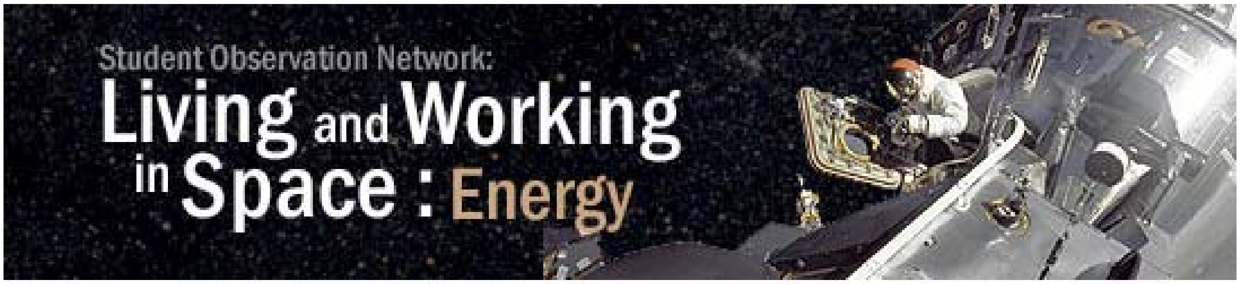
National Aeronautics and Space Administration

Solar Energy for Space Exploration
Student Resources

www.nasa.gov



Interview with a PHALCON (Power, Heating, Articulation, Lighting and Control)

Steven E. Johnson is a mission control officer for the ISS. He works at NASA Johnson Space Flight Center in Houston, Texas. His flight control position is known as PHALCON. Mission Control operates most of the functions of the ISS from the ground in the Blue Flight Control Room. You can see an online map of the Blue Flight Control Room at http://spaceflight.nasa.gov/station/reference/bluefcr/bfcr.html. The PHALCON console is far forward and to the right. Move your cursor over the consoles to find out the job for each position.

The PHALCON team performed duties related to the docking of the 21st Progress vehicle with the ISS. Steven describes the mission below in an e-mail interview on Wednesday, April 26, 2006.

"The Progress spacecraft are unmanned Russian cargo vehicles. Progress 21 launched from the Baikonur Cosmodrome in Kazakhstan on April 24, 2006, at 12:03 p.m. e.d.t., (10:03 p.m. Baikonur time).

When the 21st Progress to visited the ISS, it had just over 2.5 tons of equipment and supplies onboard. Included in its 5,040 pounds of cargo were more than 1,900 pounds of propellant, just over 100 pounds of air and oxygen, 661 pounds of water and almost 2,360 pounds of dry cargo.

The new Progress also has onboard some small crustaceans for a Russian scientific experiment called Aquarium onboard. That experiment focuses on the stability of closed ecological systems in microgravity. It could provide information useful for lengthy human spaceflights.

Progress 21 docked at the aft port of the Zvezda Service Module. Station crewmembers, Expedition 13 commander Pavel Vinogradov and NASA Science Officer Jeff Williams, opened the new arrival's hatch later in the day. While they might have sampled some of the fresh food aboard the Progress, they began unloading the Progress on Thursday.

As the power system controllers, PHALCON performed several activities related to the docking event. The inbound vehicle uses propulsion and attitude control thrusters to position itself. The thrusters can potentially spread fuel and oxidizer over the U.S. solar arrays. These contaminates can damage the solar array surfaces and decrease solar cell performance. To minimize the likelihood of damage, PHALCON positions the arrays so that the wide surface of the solar panels is not facing the Progress thrusters. This 'edge-on profile' provides the smallest surface facing the thrusters. But, often, this means the solar panels aren't facing the Sun so they can't produce as much power.

The arrays are locked in a stationary position and, therefore, they are not tracking the Sun during rendezvous and docking. However, in today's instance, ISS power use was relatively low, and power generation in the stationary solar array position was exceptionally good. The above-average power generation was due to the orbit of ISS, which allowed the solar arrays to maintain an unshadowed line-of-sight to the Sun. Following the docking, the solar arrays were returned to automatic sun-tracking mode.

There is also some risk of damage to the solar arrays when a vehicle leaves the station. Progress 20 is already docked to ISS and is the sister cargo carrier to Progress 21. Progress 20 will remain at the Pirs Docking Compartment until mid-June. Progress 20 is being loaded with trash and surplus equipment from the station. It will leave the station without any crew and be placed in an orbit so that it will burn up after entry into the Earth's atmosphere.

Although the undocking vehicle uses mechanical springs instead of thrusters, PHALCON will still perform the same solar array activities to protect against contamination in case thruster firings are needed.

There are currently two solar array panels on the ISS. (Two more solar array panels were installed during the STS-115 mission in September, 2006.) There will be eight panels when assembly of the station is complete. Each panel contains 32,800 solar cells built into 82 strings. The strings are constructed in a combination of parallel and series electrical circuits. The parallel circuits allow power to be generated and charge batteries even if one string fails. (This is similar to how most Christmas light strings will allow most lights to remain lit even if one burns out.)

However, to increase the voltage, strings also have cells connected in series.

There is one bypass diode connected to every eight solar cells. These diodes allow cells in groups of eight to be bypassed if a cell fails or is in the shadow of some part of the station.

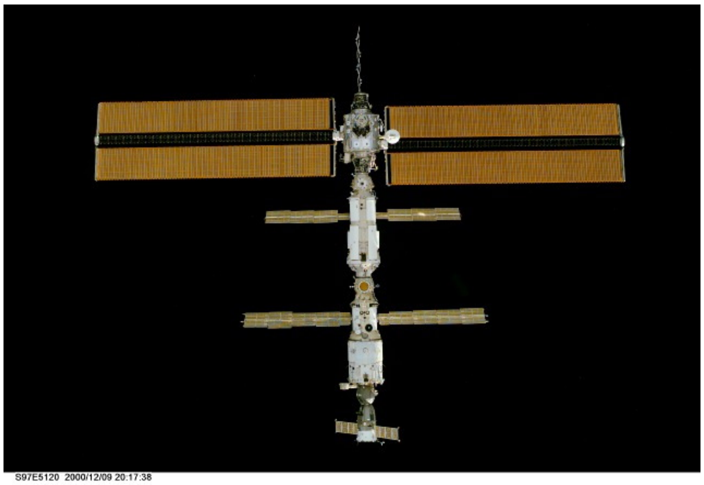
Therefore, damage or contamination of a group of solar cells or strings will not prevent the solar array from producing power. As one might suspect, damage of cells or strings reduces the amount of power the array can produce. The greater the extent of damage, the less power the solar array can produce.

All the solar cells and strings are not individually monitored from Mission Control. Therefore, we cannot tell if any given cell or string is damaged or degraded. However, through a solar array efficiency test, we can determine the approximate number of strings that are operating normally. We perform an efficiency test on each array about twice per year. A few years ago, we discovered that there is at least one failed string on one of the arrays. Using a video survey, we determined the failed string is a result of damage to the diode circuitry of the string. So, while the solar cells and the string itself may be functional, the diode that passes the power downstream is damaged. It's not likely the diode was damaged by thruster contamination. The damage is probably a result of flexing of the arrays or electrical arcing.

Individual cells, strings, and diodes cannot be replaced on orbit. Technically, the entire solar array can be replaced. However, this would be a major task, and would require significant EVA (Extravehicular Activity), also known as a spacewalk. It would be a very complicated and expensive repair mission. Unfortunately, there are no spare solar arrays. We could use one of the six remaining solar array panels that are scheduled to be installed on later shuttle missions. However, without additional spare arrays (there are no plans or funds to build any more), the result would mean that we would still be without a solar array on a future mission. It is far cheaper and less risky to leave a failed solar array in place and continue with the normal schedule for adding new solar arrays.

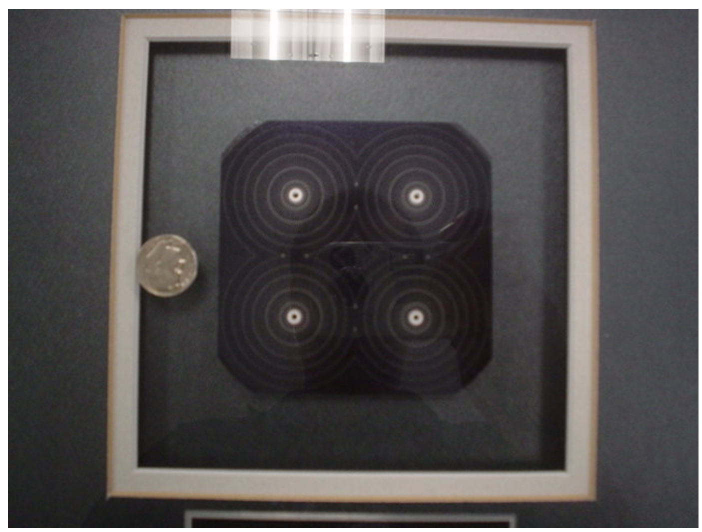
When the ISS has its full complement of eight solar arrays (and to a lesser extent, when we have four active arrays), there is an electrical switching unit that allows power to be routed from one solar array to loads of another array. That is, the loads that are normally powered by a failed array can be powered from a functioning array. That allows PHALCON the flexibility to continue supporting ISS power demands even if one (or more) solar array completely fails.

Solar Arrays for the International Space Station

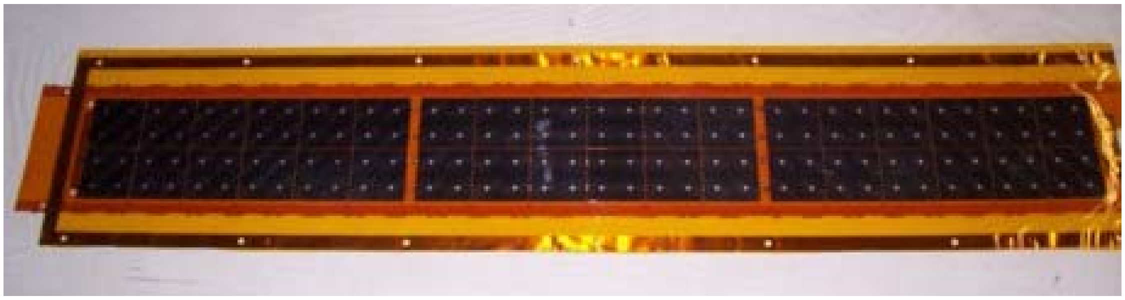


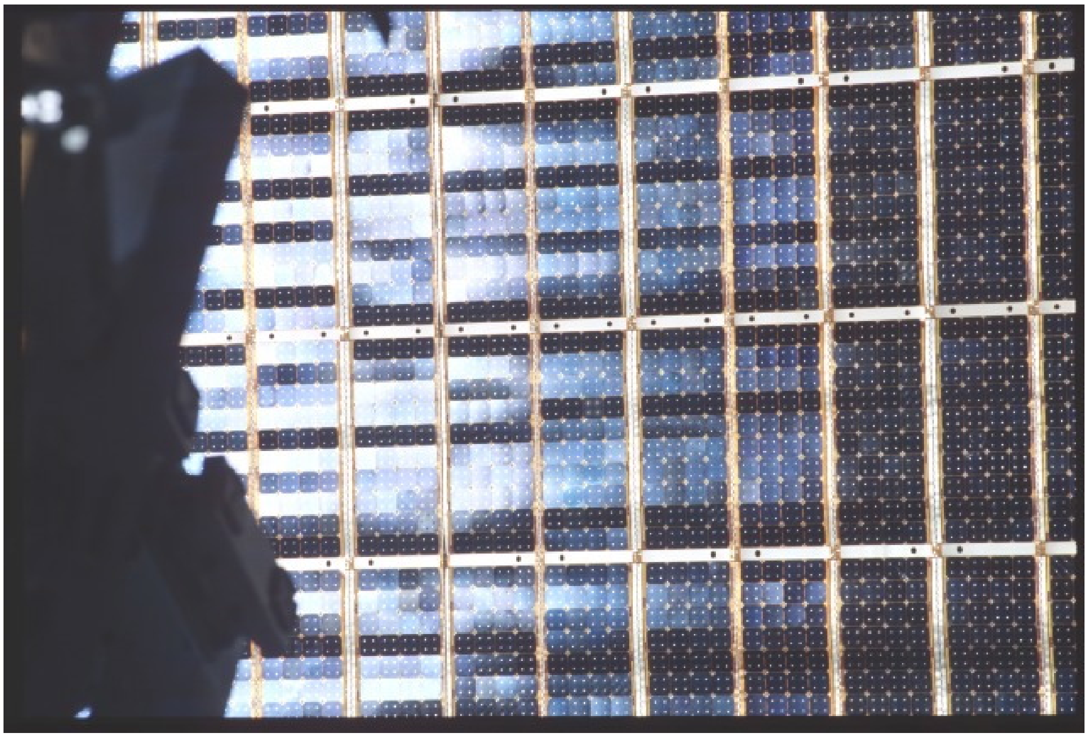
The ISS relies on huge solar panel arrays to convert solar energy into electrical power. The solar arrays are large, wing-like structures, each measuring 34 meters long and 11 meters wide (112 feet x 39 ft.). Since each array is extended in opposite directions, the total wingspan is over 73 meters (240 feet). Shown here are the two solar arrays installed by the shuttle crew of STS-97. These two arrays can supply nearly 64 kilowatts of power. This is enough to meet the needs of 30 average homes without air conditioning. The crew of STS-115 installed two additional arrays in September 2006. There will be eight solar arrays when the space station is complete.

The image to the right shows an individual solar cell. It is about 8 centimeters (0.08 meters) square. Note the size of the dime next to the solar cell. The 8 eight arrays together will contain a total of 262,400 solar cells and cover an area of about 2,500 square meters (27,000 square feet) —more than half the area of an American football field!



The solar cells are electrically connected into solar panels.   The panel shown below is similar to the solar panels on the station panel. As you can see, there are 36 solar cells making up this solar panel. This particular example is approximately 22.4 cm (57 inches) by 4.5 cm (11.5 inches).





In this close up image of the solar arrays used on the ISS, you can see many individual panels. Each panel has a border of white. If you look closely at the image, you can see that there are 40 individual cells in a panel. The panel is four cells wide and 10 cells long.

Math Connections

- How much power does each solar cell produce?

  Information:

  1. Scientists have measured the intensity of solar radiation at the space station as about 1,366 W/m^2.
  2. Each solar cell is about 12 percent efficient. This means each cell can convert about 12 percent of the energy from the Sun that falls on the cell into electric power.
  3. What is the area of each solar cell? Look in the text above.

- Using the amount of power from each cell, how much power should two arrays produce? How does this answer compare with the information in this article?

  Information: Each array contains 32,800 solar cells.

- What is the efficiency of two arrays? Why might this be different from the efficiency of a solar cell?

  Information you need to know:

  1. What is the intensity of solar radiation at the space station?
  2. What is the area of an array?
  3. What is the power output from two arrays?

Model Space Station: Power Loads and Assembly Sequence

The ISS has appliances just like your home. The information provided here is for a simplified space station. For example, ISS will eventually have eight solar arrays. This model only has four solar arrays. The equipment that requires electrical power has been simplified somewhat, but the information will help you plan for a lunar or Martian mission.

The diagrams show what systems will be added as the construction of the space station proceeds.

The load is the electrical equipment that requires power. The power is measured in Watts (W). The equipment is usually on one of two circuits: Channel 1 (Ch 1) or Channel 2 (Ch 2).

Load	**Power in Watts**	**Power Module 1**		**Power Module 2**		**Habitat Module**		**Command Module**		**Airlock**		**US Lab**		**Russian Lab**		**Japanese Lab & External Platform**	
		Ch 1	Ch 2	Ch 1	Ch 2	Ch 1	Ch 2	Ch 1	Ch 2	Ch 1	Ch 2	Ch 3	Ch 4	Ch 3	Ch 4	Ch 3	Ch 4
Battery Unit	2215 W	3	3	3	3	-	-	-	-	-	-	-	-	-	-	-	-
Fan	535 W	-	-	-	-	1	1	1	1	1	-	-	1	1	-	1	-
Atmosphere Controller	1200 W	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Control System	820 W	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-	-	-
Crew System	575 W	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-	-	-
Comm Unit	470 W	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-	-	-
Lighting Bank	360 W	-	-	-	-	1	1	1	-	1	-	1	-	-	1	-	1
Canadian Robotic Arm	3210 W	-	-	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-
Robotic Workstation	895 W	-	-	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-
Main Computer	385 W	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Air Pump	1150 W	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Experiment U.S. 1	4250 W	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Experiment U.S. 2	3005 W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Experiment U.S. 3	2275 W	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Experiment U.S. 4	2260 W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Experiment R1	2715 W	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Experiment R2	3200 W	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Experiment R3	1845 W	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Experiment J1	1985 W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Experiment J2	920 W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Experiment J3	3460 W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
						* These components have one unit, but two separate power sources.											

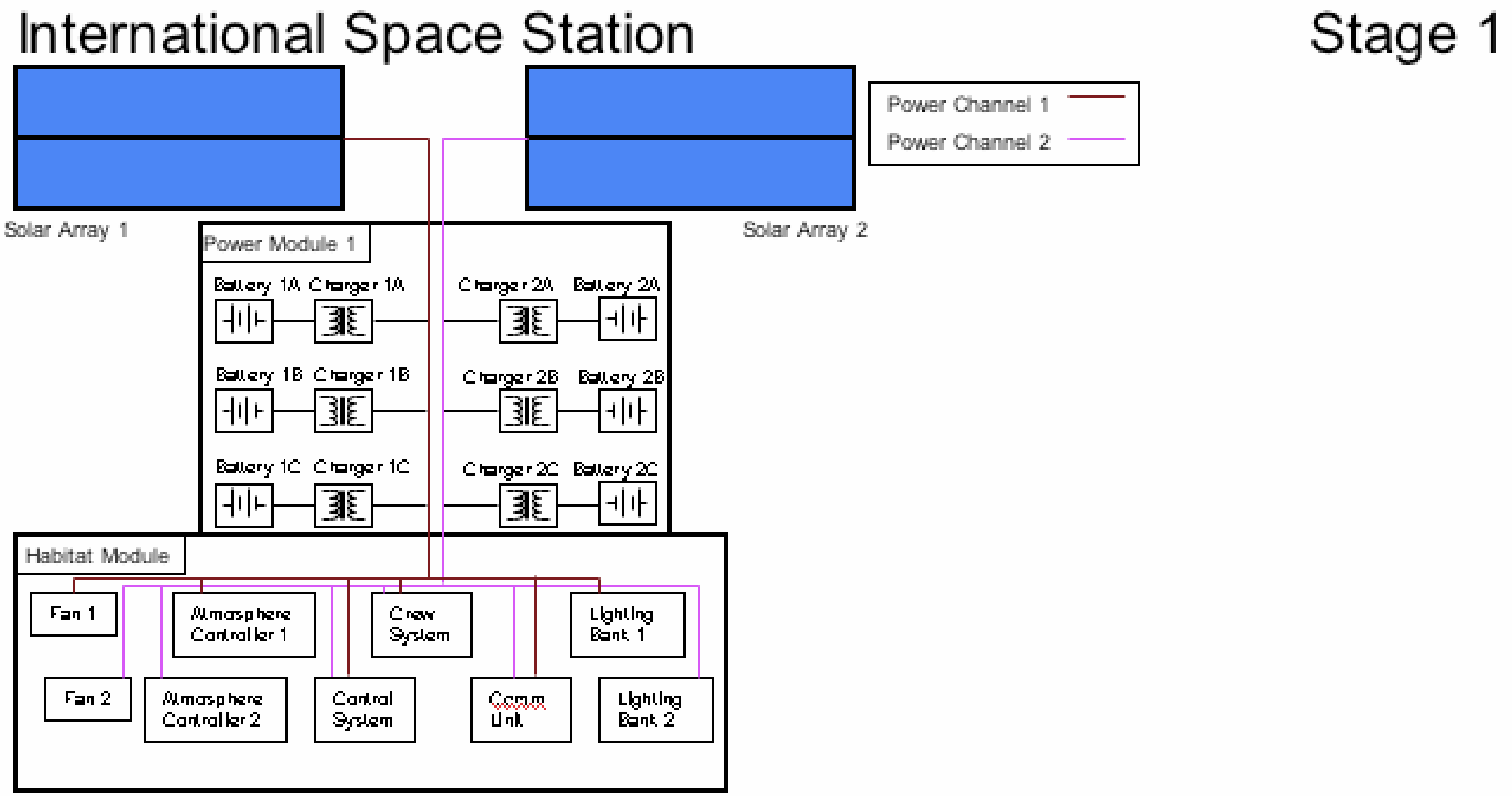
This information can be broken down by channel. A channel is similar to a circuit in your house. The chart below shows the equipment and the power each uses on Channels 1 and 2.

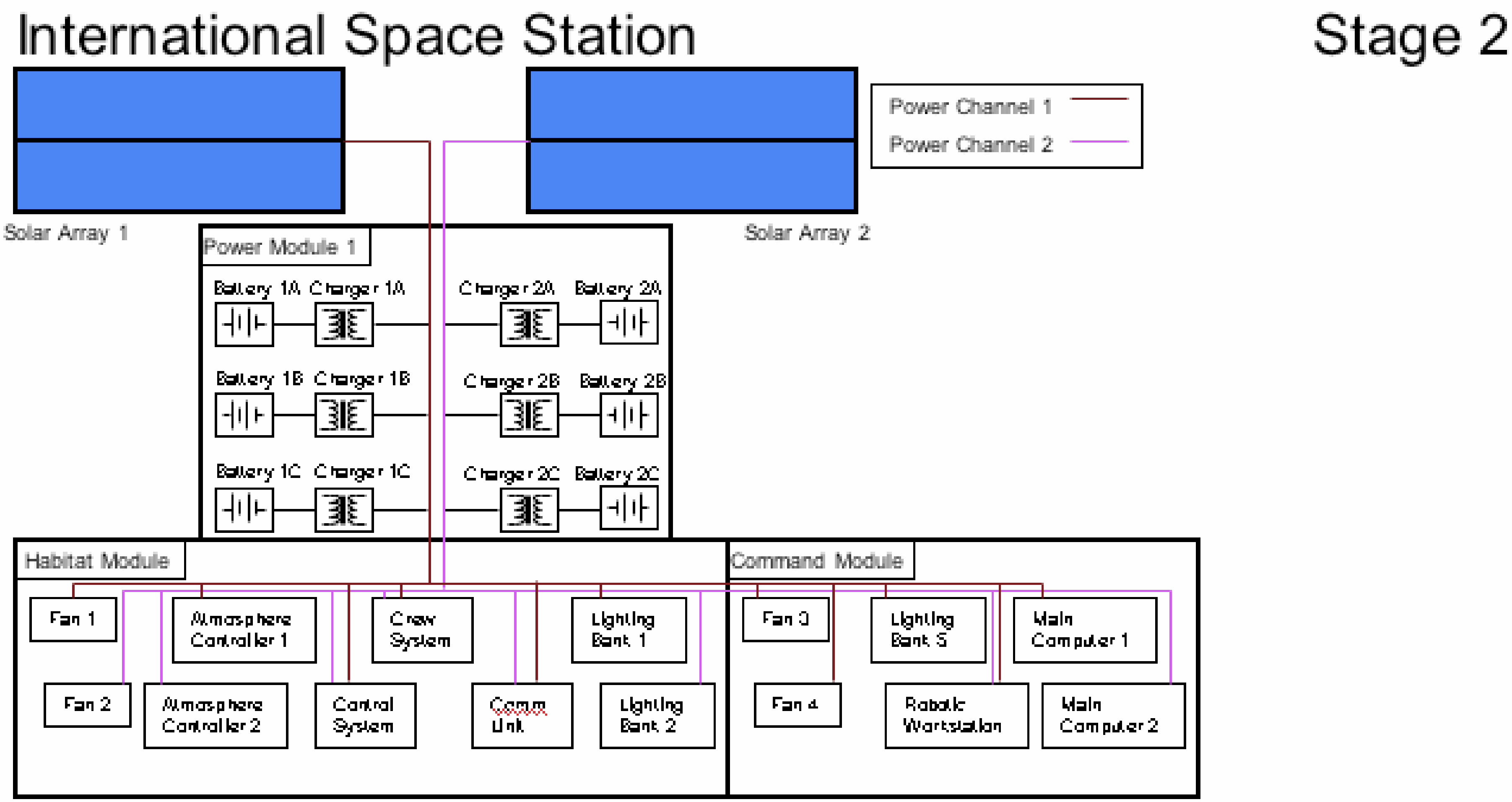
Channel 1	**#**	**Power in Watts**	**Net Power in Watts**		**Channel 2**	**#**	**Power in Watts**	**Net Power in Watts**
Battery Unit	3	2,215	6,645		Battery Unit	3	2,215	6,645
Fan	3	535	1,605		Fan	3	535	1,605
Atmosphere Controller	1	1,200	1,200		Atmosphere Controller	1	1,200	1,200
Crew System	1	575	575		Crew System	1	575	575
Control System	1	820	820		Control System	1	820	820
Ccommunications	1	470	470		communications	1	470	470
Lighting Bank	3	360	1,080		Lighting Bank	3	360	1,080
Main computer	1	385	385		Main computer	1	385	385
Robotic Workstation	1	895	895		Robotic Workstation	1	895	895
Canadian Robotic Arm	1	3,210	3,210		Canadian Robotic Arm	1	3,210	3,210
Air pump	1	1,150	1,150		Air pump	1	1,150	1,150
		Total	**18,035**				**Total**	**18,035**

The chart below shows the equipment and the power each uses on Channels 3 and 4.

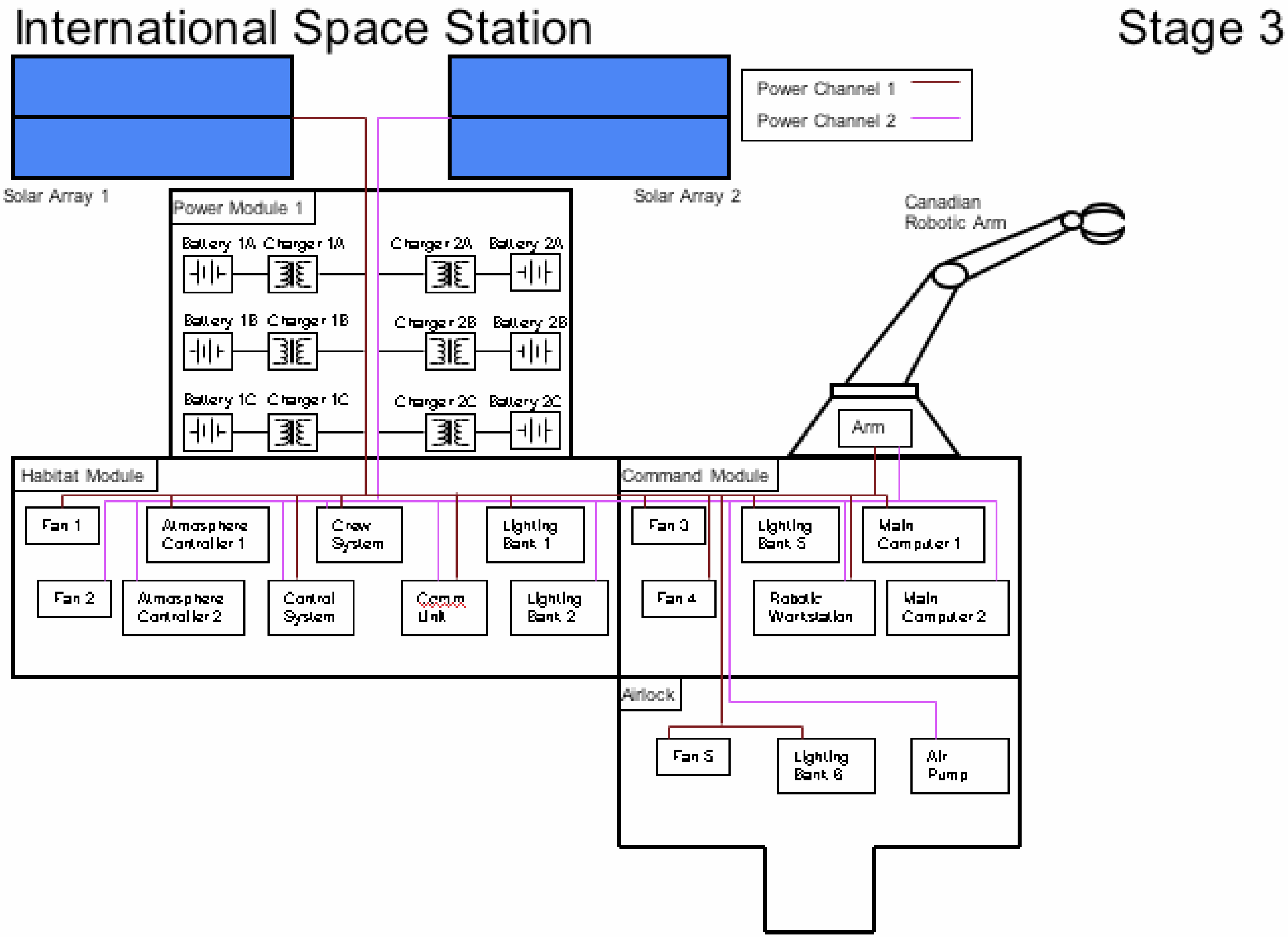
Channel 3	**#**	**Power in Watts**	**Net Power in Watts**		**Channel 4**	**#**	**Power in Watts**	**Net Power in Watts**
Battery Unit	3	2,215	6,645		Battery Unit	3	2,215	6,645
Fan	1	535	535		Fan	2	5,35	1,070
Lighting Bank	2	360	720		Lighting Bank	1	360	360
Experiment U.S. 1	1	4,250	4,250		Experiment US 2	1	3,005	3,005
Experiment U.S. 3	1	2,275	2,275		Experiment US 4	1	2,260	2,260
Experiment Russian 1	1	2,715	2,715		Experiment Russian 2	1	3,200	3,200
Experiment Russian 3	1	1,845	1,845		Experiment Japan 2	1	920	920
Experiment Japan 1	1	1,985	1,985		Experiment Japan 3	1	3,460	3,460
		Total	**20,970**				**Total**	**20,920**

The following pages show what equipment is added to the ISS at each stage of construction.

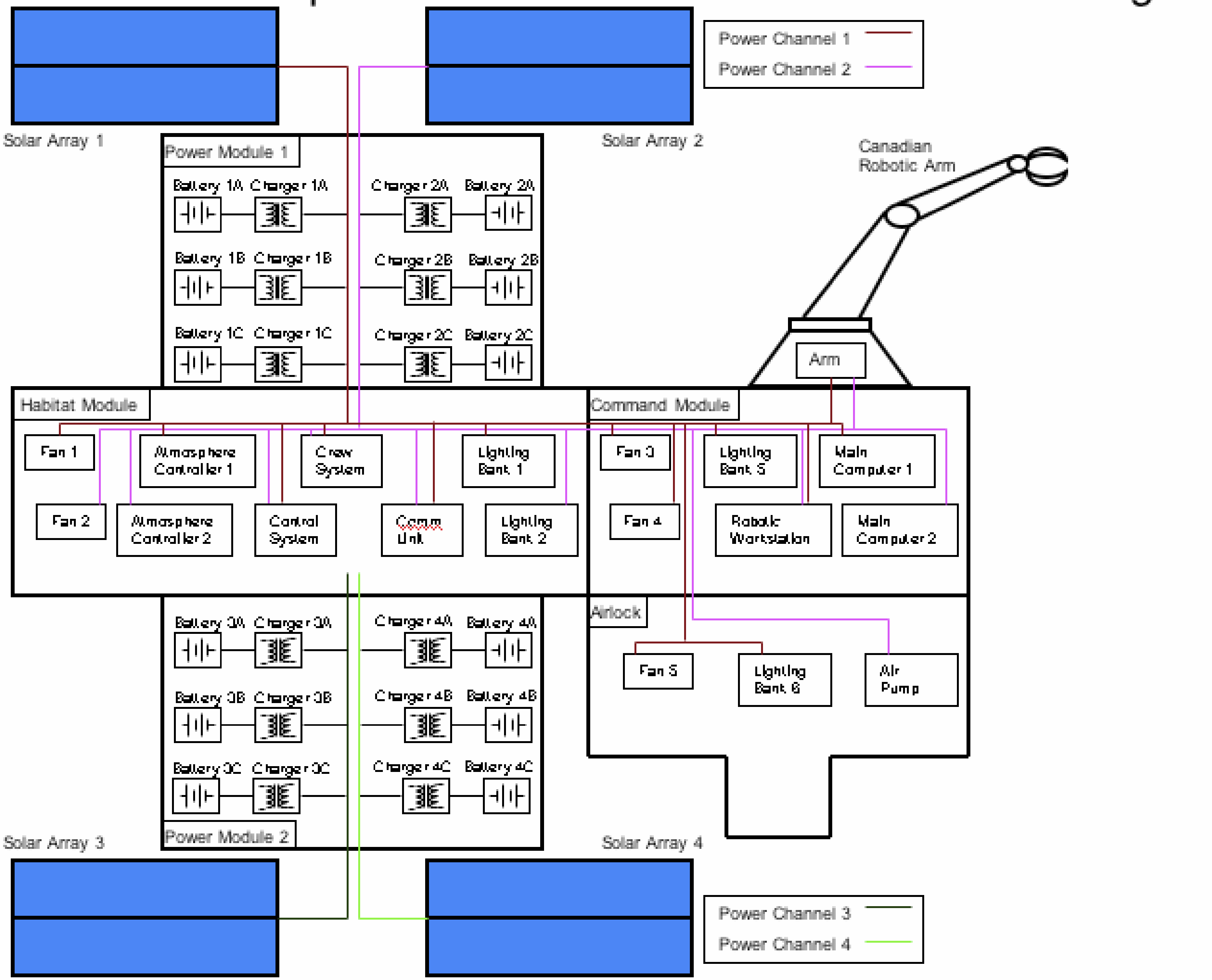


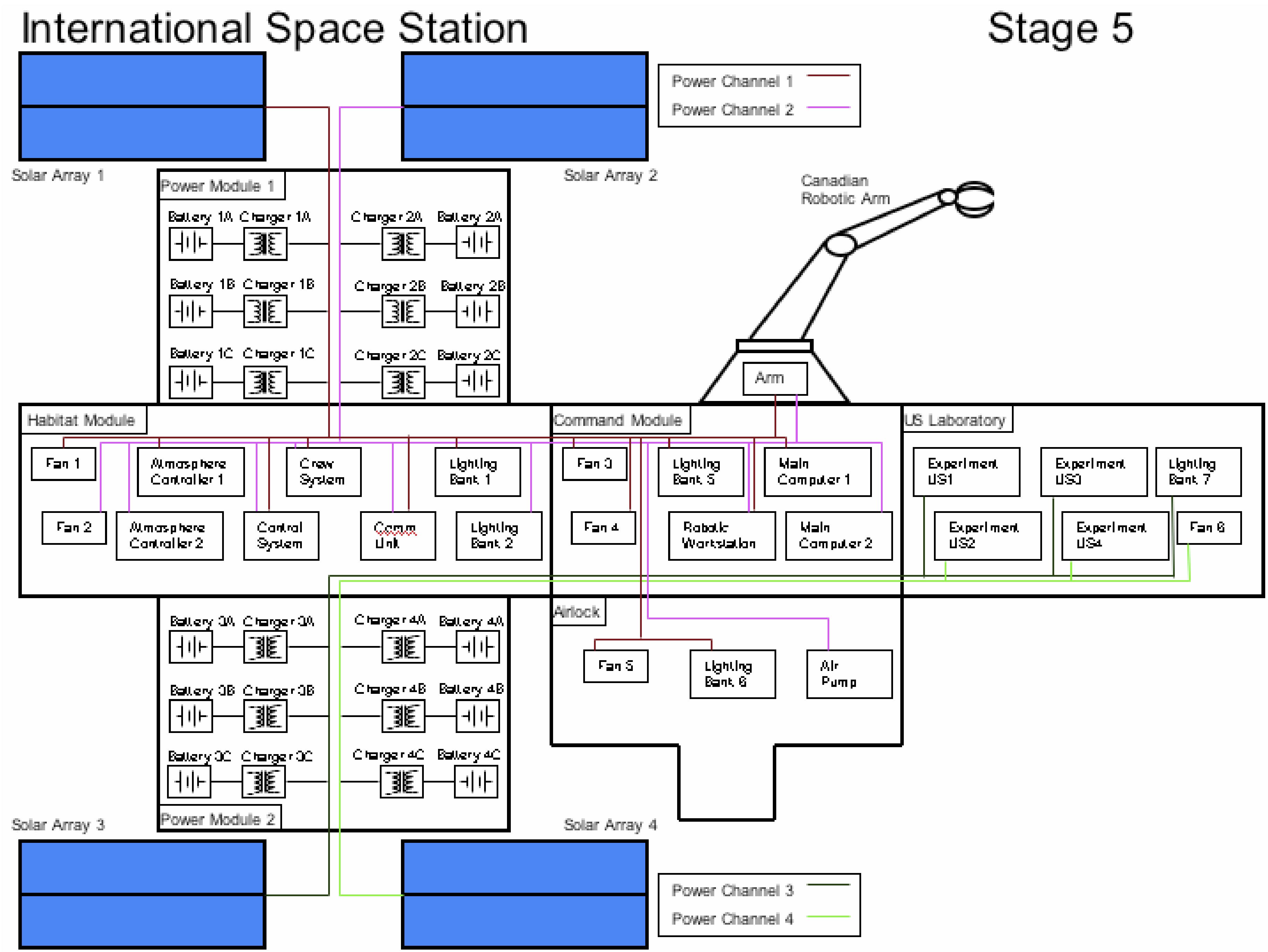


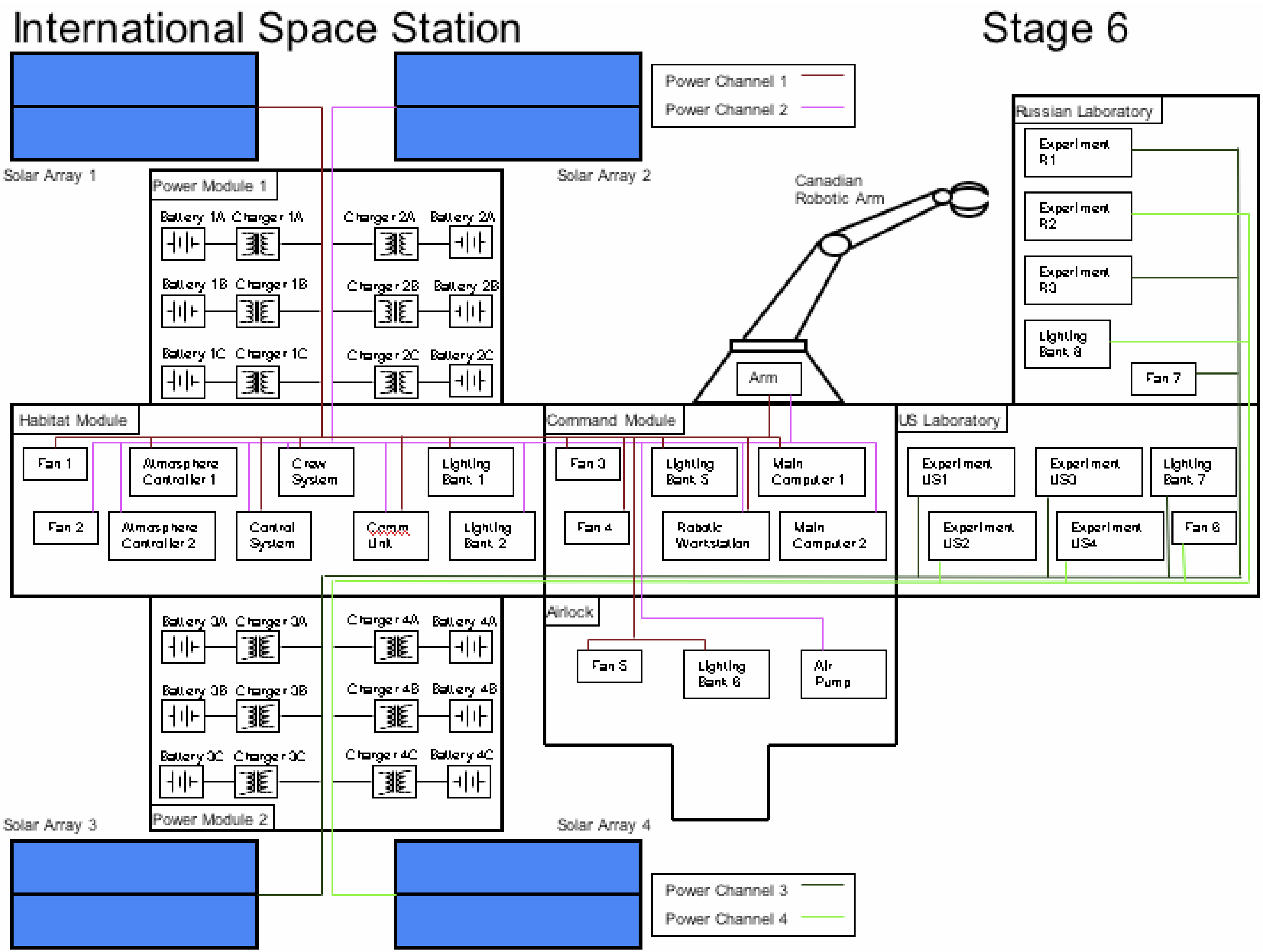
International Space Station
Stage 2
Power Channel 1
Power Channel 2
Solar Array 1
Solar Array 2
Power Module 1
Battery 1A
Charger 1A
Charger 2A
Battery 2A
Battery 1B
Charger 1B
Charger 2B
Battery 2B
Battery 1C
Charger 1C
Charger 2C
Battery 2C
Habitat Module
Command Module
Fan 1
Atmosphere Controller 1
Crew System
Lighting Bank 1
Fan 3
Lighting Bank 3
Main Computer 1
Fan 2
Atmosphere Controller 2
Control System
Comm Link
Lighting Bank 2
Fan 4
Robotic Workstation
Main Computer 2


International Space Station
Stage 3
Power Channel 1
Power Channel 2
Solar Array 1
Solar Array 2
Power Module 1
Battery 1A
Charger 1A
Charger 2A
Battery 2A
Battery 1B
Charger 1B
Charger 2B
Battery 2B
Battery 1C
Charger 1C
Charger 2C
Battery 2C
Canadian Robotic Arm
Arm
Habitat Module
Fan 1
Atmosphere Controller 1
Crew System
Lighting Bank 1
Fan 2
Atmosphere Controller 2
Control System
Comm Unit
Lighting Bank 2
Command Module
Fan 3
Lighting Bank 5
Main Computer 1
Fan 4
Robotic Workstation
Main Computer 2
Airlock
Fan 5
Lighting Bank 6
Air Pump

International Space Station

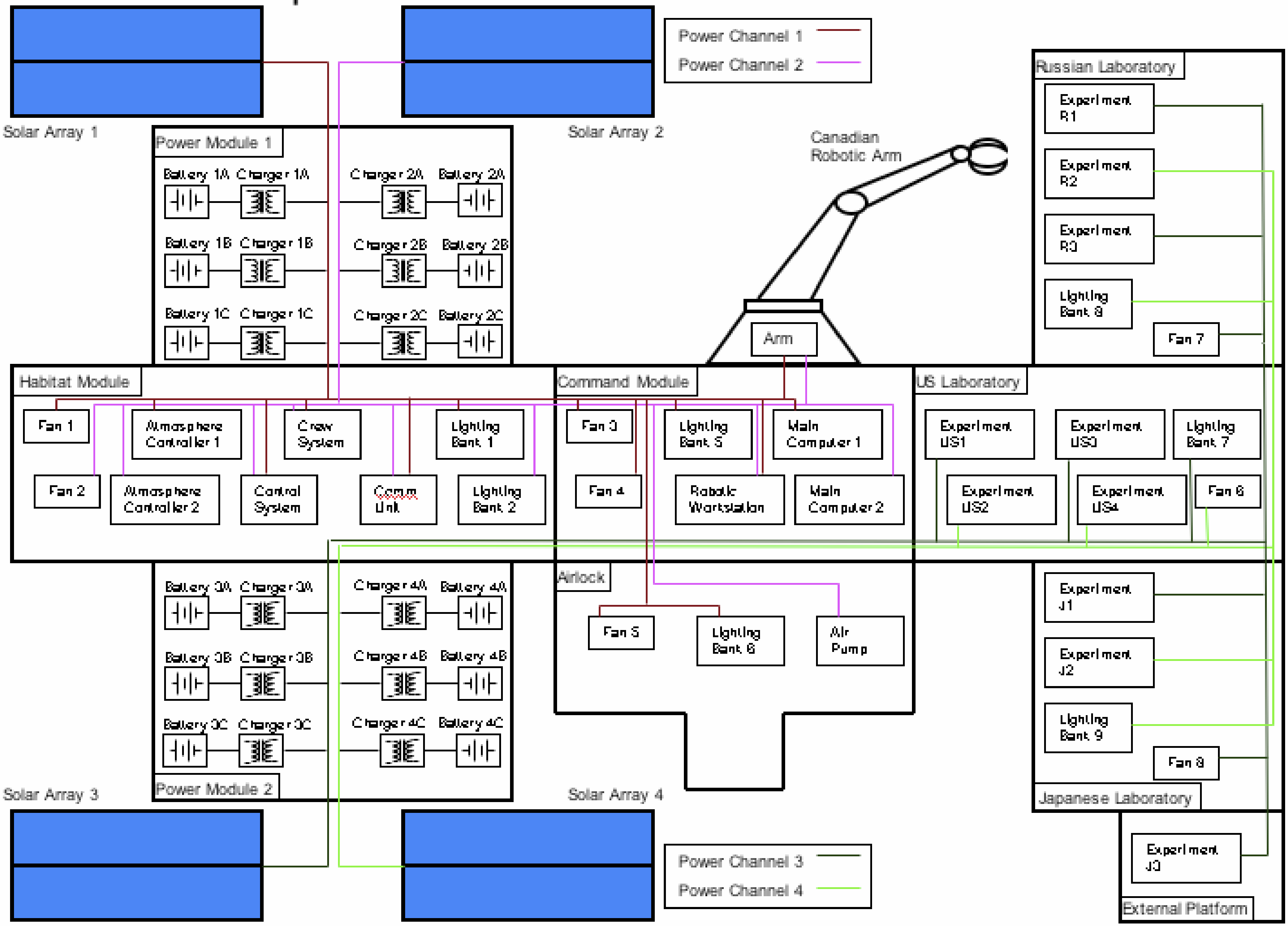



International Space Station
Stage 5
Power Channel 1
Power Channel 2
Solar Array 1
Solar Array 2
Power Module 1
Battery 1A
Charger 1A
Charger 2A
Battery 2A
Battery 1B
Charger 1B
Charger 2B
Battery 2B
Battery 1C
Charger 1C
Charger 2C
Battery 2C
Canadian Robotic Arm
Arm
Habitat Module
Fan 1
Atmosphere Controller 1
Crew System
Lighting Bank 1
Fan 2
Atmosphere Controller 2
Control System
Comm Unit
Lighting Bank 2
Command Module
Fan 3
Lighting Bank 5
Main Computer 1
Fan 4
Robotic Workstation
Main Computer 2
US Laboratory
Experiment US1
Experiment US3
Lighting Bank 7
Experiment US2
Experiment US4
Fan 6
Battery 3A
Charger 3A
Charger 4A
Battery 4A
Battery 3B
Charger 3B
Charger 4B
Battery 4B
Battery 3C
Charger 3C
Charger 4C
Battery 4C
Power Module 2
Airlock
Fan 5
Lighting Bank 6
Air Pump
Solar Array 3
Solar Array 4
Power Channel 3
Power Channel 4



International Space Station
Stage 6
Power Channel 1
Power Channel 2
Power Channel 3
Power Channel 4
Solar Array 1
Solar Array 2
Solar Array 3
Solar Array 4
Power Module 1
Power Module 2
Battery 1A
Charger 1A
Charger 2A
Battery 2A
Battery 1B
Charger 1B
Charger 2B
Battery 2B
Battery 1C
Charger 1C
Charger 2C
Battery 2C
Battery 3A
Charger 3A
Charger 4A
Battery 4A
Battery 3B
Charger 3B
Charger 4B
Battery 4B
Battery 3C
Charger 3C
Charger 4C
Battery 4C
Canadian Robotic Arm
Arm
Russian Laboratory
Experiment R1
Experiment R2
Experiment R3
Lighting Bank 8
Fan 7
Habitat Module
Fan 1
Atmosphere Controller 1
Crew System
Lighting Bank 1
Fan 2
Atmosphere Controller 2
Control System
Comm Unit
Lighting Bank 2
Command Module
Fan 3
Lighting Bank 5
Main Computer 1
Fan 4
Robotic Workstation
Main Computer 2
US Laboratory
Experiment US1
Experiment US3
Lighting Bank 7
Experiment US2
Experiment US4
Fan 6
Airlock
Fan 5
Lighting Bank 6
Air Pump

International Space Station



National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt Road
Greenbelt, MD 20771-0001

www.nasa.gov