Quest U.S. airlock	X		X	X	X-Thermal Cover	
Orbiter/PMA-2 docking		X		X		
Zevedsa SM Aft docking port		X		X		
Zara FGB docking port		X		X		
HTV /Node-2 Berthing		X		X		
ATV Docking		X		X		
Piers Docking Comp/Airlock		X	X	X		
Shuttle						STS-80 Nov. 28, 1996 loose screw jammed EVA hatch gearbox
Side hatch	X				X-Man & Pyro	
External airlock			X	X		
Overhead Escape Panel	X			X-Pyro	X-Pyro	
External airlock docking		X		X		
Soyuz						No such thing as "rapid" egress from Soyuz on the pad
Descent module	X			X		
Orbital module	X		X	X		
Fairing hatch	X				X	
Orbital Module Docking		X		X		
Salyut						
Airlock			X	X		
Docking hatches	X	X		X		
Mir						1990 Kvant 2 EVA hatch damage when opened with slight internal pressure
Docking hatches	X	X		X		
Airlock-Kvant 2			X		X	
Buran						
Side Hatch	X			X	X-TPS	
Airlock Hatch			X	X		
Shenzhou						Shenzhou 7 opening EVA hatch harder than expected
Reentry Module	X			X		
Orbital Module	X	X	X	X		
Fairing hatch	X				X	

**JSC DESIGN AND PROCEDURAL STANDARD
NASA Lyndon B. Johnson Space Center**

Crew Hatches	Document No. JPR 8080.5	Standard No. MS-4	Page 2 of 2
	Previous Revision 04/01/1991	Current as of date signed below:	

Continued from previous page

3. SEAL INTEGRITY

- a. The capability shall be provided to leak check between redundant pressure seals without pressurizing/depressurizing the adjacent pressure volumes.
- b. The capability for verification of hatch seal integrity shall be provided on both sides of the hatch.

4. THERMAL AND STRUCTURAL LOADS

- a. Hatches and associated mechanisms shall not be designed to carry primary structural loads.
- b. The design of the structure surrounding hatches used in escape operations shall consider provisions to minimize the probability of jamming which would prevent crew egress following emergency landing or ditching.
- c. Hatches and associated mechanisms shall allow for differential movement between structural frame and the hatch as well as maintain compartment sealing under these conditions.

5. VISIBILITY

- a. Hatches shall incorporate a window designed in accordance with NASA STD 3000.

REMARKS

Refer to MS-8 for hatch requirements related to ground and emergency operations; G-9 Exclusion of Shatterable Material and MS-7 Window and Glass Structure for requirements with respect to the use of glass

The requirement set forth in this standard is Lyndon B. Johnson Space Center policy and applies to all human flight equipment developed by the Center. Application to non-human flight or ground equipment is not required unless specifically indicated in the statement of standard. Establishment of the JSC Design and Procedural Standards activity, standards, and policies of application are described in JPD 8080.2.

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13. ABSTRACT (Maximum 200 words) The Johnson Space Center (JSC) Flight Safety Office has developed this compilation of historical information on spacecraft crew hatches to assist the Safety Technical Authority in the evaluation and analysis of worldwide spacecraft crew hatch design and performance. Among the programs addressed are the United States Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz (a joint US-USSR project), and Space Shuttle Orbiter; the Russian Vostok, Voskhod, Soyuz, Progress, Almaz, Salyut, Mir, and Buran; and the Chinese Shenzhou. The observations and findings are presented first by country and are then organized within each country section by program in chronological order of emergence. A host of reference sources used to augment the personal observations and comments of the author are listed in the reference section of this document. Careful attention to the selection and inclusion of photographs, drawings, and diagrams is used to give visual association and clarity to the topic areas examined. Because of the scope of this report, recommendations and conclusions are not offered.				
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