

International Space Station Environmental Control and Life Support System – Verification for the Pressurized Mating Adapters

David E. Williams
NASA, Johnson Space Center

Copyright © 2007 SAE International

ABSTRACT

The International Space Station (ISS) Pressurized Mating Adapters (PMAs) Environmental Control and Life Support (ECLS) System is comprised of three subsystems: Atmosphere Control and Supply (ACS), Temperature and Humidity Control (THC), and Water Recovery and Management (WRM). PMA 1 and PMA 2 flew to ISS on Flight 2A and PMA 3 flew to ISS on Flight 3A. This paper provides a summary of the PMAs ECLS design and the detailed Element Verification methodologies utilized during the Qualification phase for the PMAs.

INTRODUCTION

The PMAs were designed and built in two different configurations. PMA 2 and 3 have a Russian provided Androgynous Peripheral Attachment System (APAS) with a hatch on the side that the Shuttle docks to. This allows the Space Shuttle to dock to ISS using the Shuttle/MIR developed Orbiter Docking System (ODS). The APAS hatch on PMA 2/3 allows a docking target to be attached to the front of PMA 2/3 to help facilitate docking of the Space Shuttle to ISS and it provides a barrier to keep external contamination out of the interior part of the PMA when a Shuttle is not docked to ISS. On the other side of the PMA is a Common Berthing Mechanism (CBM) to attach PMA 2/3 to the different ISS Modules, as required during Assembly and as shown in Figure 1. The key PMA 2/3 ECLS design feature is to support scavenging and transferring excess Space Shuttle consumables to ISS and to provide ventilation within the PMA and between the Space Shuttle and ISS. The major difference between PMA 1 and PMA 2/3 is that PMA 1 does not have a hatch on its APAS and it does not have the hardware for scavenging and transferring consumables from the Space Shuttle to ISS. The hatch was removed from PMA 1 for structural reasons. The ISS Program made a decision early on to keep the PMA shell design the same by trading the hatch for the additional mass of two Node Control Software Multi-

plexer/Demultiplexers (MDMs) with heat pipes on the external part of PMA 1. The MDMs provides command and control of the ISS ECLS hardware in Node 1. PMA 1 also has the advantage that it did not have to be designed for interfacing with multiple ISS modules. It only supports the mating of Node 1 to the Functional Cargo Block (FCB).

The Verification of the ISS hardware is accomplished using a building block process. Verification starts at the Component Level and progresses until the Element Level Verification is complete. The primary objective of the Qualification Verification program is to ensure that the subsystems meet the section three requirements in the Prime Item Development Specifications (PIDS). The PIDS dictates whether a section three requirement is verified by test, analysis, inspection, and/or demonstration, as documented in section four of the PIDS.

The PMAs are a Protoflight Test Article since no Element Qualification Test Article exists. Therefore, no additional ground testing or evaluations can be performed on the PMAs after they had been installed in the Space Shuttle Payload Bay and launched to ISS. The ISS Program also made a decision early on to use engineering judgment and the normal preflight analysis that is done at launch minus one month (L-1 mo.) instead of performing any special PMA 2 to Node 1 ECLS THC Verification activities for the 2A series of Flights (i.e., Flights 2A, 2A.1, 2A.2a, and 2A.b) in support of Early Ingress into ISS. The PMAs are shown in Figure 4 during different stages of processing at Kennedy Space Center (KSC).

SUBSYSTEM OVERVIEWS

The PMA ECLS is comprised of three subsystems: THC, ACS, and WRM. This section will provide a general overview of these subsystems for the two different PMA configurations.

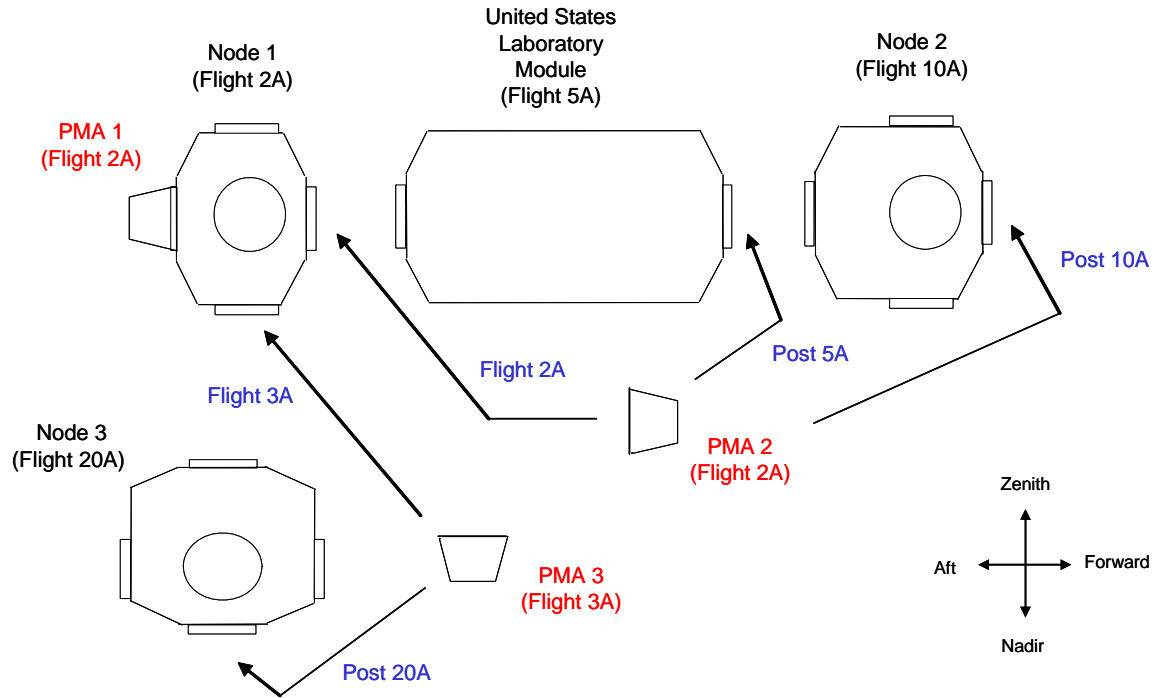


Figure 1 – Active Pressurized Mating Adapter Docking Locations

PMA 1 THC:

The purpose of the PMA 1 THC subsystem is to transfer Intermodule Ventilation (IMV) air from the Russian Segment (RS) to Node 1 via an air duct assembly, as shown in Figure 2. The PMA 1 air duct assembly consists of four parts: a rigid duct, a flexible duct, V-band clamps, and an air register that can be manually opened or closed by the crew. The air is returned from Node 1 to the RS through the PMA 1 cabin and then through the PMA 1 APAS hatch opening.

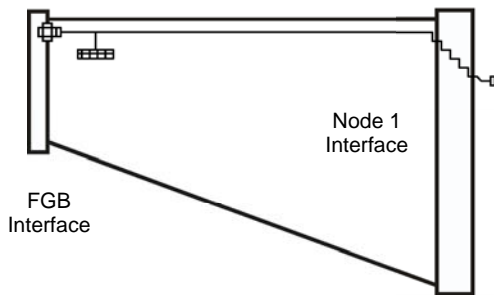


Figure 2 – PMA 1 THC Schematic

PMA 2/3 THC:

The purpose of the PMA 2/3 THC subsystem is to transfer IMV air from the Space Shuttle to the attached

ISS module via an air duct assembly, as shown in Figure 3. The PMA 2/3 air duct assembly consists of four parts: a rigid duct, a flexible duct, V-band clamps, and an air register that can be manually opened or closed by the crew. The air is returned from the attached ISS module to the Space Shuttle through the open PMA 2/3 cabin and then through the PMA 2/3 APAS hatch opening when the hatch is open. The major difference between the PMA 2/3 and the PMA 1 air duct assembly is that the PMA 2/3 ducting at the Space Shuttle interface has a flange attached to it that reduces the duct diameter since the Space Shuttle flexible ODS air transfer duct is a smaller diameter than the normal ISS flexible ducts. The other difference is that at the ISS module end of the flexible duct there is a small miter offset duct to compensate for interference between the duct and the

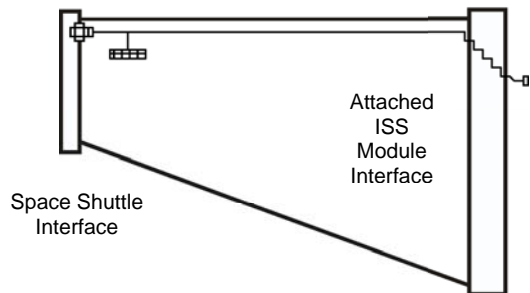
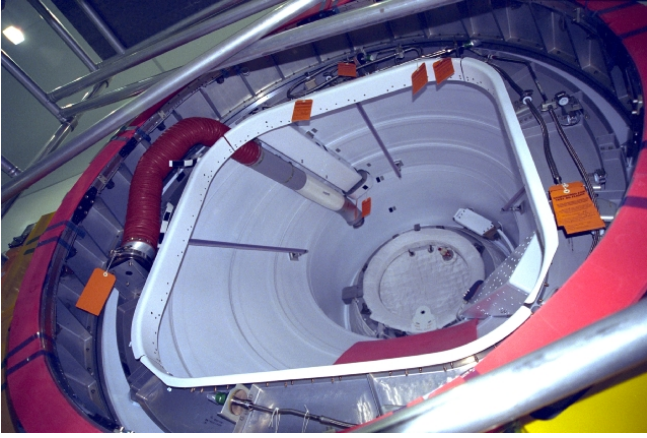
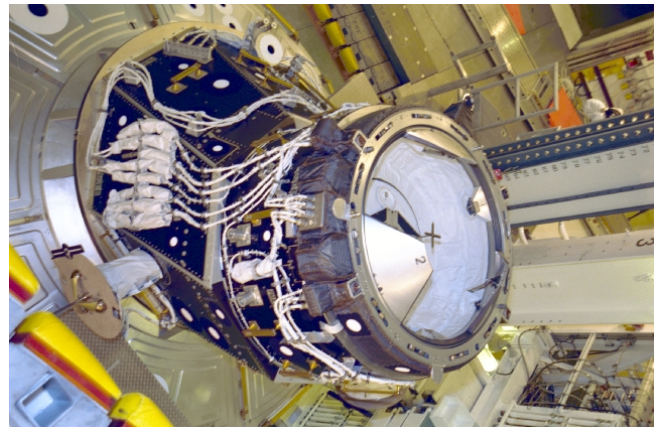


Figure 3 – PMA 2/3 THC Schematic



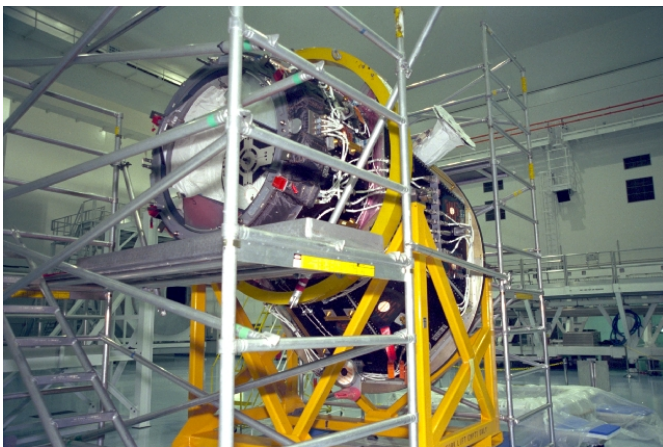
Inside PMA 3



PMA 2 Attached to Node 1



PMA 1 Attached to Node 1



PMA 3 in the Test Stands at KSC



Figure 4 – PMAs during Processing at KSC

CBM controller, when it is installed.

PMA 2/3 ACS:

The purpose of the PMA 2/3 ACS subsystem is to transfer high pressure oxygen and nitrogen from the Space Shuttle to the attached ISS Module, as shown in Figure 5. The high pressure oxygen and nitrogen is then routed within the ISS to the Airlock high pressure oxygen and nitrogen tanks via dedicated lines to refill the Airlock tanks with the Space Shuttle's excess oxygen and nitrogen. The PMA 2/3 high pressure oxygen and nitrogen distribution consists of quick disconnects (QDs), hard lines, flexible hoses, and Gamah fittings.

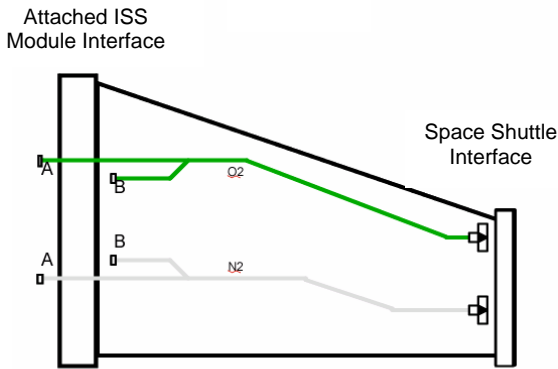


Figure 5 – PMA 2/3 ACS Schematic

PMA 2/3 WRM:

The purpose of the PMA 2/3 WRM subsystem is to support the transfer of Space Shuttle excess fuel cell water to ISS via a Space Shuttle provided flexible hose. The PMA 2/3 WRM consists only of velcro straps to restrain the Space Shuttle provided flexible hose when fuel cell water is being transferred from the Space Shuttle to the ISS Fuel Cell Water Rack, which is a scarred capability on ISS, via the Fuel Cell Water distribution.

ELEMENT LEVEL VERIFICATION PROGRAM

PMA 1 THC QUALIFICATION METHODOLOGY:

| Requirement | Verification |
|--|--|
| The PMA 1 shall exchange intermodule atmosphere with adjacent ISS pressurized elements in accordance with SSP 42122, paragraph 3.2.2.3, and SSP 42121, paragraphs 3.2.1.3.1 and 3.2.1.3.2. | The PMA 1 capability to exchange intermodule ventilation flow shall be verified by analysis. An analysis shall be performed to verify pressure drop characteristics of the Intermodule Ventilation (IMV) flow exchange between the RS and USOS pressurized module in accordance with the specified ICDs. Further, the analysis shall include those time periods when the crew enters the PMA 1 prior to ingress into the station |

| Requirement (cont'd) | Verification (cont'd) |
|----------------------|---|
| | and it shall verify that adequate circulation will be provided to remove CO2 generated by two crew persons for up to 2 hours at nominal metabolic rate. |

The requirement references two ISS Interface Control Documents (ICDs). The relevant requirements from those documents are as follows:

| SSP 42121 Interface Parameters | From Russian Segment | To Russian Segment |
|--------------------------------|---------------------------------|-------------------------------|
| Temperature | 65 to 82.4°F (18.3 to 28°C) | 65 to 85°F (18.3 to 29.4°C) |
| Flow | 127 to 148 cfm (60 to 70 l/s) | 127 to 148 cfm (60 to 70 l/s) |
| Dew Point | 40 to 57°F (4.4 to 13.9°C) | 40 to 60°F (4.4 to 15.6°C) * |
| Pressure Rise | 0.04 – 0.08 in-H2O (1-2 mm-H2O) | N/A |

* - The upper value is the specified value but during negotiations with the Russians it was shown that the air will normally have a dew point less than or equal to 57.2°F (14°C) by analysis. This is required to prevent condensation in the Soyuz when it is docked to the FGB nadir docking port, as requested by the Russians.

| SSP 42122 Interface Parameters | From Node 1 | To Node 1 |
|--------------------------------|-------------------------------|--|
| Temperature | 65 to 85°F (18.3 to 29.4°C) | 65 to 85°F (18.3 to 29.4°C) |
| Flow | 127 to 148 cfm (60 to 70 l/s) | 127 to 148 cfm (60 to 70 l/s) |
| Dew Point | 40 to 60°F (4.4 to 15.6°C) | 40 to 60°F (4.4 to 15.6°C) |
| PMA 1 Duct Pressure Loss | N/A | ≤ 0.15 in-H2O at 135 cfm (3.81 mm-H2O at 63.8 l/s) |

For the analysis Boeing – Huntington Beach looked at five different IMV configurations. The first configuration consisted of having the Russian FGB flexible drag through air duct connected to the PMA 1 air duct assembly, the PMA 1 air register closed, the PMA 1 flexible air duct not connected to the Node 1 feedthrough, and the Russian supplied IMV air coming out into the PMA 1 volume from the end of the flexible duct. This configuration was analyzed in case the first ingress into PMA 1 was by the Increment 1 crew members after docking the Soyuz to the RS. The second configuration consisted of having the Russian FGB flexible drag through air duct connected to the PMA 1 air duct assembly, the PMA 1 air register closed, the PMA 1 flexible air duct connected to the Node 1 feedthrough and the Russian supplied IMV air routed through Node 1 into the aft end of the United States (U.S.) Laboratory Module with the air coming out of the U.S. Laboratory Module aft IMV diffuser. This configuration was analyzed as one of the two preplanned nominal IMV configurations. It was thought that this

configuration would be used during the Assembly Sequence when the RS Vozdukh is providing CO2 control on ISS. The third configuration consisted of having the Russian FGB flexible drag through air duct disconnected from the PMA 1 air duct assembly, the PMA 1 air duct assembly capped at the FGB interface, the PMA 1 air register open, the PMA 1 flexible air duct connected to the Node 1 feedthrough and the PMA 1 air is coming out of the Node 1 port rack bay diffusers. This configuration was analyzed just in case the RS had to be isolated from the USOS and ventilation was required in PMA 1. The fourth configuration was similar to the third configuration except the cap on the PMA 1 duct assembly has been removed, the Russian FGB flexible drag through air duct is connected to the PMA 1 air duct assembly, and the PMA 1 air register is open. For the fourth configuration Boeing – Huntington Beach had to analyze the configuration to see if the Russian supplied IMV air would come out of the PMA 1 air register or would it come out the Node 1 port rack bay diffusers. The fifth and final configuration is the same as the fourth configuration except that the PMA 1 air register is closed forcing the Russian IMV supplied air out the Node 1 port rack bay diffusers. This configuration was analyzed as the other preplanned IMV configurations and was the one that the requirements addressed for the Assembly Complete (AC) configuration.

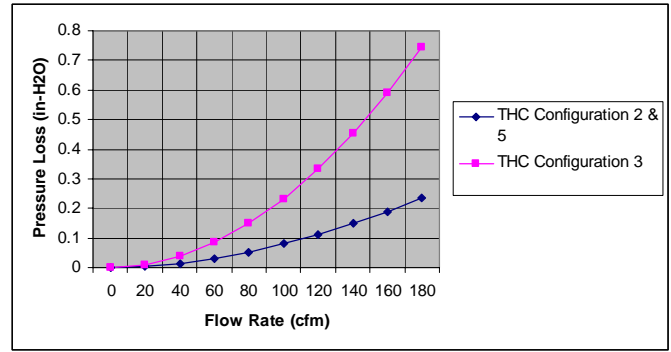
Results:

The flow rates calculated for the five different configurations are as followed:

- First Configuration: 56.3 cfm (26.5 l/s)
- Second Configuration: 122.8 cfm (57.9 l/s)
- Third Configuration: 129.0 cfm (60.8 l/s)
- Fourth Configuration: The Russian supplied IMV air was shown by analysis that it would come out the PMA 1 air register for flow rates below 180 cfm (84.9 l/s) and therefore is not a viable configuration
- Fifth Configuration: 137.7 cfm (64.9 l/s)

These analysis results are very conservative and are based on component information provided by Boeing – Huntsville, a ventilation development test that was performed at Huntington – Beach with no additional margin added to the duct pressure loss test values, and component specification data. For the components that went through a Component Qualification program the data from that process proved that the data used in the analysis was conservative.

Also, the calculated pressure loss for the PMA 1 air duct assembly at 135 cfm was < 0.14 in – H2O (3.55 mm – H2O) for the second and the fifth THC configuration, as shown in the Flow Rate vs. Pressure Loss graph below.



As for the air circulation requirement to support CO2 levels in the PMA 1 the analysis by Boeing – Huntington Beach using the first THC configuration showed that the partial pressure of carbon dioxide (ppCO2) increased above a steady state cabin level by 0.08 mmHg in 1 minute, 0.34 mmHg in 10 minutes, 0.36 mmHg in 2 hours, and by 0.363 mmHg if the THC configuration was held that way forever.

Therefore, the PMA 1 air duct assembly met all of its requirements for air exchange.

PMA 2 THC QUALIFICATION METHODOLOGY:

| Requirement | Verification |
|---|--|
| <p>The PMA shall exchange intermodule atmosphere with adjacent ISS pressurized elements in accordance with SSP 42097, paragraphs 3.2.2.3.2, B3.2.2.3.2, D3.2.2.3.2, and E3.2.2.3.2.</p> <p>The PMA shall exchange intermodule ventilation flow with the Orbiter in accordance with NSTS 21000-IDD-ISS, paragraph S.6.4.4.</p> | <p>The PMA capability to exchange intermodule ventilation flow shall be verified by analysis. An analysis shall be performed to verify pressure drop characteristics of the Intermodule Ventilation (IMV) flow exchange between the STS Orbiter and USOS pressurized modules in accordance with the applicable ICDs. Further, the analysis shall include those time periods when the crew enters the PMA prior to ingress into the station and it shall verify that adequate circulation will be provided to remove CO2 generated by two crewmembers for up to 2 hours at nominal metabolic rate. The verification is considered successful when the analysis results indicates compliances with the interface requirements in accordance with the ICD for flow and pressure and that the CO2 levels remain below 10 mmHg for two crewmembers for up to 2 hours.</p> |

The requirement references four ISS ICDs and the Shuttle to ISS Interface Definition Document (IDD). The relevant requirements from those documents are as follows:

| SSP 42097 Interface Parameters | From Node 2 to PMA 2 | To Node 2 from PMA 2 |
|--------------------------------|-----------------------------|--|
| Temperature | 65 to 85°F (18.3 to 29.4°C) | 65 to 85°F (18.3 to 29.4°C) |
| Flow | ≥ 125 cfm (≥ 59 l/s) | ≥ 125 cfm (59 l/s) |
| PMA 2 Duct Pressure Loss | N/A | 0.23 in – H2O (5.84 mm – H2O) when Shuttle supplies 69 ± 5 cfm (33 ± 2 l/s) of air |

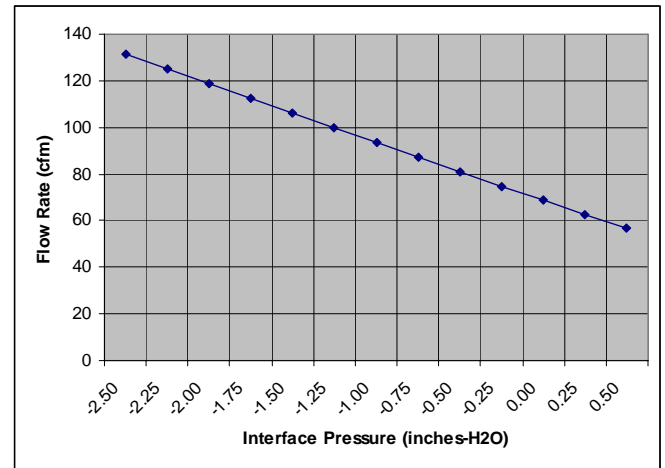
| SSP 42097 Appendix B Interface Parameters | From U.S. Laboratory Module to PMA 2 | To U.S. Laboratory Module from PMA 2 |
|---|--------------------------------------|--|
| Temperature | 65 to 85°F (18.3 to 29.4°C) | 65 to 85°F (18.3 to 29.4°C) |
| Flow | ≥ 140 cfm (≥ 66 l/s) | ≥ 140 cfm (66 l/s) |
| PMA 2 Duct Pressure Loss | N/A | 0.28 in – H ₂ O (7.11 mm – H ₂ O) when Shuttle supplies 69 ± 5 cfm (33 ± 2 l/s) of air |

| SSP 42097 Appendix D Interface Parameters | From Node 1 to PMA 3 | To Node 1 from PMA 3 |
|---|-----------------------------|---|
| Temperature | 65 to 85°F (18.3 to 29.4°C) | 65 to 85°F (18.3 to 29.4°C) |
| Flow | N/A | 120 cfm (57 l/s) |
| PMA 3 Duct Pressure Loss | N/A | ≤ 0.32 in – H ₂ O (8.13 mm – H ₂ O) |

| SSP 42097 Appendix E Interface Parameters | From Node 3 to PMA 3 | To Node 3 from PMA 3 |
|---|-----------------------------|--|
| Temperature | 65 to 85°F (18.3 to 29.4°C) | 65 to 85°F (18.3 to 29.4°C) |
| Flow | ≥ 125 cfm (≥ 59 l/s) | ≥ 130 cfm (61 l/s) |
| PMA 3 Duct Pressure Loss | N/A | ≤ 0.23 in – H ₂ O (5.84 mm – H ₂ O) when Shuttle supplies 69 ± 5 cfm (33 ± 2 l/s) of air |

| NSTS-21000-IDD-ISS Interface Parameters | From Space Shuttle to PMA 2/3 | To Space Shuttle from PMA 2/3 |
|---|--|-------------------------------|
| Temperature | 55 to 85°F (12.7 to 29.4°C) | 65 to 85°F (18.3 to 29.4°C) |
| Dew Point | 39 to 61°F (3.9 to 16.1°C) | 40 to 60°F (4.4 to 15.6°C) |
| Flow | see Flow Rate vs. Interface Pressure graph** | N/A |

** - Space Shuttle provided ODS Booster Fan interface verification data. Better interface data was provided after the verification was closed and is documented in NSTS-21000-IDD-ISS. This graph is more conservative than the data that was provided later by the Space Shuttle.



supplied IMV air coming out into the PMA 2/3 volume from the end of the flexible duct. This configuration was analyzed to support the first ingress into PMA 2/3 from the Space Shuttle. The second configuration consisted of having the Space Shuttle provide IMV air to PMA 2/3, the PMA 2/3 air register closed, the PMA 2/3 flexible air duct connected to the attached ISS pressurized module feedthrough and the Space Shuttle supplied IMV air routed to the attached ISS pressurized module. This configuration was analyzed as one of the nominal preplanned IMV configuration and was the one that the requirements for Node 1 to PMA 3 addressed. The third configuration consisted of having no Space Shuttle provided IMV air to PMA 2/3, the PMA 2/3 air duct assembly capped at the Space Shuttle interface, the PMA 2/3 air register open, the PMA 2/3 flexible air duct connected to the attached ISS pressurized module feedthrough and the PMA 2/3 air coming out into the attached ISS pressurized module. This configuration was analyzed to support ingress into PMA 2/3 when the Space Shuttle is not present. The fourth and final configuration consisted of having Space Shuttle provide IMV air to PMA 2/3, the PMA 2/3 air register open, the PMA 2/3 flexible air duct connected to the attached ISS pressurized module feedthrough and the IMV air is coming out into the attached ISS pressurized module. This configuration was analyzed as the other possible nominal IMV configuration and is the one that the requirements addressed except for the Node 1 to PMA 3 interface.

Results:

The calculated results are as follows:

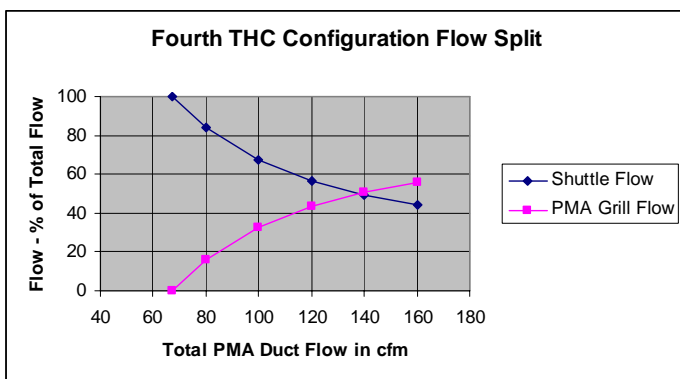
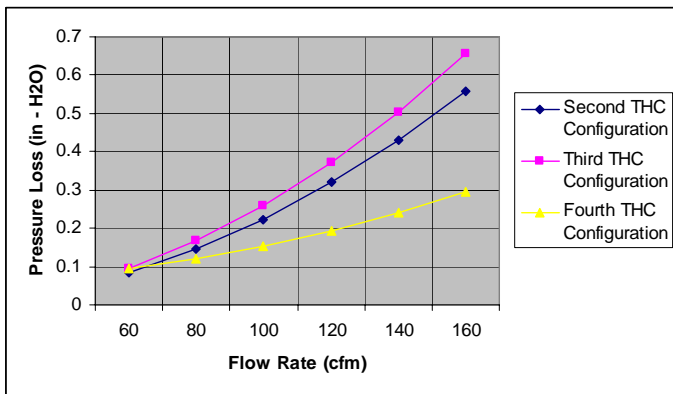
- First Configuration: Calculated flow rate out of the PMA 2/3 ducting was 65.6 cfm (31.0 l/s)
- Second Configuration: The PMA 3 pressure drop for Node 1 interface is 0.319 in – H₂O (8.1 mm – H₂O) at 120 cfm (57 l/s), as shown in the Pressure Loss vs. Flow Rate graph below

For the analysis Boeing – Huntington Beach looked at four different IMV configurations. The first configuration consisted of having the Space Shuttle provide IMV air to PMA 2/3, the PMA 2/3 air register closed, the PMA 2/3 flexible air duct not connected to the attached ISS pressurized module feedthrough, and the Space Shuttle

Based on the results, the PMA 2/3 air duct assembly

- Third Configuration: No results were discussed in the Verification Report but the Pressure Loss vs. Flow Rate data was provided in the graph below
- Fourth Configuration: The results are as shown in the Table below for U.S. Laboratory Module, Node 2, and Node 3 interfaces and in the graph below

| PMA 2/3 Interface | Assumed Flow Rate from PMA 2/3 | Calculated Orbiter Flow Rate | Calculated PMA 2/3 Pressure Drop |
|---------------------------------|--------------------------------|------------------------------|---|
| PMA 2 to Node 2 | 125 cfm (59 l/s) | 68.4 cfm (32.3 l/s) | 0.205 in - H ₂ O (5.2 mm - H ₂ O) |
| PMA 2 to U.S. Laboratory Module | 140 cfm (66 l/s) | 69.1 cfm (32.6 l/s) | 0.241 in - H ₂ O (6.1 mm - H ₂ O) |
| PMA 3 to Node 3 | 130 cfm (61l/s) | 68.6 cfm (32.4 l/s) | 0.217 in - H ₂ O (5.5 mm - H ₂ O) |



As for the air circulation requirement to support CO₂ levels in the PMA 2/3 the analysis by Boeing – Huntington Beach using the first THC configuration showed that the partial pressure of carbon dioxide (ppCO₂) increased above a steady state cabin level by 0.083 mmHg in 1 minute, 0.296 mmHg in 10 minutes, 0.310 mmHg in 2 hours, and by 0.310 mmHg if the THC configuration was held that way forever.

met all of the requirements for air exchange.

The Verification Report also provided additional information for the PMA 3 to Node 1 extension duct. The extension duct allows the normal PMA 3 duct to reach the desired Node 1 IMV feedthrough. The PMA 3 – 63 inch (160 cm) extension duct had a pressure loss of 0.134 in – H₂O (3.4 mm – H₂O) at 120 cfm (57 l/s).

PMA 2/3 ACS QUALIFICATION METHODOLOGY:

High-Pressure Nitrogen:

| Requirement | Verification |
|--|---|
| PMA shall deliver recharge nitrogen to the adjacent ISS pressurized element at the pressure, temperature, and up to the flow rate as specified in SSP 42097, paragraphs 3.2.2.3.3.5, B3.2.2.3.4, and E3.2.2.3.5. | The PMA capability to receive recharge nitrogen from STS and deliver it to the adjacent ISS element shall be verified by analysis and inspection. An analysis shall be done to verify the interface conditions are met in the design of the distribution plumbing in accordance with applicable ICDs. Inspection of the drawings and layouts shall be conducted to account for plumbing and interface connections to the adjacent distribution lines. |
| The PMA shall receive recharge nitrogen from the Orbiter in accordance with NSTS 21000-IDD-ISS, paragraph S.6.4.3.2. | The verification is considered successful when the results of the analysis indicates compliance with the interface requirements as specified in SSP 42097 and NSTS 21000-IDD-ISS, paragraph S.6.4.3.2, and the inspection will indicate full compliance for all distribution hardware. |

The requirement references three ISS ICDs and the Shuttle to ISS Interface Definition Document (IDD). The relevant requirements from those documents are as follows:

| SSP 42097 (Appendix B, Appendix E) Interface Parameters | From Node 2 (U.S. Laboratory Module, Node 3) to PMA 2/3 | To Node 2 (U.S. Laboratory Module, Node 3) from PMA 2/3 |
|---|---|---|
| Temperature | N/A | 25 to 113°F (-3.9 to 45°C) |
| Flow Rate | N/A | ≤ 3 lbm/hr (≤ 1.4 kg/hr) |
| Maximum Pressure | N/A | 3400 psia (23.4 MPa) |

| NSTS-21000-IDD-ISS Interface Parameters | From Space Shuttle to PMA 2/3 | To Space Shuttle from PMA 2/3 |
|---|-------------------------------|-------------------------------|
| Temperature | 25 to 113°F (-3.9 to 45°C) | N/A |
| Space Shuttle Flow Rate*** | ≤ 32.5 lbm/hr (≤ 14.7 kg/hr) | N/A |
| Space Shuttle Maximum Pressure | 3300 psia (22.7 MPa) | N/A |

*** - The flow rate is restricted by the ISS recharge distribution subsystem

For the analysis Boeing – Huntington Beach analyzed the pressure loss for the longer of the two possible paths at the conditions called in the ISS ICDs.

Results:

The calculated pressure loss for the PMA 2/3 Nitrogen Recharge subsystem was 0.017 psid (0.117 kPa differential) with an additional 10% margin added to the calculated results. The analysis results for this subsystem is very conservative and is based on flex hose information provided by Boeing – Huntsville and QD pressure drop information provided by the QD supplier. The QD also went through a Component Qualification program and the data from that process proved that the data initially supplied by the QD supplier and used in the analysis was conservative.

The requirement for this subsystem did not have any pressure loss pass/fail requirement but the value was very low and it was agreed based on that fact that the analysis part of the Verification was acceptable.

The inspection memorandum for PMA 2/3 also showed that the drawing called out in the memorandum met the inspection part of the Verification.

High-Pressure Oxygen:

| Requirement | Verification |
|---|--|
| <p>PMA shall deliver recharge oxygen to the adjacent ISS pressurized element at the pressure, temperature, and up to flow rate as specified in SSP 42097, paragraphs 3.2.2.3.3.4, B3.2.2.3.3, and E3.2.2.3.4.</p> <p>The PMA shall receive recharge oxygen from the Orbiter in accordance with NSTS 21000-IDD-ISS, paragraph S.6.4.3.1.</p> | <p>The PMA capability to receive recharge oxygen from STS and deliver it to the adjacent ISS element shall be verified by analysis and inspection. An analysis shall be done to verify the interface conditions (specified in ICD) are met in the design of the distribution plumbing. Inspection of the drawings and layouts shall be conducted to account for plumbing and interface connections to the adjacent distribution lines.</p> <p>The verification is considered successful when the results of the analysis indicates compliance with the interface requirements as specified in SSP 42097 and NSTS 21000-IDD-ISS, paragraph S.6.4.3.1, and the inspection will indicate full compliance for all distribution hardware.</p> |

The requirement references three ISS ICDs and the Shuttle to ISS Interface Definition Document (IDD). The relevant requirements from those documents are as follows:

| SSP 42097 (Appendix B, Appendix E) Interface Parameters | From Node 2 (U.S. Laboratory Module, Node 3) to PMA 2/3 | To Node 2 (U.S. Laboratory, Node 3) from PMA 2/3 |
|---|---|--|
| Temperature | N/A | 25 to 113°F (-3.9 to 45°C) |
| Flow Rate | N/A | ≤ 16 lbm/hr (≤ 7.3 kg/hr) |
| Maximum Pressure | N/A | 1050 psia (7.2 MPa) |

| NSTS-21000-IDD-ISS Interface Parameters | From Space Shuttle to PMA 2/3 | To Space Shuttle from PMA 2/3 |
|---|-------------------------------|-------------------------------|
| Temperature | 33 to 113°F (0.6 to 45°C) | N/A |
| Space Shuttle Flow Rate*** | ≤ 50 lbm/hr (≤ 22.7 kg/hr) | N/A |
| Space Shuttle Maximum Pressure | 1050 psia (7.2 MPa) | N/A |

*** - The flow rate is restricted by the ISS recharge distribution subsystem

For the analysis Boeing – Huntington Beach analyzed the pressure loss for the longer of the two possible paths at the conditions called in the ISS ICDs.

Results:

The calculated pressure loss for the PMA 2/3 Oxygen Recharge subsystem was 0.67 psid (4.62 kPa differential) with an additional 10% margin added to the calculated results. The analysis results for this subsystem is very conservative and is based on flex hose information provided by Boeing – Huntsville and QD pressure drop information provided by the QD supplier. The QD also went through a Component Qualification program and the data from that process proved that the data initially supplied by the QD supplier and used in the analysis was conservative.

The requirement for this subsystem did not have any pressure loss pass/fail requirement but the value was very low and it was agreed based on that fact that the analysis part of the Verification was acceptable.

The inspection memorandum for PMA 2/3 also showed that the drawing called out in the memorandum met the inspection part of the Verification.

PMA 2/3 WRM QUALIFICATION METHODOLOGY:

| Requirement | Verification |
|---|--|
| <p>The PMA shall provide installation provisions (clamps, tie-down, etc.) to secure the Space Transportation System (STS) provided flexible hose for transfer of STS fuel cell water to ISS pressurized elements in accordance with SSP 42097, paragraph 3.2.2.3.3.</p> | <p>This PMA capability to accommodate fuel cell water transfer hose shall be verified by inspection and analysis. An inspection of the drawings shall be performed to verify the locations of installation provisions. An analysis shall be performed to verify the design of the installation provisions will be compatible with transfer of fuel cell water in accordance with the specified ICD.</p> <p>The verification shall be considered successful when the results of the inspection and analysis indicate that fuel cell water transfer hose can be secured in place during water transfer at specified condition.</p> |

Results:

Since the Space Shuttle provided fuel cell water transfer hose for PMA 2/3 was deferred until later in the

Assembly Sequence after the delivery of the ISS fuel cell rack it was decided that the analysis Verification by the Space Shuttle Program was not required until later. Since then the fuel cell water rack has been cancelled and the analysis Verification is not required. Boeing – Huntington Beach did show in the inspection memorandum for PMA 2/3 that the drawing called out in the memorandum did meet the inspection part of the Verification.

CONCLUSION

The Verification of the PMAs utilized a building block approach from the Component Qualification data through to the Element Level Verification. This paper provides a general overview of the ISS ECLS subsystems in the PMAs and of the ISS ECLS Element Level Verification program. It also showed that the PMAs met the ISS ECLS Element Level requirements.

REFERENCES

1. "Prime Item Development Specification for the Pressurized Mating Adapter"; SP-M-301, Revision L plus SCN 071; August 24, 2004.
2. "Addendum Specification for Pressurized Mating Adapter – 1 (PMA – 1)"; S684-10115, Revision H; August 30, 2002.
3. "U.S. On-Orbit Segment Pressurized Mating Adapter-1 to Russian Segment FGB Interface Control Document, Part 1"; SSP 42121, Revision B; December 15, 1998.
4. "Resource Node 1 to Pressurized Mating Adapter-1 Interface Control Document, Part 1"; SSP 42122, Revision D plus IRNs, 0019, 0016, and 0020; December 20, 2002.
5. "Space Station Program Pressurized Mating Adapter 2 & 3 to U.S. Pressurized Elements Core (Node 2 to PMA 2) Interface Control Document, Part 1"; SSP 42097, Revision D, December 31, 2002.
6. "Pressurized Mating Adapter 2 & 3 to United States Pressurized Elements (USL to PMA-2) Interface Control Document, Part 1, Appendix B"; SSP 42097, Revision E, June 30, 2006.
7. "Pressurized Mating Adapter 2 & 3 to United States Pressurized Elements (Node 1 to PMA-3) Interface Control Document, Part 1, Appendix D"; SSP 42097, Revision E, June 30, 2006.
8. "Space Station Program Pressurized Mating Adapter 2 & 3 to United States Pressurized Elements (Node Element 3 to Pressurized Mating Adapter 3) Interface Control Document, Part 1, Appendix E"; SSP 42097, Revision E, June 18, 2004.
9. "International Space Station Interface Definition Document"; NSTS-21000-IDD-ISS; Revision A; February 18, 1998.

10. Boeing – Huntington Beach; "International Space Station Pressurized Mating Adapter 1 ECLSS Verification Analysis Report"; MDC 97H0377B; January 30, 1988.
11. Boeing – Huntington Beach; "International Space Station Pressurized Mating Adapter 2/3 ECLSS Verification Analysis Report"; MDC 96H0616B; January 30, 1988.
12. "Fluids Drawing Inspections for PMA Requirements" Memorandum; A3-J071 DR-M-9800382; March 2, 1998.
13. Erwin, Lowell; Email titled "Evaluation of Shuttle IMV Supply"; March 4, 1998.

CONTACT

David E. Williams
 NASA, Lyndon B. Johnson Space Center /
 Mail Stop: EC6
 2101 NASA Parkway
 Houston, TX 77058

ACRONYMS

| | |
|-------------------|---|
| °C: | degree celsius |
| °F: | degree fahrenheit |
| AC: | Assembly Complete |
| ACS: | Atmosphere Control and Supply |
| APAS: | Androgynous Peripheral Attachment System |
| CBM: | Common Berthing Mechanism |
| cfm: | cubic feet per minute |
| cm: | centimeter |
| CO ₂ : | carbon dioxide |
| ECLS: | Environmental Control and Life Support |
| FGB: | Functional Cargo Block (Russian to English Translation) |
| H ₂ O: | water |
| hr: | hour |
| ICD: | Interface Control Document |
| IDD: | Interface Definition Document |
| IMV: | Intermodule Ventilation |
| in: | inch |
| ISS: | International Space Station |
| kg: | kilogram |
| kPa: | kilopascal |
| KSC: | Kennedy Space Center |
| lbm: | pound mass |
| l/s: | liter per second |
| MDM: | Multiplexer/Demultiplexer |
| mm: | millimeter |
| mmHg: | millimeter of mercury |
| MPa: | megapascal |
| NSTS: | National Space Transportation System |
| ODS: | Orbiter Docking System |
| PIDS: | Prime Item Development Specification |
| PMA: | Pressurized Mating Adapter |
| psia: | pounds per square inch absolute |
| psid: | pounds per square inch differential |
| QD: | Quick Disconnect |

RS: Russian Segment
SSP: Space Station Program

THC: Temperature and Humidity Control
U.S.: United States
USOS: United States On-Orbit Segment
WRM: Water Recovery and Management