

SPACE SHUTTLE ORBITER PAYLOAD BAY DOOR MECHANISMS

Bill M. McAnally*

ABSTRACT

The opening, closing, and latching of the first large clamshell door to operate in space presents some unusual challenges for the mechanism designer of the Space Shuttle Program. This paper describes the requirements, hardware configuration, design trade-offs, and qualification testing in process to meet the challenge and to make the system operational for the Shuttle orbiter's approaching first orbital flight. This work was conducted under NASA Contract NAS9-14000.

INTRODUCTION

The unique, reusable, cargo-carrying "space airplane," called the Space Shuttle orbiter, can also be described as a contemporary delta-wing aircraft launched into orbit as a spacecraft, then returned from orbit to a conventional landing. The orbiter's cavernous cargo or payload bay will enable it to transport various sizes, shapes, and weights of payloads to and from earth orbit.

The payload bay doors are designed around the payload requirements that call for an envelope 4.6 meters (15 feet) in diameter and 18.3 meters (60 feet) long. The doors provide the aerodynamic fairing required for the mid fuselage and the complete environmental envelope for the payload bay. They react fuselage torsional loads in addition to supporting their own flight and purge pressure loadings. They also provide structural support for the fixed and deployable environmental control system radiators that are attached to the inner surface of the doors. The payload bay doors are hinged along the side and split at the top centerline—i.e., one door per side 18.3 meters (60 feet) long. Each side consists of four 4.6-meter (15-foot) segments that are interconnected through expansion joints that allow the door to act as one 18.3-meter (60-foot) door. The doors have the structural integrity and capability of being opened and closed in zero gravity; but in 1 g, they require ground support equipment assistance in both the vertical (launch) position and the horizontal position.

The payload bay door mechanisms include the elements associated with remote operation and latching of the payload bay doors and deployable radiators. The functions of these mechanisms include (1) closing and opening the doors and retaining the doors in an open position; (2) unlatching and structurally securing (latching) the closed doors to the orbiter structure; (3) stowing, deploying, and retaining the radiators in the deployed position; (4) unlatching and structurally securing (latching) the deployable radiators to the payload bay doors; and (5) providing controls and measurements to indicate door, radiator, and latch mechanism status. Table I summarizes the number of components to perform these functions.

*B. M. McAnally is Engineering Manager of Mechanical/Actuation Systems for the Space Shuttle Program at the Rockwell International Space Systems Group at Downey, California.

DESIGN REQUIREMENTS

The mechanisms have been designed to satisfy a wide variety of structural, mechanical, and mission-unique requirements. Among these are the following:

- Last for 100 orbital missions and 10 years.
- Operate in 1-g and 0-g conditions.
- Maintain orbiter structural integrity.
- Provide load paths for torsional door capability.
- Maintain orbiter door outer mold-line smoothness.
- Accommodate thermal/structural deflections and maintain pressure/thermal sealing.
- Latch to overcome deformation, deflections, misalignment, friction, pressure seals, and thermal barriers.
- Maintain payload clearance.
- Withstand nonoperating temperature range of -110.6°C (-167°F) to $+171.1^{\circ}\text{C}$ ($+340^{\circ}\text{F}$).
- Operate within temperature range of -73.3°C (-100°F) to $+121.1^{\circ}\text{C}$ ($+250^{\circ}\text{F}$).
- Tolerate a single electrical power, motor, or switch failure.

CONFIGURATION DESCRIPTION

Door Mechanisms Overview

The doors are opened soon after orbit insertion and remain open until just prior to reentry, as shown in Figure 1. The two 18.3-meter (60-foot) doors require structural latching of approximately 33.5 lineal meters (110 lineal feet) of door edge—18.3 meters (60 feet) at the upper centerline and 7.6 meters (25 feet) each at both the forward and aft end—as depicted in Figure 2. The doors are opened/closed and latched sequentially, either manually from the on-board control panel or automatically from the on-board computer, by electromechanical actuators. Figure 3 depicts the door opening/closing and latching sequence, revealing the use of ganged latches (four latches in each gang). The door mechanisms are broken into four basic subelements: door drive actuation, forward bulkhead latches, aft bulkhead latches, and centerline latches.

Door Drive Actuation

The actuation system drives the door to the required positions, as illustrated in Figure 4. There are two actuation systems, one on each side of the orbiter, driving an 18.3-meter (60-foot) “half door” at six points along the hinge line. The six gear boxes are connected by torque tubes to each other and to an electromechanical power drive unit. The output of the six gear boxes is transmitted through the drive linkage to the door, as noted in Section A-A of Figure 4. The door actuation system is sized for operating the doors in 1-g conditions with ground support equipment assist when the orbiter is either horizontal or vertical.

Forward Bulkhead Latches

The forward bulkhead latches connect the doors to the forward structural bulkhead, as depicted in Figure 5. The forward latches consist of a right-hand gang (four latches) and a left-hand gang

(four latches), each latch operating in a sequential manner controlled by the kinematics of the ganged mechanism. The latch mechanism is mounted on the door, and the mating hook rollers are mounted on the bulkhead. The latches also help to maintain door sealing to the fuselage structure, as shown in Figure 6. Note that the sliding seal, which requires the engaged latch hooks to slide fore and aft on the rollers, allows for relative movement between the door and forward bulkhead. Each ganged mechanism is driven by a single electromechanical rotary actuator (two motors).

Aft Bulkhead Latches

The aft bulkhead latches connect the doors to the aft structural bulkhead in much the same manner as the forward bulkhead latches (Figure 7), the only difference being the added fore/aft shear tie at each latch on the aft bulkhead (identified as a “passive roller” in Figure 7). The tie is required to effect an adequate door-to-structure seal with the given aft bulkhead seal configuration of Figure 6.

Upper Centerline Latches

The upper centerline latches connect the right-hand and left-hand doors along the upper centerline, as shown in Figure 8. There are four gangs of latches (four latches each), the active latches on the right-hand door and the mating rollers on the left-hand door. Within each gang, the four latches are connected by torque tubes to each other and to a single electromechanical rotary actuator. Each latch gang also contains one passive shear fitting to carry fore and aft shear loads. Again, the latches also help to maintain door-to-door sealing, as shown in Figure 6. Alignment rollers are used at each latch to ensure proper engagement of the opposite door under any warpage condition (Figure 9).

Radiator Mechanisms Overview

The environmental control deployable radiators are hinge-mounted to the forward 9.1-meter (30-foot) sections of the payload bay door, as shown in Figure 10. Each 9.1-meter (30-foot) radiator consists of two 4.6-meter (15-foot) panels interconnected to operate as one. After the payload bay doors are opened, the radiators are deployed to a predetermined position to provide dual-sided radiative surfaces to dissipate heat accumulated from orbiter systems. The radiators are opened/closed and latched manually from the on-board control panel by electromechanical actuators. The radiator mechanisms are broken into two basic subelements: radiator drive actuation and radiator latches.

Radiator Drive Actuation

The actuation system drives the radiator to a position 0.62 radians (35.5 degrees) away from the payload bay door, as shown in Figure 10. The drive system is very similar to the payload bay door drive system, one on each door driving a 9.1-meter (30-foot) deployable radiator at four points along the hinge line. The four gear boxes are connected by torque tubes to each other and to the electromechanical power drive unit. The output of the four gear boxes is transmitted through the drive linkage to the radiator.

Radiator Latches

The radiator latches provide the mechanisms to attach the deployable radiators structurally to the doors during boost to orbit and reentry. Each 9.1-meter (30-foot) radiator has 12 latches, in two groups of six each, each group being driven by one electromechanical power drive unit and three rotary gear boxes, as depicted in Figure 10.

DESIGN DETAILS

The structural integrity required to ensure a safe deorbit of the orbiter vehicle reflects the criticality of the payload bay door mechanisms. Remotely unlatching, opening, then closing and latching 18.3 meters (60 feet) of the orbiter mid body on orbit and prior to reentry are the primary challenges. In addition, the deployable radiators must first be remotely opened, closed, and latched in order to close the payload bay doors for reentry. The on-orbit conditions, along with the boost and reentry to earth landing conditions, are presented in a design load matrix in Table II.

Latched conditions during boost to orbit and reentry to landing are generally basic requirements. However, the latching conditions on orbit present the challenge, primarily because of the size of the doors and the thermal distortions resulting from long-duration orientations of the orbiter to the sun and deep space. Figure 11 presents fore and aft design deflections at the door centerline. Only the door mechanisms are discussed here, since the radiator mechanisms are so similar in design and operation.

The electrical commands to open and close the doors are initiated as a function of mission elapsed time, mission event, or manual switch operation. Only the door closing sequence is discussed here, since the opening sequence is basically the reverse of closing. Before the payload bay door can be closed, the right- and left-hand deployable radiators must be stowed and latched strictly by manual switch operations.

Receipt of the door CLOSE command initiates the following steps:

1. Initiate CLOSE command for left door.
 - a. When door reaches READY TO LATCH position, a signal is generated to initiate the next step.
 - b. If after 126 seconds READY TO LATCH signals are not received, a malfunction signal is generated in the cockpit CRT display, requiring the crew to take corrective action.
2. Initiate CLOSE command for forward and aft left bulkhead four-latch gangs.
 - a. When latches are closed, a signal is generated to initiate the next step and turn off applicable drive motors.
 - b. If after 60 seconds latches are not closed, a malfunction signal is generated in the cockpit CRT display, requiring the crew to take corrective action.
3. Initiate CLOSE command for right-hand door.
 - a. Same as Step 1a
 - b. Same as Step 1b
4. Initiate CLOSE command for forward and aft right bulkhead four-latch gangs.
 - a. Same as Step 2a
 - b. Same as Step 2b

5. Initiate CLOSE command for forward and aft centerline four-latch gangs.
 - a. When latches are closed, a signal is generated to initiate the next step.
 - b. If after 40 seconds latches are not closed, a malfunction signal is generated in the cockpit CRT display, requiring the crew to take corrective action.
6. Initiate CLOSE command for the mid centerline four-latch gangs.
 - a. Same as Step 5a
 - b. Same as Step 5b
7. Generate signals for crew display: PAYLOAD BAY DOORS CLOSED.

The above sequence can be stopped and/or reversed at any point.

As noted earlier, the door mechanisms consist of 32 latches: 8 at the forward door edge, 8 at the aft door edge, and 16 along the door centerline. The latches are all approximately 0.91 meters (3 feet) apart. Once the doors are unlatched on orbit and each door is opened 3.11 radians (178 degrees), the huge doors and the "opened" fuselage structure are exposed to varying thermal conditions: the open payload bay (and inner surface of the doors) may be exposed to deep space, while the lower side of the orbiter (and outer surface of the doors) may be exposed to the sun; or sun may be on one side of the orbiter with deep space exposure on the other. These are just two examples of many orientations that create a wide excursion of thermal deformations to be overcome during closing and latching of the doors. In addition, the door structure is graphite-epoxy construction while the fuselage structure is aluminum. Again, the on-orbit thermal deflections are more significant in the design because of the large size of the doors.

Because of these deflections, the actuation system required to drive the door to the fully closed position and to ensure that the forward and aft edge of the door is in total contact with the bulkhead structure for "simple latching" would be prohibitive from a power, space, and weight standpoint. Therefore, of all the means considered, the mechanically sequenced ganged latching concept was chosen.

To close the door, the actuation system drives the left-hand door to an approximate 0.03-radian (1.75-degree) open position, overcoming a 1.8-kilogram-per-running-centimeter (10-pound-per-running-inch) seal and thermal barrier load along the hinge line and bulkheads near the hinge line. The door drive must also overcome sliding friction ($\mu = 0.3$) on the bulkhead seals and thermal barriers, hinge line warpage, "oil canning" of the doors, mechanical linkage friction ($\mu = 0.3$), and various fluid and electrical lines crossing over the hinge line from the fuselage to the door and radiator. Therefore, the power drive unit has an output of 7.32×10^8 dyne-centimeters (648 inch-pounds) of torque transmitted through the aluminum torque shafts to the six geared rotary actuators, each with an output of approximately 90.38×10^8 dyne-centimeters (8000 inch-pounds) of torque. The output of the six actuators is transmitted to the door structure through the interconnecting door drive linkage, placing the door, not fully closed, within the reach of the first bulkhead latch. Then the latches must pull the door completely closed.

As the door moves through the 0.07-radian (4-degree) open position, READY TO LATCH switches on the forward and aft bulkheads are "picked up," initiating the bulkhead latch actuators. The door is then within the 5.1-centimeter (2-inch) reach capability of the No. 1 bulkhead latch closest to the door hinge line (Figure 12). Continued door movement to the 0.03-radian (1.75-degree) open position "picks up" the forward and aft bulkhead DOOR CLOSED switch, shutting off power to the door drive system.

The forward and aft bulkhead latch rotary actuators, with output torques of 16.04×10^8 dyne-centimeters (14,200 inch-pounds) each, transmit power to each of the four latches in the gang

through the mechanical linkage. The kinematics of the ganged linkage is such that the No. 1 latch first engages the door, pulling it to a position within reach of the No. 2 latch. As the No. 2 latch continues to pull the door further closed, the door comes within reach of the No. 3 latch, and so on until the No. 4 latch finally pulls the door into total contact with the bulkhead structure.

The ganged latches, mechanically sequenced, thus provide a unique “zippering effect” to close the door. The bulkhead latch actuator must overcome a 1.8-kilogram-per-running-centimeter (10-pound-per-running-inch) seal and thermal barrier load along the bulkhead, sliding friction ($\mu = 0.3$) on the seals and barriers, mechanism friction ($\mu = 0.18$), door stiffness, and the previously discussed thermal distortions. The latch mechanisms are structurally designed to take full actuator stall output (jamming) to within 0.17 radian (10 degrees) of the mechanism on-center position. As the bulkhead latch actuators drive the four-latch gang to the on-center or door-closed position, a switch within the actuator shuts off the actuator and triggers the right-hand door closing sequence.

Some on-orbit thermal distortion conditions result in the tendency of the doors to overlap at the upper centerline—as much as 5.1 centimeters (2 inches) under the worst conditions. Thus, alignment rollers are used along the centerline to force the doors into position (Figure 9) and provide a safe centerline latch engagement envelope.

The right door is closed and latched in the same manner and to the same design requirements as the left-hand door, leaving the upper 18.3-meter (60-foot) centerline of the two door halves to be latched. The full travel of the forward and aft bulkhead latch actuators latching the right-hand door trips a switch inside the actuator, thus initiating the upper centerline door-to-door latches. But the 18.3 meters (60 feet) of centerline latches consist of 16 latches in 4 groups, each group ganging four latches together (as noted in Figure 8). This design results from the varying distorted relationship between the two door halves at the centerline. Only the most forward and most aft four-latch gangs are actuated first. The doors are relatively close together at these points because the door ends are latched to the forward and aft bulkheads. Once the most forward and most aft centerline four-latch gangs are latched, they pull the central 9.1 meters (30 feet) of the centerline door halves closer together, thus making it easier and more positive for the remaining two latch gangs to complete the centerline latching.

Each four-latch gang is identical—a rotary actuator transmitting 45.19×10^8 dyne-centimeters (4000 inch-pounds) of output torque through connecting aluminum torque tubes to the four-latch hooks. The actuator is designed to overcome seal and thermal barrier loads and friction, mechanical friction, door stiffness, and thermal distortions of similar values found in the bulkhead and door drive actuation systems. In addition, each four-latch gang has a passive shear fitting engagement requirement, as shown in Figure 8. The fore and aft shear load capability of 7491 kilograms (16,500 pounds) per fitting provides the load path for the torsional door requirement.

Somewhat different from the bulkhead latch gang, the centerline four-latch hooks within a gang move together to latch simultaneously. However, a similar “zippering” effect occurs in that the full travel of the latch actuators in the forward and aft four-latch gangs trips a switch in each actuator, shutting off its own power and causing power to be applied to the two centermost four-latch gangs. Full travel of these centermost two actuators, and thus completion of the payload bay door closure, trips a switch in each actuator to stop the actuator and provide a DOOR CLOSED display in the cockpit. Thus, the orbiter structure returns to the appropriate, smooth, aerodynamic contour required for a safe reentry into the earth’s atmosphere; and structural continuity enables the orbiter vehicle to maneuver to a safe landing at the designated landing site.

TEST PROGRAM

At this writing, a significant amount of testing and analysis remains to be done before the payload bay door mechanisms are certified for the first manned orbital flight of the orbiter vehicle, now scheduled for 1979. The two basic segments of the test program are component testing and major payload bay door test article (PBDTA) tests. Components will be qualified by the individual component suppliers through analysis and testing. These tests are presently in process.

The PBDTA will integrate the payload bay door subsystems and must functionally verify, under simulated on-orbit environmental conditions (zero gravity and thermal deformation), the latching and door drive actuation systems. Other significant tests will involve 1-g operation in both the horizontal and vertical positions.

The test article will consist of a partial set of door assemblies, a simulated mid fuselage, environmental seals and thermal barriers, radiator panels, and latching/actuation mechanisms. The test article is presently being fabricated, the test start date scheduled in early 1979.

CONCLUDING REMARKS

While the payload bay door mechanisms generally reflect conventional aircraft design, the unusual Shuttle applications and critical functions require remote "zipper latching" of a large clamshell door on a "space airplane" that operates in both 1-g and 0-g conditions. The challenge is to ensure that all critical conditions are thoroughly considered in design, development, testing, and implementation.

**TABLE I – ELECTROMECHANICAL
COMPONENT COUNT**

Component	Doors	Radiator	Total
Power drive units	10	6	16
Rotary actuators	12	20	32
Latches	32	24	56
Hinges	26	12	38
Passive fittings	40	4	44
Shafts	52	20	72
Couplings	72	52	124
Switches	68	24	92
Push-pull rods	36	24	60
Shaft support bearings	84	22	106

TABLE II – DESIGN LOADS

Loading Considered	Mechanism			
	Fwd, Aft, & Centerline Door Latch	Door Drive	Radiator Latch	Radiator Drive
Flight Phase				
Ascent	X		X	
Boost	X		X	
On orbit	X	X	X	X
Opening/Closing on Orbit				
Stall/jam*	X	X	X	X
Seal stiffness/friction**	X	X		
Thermal deflection**	X	X	X	X

*Critical condition with regard to strength
**Critical condition with regard to closure

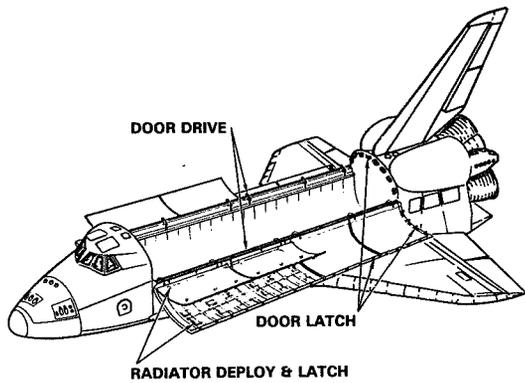


Figure 1 – Payload Bay Door/Radiator System

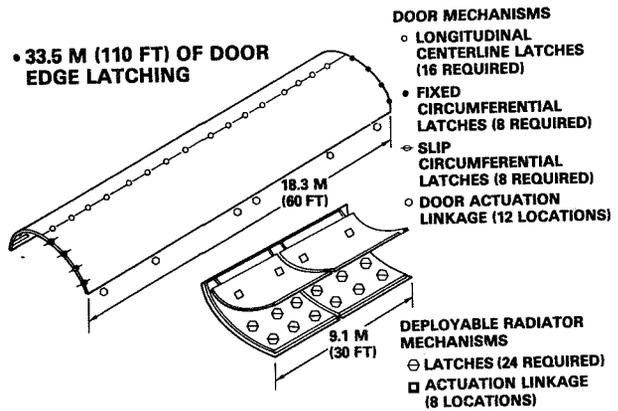


Figure 2 – Configuration of Payload Bay Door Mechanisms

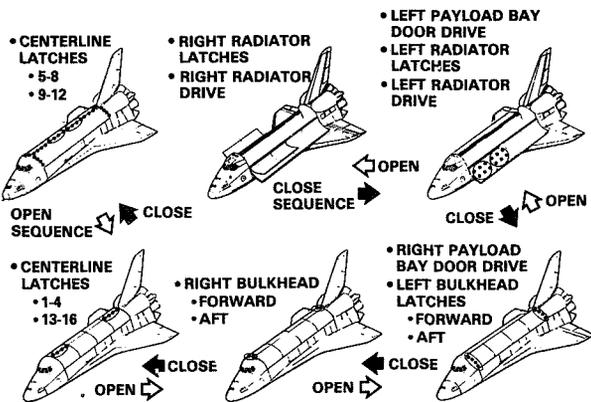


Figure 3 – On-Orbit Payload Bay Door and Radiator Open/Close Sequence

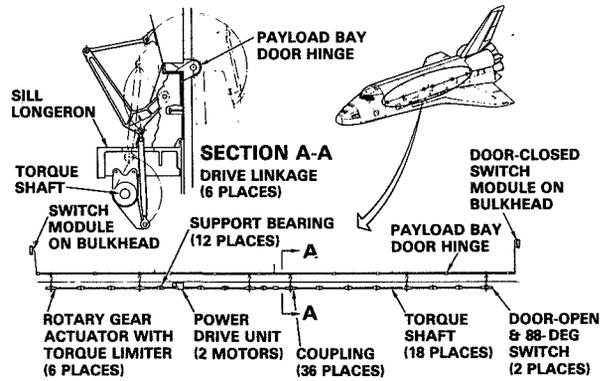


Figure 4 – Payload Bay Door Drive System

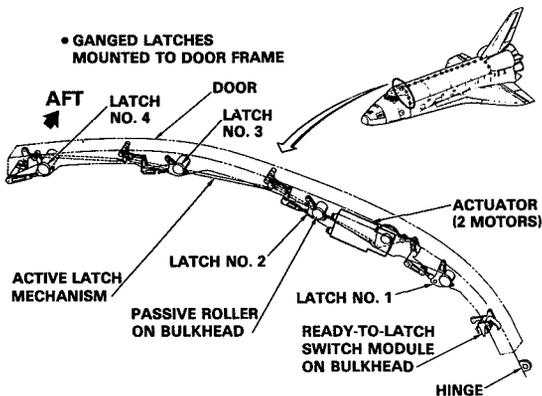


Figure 5 – Forward Bulkhead Circular Latch System

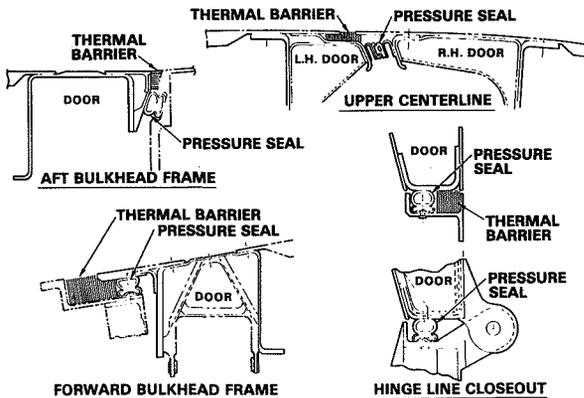


Figure 6 – Payload Bay Door Environmental Seals

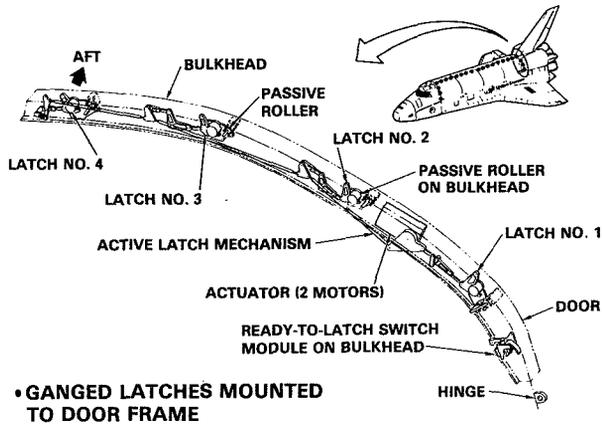


Figure 7 – Aft Bulkhead Circular Latch System

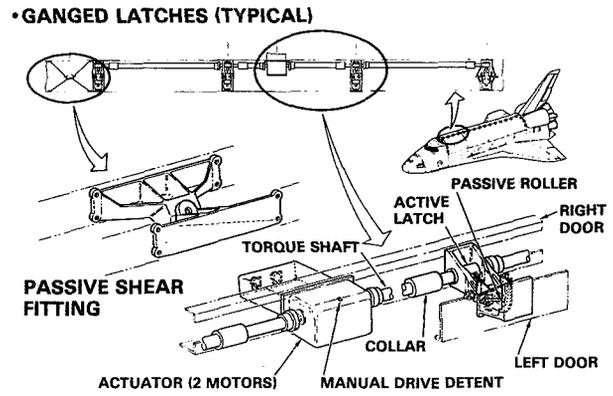


Figure 8 – Payload Bay Door Centerline Latch System

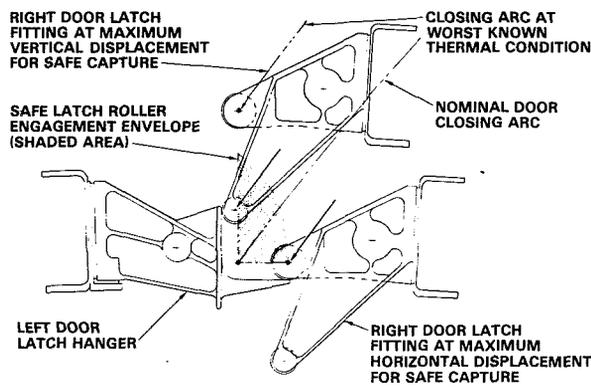


Figure 9 – Payload Bay Door Centerline Engagement and Latching

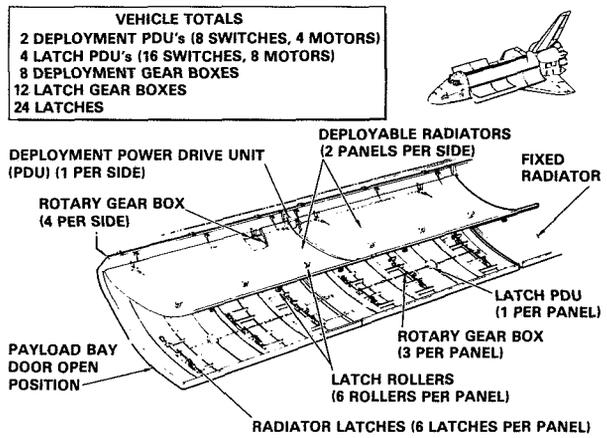


Figure 10 – Deployable Radiator Mechanisms

RELATIVE GAP CENTIMETERS (INCHES)	ASCENT (MECHANICAL)		DESCENT (MECHANICAL AND THERMAL)		ON ORBIT (THERMAL)	
	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
A	1.04 (0.41)	0.74 (0.29)	1.30 (0.51)	1.63 (0.64)	0.23 (0.09)	1.09 (0.43)
B	0.91 (0.36)	1.70 (0.67)	2.29 (0.90)	1.12 (0.44)	1.04 (0.41)	0.97 (0.38)

Figure 11 – Centerline Maximum Deflections

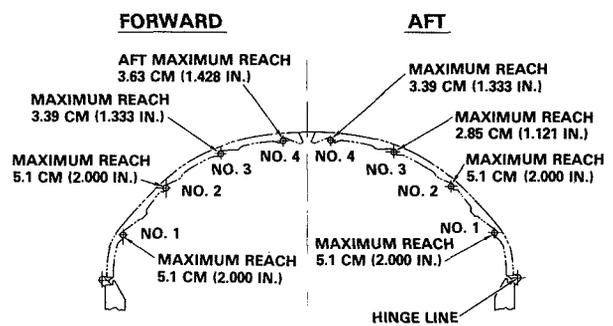


Figure 12 – Bulkhead Latch Reach Capability