
Space Exploration

P3 and P4 to expand station capabilities, providing a third and fourth solar array



The Port Three (P3) and Port Four (P4) Truss segments are slated for launch to the International Space Station aboard Space Shuttle Atlantis no earlier than August 28, 2006, from Kennedy Space Center, Fla. The truss is the next major addition to the 11-segment integrated Truss Structure that will eventually span more than 300 feet to carry power, data and temperature control for the orbital outpost's electronics.

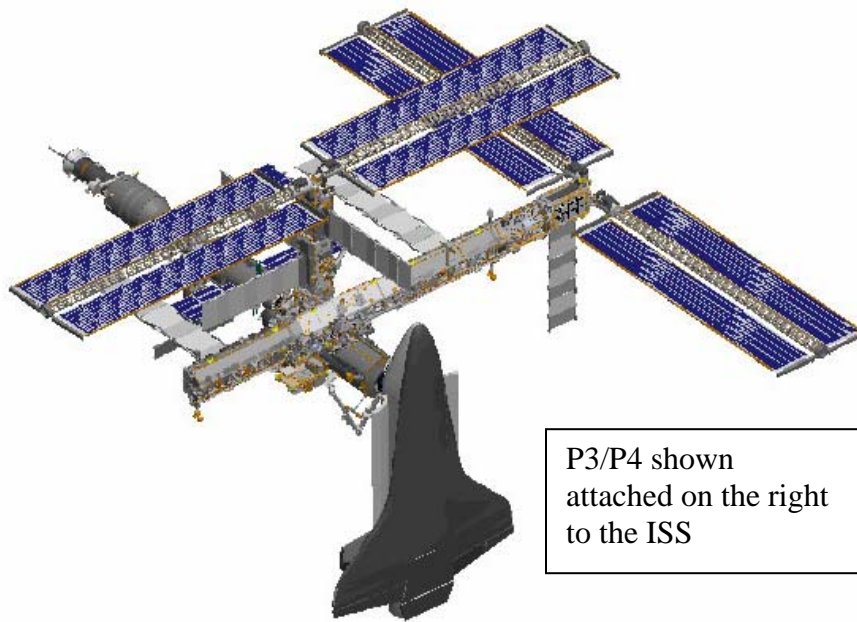
P3/P4 Specifications	
Dimensions:	45.3 ft long by 16 feet wide by 15.6 feet high
Weight:	34,885 lbs

The integrated truss segments started with Starboard zero (S0) as the center assignment and were numbered in ascending order outward to the port and starboard sides. At one time, there was an S2 and P2 planned, but were eliminated when the station design was scaled back. From S0, the truss segments are P1, P3, P4, P5 and P6 and S1, S3, S4, S5, and S6. P6 is presently on orbit and attached to segment Z1. P6 will be eventually relocated and attached to P5.

The primary cargo delivered on STS-115/Mission 12A is the Integrated Truss Segment P3/P4, which mates to P1 and provides an attachment point for P5. These new segments also provide a second set of Solar Array Wings (SAWs) and the first alpha joint. The segments also support utility routing, power distribution, and a translation path for the Mobile Remote Service Base System (MBS).

P3 and P4 will be removed from the space shuttle payload bay using the shuttle arm (SRMS – Shuttle Remote Manipulator System) and it will be handed off to the Station arm (SSRMS – Space Station Remote Manipulator System), where it will be maneuvered and attached to P1.

The P3 primary structure is made of a hexagonal shaped aluminum structure and includes four bulkheads and six longerons. The secondary structure includes brackets, fittings, attach platforms, EVA equipment and miscellaneous mechanisms.



Major P3 subsystems include the Segment-to-Segment Attach System (SSAS), Solar Alpha Rotary Joint (SARJ), and Unpressurized Cargo Carrier Attach System (UCCAS). The primary functions of the P3 truss segment are to provide mechanical, power and data interfaces to payloads attached to the two UCCAS platforms; axial indexing for solar tracking via the SARJ,

translation and work site accommodations for the Mobile Transporter, accommodations for ammonia servicing of the outboard PV modules and two Multiplexer/Demultiplexers (MDMs), which are basically computers. The P3 also provides a passive attachment point to the P1 segment via the SSAS and pass through of power and data to and from the outboard segments.

The UCCAS will allow platforms to be attached to P3 for the storage of additional science payloads or spare Orbital Replacement Units. It has a capture latch to grip and secure a payload, a berthing target to align payloads to the mechanism and an Umbilical Mechanism Assembly which has a connector that provides power and data to the payload.

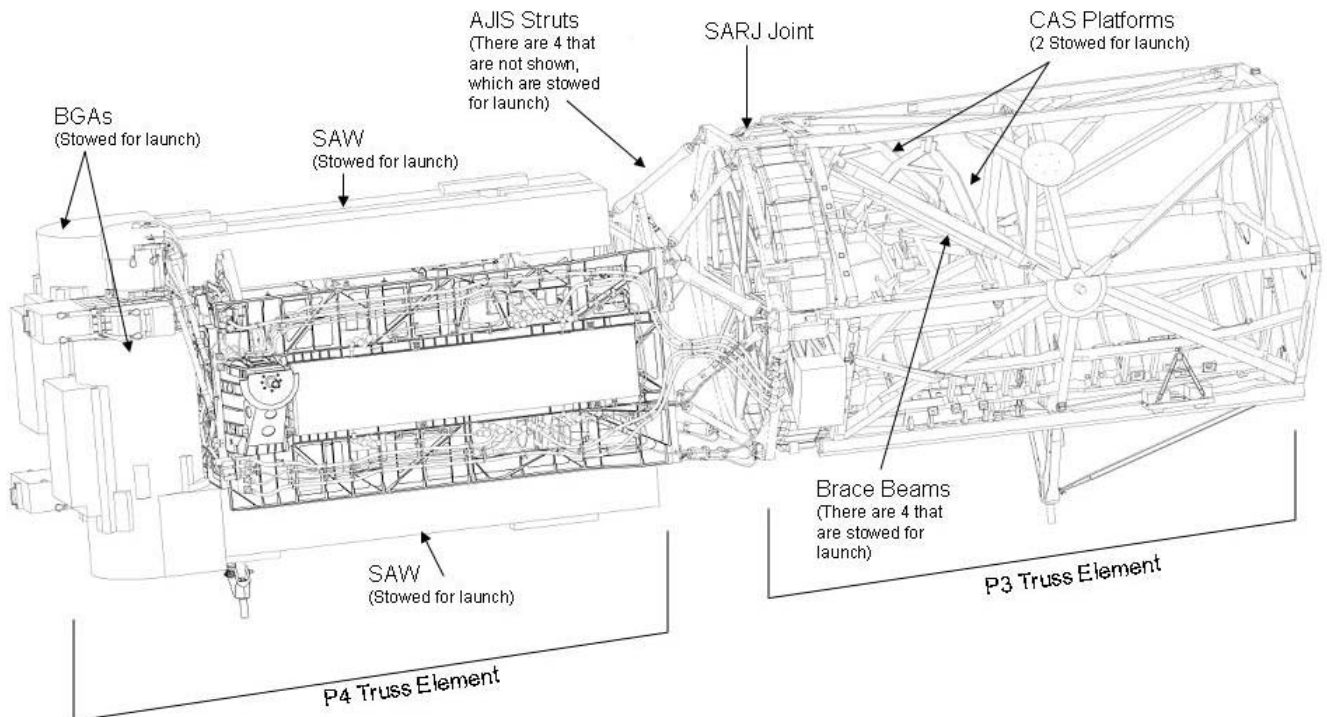
Major subsystems of the P4 Photovoltaic Module (PVM), include the Photovoltaic Radiator (PVR), the Alpha Joint Interface Structure (AJIS), and Modified Rocketdyne

Truss Attachment System (MRTAS). The P4 Photovoltaic Module includes all equipment outboard of the Solar Alpha Rotary Joint (SARJ) outboard bulkhead, namely the two Photovoltaic Array Assemblies (PVAAs) and the Integrated Equipment Assembly (IEA). Each PVAA consists of a Solar Array Wing (SAW) and Beta Gimbal Assembly (BGA). The PVR provides thermal cooling for the IEA. The Alpha Joint Interface Structure (AJIS) provides the structural transition between P3 and P4 structures. P4 contains the passive side of the MRTAS which will provide the structural attachment for P5 on P4.

P3 consists of the Solar Alpha Rotary Joint (SARJ) which continuously rotates to keep the Solar Array Wings (SAW) on P4 and P6 oriented towards the sun as the station orbits the Earth. Each SAW is also oriented by the BGA which can change the pitch of the wing. Each wing measures 115 feet by 38 feet and extends out to each side of the Integrated Equipment Assembly. There are two wings on P4.

The P3/P4 Integrated Truss Structure is the primary payload for the STS-115 mission and contains several discrete elements: two **Solar Array Wings (SAW)**, **Integrated Equipment Assembly (IEA)**, **Solar Alpha Rotary Joint (SARJ)**, two **Beta Gimbal Assemblies (BGA)** and **Photovoltaic Thermal Control Subsystem**.

Following are specific details on each of the major elements:

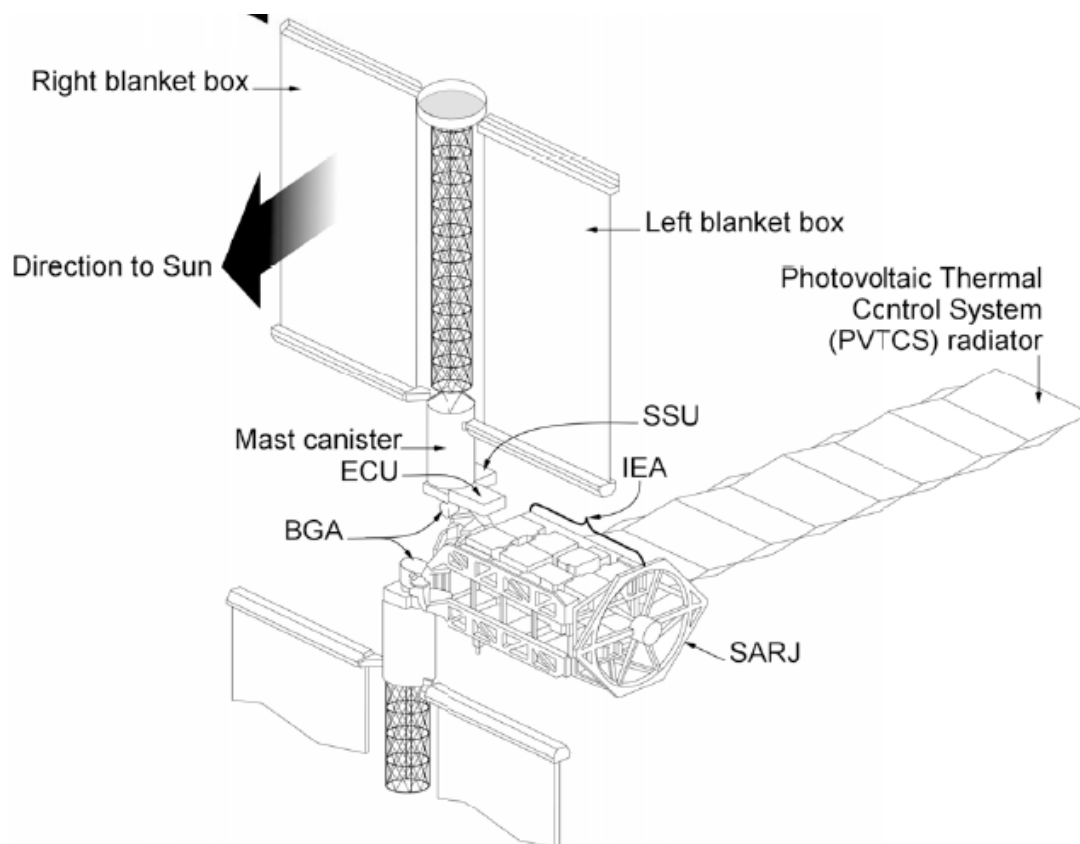


P4 Photovoltaic Module (power module)

Electrical power is the most critical resource for the ISS because it allows astronauts to live comfortably, safely operate the station, and perform complex scientific experiments. Since the only readily available source of energy for spacecraft is sunlight, technologies

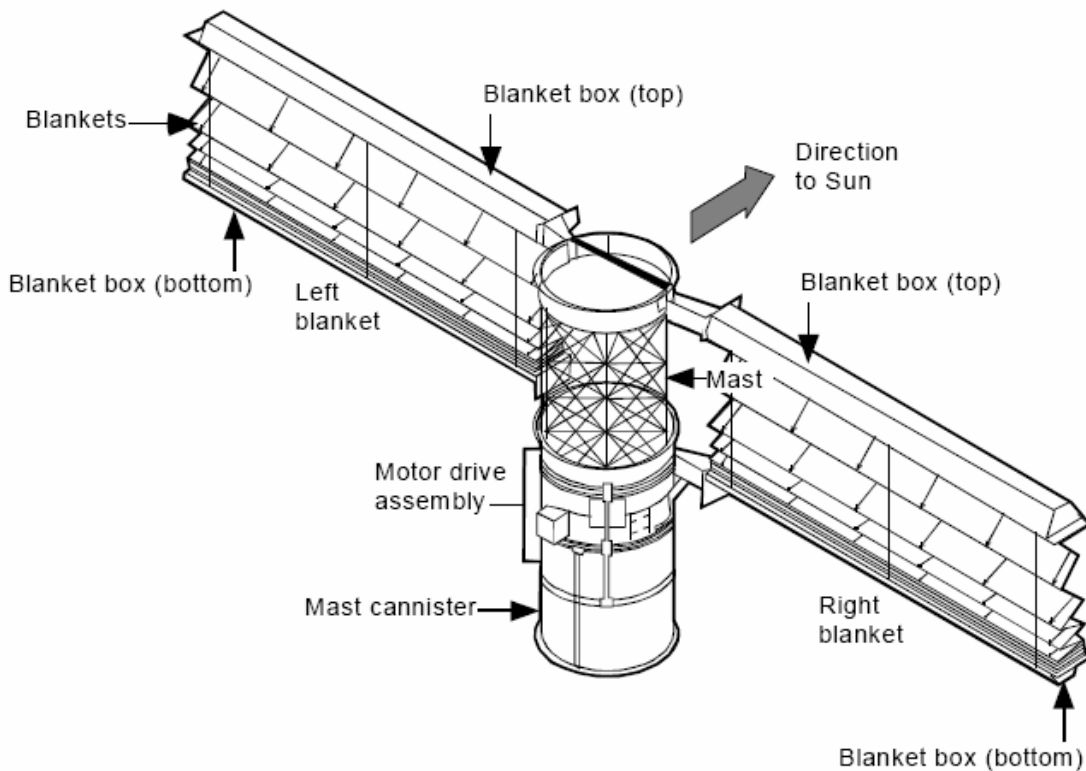
were developed to efficiently convert solar energy to electrical power. One way to do this is by using large numbers of solar cells assembled into arrays to produce high power levels. The cells are made from purified crystal ingots of silicon that directly convert light to electricity through a process called photovoltaics. Solar cells do the job, but a spacecraft orbiting the Earth is not always in direct sunlight so energy has to be stored. Storing power in rechargeable batteries provides a continuous source of electricity while the spacecraft is in the Earth's shadow.

NASA and Lockheed Martin developed a method of mounting the solar arrays on a "blanket" that can be folded like an accordion for delivery to space. Once in orbit, astronauts deploy the blankets to their full size. Gimbals are used to rotate the arrays so that they face the Sun to provide maximum power to the Space Station. The solar arrays track the sun in two axes: beta and alpha. The complete power system, consisting of U.S. and Russian hardware, will generate 75 to 110 kW (kilowatts) total usable power, about as much as 55 houses would typically use.



P4 is the second of four PVMs that will eventually be brought up to the International Space Station, converting sunlight to electricity. The first one, named P6, was brought on orbit by the STS-97 crew in November 2000. The primary functions of the P4 Photovoltaic module are to collect, store, convert and distribute electrical power to loads within the segment and to other ISS segments. The P4 PVM consists of two Beta Gimbal/PV Array assemblies, two Beta Gimbal Transition Structures, one integrated Equipment Assembly and associated cabling and tubing. The P4 PVM components were assembled by Boeing in Tulsa, Okla. and Lockheed Martin in Sunnyvale, Calif. prior to final assembly and testing by Boeing at Kennedy Space Center, Fla.

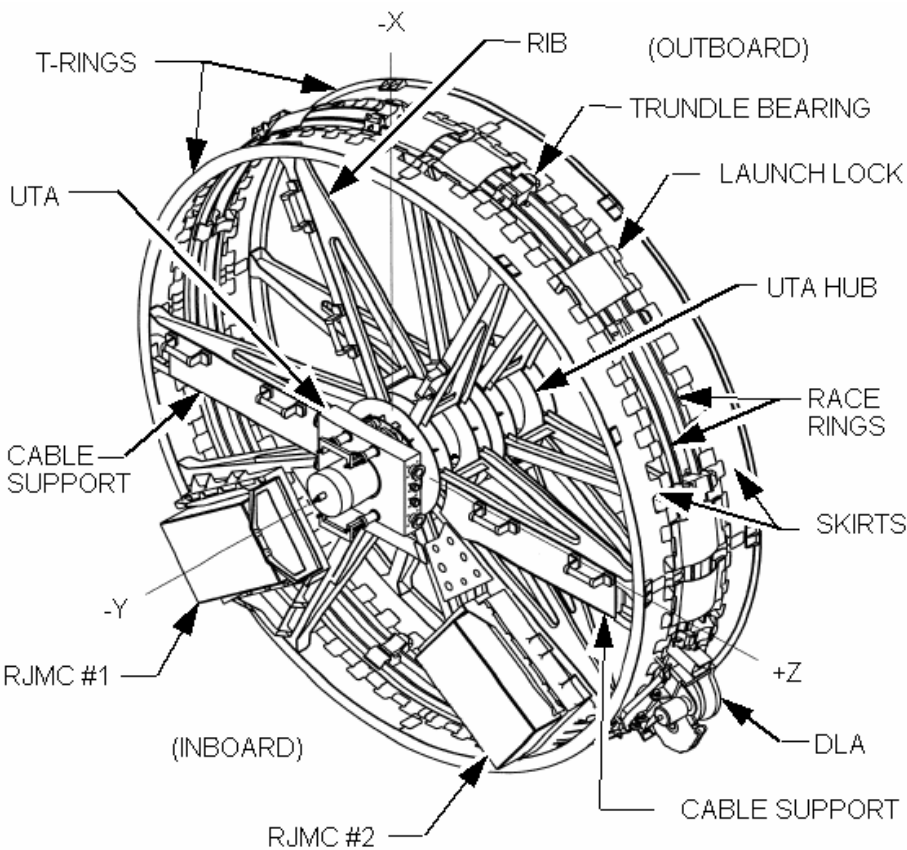
There are two solar array wings (SAW) designed, built and tested by Lockheed Martin in Sunnyvale, Calif. on the P4 module, each deployed in the opposite direction from each other. Each SAW is made up of two solar blankets mounted to a common mast. Prior to deployment, each panel is folded accordion style into a Solar Array Blanket Box (SABB) measuring 20 inches high and 15 feet in length. Each blanket is only about 20 inches thick while in this stored position. The mast consists of interlocking battens which are stowed for launch inside a Mast Canister Assembly (MCA) designed, built and tested by ATK-Able. When deployed by the astronauts, the SAW deploys like an erector set as it unfolds. It has two arms like a human torso when mounted on P4 which are rotated outwards by astronauts during a spacewalk so they can be fully deployed. Because these blankets were stored for such a long time, NASA, Boeing and Lockheed Martin conducted extensive testing to ensure they would unfold properly once on orbit to ensure there would be no problems with the blankets sticking together. This testing was completed in July 2003.



When fully deployed, the SAW extends 115 feet and spans 38 feet across and extends out to each side of the Integrated Equipment Assembly. Since the second SAW is deployed in the opposite direction, the total wing span is over 240 feet.

Each Solar Array Wing weighs over 2,400 pounds and use nearly 33,000 (32,800 per wing) solar array cells, each measuring 8-cm square with 4,100 diodes. The individual cells were made by Spectrolab and ASEC. There are 400 solar array cells to a string and there are 82 strings per wing. Each SAW is capable of generating nearly 32.8 Kilowatts (kW) of direct current power. There are two SAWs on the P4 module yielding a total power generation capability approaching 66 kW, enough power to meet the needs of 30 average homes – without air conditioning (based on an average 2kW of power.)

P3 consists of the **Solar Alpha Rotary Joint (SARJ)**, which continuously rotates to keep the solar array wings on P4 and P6 oriented towards the sun as the station orbits the earth. Located between P3 and P4, the SARJ is a 10 foot diameter rotary joint that



tracks the sun in the alpha axis that turns the entire P4 module (and eventually the P6 module when it is relocated). The SARJ weighs approximately 2,500 pounds. The SARJ can spin 360 degrees using bearing assemblies and a servo control system to turn. All of the power will flow through the Utility Transfer Assembly (UTA) in the SARJ. Roll ring assemblies allow transmission of data and power across the rotating

interface so it never has to unwind. Under contract to Boeing, the SARJ was designed, built and tested by Lockheed Martin in Sunnyvale, Calif.

The solar array wings are also oriented by the **Beta Gimbal Assembly (BGA)**, which can change the pitch of the wings by spinning the solar array. The BGA measures 3 x 3 x 3 feet and provides a structural link between the Integrated Equipment Assembly (IEA.) The BGA's most visual functions are to deploy and retract the SAW and rotate it about its longitudinal axis. The BGA consist of three major components: the Bearing, Motor and Roll Ring Module (BMRRM), the Electronic Control Unit (ECU) and the Beta Gimbal Transition Structure are mounted on the BGA Platform. The BGA was designed by Boeing Rocketdyne in Canoga Park, Calif., which has since been acquired by Pratt and Whitney. The Sequential Shunt Unit (SSU) that serves to manage and distribute the power generated from the arrays is also mounted on each BGA Platform. The SSU was designed by Space Systems Loral.

Both the SARJ and BGA are pointing mechanisms and they can follow an angle target and rotate to that target. On-orbit controllers continuously update those targets so it keeps moving continuously as the station orbits the Earth every 90 minutes, maintaining contact with the sun at the same orbital rate. The SARJ mechanism will move much more than the BGA. The BGA will move about four or five degrees per day, whereas the SARJ will rotate 360 degrees every orbit or about 4 degrees per minute. The SARJ will be the first one to be installed on station and it is unique because it rotates the entire

truss element, allowing it to rotate in the alpha axis rotation. The station has been using the P6 BGA to move as an alpha joint. Eventually, the SARJ will provide primary rotation with BGA doing minor movements and will be tested on this flight, but won't be activated until assembly mission 12A.1.

P4 Integrated Equipment Assembly (IEA)

The IEA has many components: 12 Battery Subassembly orbital replacement units (ORUs), six Battery Charge/Discharge Units (BCDU) ORUs, two Direct Current Switching Units (DCSUs), two Direct Current to Direct Current Converter Units (DDCUs), two Photovoltaic Controller Units (PVCUs), and integrates the Thermal Control Subsystem which consists of one Photovoltaic Radiator (PVR) ORU and two Pump Flow Control Subassembly (PFCS) ORU's used to transfer and dissipate heat generated by the IEA ORU boxes. In addition, the IEA provides accommodation for ammonia servicing of the outboard PV modules as well as pass through of power, data to and from the outboard truss elements. The structural transition between the P3 and P4 segments is provided by the Alpha Joint Interface Structure.

The Integrated Equipment Assembly measures 16 x 16 x 16 feet, weighs nearly 17,000 pounds and is designed to condition and store the electrical power collected by the photovoltaic arrays for use on board the Station.

The IEA integrates the energy storage subsystem, the electrical distribution equipment, the thermal control system, and structural framework. The IEA consists of three major elements:

1. The power system electronics consisting of the Direct Current Switching Unit (DCSU) used for primary power distribution; the Direct Current to Direct Current Converter Unit (DDCU) used to produce regulated secondary power; the Battery Charge/Discharge Unit (BCDU) used to control the charging and discharging of the storage batteries; and the batteries used to store power.
2. The Photovoltaic Thermal Control System (PVTCS) consisting of: the coldplate subassembly used to transfer heat from an electronic box to the coolant; the Pump Flow Control Subassembly (PFCS) used to pump and control the flow of ammonia coolant; and the Photovoltaic Radiator (PVR) used to dissipate the heat into deep space. Ammonia unlike other chemical coolants has significantly greater heat transfer properties.
3. The computers used to control the P4 module ORUs consisting of two Photovoltaic Controller Unit (PVCU) Multiplexer/Demultiplexers (MDMs).

The IEA power system is divided into two independent and nearly identical channels. Each channel is capable of control (fine regulation), storage and distribution of power to the ISS. The two PVAA's are attached the outboard end of the IEA and the AJIS to the inboard end.

Power received from each PVAA is fed directly into the appropriate Direct Current Switching Unit (DCSU). The DCSU is a high-power, multi-path remotely controlled unit

that is used for primary and secondary power distribution, protection and fault isolation within the IEA. It also distributes primary power to the ISS. During periods of isolation (Isolation means during periods of sunlight), the DCSU routes primary power directly to the ISS from its PVAA and also routes power to the power storage system for battery charging. During periods of eclipse, the DCSU routes power from the power storage system to the ISS. The DCSU measures 28" by 40" by 12" and weighs 238 pounds.

Primary power from the DCSU is also distributed to the Direct Current to Direct Current Converter Unit (DDCU). The DDCU is a power processing system that conditions the coarsely regulated power from the PVAA to 123 +/- 2 VDC. It has a maximum power output of 6.25 kW. This power is used for all P4 operations employing secondary power. By transmitting power at higher voltages and stepping it down to lower voltages where the power is to be used, much like municipal power systems, the station can use smaller wires to transmit this electrical power and thus reduce launch loads. The converters also isolate the secondary system from the primary system and maintain uniform power quality throughout the station. The DDCU measures 27.25" by 23" by 12" and weighs 129 pounds.

Primary power from the DCSU is also distributed to the three power storage systems located within each channel of the IEA. The power storage system consists of a Battery Charge/Discharge Unit (BCDU) and two Battery Subassembly ORUs. The BCDU serves a dual function of charging the batteries during solar collection periods, and providing conditioned battery power to the primary power busses (via the DCSU) during eclipse periods. The BCDU has a battery charging capability of 8.4 kW and a discharge capability of 6.6 kW. The BCDU also includes provisions for battery status monitoring and protection from power circuit faults. Commanding of the BCDU is from the PVCU. The BCDU measures 28" by 40" by 12" and weighs 235 pounds.

Each Battery Subassembly ORU consists of 38 lightweight Nickel Hydrogen cells and associated electrical and mechanical equipment. Two battery Subassembly ORUs connected in series are capable of storing a total of 8 kW of electrical power. This power is fed to the ISS via the BCDU and DCSU respectively. The batteries have a design life of 6.5 years and can exceed 38,000 charge/discharge cycles at 35% depth of discharge. Each battery measures 41" by 37" by 19" and weighs 372 pounds. Because of delays in launching the P3/P4 elements, the batteries were replaced in March 2005 for the lower deck and August 2005 for the upper deck.

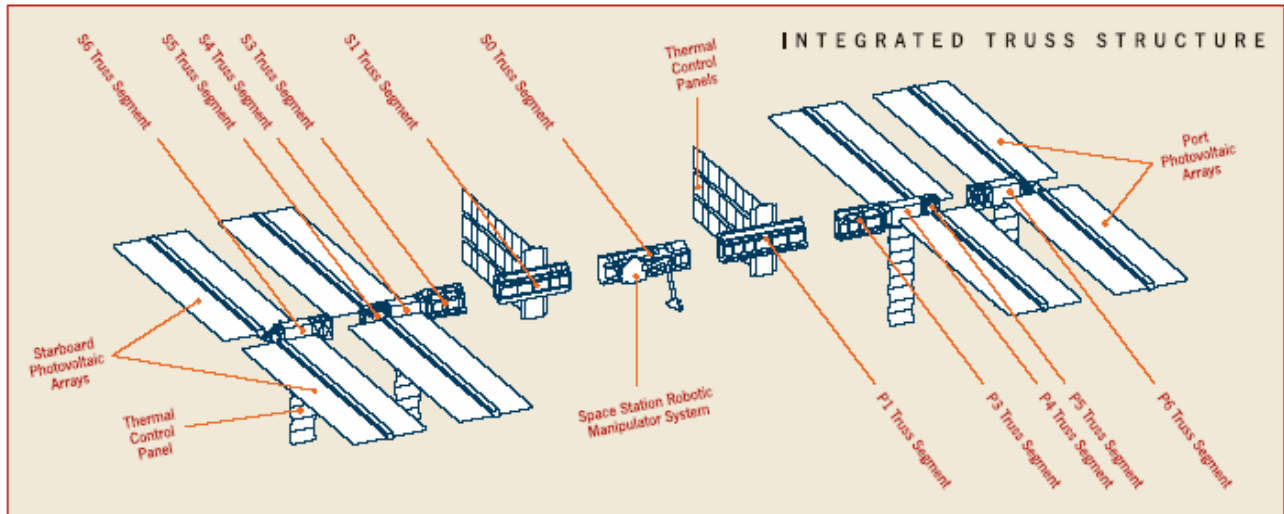
In order to maintain the IEA electronics at safe operating temperatures in the harsh space environments, they are conditioned by the Photovoltaic Thermal Control System (PVTCS). The PVTCS consist of ammonia coolant, eleven coldplates, two Pump Flow Control Subassemblies (PFCS) and one Photovoltaic Radiator (PVR).

The coldplate subassemblies are an integral part of IEA structural framework. Heat is transferred from the IEA orbital replacement unit (ORU) electronic boxes to the coldplates via fine interweaving fins located on both the coldplate and the electronic boxes. The fins add lateral structural stiffness to the coldplates in addition to increasing the available heat transfer area.

The PFCS is the heart of the thermal system. It consists of all the pumping capacity, valves and controls required to pump the heat transfer fluid to the heat exchanges and radiator, and regulate the temperature of the thermal control system ammonia coolant. The PVTCS is designed to dissipate 6,000 Watts of heat per orbit on average and is commanded by the IEA computer. Each PFCS consumes 275 Watts during normal operations and measures approximately 40 x 29 x 19 inches, weighing 235 pounds.

The PVR – the radiator – is deployable on orbit and comprised of two separate flow paths through seven panels. Each flow path is independent and is connected to one of the two PFCSs on the IEA. In total, the PVR can reject up to 14 kW of heat into deep space. The PVR weighs 1,633 pounds and when deployed measures 44 x 12 x 7 feet.

P3/P4 Facts in brief:



Manufacturer: Boeing

Dimensions: 45.3 ft long by 16 feet wide by 15.6 feet high

Weight: 34,885 lbs

Structure: Primarily aluminum

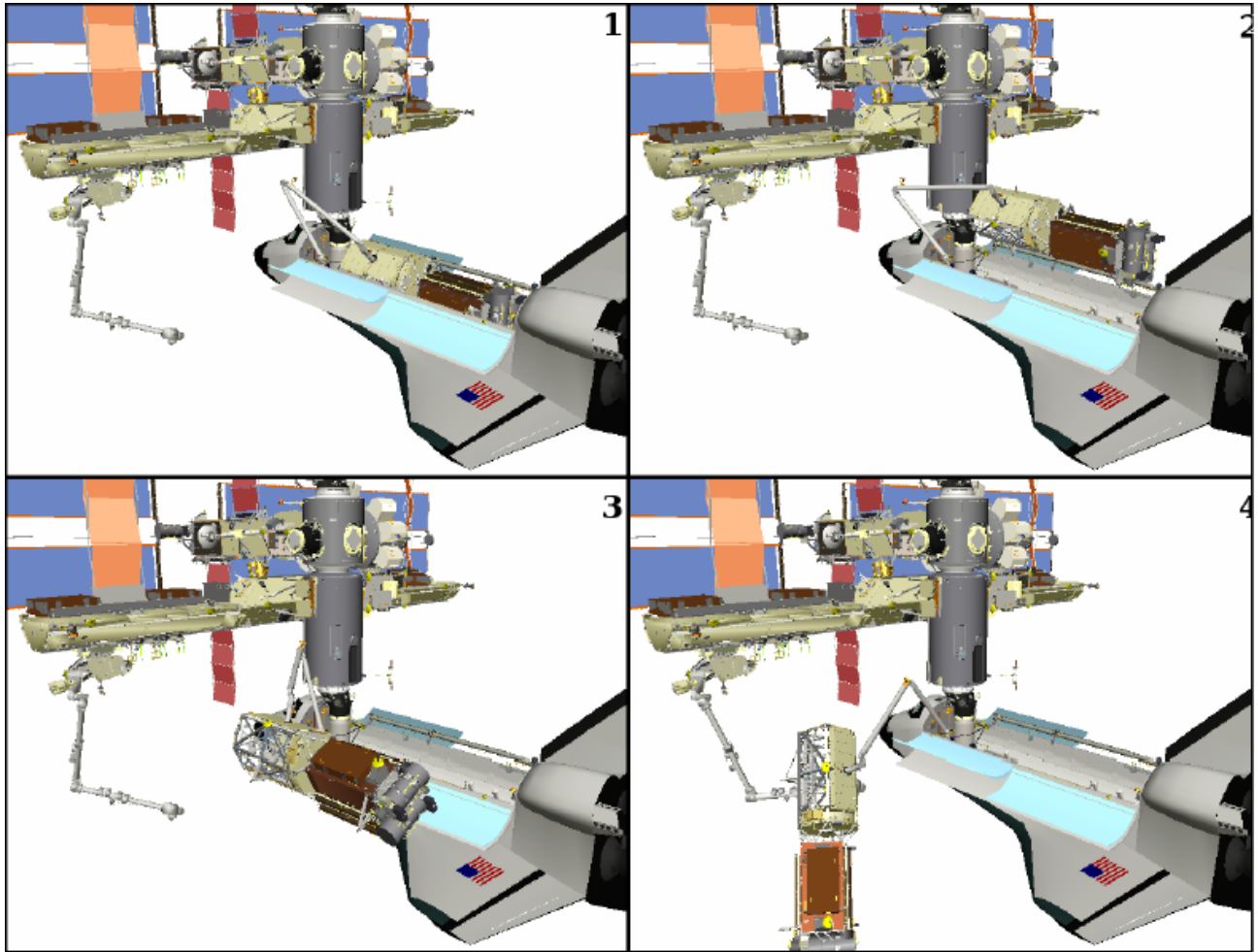
Major components: The P3 primary structure is made of a hexagonal shaped aluminum structure and includes four bulkheads and six longerons. The secondary structure includes brackets, fittings, attach platforms, EVA equipment and miscellaneous mechanisms. The P4 Photovoltaic module includes all equipment outboard of the Solar Alpha Rotary Joint (SARJ) outboard bulkhead, namely the two Photovoltaic Array assemblies and the Integrated Equipment Assembly (IEA).

Purpose: To carry power, data and environmental services along the integrated truss structure. Also, to provide active thermal protection to electrical components throughout the station and to allow the connection of platforms to store spare parts.

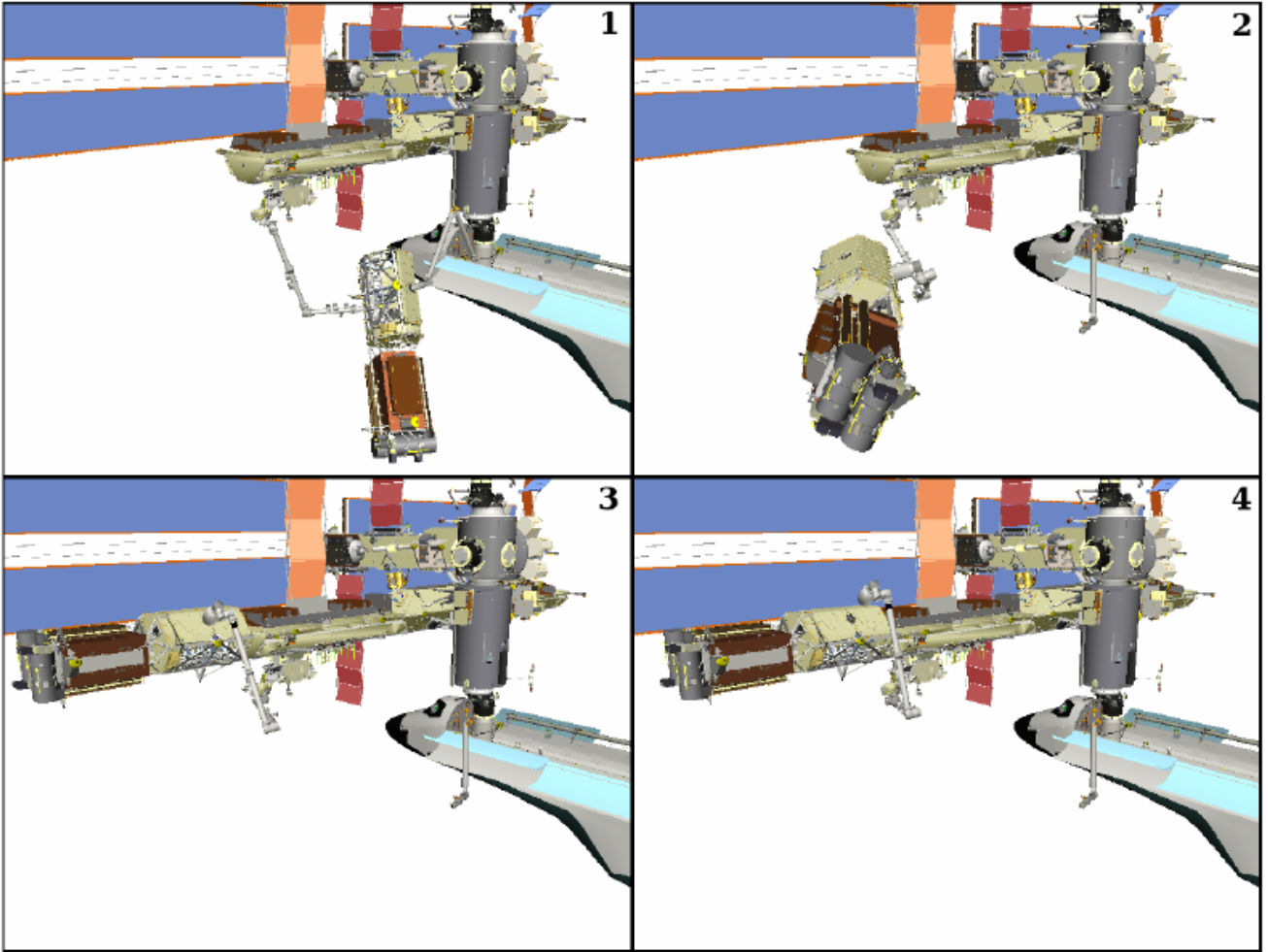
Construction: P3 was designed by the Boeing design team at Huntington Beach, Calif. Boeing (now Pratt and Whitney) Rocketdyne Power and Propulsion in Canoga Park, Calif. designed P4. Assembly of P3 and P4 in Tulsa, Okla. started in 1997. P3 was delivered to the Space Station Processing Facility at Kennedy Space Center on November 17, 1999 and P4 was delivered on July 29, 2000. P3 and P4 were handed off to NASA on September 26, 2002.

Major Subcontractors: Lockheed Martin, Honeywell, Hamilton Sundstrand, Pratt and Whitney Rocketdyne

Installation: P3/P4 is to be installed during STS-115 to the P1 truss via the Segment to Segment Attachment System (SSAS).



P3/P4 SRMS unberth and SSRMS handoff operations is shown above.



P3/P4 SSRMS maneuver and installation is shown above

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