Alpha Magnetic Spectrometer-02 (AMS-02) Master Verification Plan

Engineering Directorate

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Basic - Draft
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National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
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ALPHA MAGNETIC SPECTROMETER-02 (AMS-02) MASTER VERIFICATION PLAN

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DOCUMENT CHANGE/REVISION LOG

CHANGE/ REVISION	DATE	DESCRIPTION OF CHANGE	PAGES AFFECTED
Basic	August 2006	Initial release for baseline	All

FOREWARD

This volume of the Alpha Magnetic Spectrometer – 02 contains the AMS-02 Payload and subsystem verification requirements and plans. The requirements are derived directly from JSC 29879, Project Technical Requirements Specification (PTRS) for the Alpha Magnetic Spectrometer-02 (AMS-02) Payload Integration Hardware (PIH); SSP 57213, AMS-02 Hardware Interface Control Document (ICD); JSC 49978, Phase II Flight Safety Data Package for the AMS-02; with additional items from JSC 29095, AMS-02 Experiment/PIH Interfaces, Part II (ICD); JSC 28792, Structural Verification Plan for the Space Transportation System and International Space Station (SVP). The Office of Primary Responsibility (OPR) for this is the AMS Project Office (APO) of the Engineering Directorate Office.

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1. Introduction

1.1 PURPOSE AND SCOPE

The purpose of this Alpha Magnetic Spectrometer – 02 (AMS-02) Master Verification Plan (MVP) is to establish the plan for, and document the results of the AMS-02 Payload's verification activities. The AMS-02 is a multi-agency/organization payload utilizing components designed and managed at locations world-wide. The activities documented within the AMS-02 MVP confirm that the AMS-02 components and end items comply with their specifications, function properly as an integrated unit when interfaced with program/vehicle components, and are ready for use as a part of the flight system. Appendices C & D of this MVP include a "Results" column for documenting the objective evidence (results) of verification activities performed during the Flight Production and Certification Phase. The first baseline of the MVP when finalized is to establish the plan for verification, and all columns of the appendices are completed except the "Results" column (i.e., results are TBS). During the Flight Production and Certification Phase, the planned verification activities are performed and the "Results" column is documented (including TPS #, "use as is" DR # or waiver, memo or report, etc., as appropriate). The MVP, with the appendices "Results" column documented, is released with the appropriate revision number and change record information. This revised release of the MVP form a part of the Certification Data Package.

Safety verifications, taken directly from the AMS-02 Phase II Hazard Reports, are reported in the format compatible with NSTS/ISS 13830, "Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle, International Space Station." Reporting of the Status of the Safety Verifications will be reported directly to the Payload Safety Review Panel as a post Phase III Safety Verification Tracking Log (SVTL) as a primary means of reporting, this document as a second documentation location lagging in publication after the SVTL.

This MVP will be used by the AMS-02 Project to plan for, and document the results of, the verification of AMS-02 components. This MVP includes the verification of AMS-02 functional capabilities and subsystem performance through analyses using non-real-time tools, tests using real-time test facilities, inspection as it applies to the manufacturing processes used in hardware fabrication and software generation, and demonstration as it applies to human factors, serviceability, accessibility, and transportability of the system features.

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

This document is prepared and maintained in accordance with EA-WI-023, Project Management of GFE Flight Projects. The responsibility for the development of this document lies with the AMS-02 Project Office (APO) of the Engineering Directorate. Change authority will be the AMS-02 Configuration Control Board (CCB) with the concurrence of all signatories.

1.3 DEFINITIONS

The term "verification" refers to the formal process, using the method of test, analysis, inspection or demonstration, to confirm that a system and its hardware and software components satisfy all specific performance and operational requirements. That is, it is the proof that a system meets all its "shalls".

The following definitions differentiate between requirements and other non-binding statements.

Shall:	This is the only verb used for defining binding requirements.
Should/May:	These verbs are used for stating non-mandatory goals.
Will:	This verb is used for stating facts or declaration of purpose.

Wording of the Safety Verification Methods is reviewed and approved by the Payload Safety Review Panel and all such verifications are by default the equivalent of "Shall" requirements, as all must be closed prior to approval for launch by the launch manager.

2. Applicable and Reference Documents

2.1 APPLICABLE DOCUMENTS

The following documents, of the exact date and revision shown, form a part of this document to the extent specified herein.

Document Number	Revision/ Release Date	Document Title
SSP 57003	Revision B 06/17/03	Attached Payload Interface Requirements Document
SSP 57214	Original TBD	AMS-02 Hardware Interface Control Document
JSC 29789	Revision A 08/17/04	Project Technical Requirements Specification for the Alpha Magnetic Spectrometer-02 (AMS-02) Payload Integration Hardware (PIH)
JSC 28792	Revision D 03/05	AMS-02 Structural Verification Plan for the Space Transportation System and the International Space Station
JSC 29095 Part II	Revision A 12/04	AMS-02 Experiment/Payload Integration (PIH) Interfaces (ICD-C)
JSC 49978	Original TBD	Phase II Flight Safety Data Package for the AMS-02

2.2 REFERENCE DOCUMENTS

The following documents are reference documents used in the development of this MVP. These documents do not form a part of this MVP, and are not controlled by their reference herein.

Document Number	Revision/ Release Date	Document Title
SSP 57004	Revision B 06/13/03	Attached Payload Hardware Interface Control Document Template
NSTS 1700.7B	Latest Revision	Safety Policy and Requirements for Payloads Using the STS
NSTS 1700.7B ISS Addendum	Latest Revision	Safety Policy Requirements for Payloads Using the International Space Station (ISS Addendum)
NSTS/ISS 13830	Latest Revision	Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle, International Space Station

2.3 ORDER OF PRECEDENCE

In the event of a conflict between this document and an applicable document cited herein, the text of this document takes precedence.

3. AMS-02 Description

3.1 AMS-02 REQUIREMENTS FLOWDOWN

The AMS-02 verification requirements are obtained from the following documents:

TABLE 3-1 AMS-02 VERIFICATION REQUIREMENT SOURCE

JSC 29789	AMS-02 Project Technical Requirements Specification
SSP 57003	Attached Payload Interface Requirements Document
SSP 57213	AMS-02 Hardware Interface Control Document
JSC 28792	AMS-02 Structural Verification Plan for the Space Transportation System and the International Space Station
JSC 29095 Part II	AMS-02 Experiment/Payload Integration (PIH) Interfaces (ICD-C)
JSC 49978	Phase II Flight Safety Data Package for the AMS-02

3.2 AMS-02 ARCHITECTURE

The AMS-02 experiment is a state-of-the-art particle physics detector being designed, constructed, tested and operated by an international team organized under United States Department of Energy (DOE) sponsorship. The AMS Experiment will use the unique environment of space to advance knowledge of the universe and potentially lead to a clearer understanding of the universe's origin. Specifically, the science objectives of the AMS are to search for antimatter (anti-helium and anti-carbon) in space, to search for dark matter (90% of the missing matter in the universe) and to study astrophysics (to understand Cosmic Ray propagation and confinement time in the Galaxy).

The AMS-02 Experiment utilizes a large cryogenic superfluid helium (SFHe @ 2° K) superconducting magnet to produce a strong, uniform magnetic field (~ 0.8 Tesla) within the interior of the magnet. The experiment has planes of detectors above, in the center of, and below the magnet (Figures 4.1-1 and 4.1-2). Electrically charged particles will curve when they pass through the magnetic field. Particles made of matter will curve one way, and those of antimatter will curve the opposite way. The positions of electrons released as the charged particles pass through the detectors will be electronically recorded (Figure 4.1-3). Physicists will be able to study the trajectory of curvature and determine the charge of the particles from the direction of curvature. They will also be able to determine the mass of the particles from the amount of curvature. They will then be able to tell whether it was matter or antimatter.

An Implementing Arrangement (IA) between NASA and DOE signed in September 1995 established two flights for AMS: an Engineering Test on Shuttle (STS-91 – June 1998) and a 3-year Science Mission on ISS (Launch Ready September 2007 – Date under review). The flight of AMS-01 was a precursor flight of the detectors proposed for AMS-02. AMS-01 utilized a permanent magnet in place of the cryomagnet. The purpose of the precursor flight was to verify operation of the AMS experiment, verify command and data communications, collect thermal data for the ISS flight, determine actual accelerations on some AMS internal instruments and establish experimental background data.

The AMS-02 will be transported to the International Space Station (ISS) in the cargo bay of the Space Shuttle (Figure 4.1-4) for installation on the external truss of the ISS (Figures 4.1-5 and 4.1-6). The AMS-02 is scheduled to remain on the ISS for at least three operational years of data collection. Do to limited space shuttle flights, AMS-02 is not scheduled to return to Earth and will remain on the ISS.

The major subsystems of the AMS-02 are listed below:

- Cryogenic Superconducting Magnet
- Unique Support Structure – 02 (USS-02) with integral Vacuum Case (VC)
- Transition Radiation Detector and associated Gas System (TRD)
- Time-of-Flight (TOF) Scintillator Assemblies
- Silicon Tracker
- Tracker Alignment System (TAS)
- Anti-Coincidence Counters (ACC)
- Ring Imaging Cerenkov Counter (RICH)
- Electromagnetic Calorimeter (ECAL)
- Star Tracker
- Global Positioning System (GPS)
- Data and Interface Electronics
- Thermal Control System (TCS)
- Micrometeoroid and Orbital Debris (MMOD) Shields
- Payload Attach System (PAS) (Passive Half)
- Digital Data Recording System – 02 (DDRS-02)

- Space Shuttle Program (SSP) and ISS Program (ISSP) Provided Hardware

o Flight Releasable Grapple Fixture (FRGF)	SSP
o Remotely Operated Electrical Umbilical (ROEU)	SSP
o Power Video Grapple Fixture (PVGF)	ISSP
o Umbilical Mechanism Assembly (UMA) (passive half)	ISSP
o External Berthing Camera System (EBCS)	ISSP

The AMS-02 Payload also requires the use of the Shuttle Remote Manipulator System (SRMS) and the Space Station Remote Manipulator System (SSRMS) for removing the payload from the Orbiter Cargo Bay and berthing it on the station. The payload requires an active ISS PAS and an active UMA, which are ISS hardware and part of the Integrated Truss Segment (ITS). Figure 3.2-1 shows the AMS-02 interfaces. Figure 3.2-2 is a cut-away view Payload and shows the location of most of its major sub-elements. Figure 3.2-3 shows the experiment stack and the physical relationship of the detectors to one another.

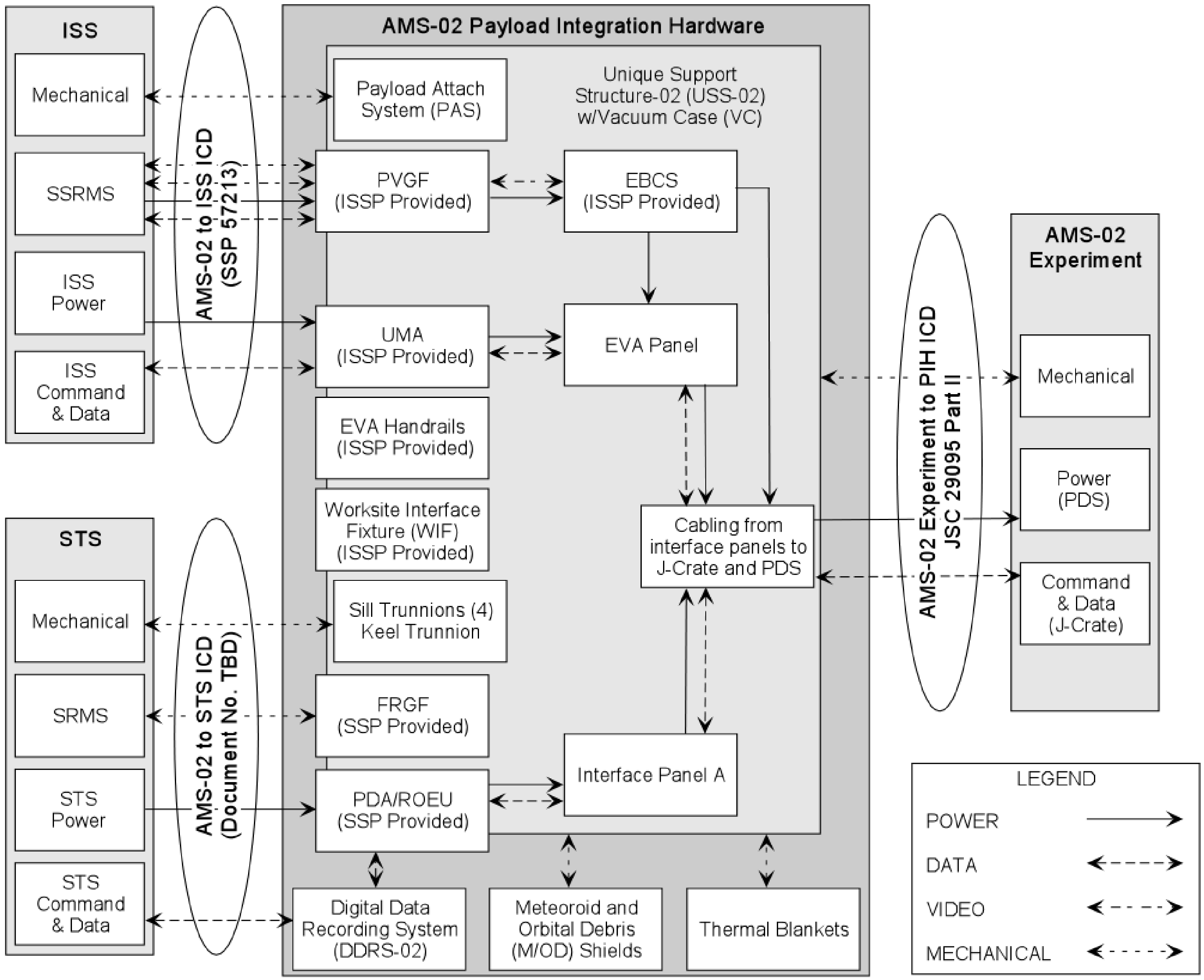


Figure 3.2-1 The AMS-02 System Interfaces

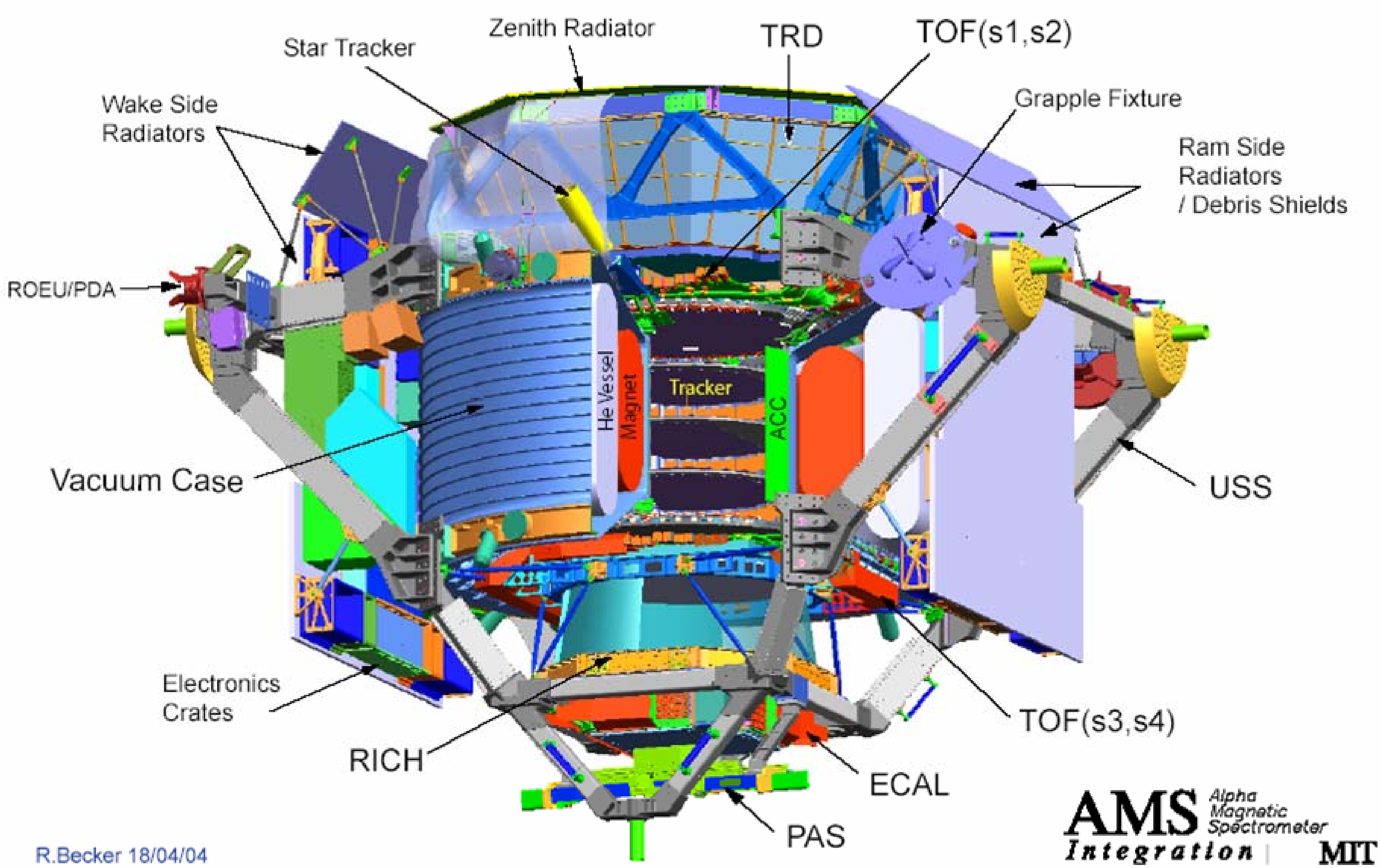


Figure 3.2-2 The AMS-02 Payload Components

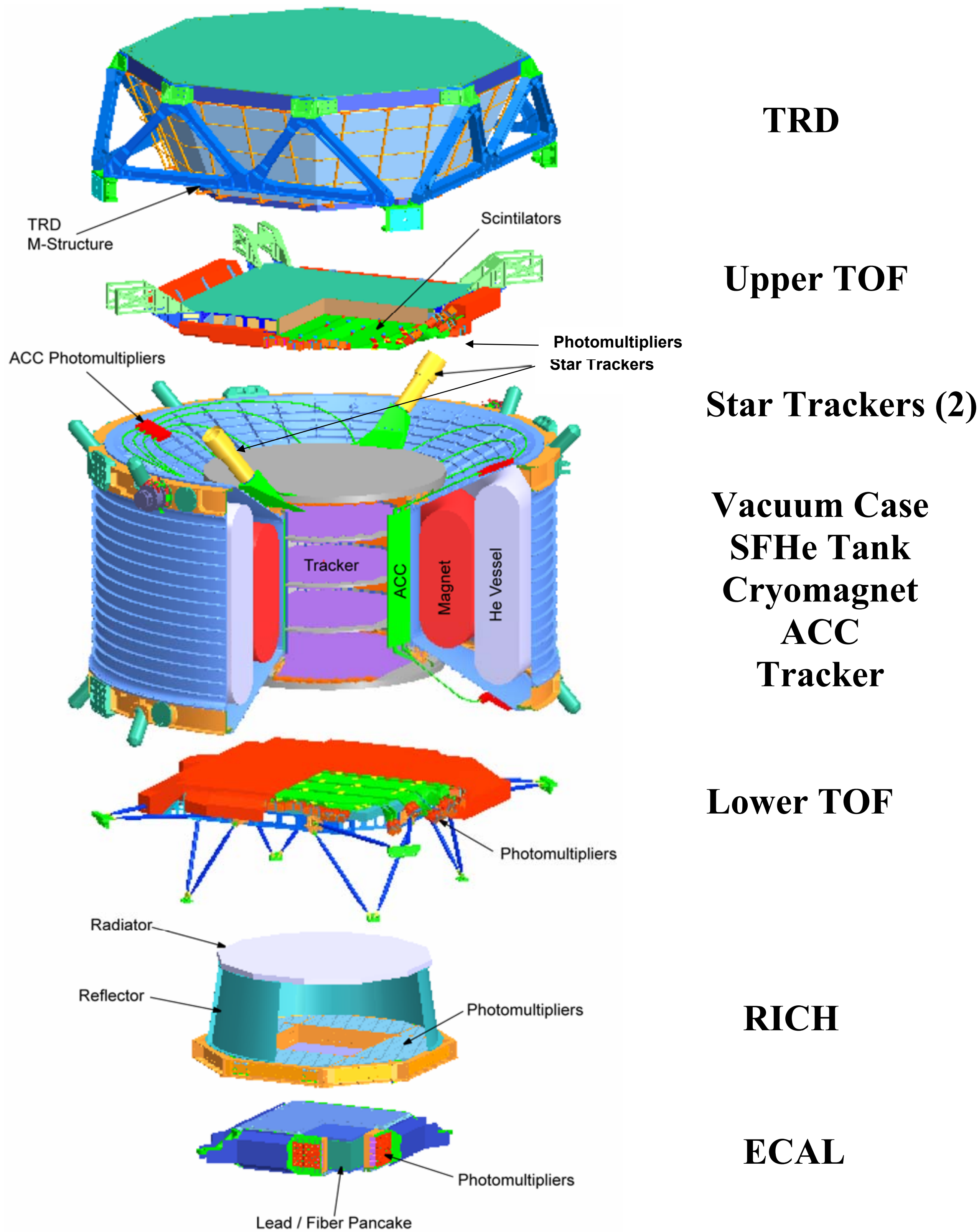


Figure 3.2-3 The AMS-02 Experiment Elements

3.3 END ITEM ARCHITECTURES

3.3.1 AMS-02 Payload

The fully integrated AMS-02 Payload is the primary end item of the AMS-02 Project. An overview of the Payload was provided in Section 3.2. The AMS-02 Payload is comprised of the *Payload Integration Hardware* (PIH), designed and built by NASA/JSC and the *Experiment Hardware*, designed and built by the AMS Collaboration under the sponsorship of the U.S. Department of Energy (DOE).

3.3.1.1 AMS-02 Payload Integration Hardware (PIH)

The PIH provides the structural, mechanical, electrical, and data interfaces between the experiment and the Shuttle for transportation to the ISS and between the experiment and the ISS for the remainder of its on-orbit life. The following paragraphs describe the structures and elements that comprise the PIH.

3.3.1.1.1 AMS-02 Unique Support Structure-02 (USS-02)

The Unique Support Structure – 02 (USS-02) is the primary structural element of the AMS-02 Payload (Figure 3.3.1.1.1-1). Its purpose is to structurally support the Cryomagnet Cold Mass and the AMS-02 Experiment during launch, landing, and on-orbit loading and provides the mechanical and structural interfaces to the Shuttle and ISS.

The USS-02 (Figures 3.3.1.1.1-2 and 3.3.1.1.1-3) consists of five subassemblies: Upper USS-02, Vacuum Case (VC), Lower USS-02, Keel, and the AMS Payload Attach System (PAS). These subassemblies are bolted and shear pinned together to form the top-level USS-02.

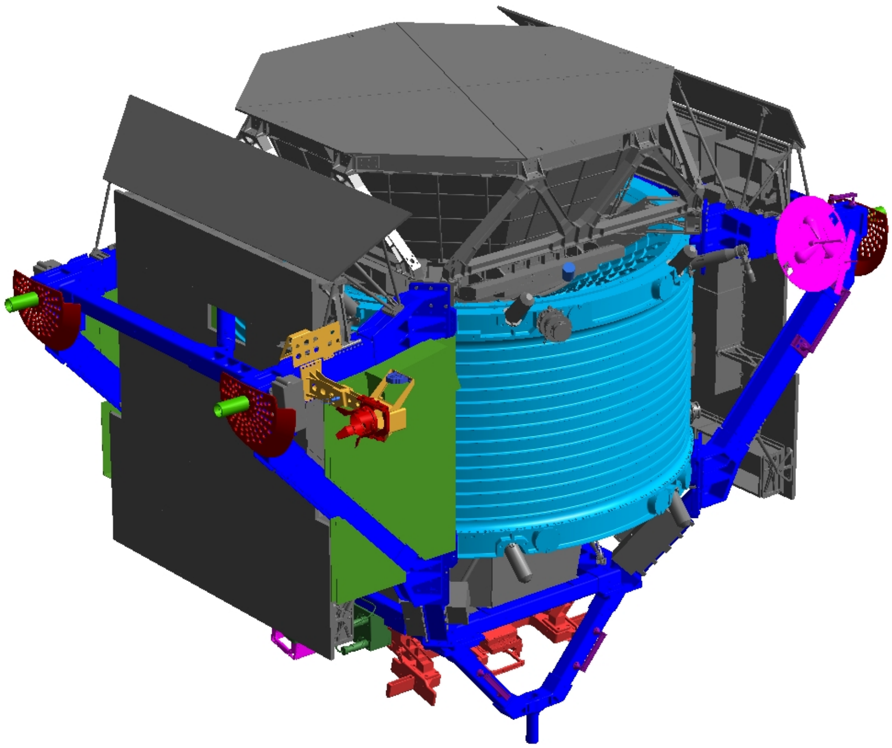


Figure 3.3.1.1.1-1 AMS-02 with USS-02 Highlighted

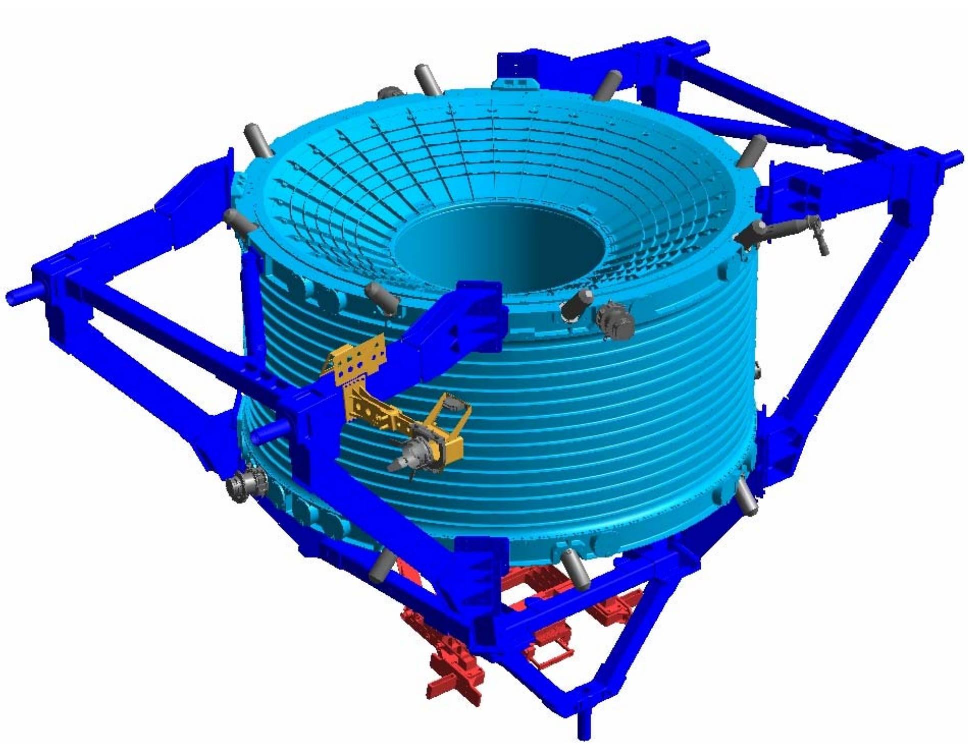


Figure 3.3.1.1.1-2 Unique Support Structure (USS) – 02

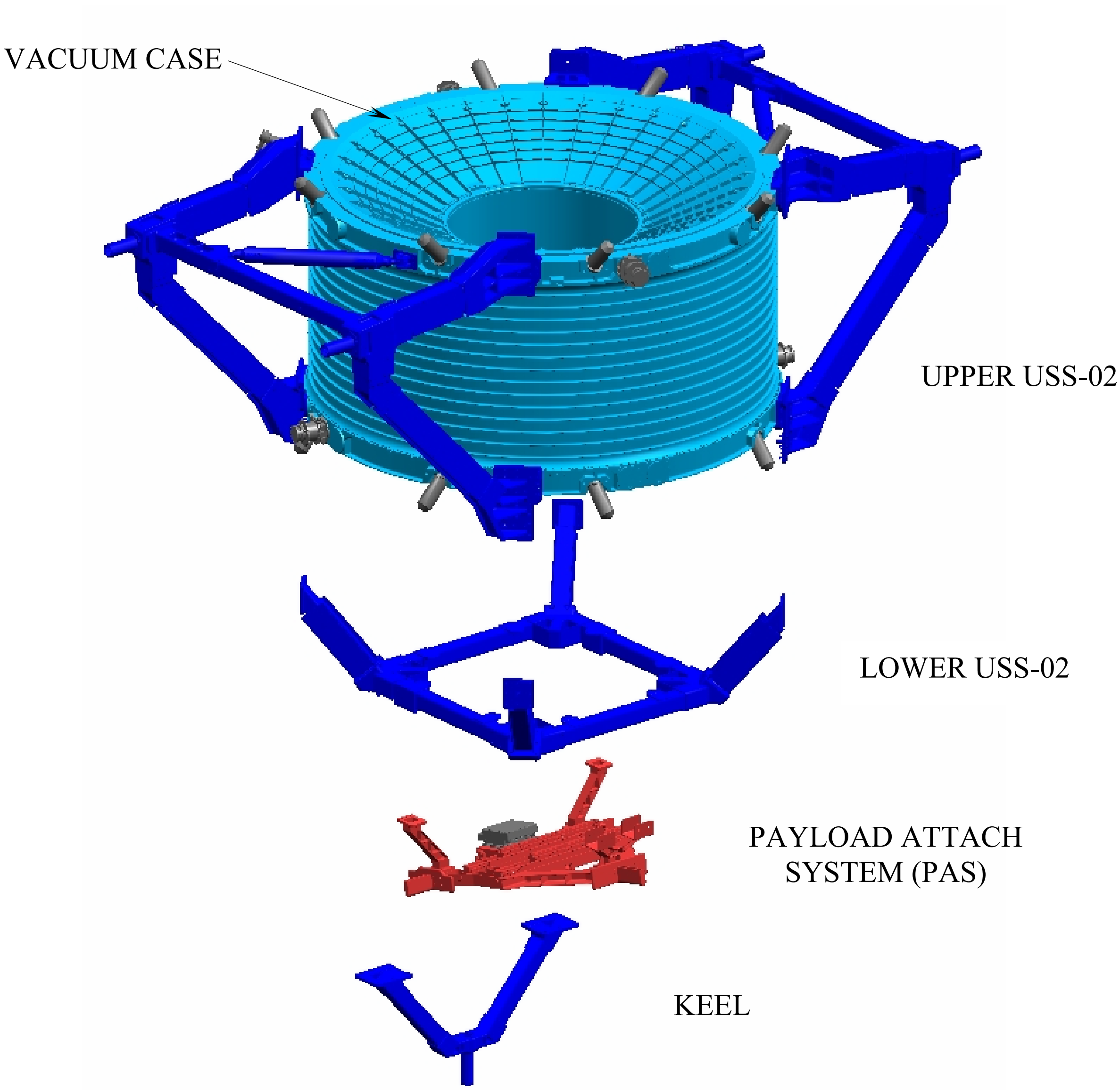


Figure 3.3.1.1.1-3 Subassemblies of the Unique Support Structure (USS) – 02

The Upper USS-02, Lower USS-02 and Keel are comprised of joints riveted to hollow tubes (Figure 3.3.1.1.1-4. The joints are made of machined aluminum alloy (7050-T7451) plate. The hollow tubes are extruded from an aluminum alloy (7075-T73511) and machined to their final configuration.

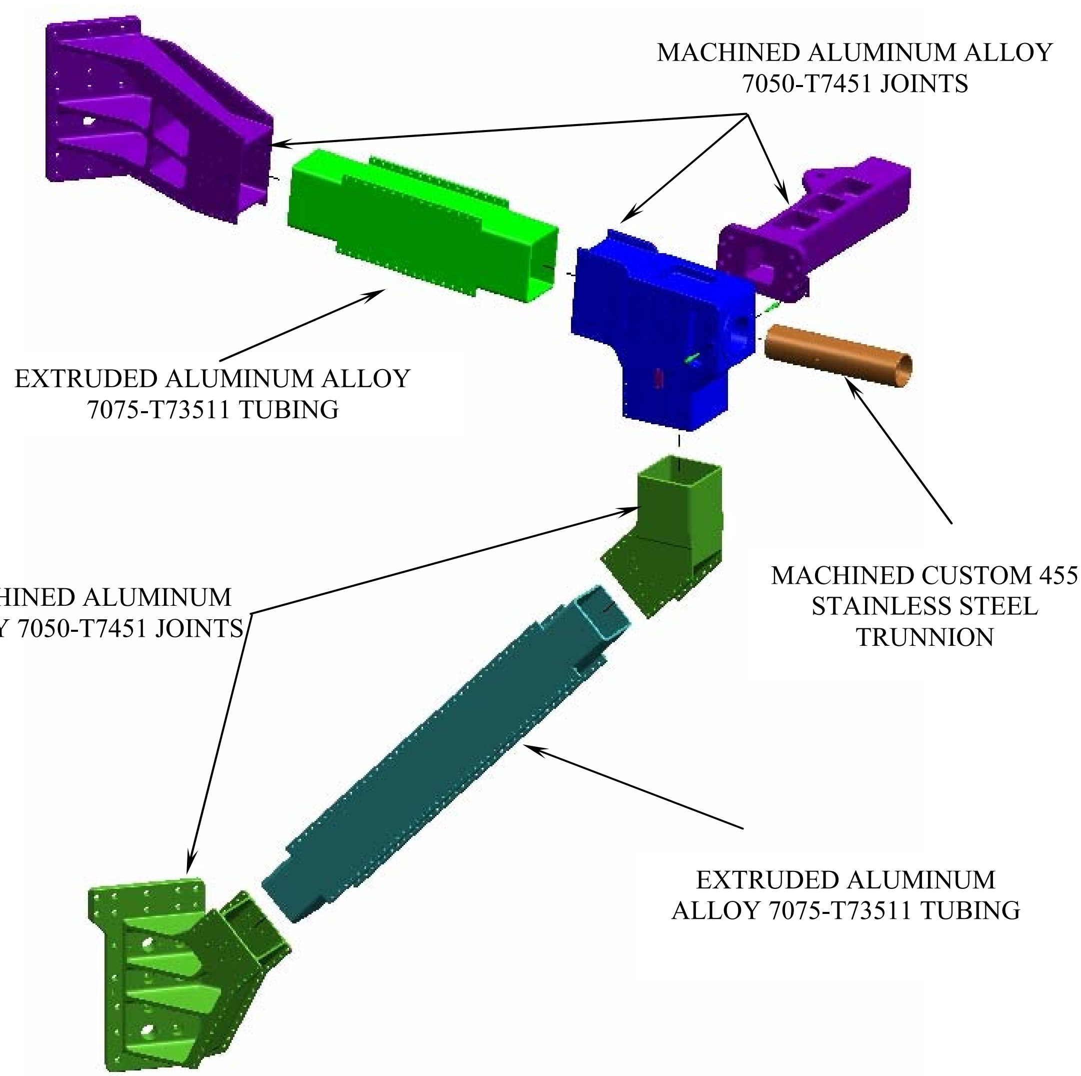


Figure 3.3.1.1.1-4 USS-02 Construction with Aluminum Tubes and Machined Joints

The Upper USS-02 includes two struts (Figure 3.3.1.1.1-5). The struts are fabricated from machined 6061-T6511 extruded aluminum tubing with machined end fittings that are riveted to the tube. Rod-end bearings are threaded into the end fittings. The struts are pinned to the Upper USS-02 at both ends using custom-made steel shear pins fabricated from 455 stainless steel.

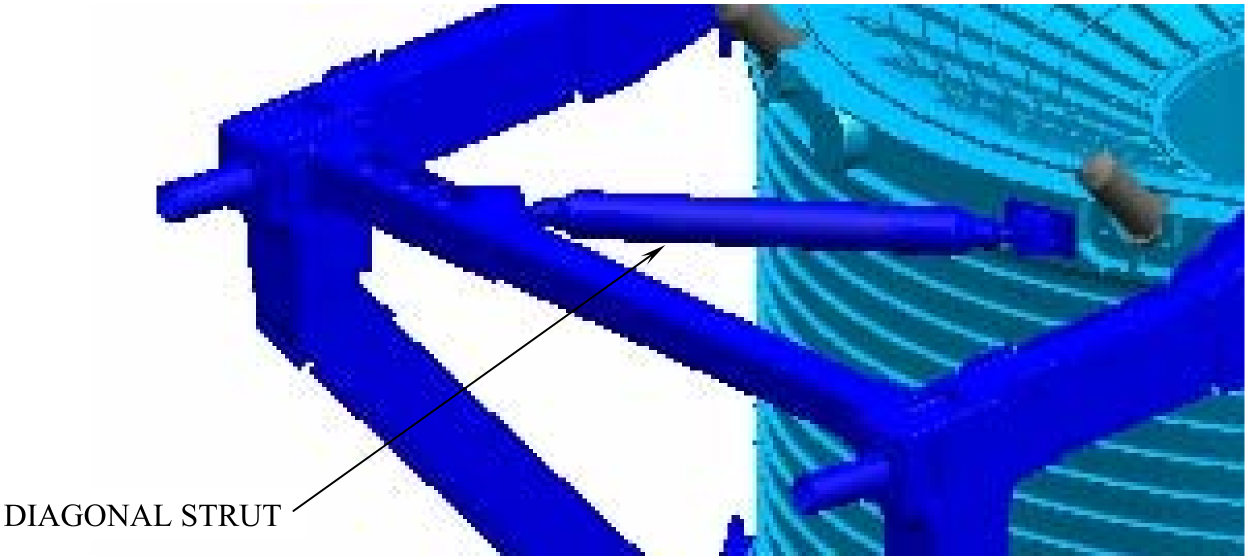


Figure 3.3.1.1.1-5 Location of the Diagonal Strut on the USS-02

3.3.1.1.2 AMS-02 Vacuum Case (VC)

The VC serves a dual purpose: It is a primary structural support that works in conjunction with the USS-02 to form the foundation structure of the AMS-02 and serves as a vacuum jacket for the superfluid helium tank and superconducting magnet which are suspended inside by 16 support straps. The Vacuum Case assembly and cross section is shown in Figure 3.3.1.1.2-1. The main structural components of the VC are described in the following paragraphs.

The weight of the VC is 1626 lbs (738 kg), which includes all of the Feed-thru and Strap Port blank cover plates. The VC attaches to the USS-02 at the eight Interface plates and the two Clevis Plates. Since the VC is an integral part of the primary structure with the USS-02, a Structural Test Article (STA) was developed and fabricated at the same time as the Flight VC. The STA VC will be used for much of the AMS-02 structural testing. The Flight unit and the STA unit are identical.

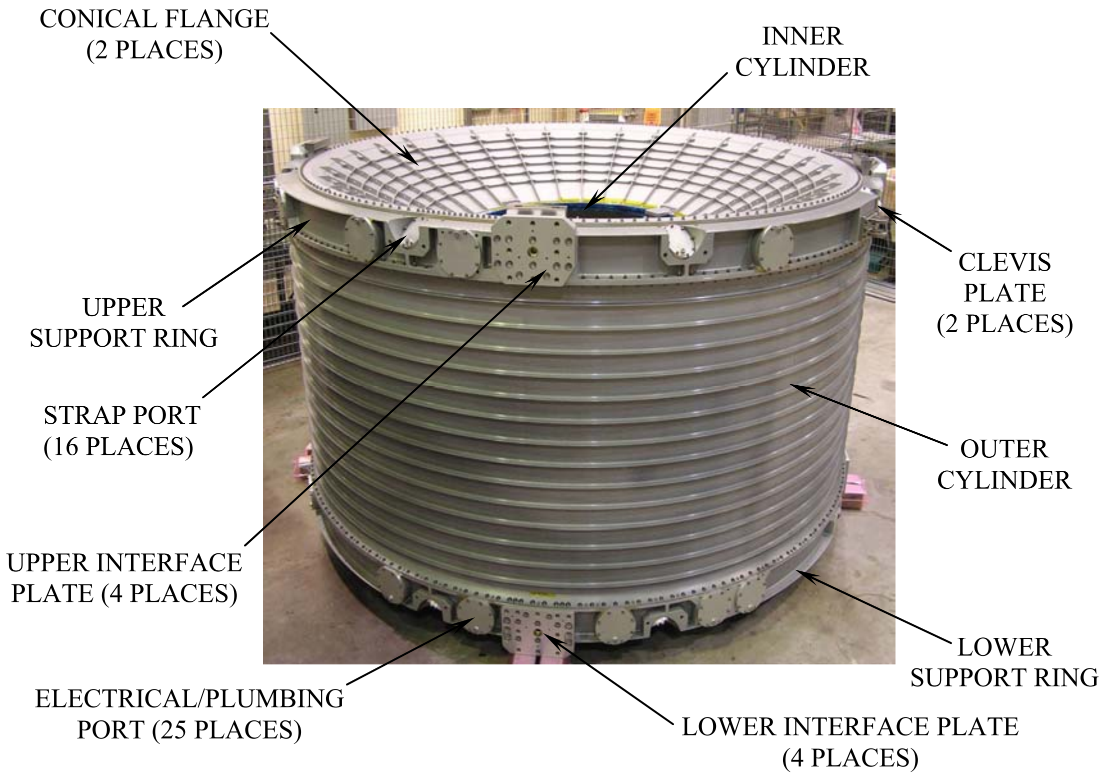


Figure 3.3.1.1.2-1 Vacuum Case

3.3.1.1.2.1 Conical Flanges

The Upper and Lower Conical Flanges are made of spin formed Al 2219-T62. The Conical Flanges start as an annealed plate (T0) and spin formed to rough shape using two dies. They are then solution heat treated and quenched (T42) followed by aging to final condition (T62) to complete a spin form blank. The blanks are then machined to final dimensions.

3.3.1.1.2.2 Support Rings

The Upper and Lower Support Rings are made of rolled ring forged Al 7050-T7451. The forging is then machined to final dimensions. The Support Rings contain all of the ports for the magnet support straps along with ports for electrical/plumbing feed-throughs and cyrocooler interfaces. The dove-tail O-ring grooves, which prevent the O-ring from falling out during VC assembly, are machined into the sealing faces of the feed thru ports.

3.3.1.1.2.3 Outer Cylinder

The Outer Cylinder is milled from a rolled ring forging of Al 7050-T7451. The forging is machined to provide reinforcing ribs along the height of the cylinder. The ribs are spaced approximately 3.0 inches apart and are 0.10 inch thick.

3.3.1.1.2.4 Inner Cylinder

The Inner Cylinder is made from an Al 2219-T852 rolled ring forging milled to the final dimensions. The inner cylinder provides the interior cavity for mounting the Anti-coincidence Counters and the Silicon Tracker.

3.3.1.1.2.5 Clevis Plates

The Clevis Plates are fabricated from CRES A286 and are used for attaching the diagonal struts from the USS-02 to the Upper Support Ring

3.3.1.1.2.6 Interface Plates

The Upper and Lower Interface Plates are fabricated from Al 7050-T7451 plate and are the main interface with the USS-02 at 8 locations.

3.3.1.1.2.7 Feed-thru Cover Plates

The Feed-thru Port Cover Plates are fabricated from Al 6061-T651 plate. The Feed-thru Cover Plates protect the access ports during ground processing and seal unused ports for flight. Plates can be removed to allow for the installation of plumbing components or electrical feed-thrus for the Cryomagnet System. Strap Port blank cover plates are used to protect the surfaces of the strap ports until the straps are installed

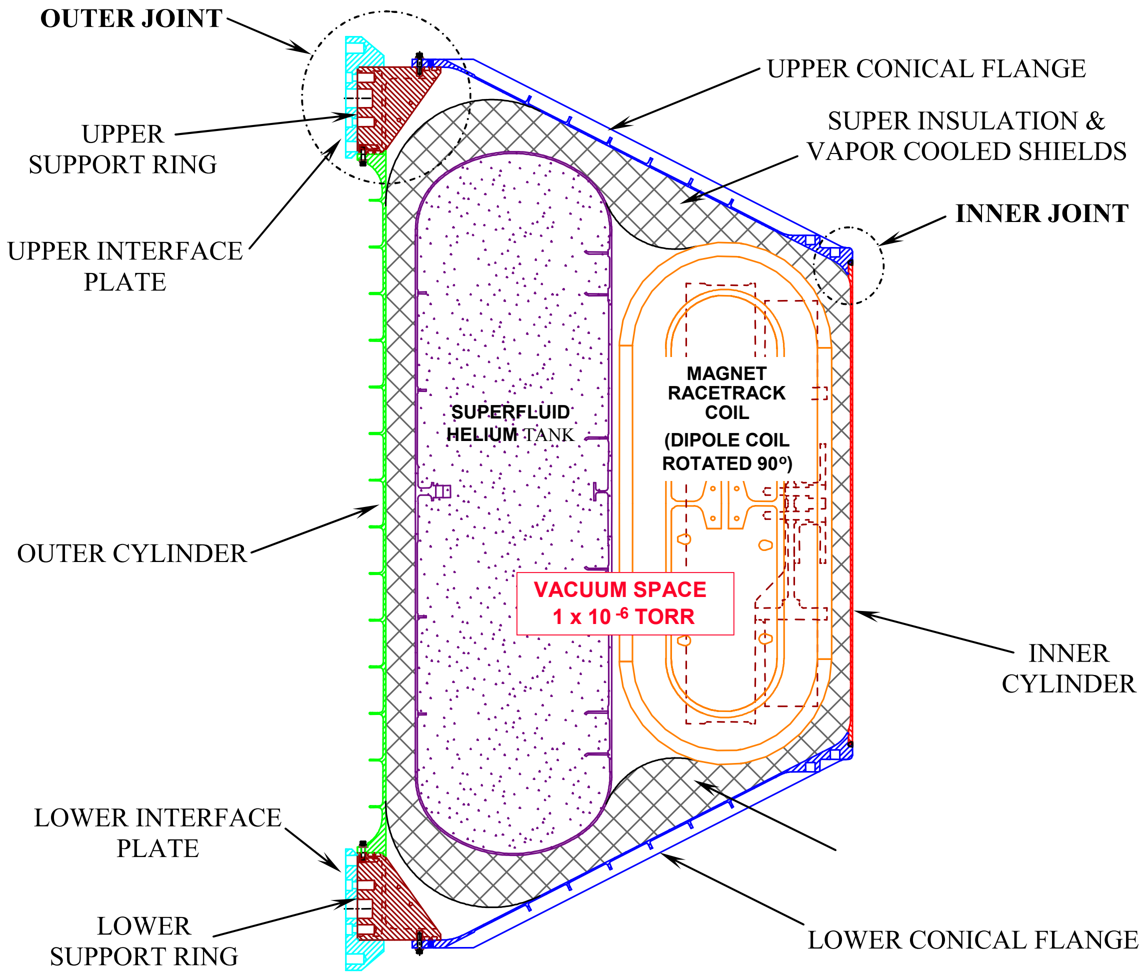


Figure 3.3.2.2.1-2 Vacuum Case Cross Section

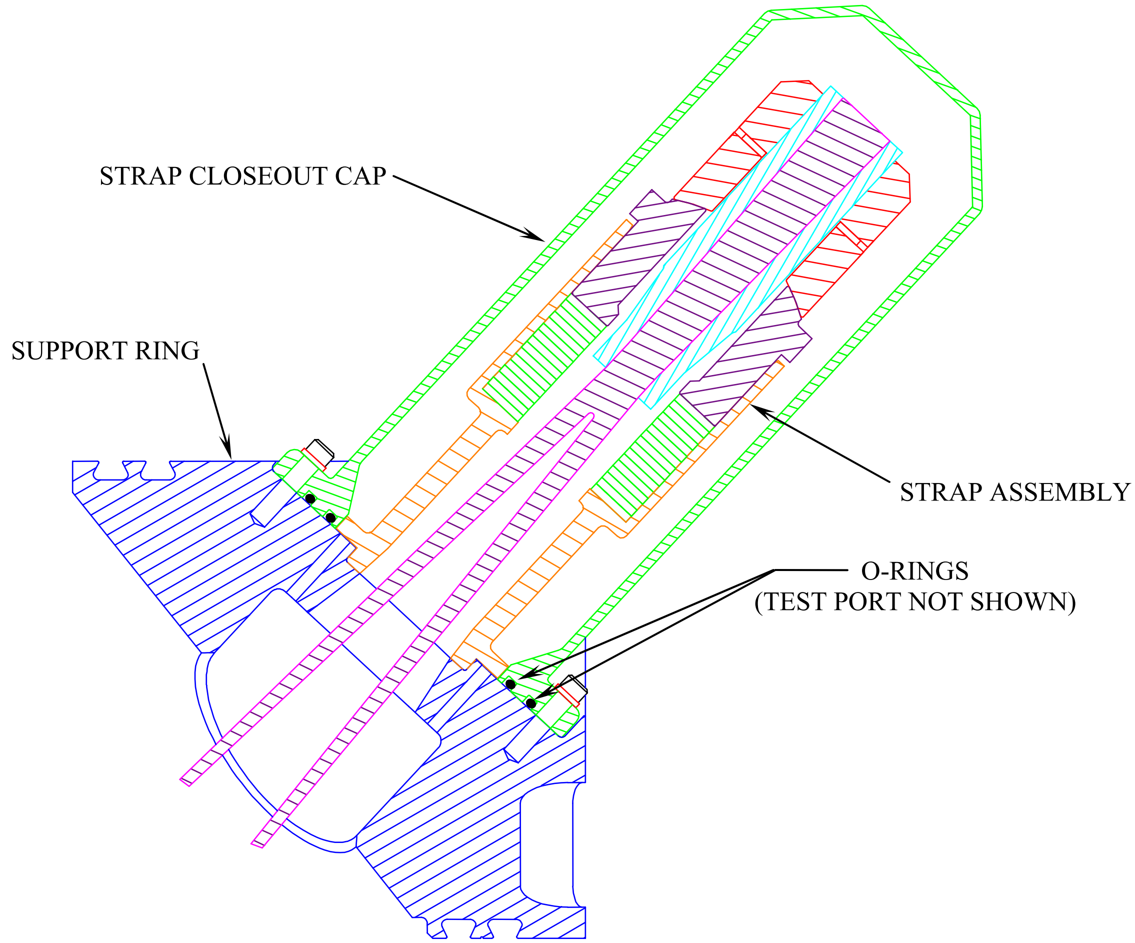


Figure 3.3.2.2.1-4 Strap Port Cross Section

3.3.1.1.3 AMS-02 Sill and Keel Trunnions and Scuff Plates

The AMS-02 sill and keel trunnions and scuff plates form the structural interface between the AMS-02 Payload and the Shuttle Orbiter in the Orbiter payload bay. The trunnion and keep pins are manufactured to comply with Payload Deployment and Retrieval System requirements for dimension and strength. Scuff plates are required due to the requirement of the AMS-02 to be handled by the Orbiter Remote Manipulator System. Figure 3.3.1.1.3-1 shows the locations of the trunnions, keel pin and scuff plates.

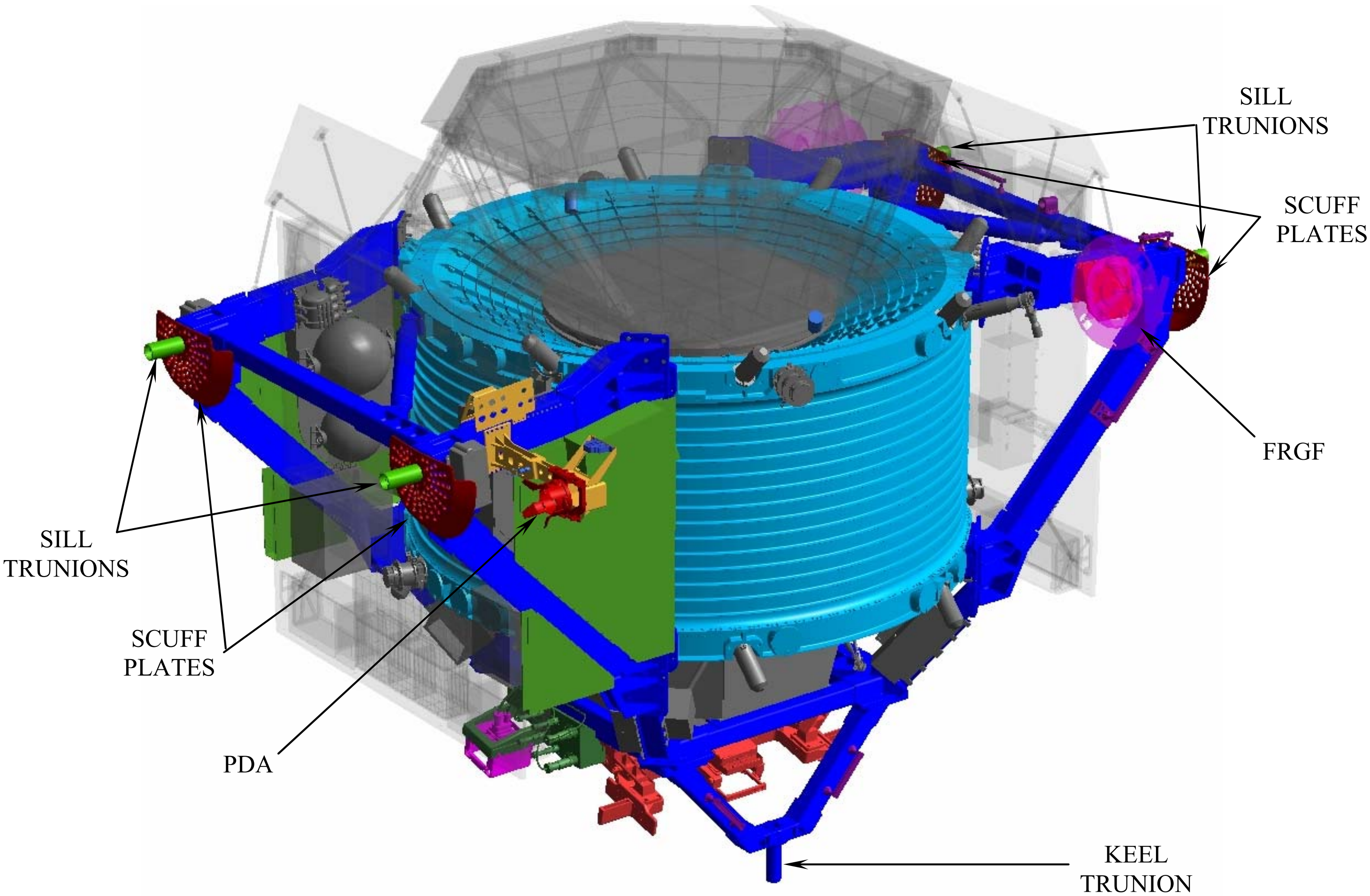


Figure 3.3.1.1.3-1 AMS-02 Shuttle Interfaces

Figures 3.3.1.1.3-2 and 3.3.1.1.3-3 provide more detailed views of the trunnion pins and scuff plates and of the keel pin.

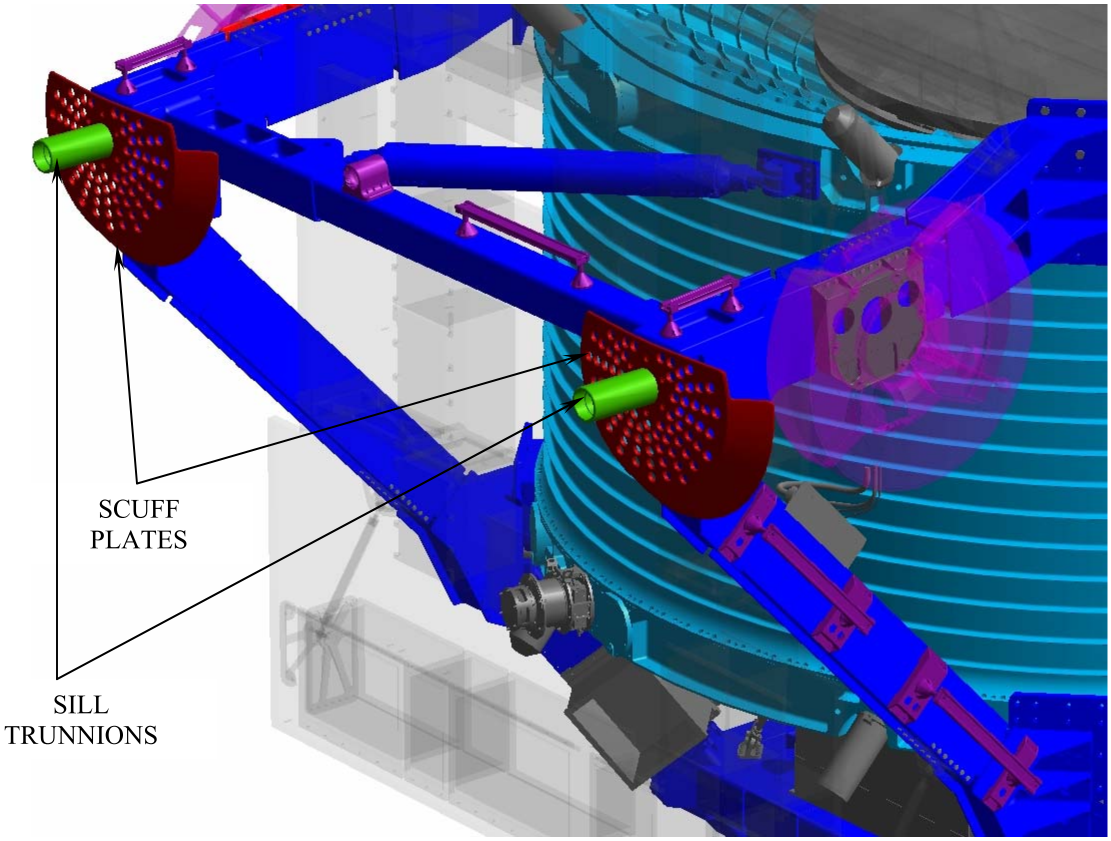


Figure 3.3.1.1.3-2 AMS-02 Shuttle Interfaces – Sill Trunnions and Scuff Plates

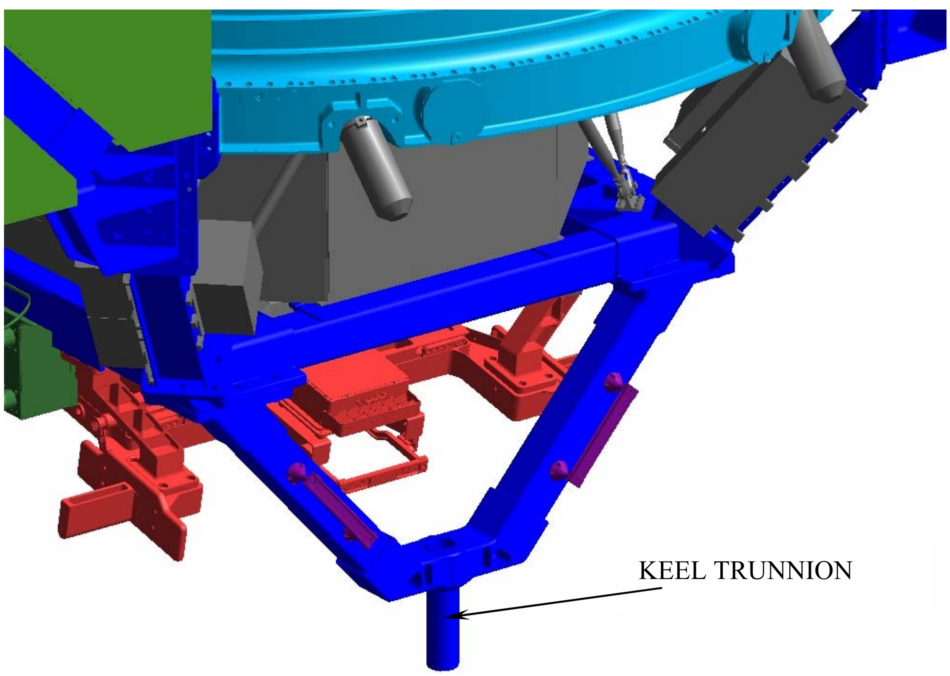


Figure 3.3.1.1.3-3 AMS-02 Shuttle Interfaces – Keel Trunnion

3.3.1.1.4 AMS-02 EVA Aids

The EVA aids that the AMS-02 requires consist of EVA compatible handrails that are custom made for the AMS-02 and the installation of WIF (worksite interface) sockets on the USS-02. Handrails are designed to be compatible with the requirements of JSC 28918, “EVA Design Requirements and Considerations.” The AMS-02 utilizes nine handrails and two WIF sockets. The positioning of the handrails and WIF sockets are dictated by the requirements of contingency EVA activities associated with GFE hardware (PVGF, FRGF, ROEU) and the AMS-02 (ROEU Bracket Folding, cable connection exchange, PAS EVA Mechanism Release.) Figures 3.3.2.4-1 through 3.3.2.4-4 show the locations of the handrails and EVA interfaces.

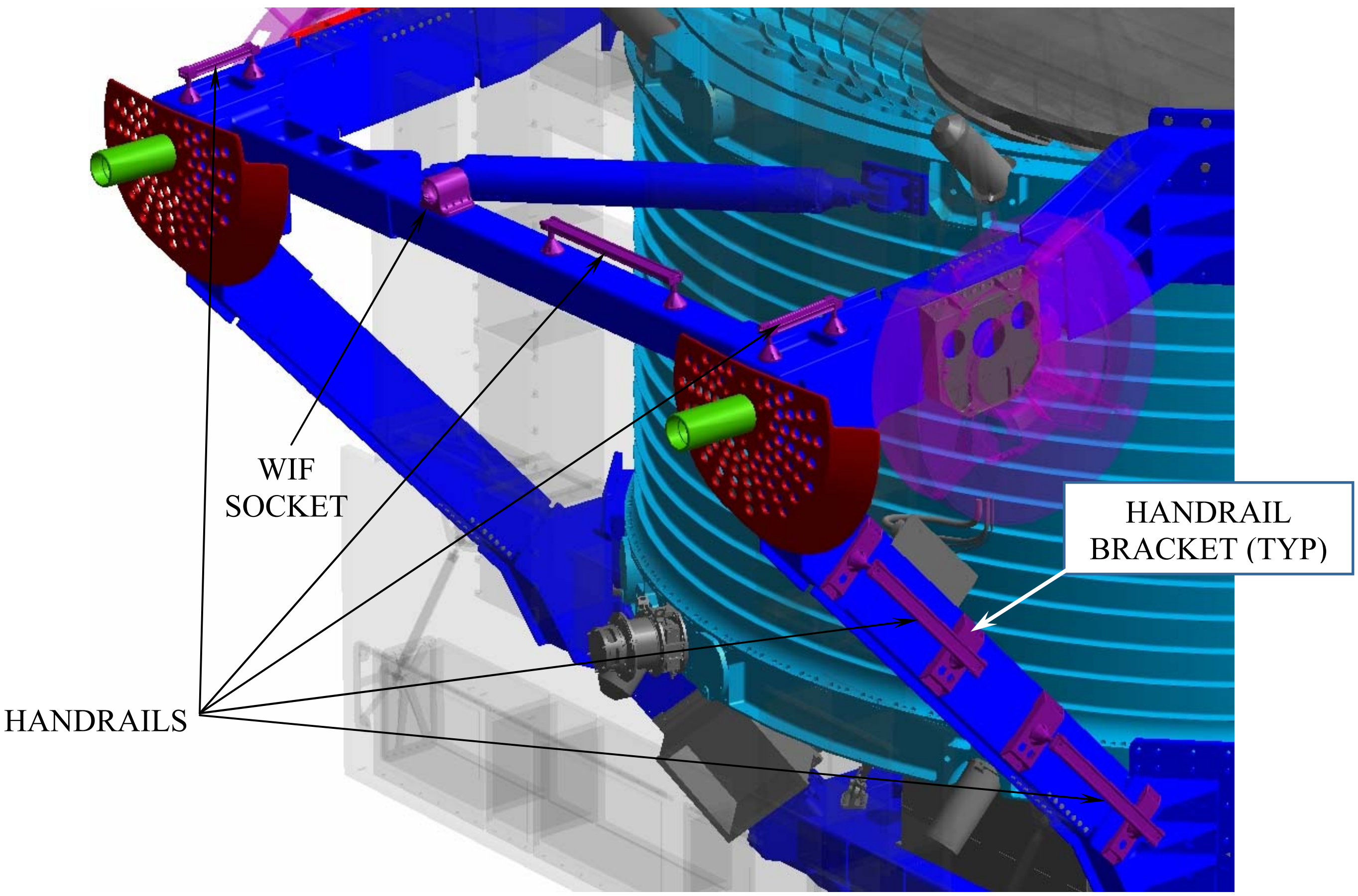


Figure 3.3.1.1.4-1 EVA Interfaces – WIF Socket and Handrails

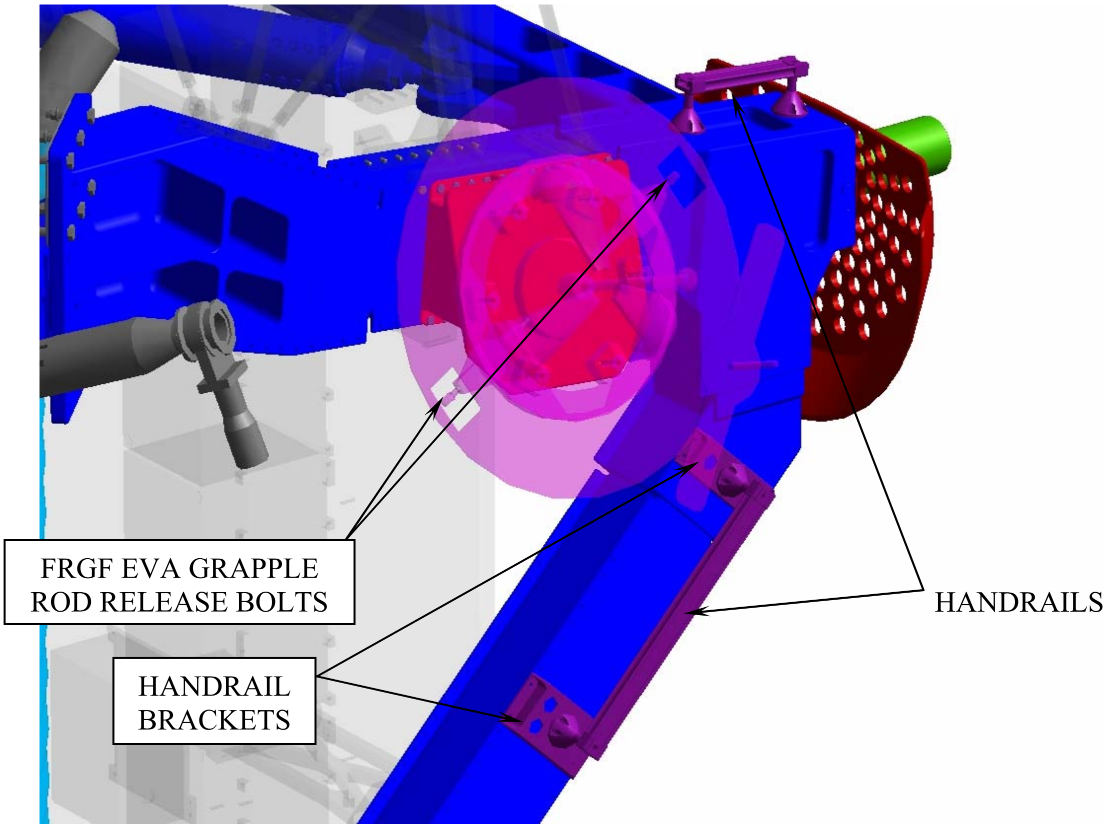


Figure 3.3.1.1.4-2 EVA Interfaces – Handrails and FRGF Release Bolts

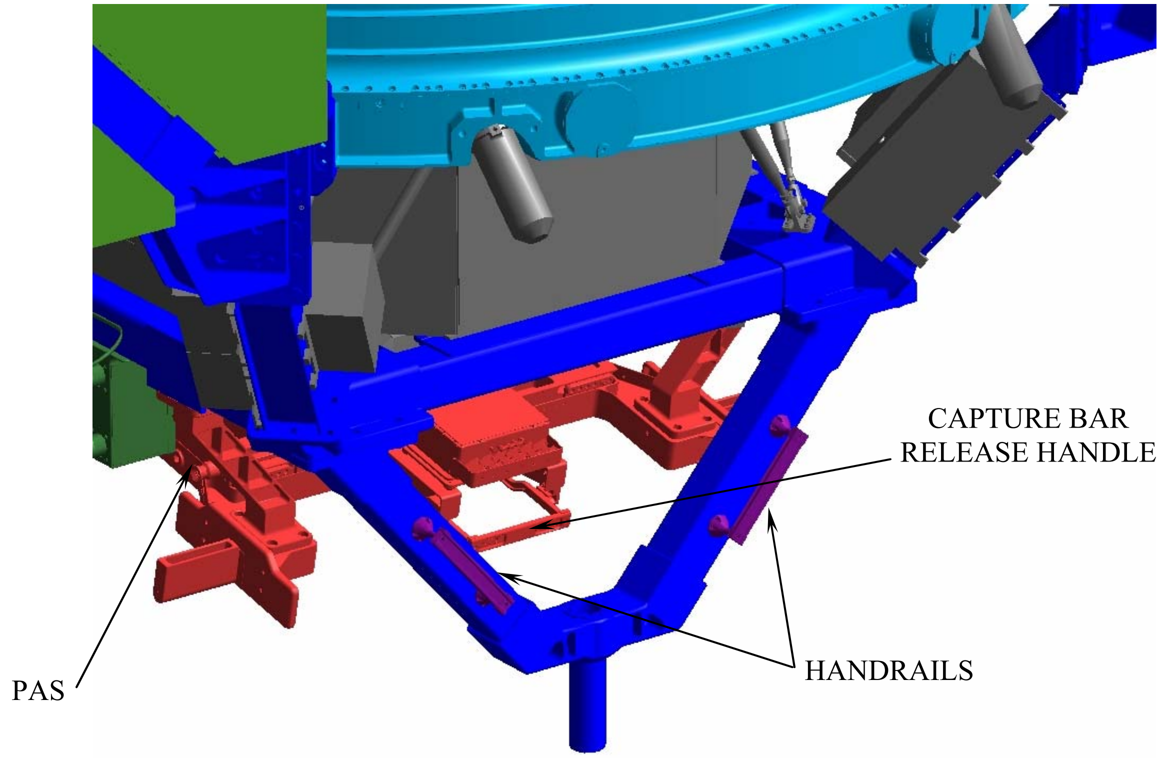


Figure 3.3.1.1.4-3 EVA Interfaces – Handrails and PAS Capture Bar Handle

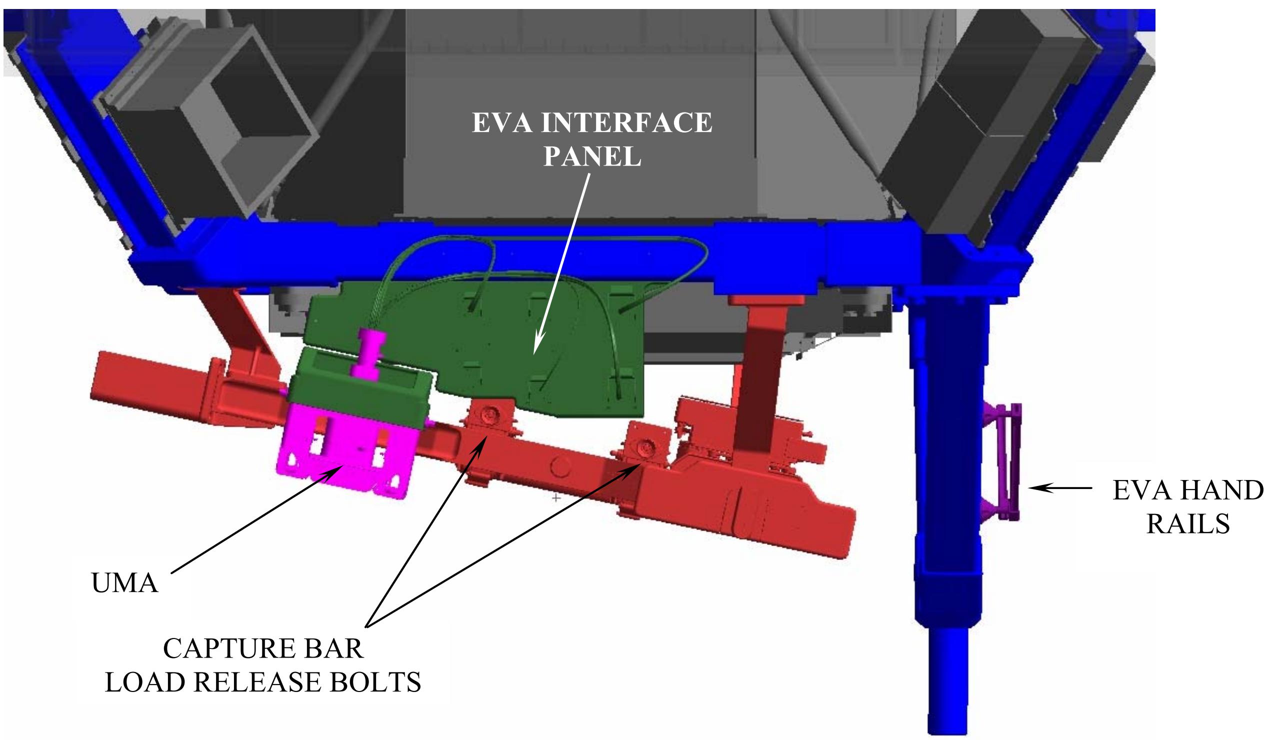


Figure 3.3.1.1.4-4 EVA Interfaces – PAS Capture Bar Handle

3.3.1.1.5 AMS-02 Passive Payload Attach System (PAS) with EVA Release Mechanism

The AMS-02 Passive PAS is the mechanical and structural interface between the AMS-02 and the ISS. The passive PAS provided by the AMS-02 interfaces with the active PAS that is an integral component of the ISS truss. The AMS-02 will interface with the ISS through the S3 upper inboard PAS location. Figures 3.3.1.1.5-1 and 3.3.1.1.5-2 show the PAS and its location on the AMS-02.

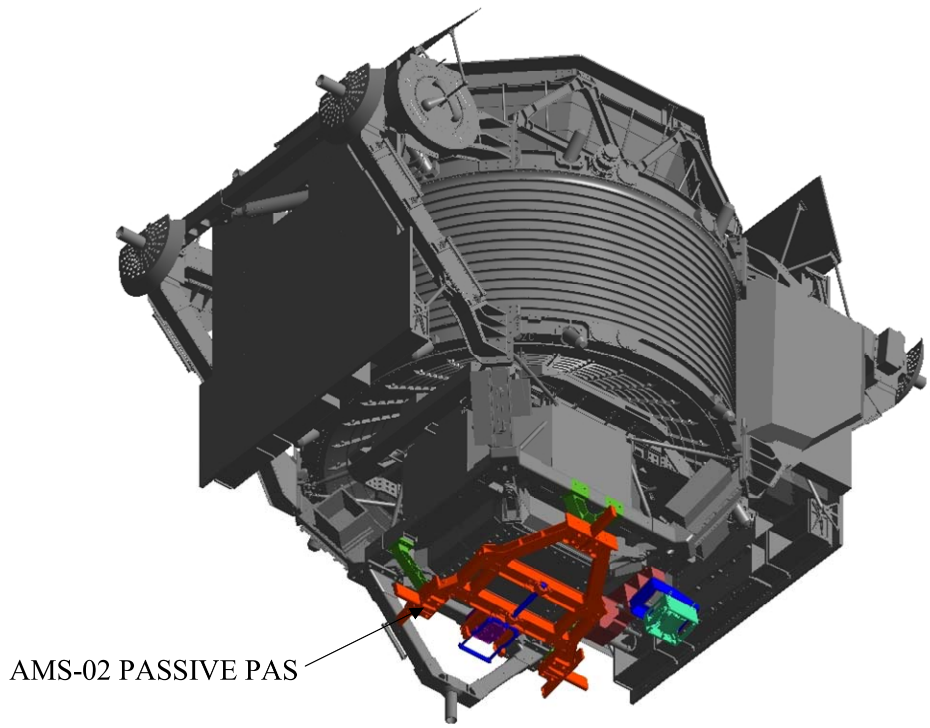


Figure 3.3.1.1.5-1 The Passive PAS on the bottom of the AMS-02 Payload (1 of 2)

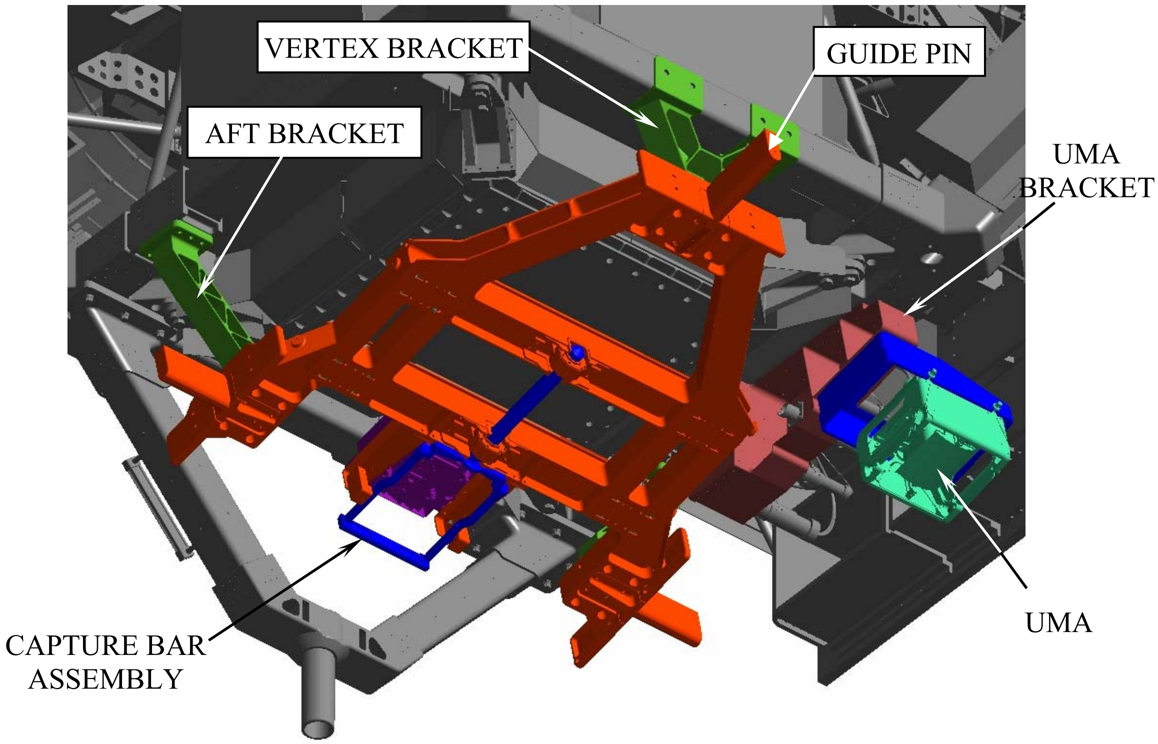


Figure 3.3.1.1.5-2 The Passive PAS on the bottom of the AMS-02 Payload (2 of 2)

The PAS (active and passive) consists of three basic pairs of components that interact to mate the payload to the ISS: the active half Capture Claw (ISS) and passive half Capture Bar (AMS-02); the three active half Guide Vanes (ISS) and the passive half Guide Pins (AMS-02); and the active Umbilical Mechanism Assembly (UMA) (ISS) and the passive UMA (ISS Provided mounted on the AMS-02 PAS). The Capture Claw, Capture Bar, Guide Vanes, and Guide Pins provide the structural attachment for the Payload to ISS and the active and passive UMA provide power and data connection from ISS to the Payload. Figures 3.3.1.1.5-3 through 3.3.1.1.5-5 show additional details of the interface and mechanisms of the active and passive PAS.

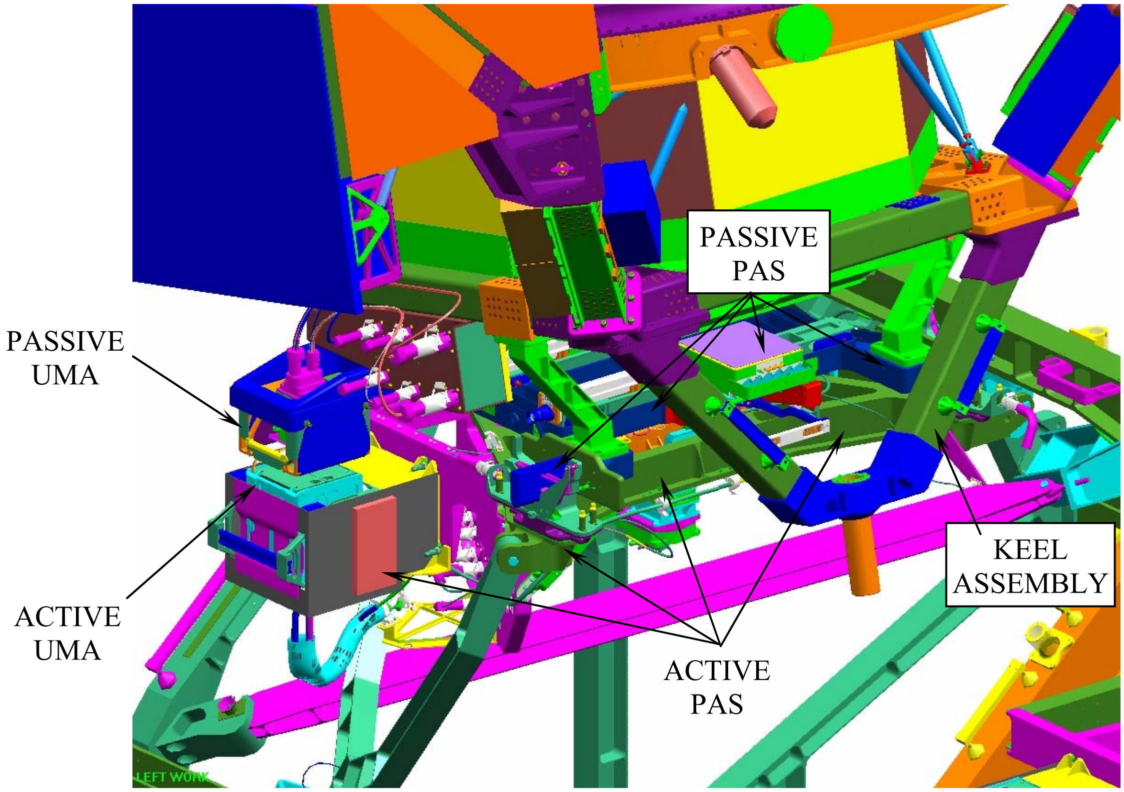


Figure 3.3.1.1.5-3 The AMS-02 Passive PAS attached to the ITS3 Active PAS (1 of 3)

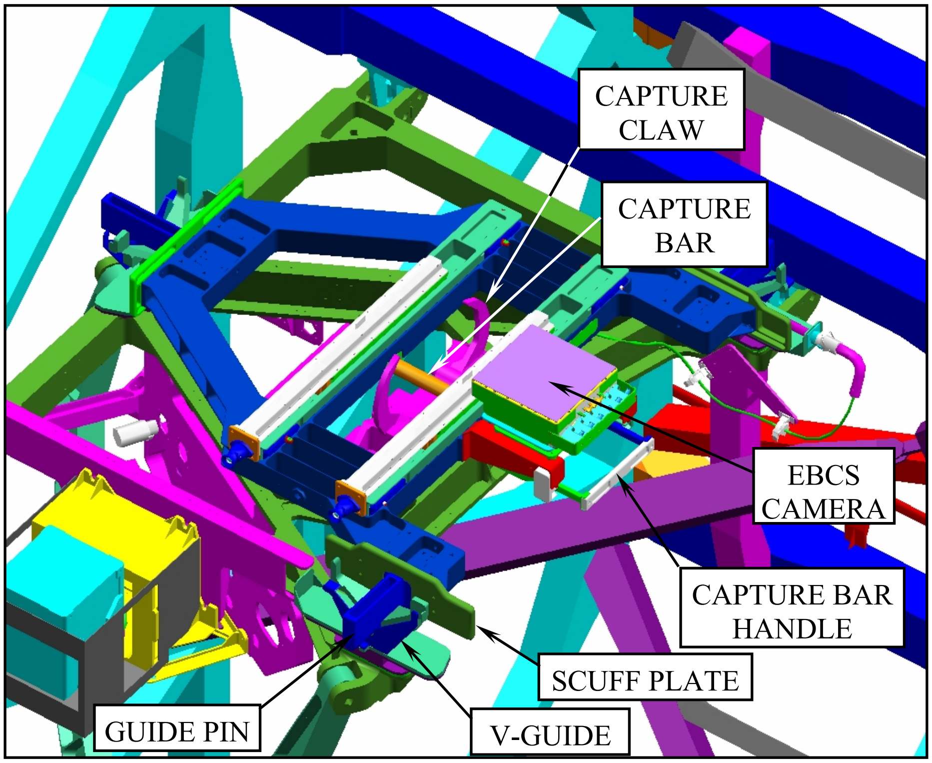


Figure 3.3.1.1.5-4 AMS-02 Passive PAS attached to the ITS3 Active PAS (2 of 3)

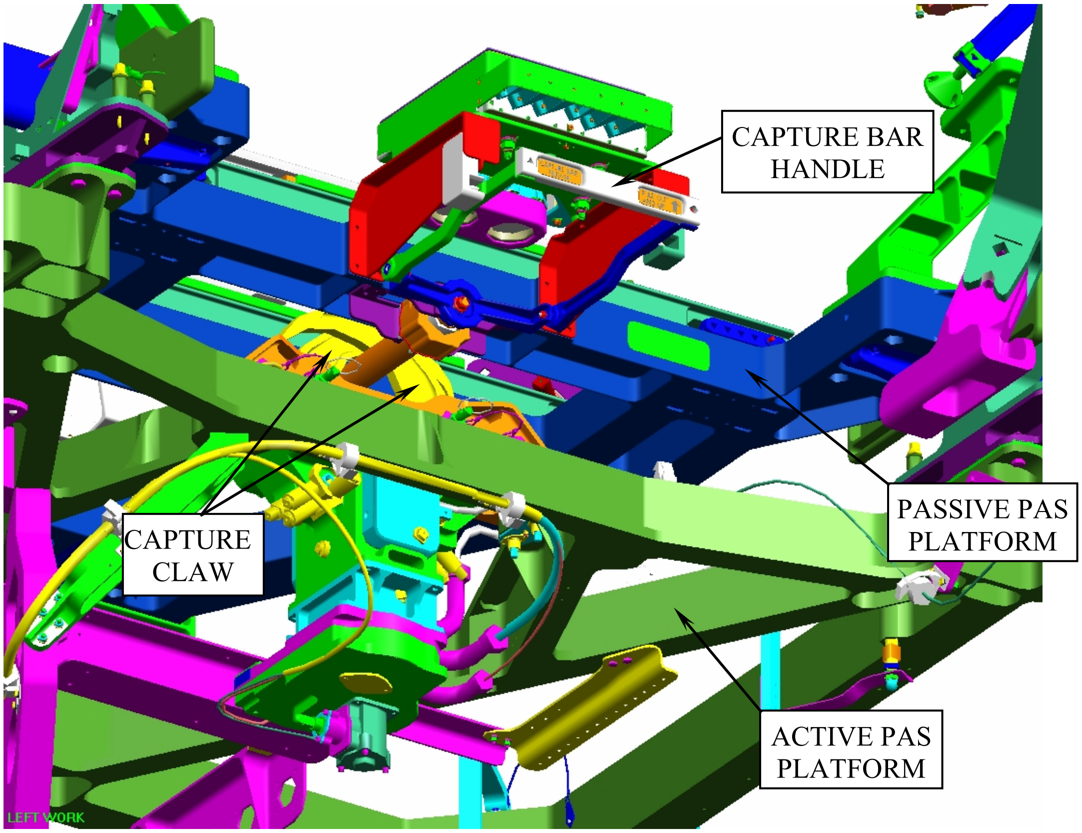


Figure 3.3.1.1.5-5 AMS-02 Passive PAS attached to the ITS3 Active PAS (3 of 3)

Per SSP 57003, the AMS-02 PAS incorporates a mechanism to unload the capture bar and release the Payload from the ISS. To unload and release the AMS-02 Payload from ISS, an EVA crewmember first unloads the capture bar, by driving two EVA bolts using the Pistol Grip Tool (PGT). Turning the bolts a defined number of turns and alternating between the two bolts lowers the Capture Bar and relieves any load in the system. The crewmember then retracts the capture bar by reaching thru the AMS-02 Keel structure, grasping the Capture Bar Assembly handle, and pulling the capture bar out towards the keel and up towards the Payload. Once the capture bar is retracted, the Payload is free from the PAS and the ISS. Figure 3.3.1.1.5-6 shows the PAS with the EVA interfaces for operating the EVA release mechanism indicated.

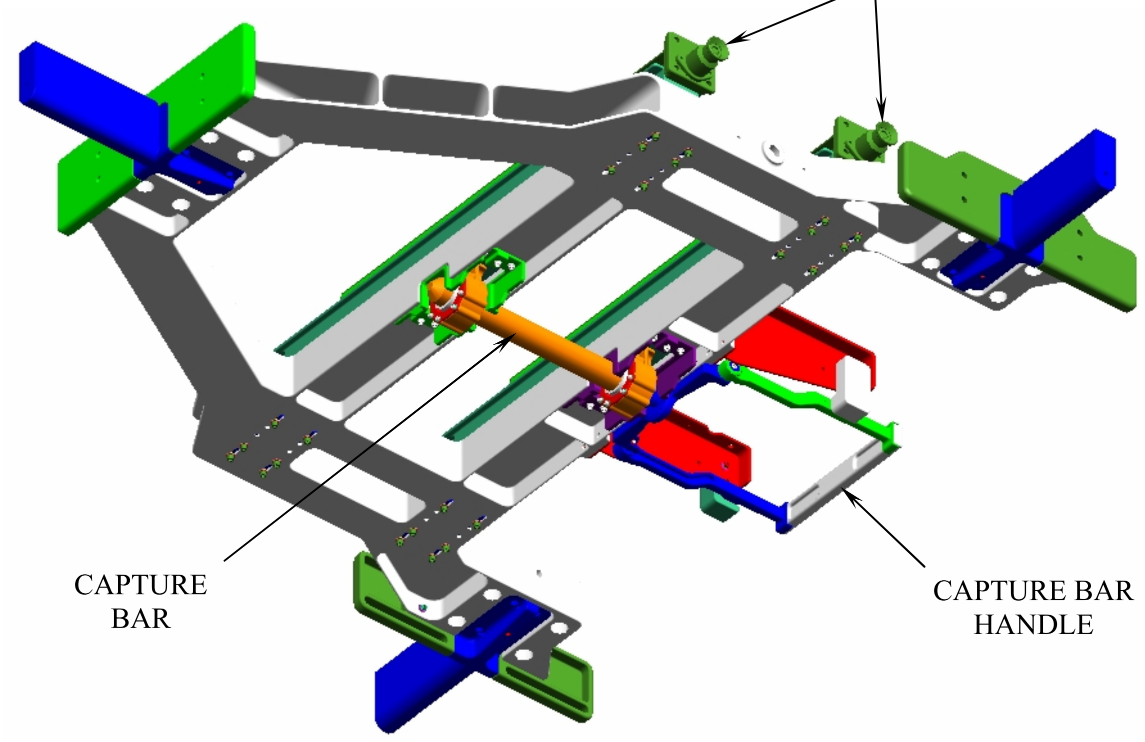


Figure 3.3.1.1.5-6 PAS EVA Releasable Capture Bar

The AMS-02 PAS Assembly is bolted to the Lower USS-02 via four brackets, the Vertex Bracket, two Aft Brackets and the UMA Bracket. The AMS-02 PAS Assembly (Figure 3.3.1.1.5-7) consists of five bolted subassemblies, the PAS Base Assembly, EVA Extension Assembly, PAS Bridge Assembly, Capture Bar Assembly, and EBCS Avionics Assembly.

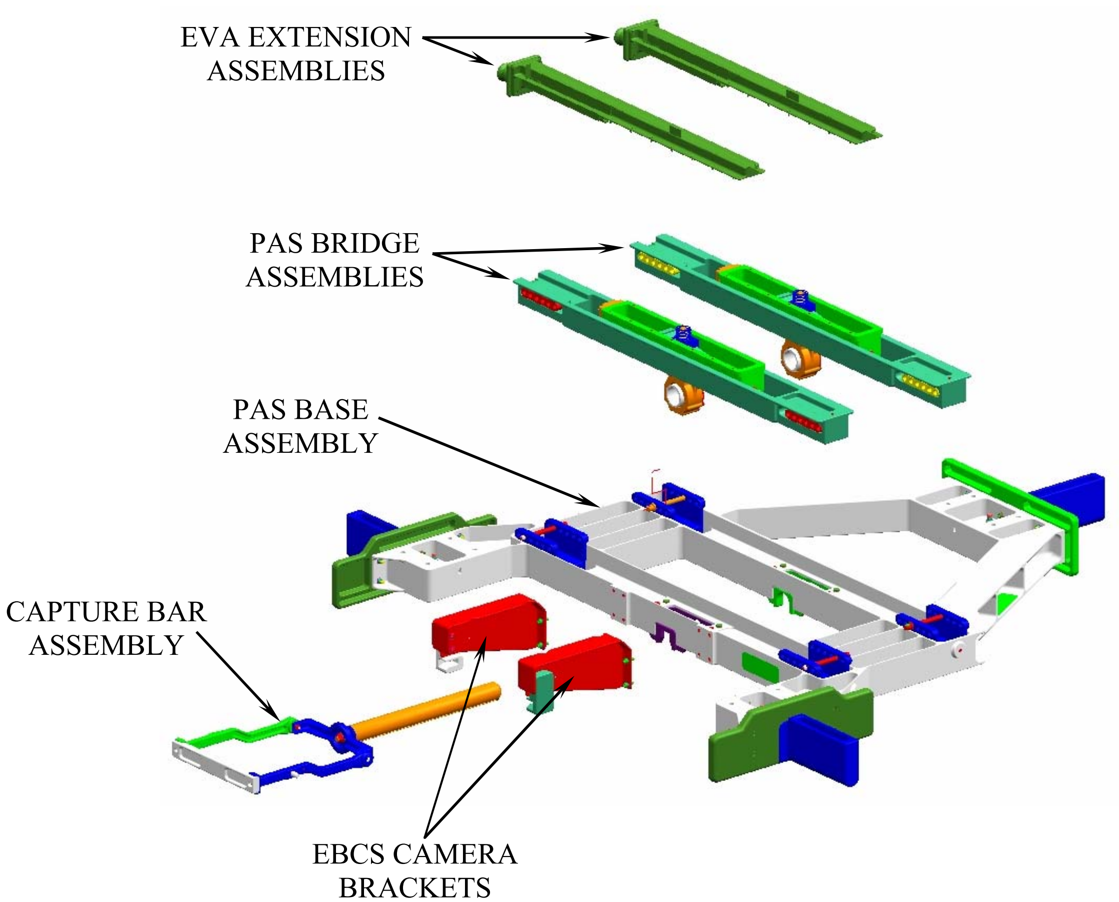


Figure3.3.1.1.5-7 AMS-02 PAS Component Detailed Description

3.3.1.1.6 AMS-02 ROEU Support Bracket

The AMS-02 utilizes a Remotely Operated Electrical Umbilical (ROEU) to provide electrical and communications links to the Orbiter while the AMS-02 is secure in the payload bay. In order to position the passive half of the ROEU, the Payload Disconnect Assembly (PDA) that is attached to the AMS-02 in the correct position to mate with the Orbiter active half of the ROEU the AMS-02 ROEU support bracket is required. This bracket is designed to be EVA foldable once the AMS-02 is installed on the ISS. In the event that there is need for additional clearance between the AMS-02 and a payload to be installed on the adjacent PAS site. The rotation/folding mechanism utilizes a simple pin rotation point and two EVA compatible pip pins. The pip pins are used to secure the PDA in either the extended or folded position. The rotating components incorporate stops to align the holes for the pip pins to be inserted in each position. Figures 3.3.1.1.6-1 and 3.3.1.1.6-2 show the ROEU Support Bracket and the Bracket Folding Mechanism.

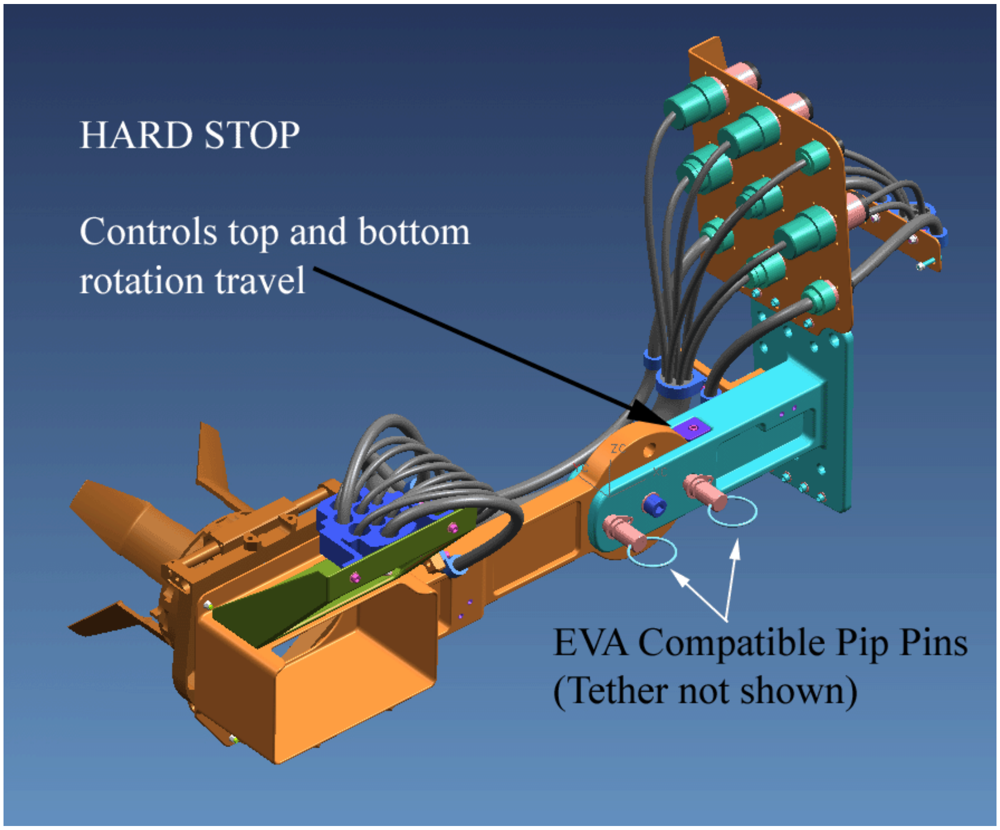


Figure 3.3.1.1.6-1 ROEU Bracket Folding Mechanism

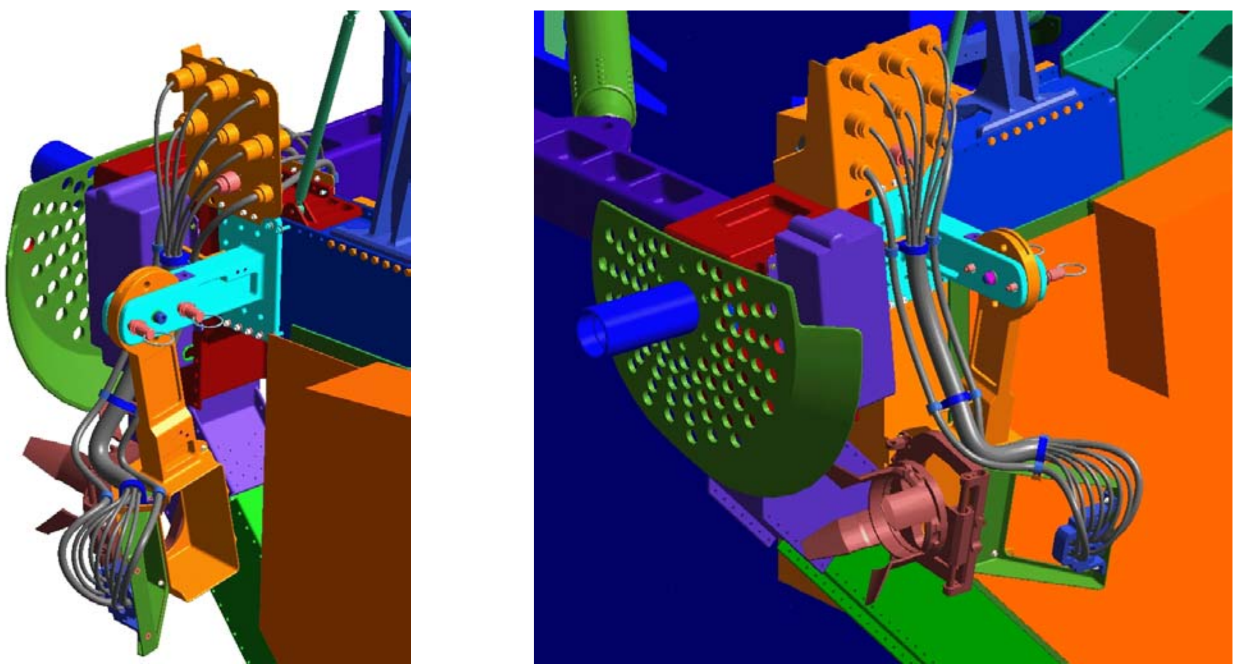


Figure 3.3.1.1.6-2 ROEU Bracket Folding Mechanism - Folded

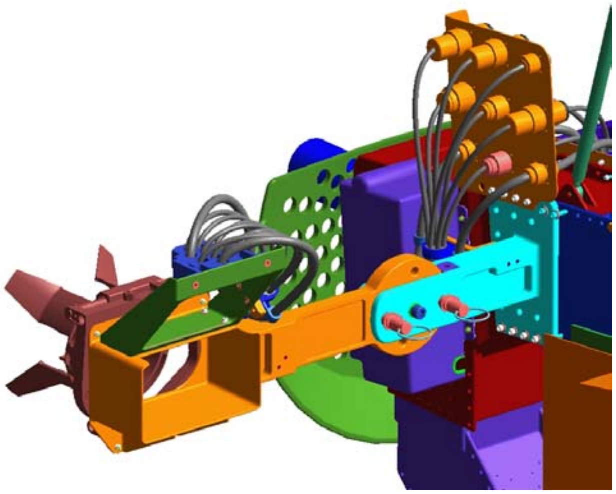
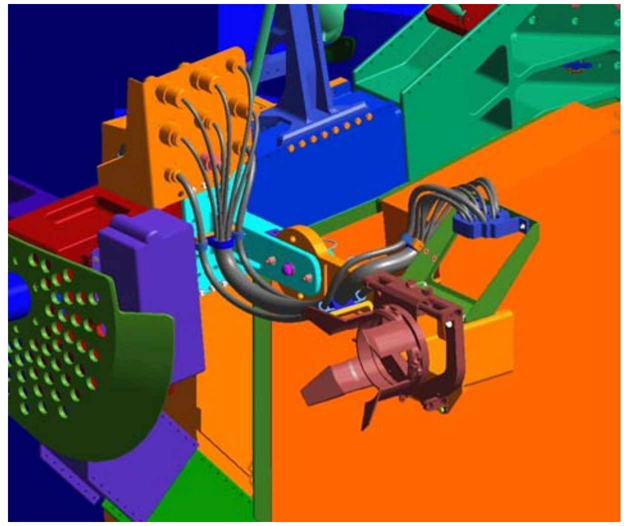



Figure 3.3.1.1.6-3 ROEU Folding Mechanism in Nominal Flight Configuration – Unfolded

3.3.1.1.7 AMS-02 Power and Data Interfaces

The AMS-02 will interface with three sources of power, the shuttle Orbiter, the ISS at the S3 Truss upper inboard PAS position and with the Space Station Remote Manipulator System (SSRMS). On board the Orbiter all power is routed through the Remotely Operated Electrical Umbilical. The PIH associated with the Shuttle Program provided ROEU PDA includes the wiring into the AMS-02 Power Distribution System (PDS) and the structural interface (See 3.3.1.1.6). The power supplied by the ISS through the truss connection at the PAS is provided through the ISS provided Passive UMA connector. The Passive UMA connector is wired into the AMS-02 PDS as part of the PIH and the structural interface is provided as part of the PAS (See 3.3.1.1.5). The electrical power provided to the AMS-02 during SSRMS handling goes through the ISS provided Power Video Grapple Fixture (See 3.3.1.1.9) and wired into the AMS-02 power distribution system utilizing a fuse to limit the maximum current the AMS-02 can draw through the SSRMS.

3.3.1.1.8 AMS-02 Power Video Grapple Fixture (PVGF)

A PVGF, mounted on the aft port side of the Upper Trunnion Bridge Beam of the AMS-02 payload, provides an additional structural/mechanical interface with the Mobile Servicing System allowing the SSRMS or the Payload/Orbiter Replacement Unit (ORU) Accommodation to grapple the payload. The PVGF mounts to the PVGF Bracket using six high strength (200 ksi ultimate) ⅜" diameter bolts. The PVGF Bracket is mounted to the Upper Trunnion Bridge Beam with 24 high strength (180 ksi ultimate) ¼" diameter bolts. The PVGF attachment location on AMS-02 is shown in figure 3.3.1.1.8-1. An exploded view of the attachment hardware is shown in Figure 3.3.1.1.8-2. Electrically the PVGF will provide pass-through power from the SSRMS to AMS-02, but not data communication. Power supplied to AMS-02 during this operation is for heater operations only.

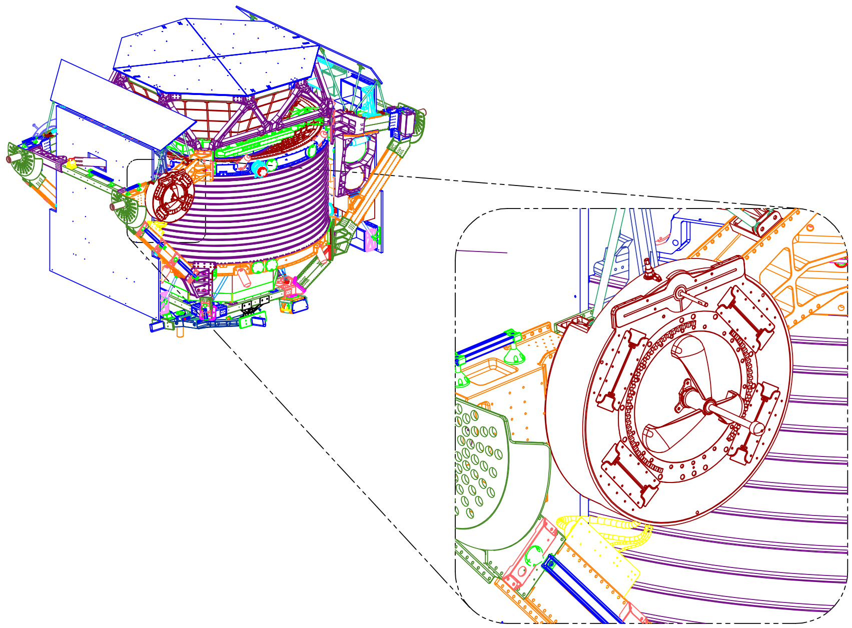


Figure 3.3.1.1.8-1 PVGF Mounted to the Upper Trunnion Bridge Beam USS-02

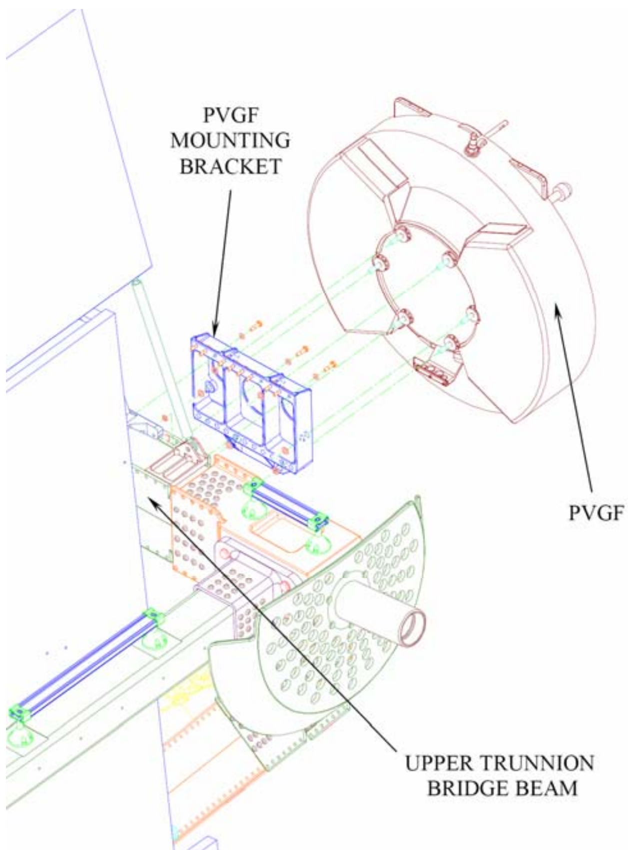


Figure 3.3.1.1.8-2 The PVGF to USS-02 Mounting Hardware

3.3.1.1.9 <u>AMS-02 External Berthing Camera System (EBCS)</u>

The EBCS is a camera and avionics package provided by the ISS Program that is structurally mounted to the passive PAS assembly on the AMS-02 (Figure 3.3.1.1.9-1). The EBCS provides visual cues to the SSRMS operator through robotic workstation monitors to assist in the berthing of the payload to the active PAS on the ISS truss. The system is comprised of an avionics package which contains both primary and secondary video cameras and an EBCS Target which his mounted on the active PAS site. Electrical and video connections are made through the SSRMS and PVGF when the PVGF is grappled by the SSRMS. The electrical services of EBCS include video, power, heater power and AMS-02 heater power. The EBCS Avionics mounting is the responsibility of AMS-02. The mounting requirements are defined in SSP 57003 Section 3.7.6.1, SSP 57004 Figures 3.1.2.2-1 and SSP 57004 Figures 3.7.1-1. Additional mounting data is contained in MDR-BCS-TM-7498, EBCS Avionics Package Detailed Installation Instructions produced by MD Robotics per NASA contract NAS9-00089.

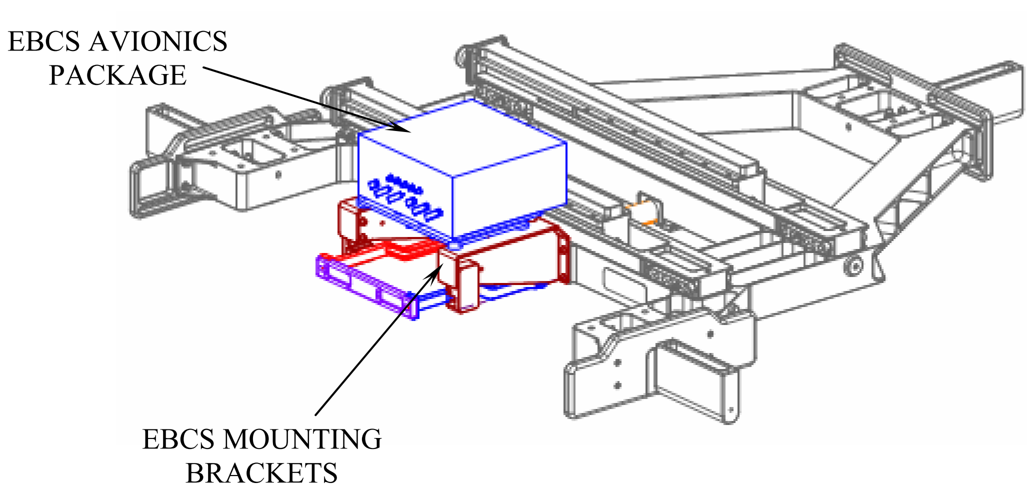


Figure 3.3.1.1.8-1 The EBCS Mounted on the AMS-02 Passive PAS

3.3.1.1.10 <u>AMS-02 Flight Releasable Grapple Fixture (FRGF)</u>

An FRGF, mounted to the AMS-02 payload, will be used by the Shuttle Remote Manipulator (SRMS) to lift the AMS-02 out of the Orbiter payload bay. The FRGF is mounted to the FRGF Bracket using six high strength (200 ksi ultimate) ⅜" diameter bolts. The FRGF Bracket is bolted to the forward face of the port Upper Trunnion Bridge Beam using 24 high strength (180 ksi ultimate) ¼" diameter bolts. The FRGF placement on the USS-02 is shown in Figure 3.3.1.1.10-1. An exploded view of the attachment hardware is shown in Figure 3.3.1.1.10-2.

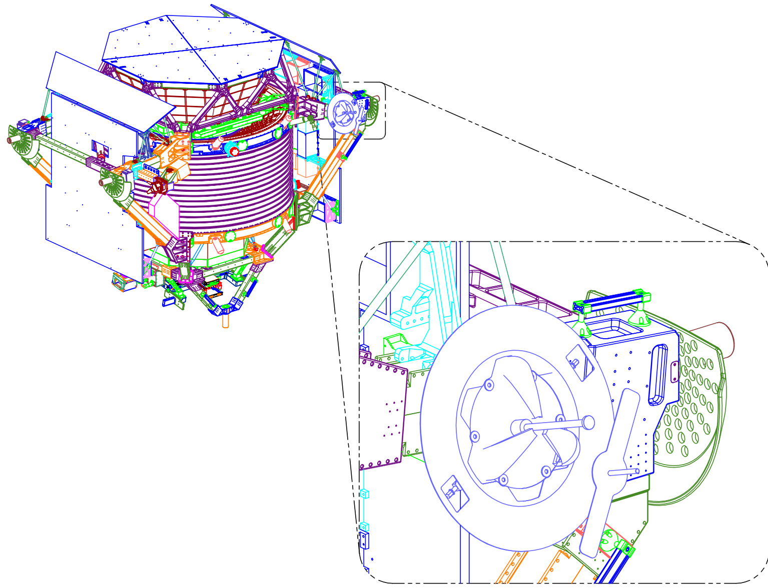


Figure 3.3.1.1.10-1 The FRGF Mounted to the Upper Trunnion Bridge Beam USS-02

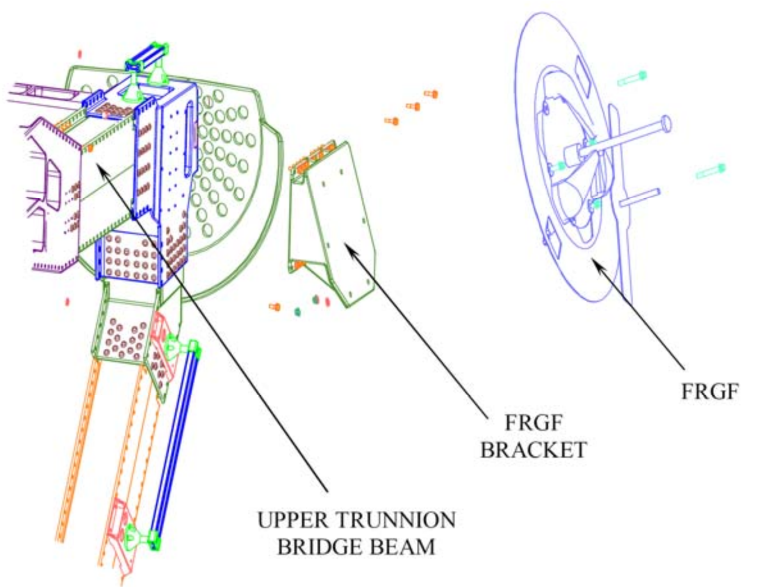


Figure 3.3.1.1.10-1 FRGF to USS-02 Mounting Hardware

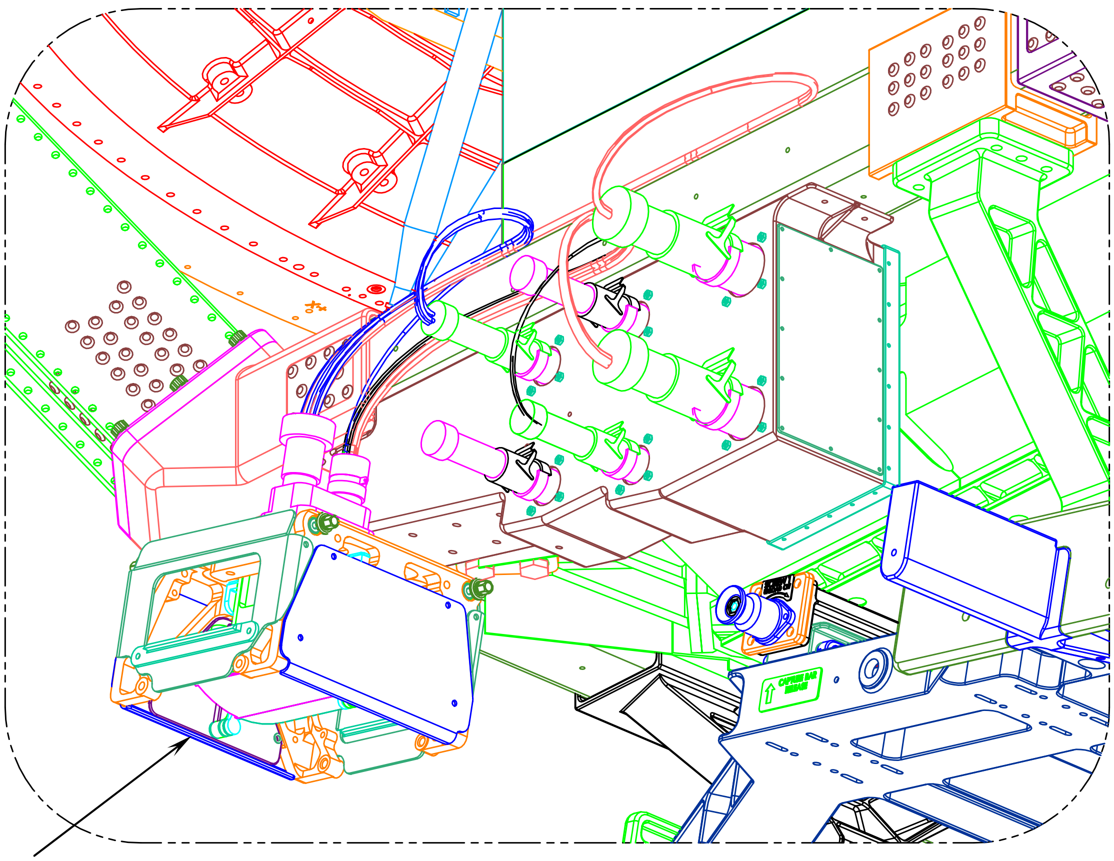
3.3.1.1.11 AMS-02 Payload Disconnect Assembly/Remote Electrically Operated Umbilical (PDA/ROEU)

The PDA for the ROEU is the AMS-02 half of the ROEU system. The PDA is used to make the electrical interface between the Shuttle and the AMS-02 payload. The PDA is mounted to the ROEU bracket which is attached to both the Primary Sill Joint and the Upper Trunnion Bridge

Beam with 12 high strength (180 ksi Ultimate Strength) ¼" diameter bolts. The PDA mounted to the ROEU Bracket Assembly is shown in Figures 3.3.1.1.6-1 through 3.3.1.1.6-3.

3.3.1.1.12 AMS-02 Umbilical Mechanism Assembly (UMA)

The passive UMA is used to electrically connect the AMS-02 payload to the ISS truss attach site. The UMA attaches to the lower USS-02, as shown in figure 3.3.1.1.12-1, and interfaces with the active UMA mounted to the ISS PAS site as per SSP-57003.



UMA

Figure 3.3.1.1.12-1 The UMA Mounted to the EVA Connector Panel

3.3.1.2 AMS-02 Experiment Hardware

The AMS-02 Experiment utilizes a large cryogenic superfluid helium (SFHe @ 2° K) superconducting magnet to produce a strong, uniform magnetic field (~ 0.8 Tesla) within the core of the magnet. The experiment has planes of detectors above (TRD, Upper TOF), in the center of (Silicon Tracker, ACC), and below (Lower TOF. RICH, ECAL) the magnet (reference Figure 3.2-1). In addition to the detectors, the experiment has a number of subsystems that interface with the detectors to provide power, collect experiment data, provide precise time and positioning data, and keep the instruments within thermal limits. The following paragraphs provide descriptions of the detectors and subsystems that comprise the experiment hardware.

3.3.1.2.1 AMS-02 Cryogenic Superconducting Magnet (Cryomag)

The Cryogenic Superconducting Magnet, or Cryomagnet, is at the heart of the AMS-02 experiment. Trajectories of incoming particles are bent by the magnetic field. The Silicon tracker detects this trajectory, which allows AMS-02 to identify the magnitude and sign of the particles' electrical charge. The magnet has a bending power of 0.86 Tm^2, which combined with the spatial resolution of the tracker, allows measurements of particles extending into the multi-TeV energy range. The high field strength of the Cryomagnet is possible through the use of superconductors that are chilled by a superfluid helium (SFHe) Cryosystem serving as a 1.8 K heat sink.

Most of the Cryomagnet (Figure 3.3.1.2.1-1) and related special test equipment has been developed and manufactured by Eidgenossische Technische Hochschule (ETH) in Zurich through a sub-contract with Space Cryomagnetics, Limited (SCL) in Culham, England and Hans Bieri Engineering (HBE) in Winterthur, Switzerland. The magnet and its cryosystem are controlled through the Cryomagnet Avionics Box (CAB), which is being developed by Computadoras, Redes e Ingeniería SA (CRISA) in Madrid, Spain. The Vacuum Case (VC) was designed by Lockheed Martin and was built at the Standard Tool and Die Company (STADCO) in Los Angeles. The entire system is currently estimated to weigh 7050 lbs (3198 Kg).

The magnet consists of 14 coils. The primary component of the field is created by the two large dipole coils. The twelve racetrack coils further shape the field, raising the strength within the bore of the magnet to 8600 G while minimizing the stray field external to the VC. The external field has a maximum value of 2000 G at the outer surface of the vacuum case and drops rapidly as distance increases away from the center of the AMS-02. To generate the required field of 8600 G, the AMS-02 magnet will run with a nominal current of 459.5 A. The field in the primary measurement volume and the fringe field will be completely mapped as part of the magnet functional testing.

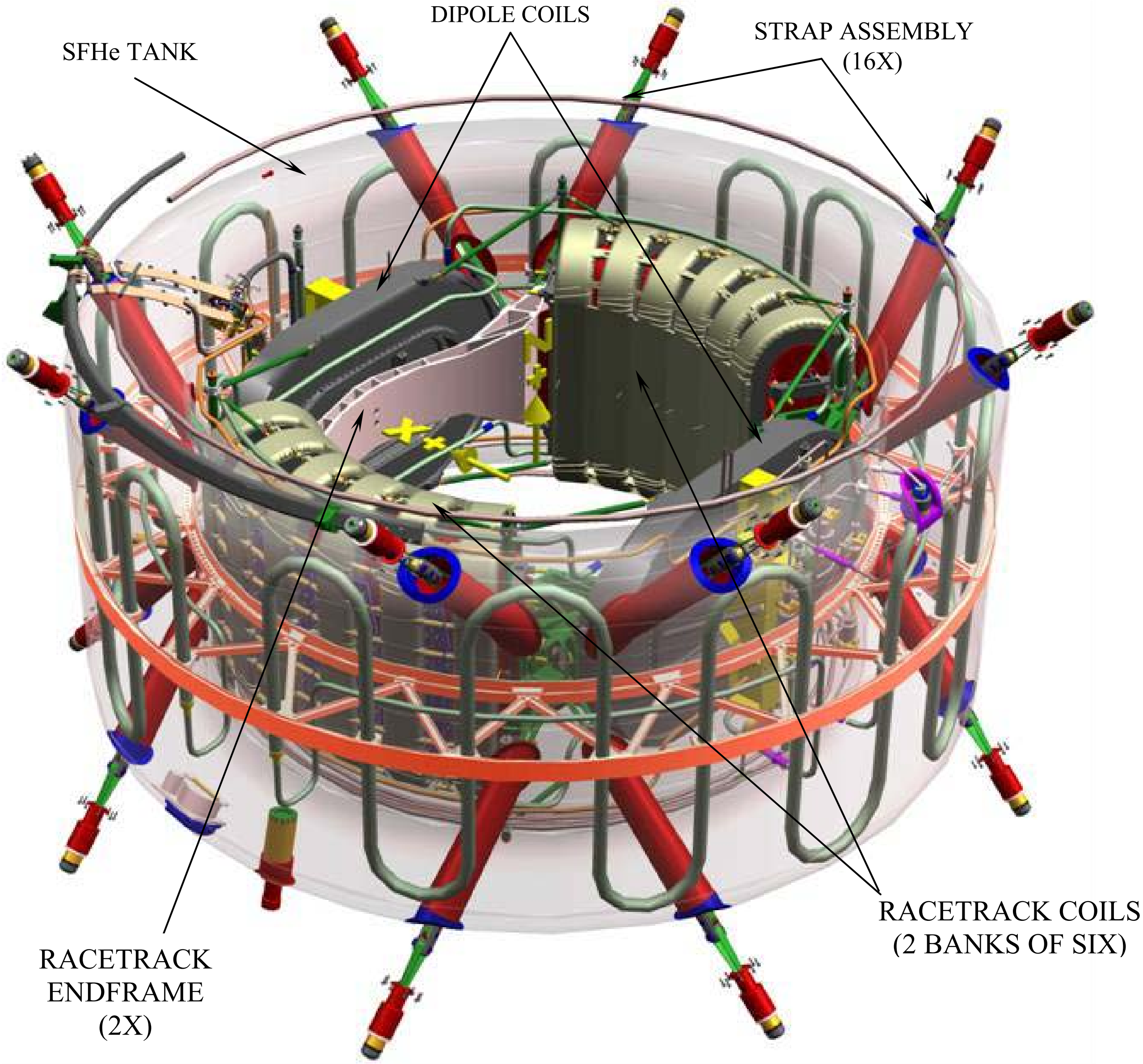


Figure 3.3.1.2.1-1 Cryomagnet, Helium Tank, and Support Straps

Each magnet coil is comprised of superconducting wire wrapped around a structural support made of Al 6061, which keeps the coil in its elliptical shape. The large racetrack end frames are also made of Al 6061, hold the coils in their proper relative positions and resists the magnetic forces generated when the magnet is active. These magnetic forces are on the order of 250 tons and are much larger than any other loads the magnet will see during either flight or ground operations.

The magnet is attached to the Vacuum Case (VC) by sixteen support straps (also shown in Figure 3.3.1.2.1-1). Each strap attaches to one of the VC support rings and a clevis at the corner of the racetrack end frames. The design prevents the high magnetic operational loads from being transmitted back to the rest of the structure and the thermal loads of the rest of the structure from being transmitted to the coils. Figure 3.3.1.2.1-2 shows the basic construction of the strap.

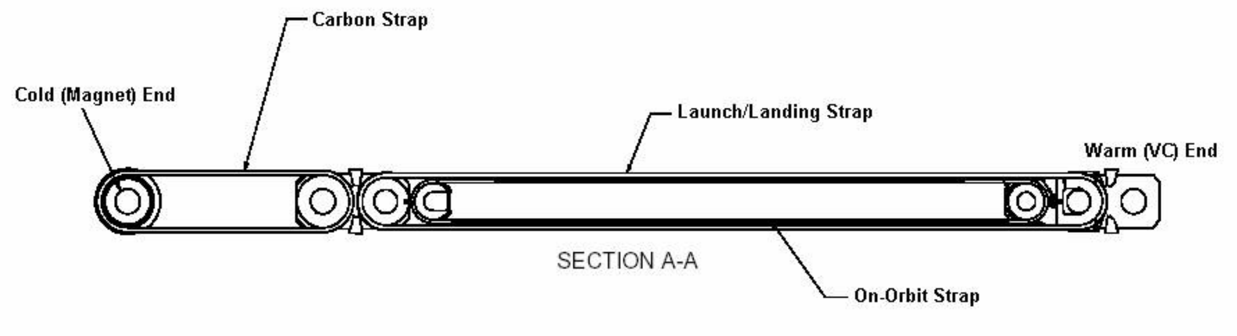


Figure 3.3.1.2.1-2 Support Strap Construction

The warm end of each strap assembly rests on a stack of Belleville washers inside a cylindrical fitting known as the "wineglass." The wineglass is in turn bolted to one of the support rings of the VC. An overall schematic of the fitting is shown in Figure 3.3.1.2.1-3. The Belleville washers are present in order to reduce the stiffness of the overall system and avoid causing long-term assembly stresses in the VC. This low-stiffness response will continue until the washer stack fully flattens and becomes for all practical purposes infinitely rigid.

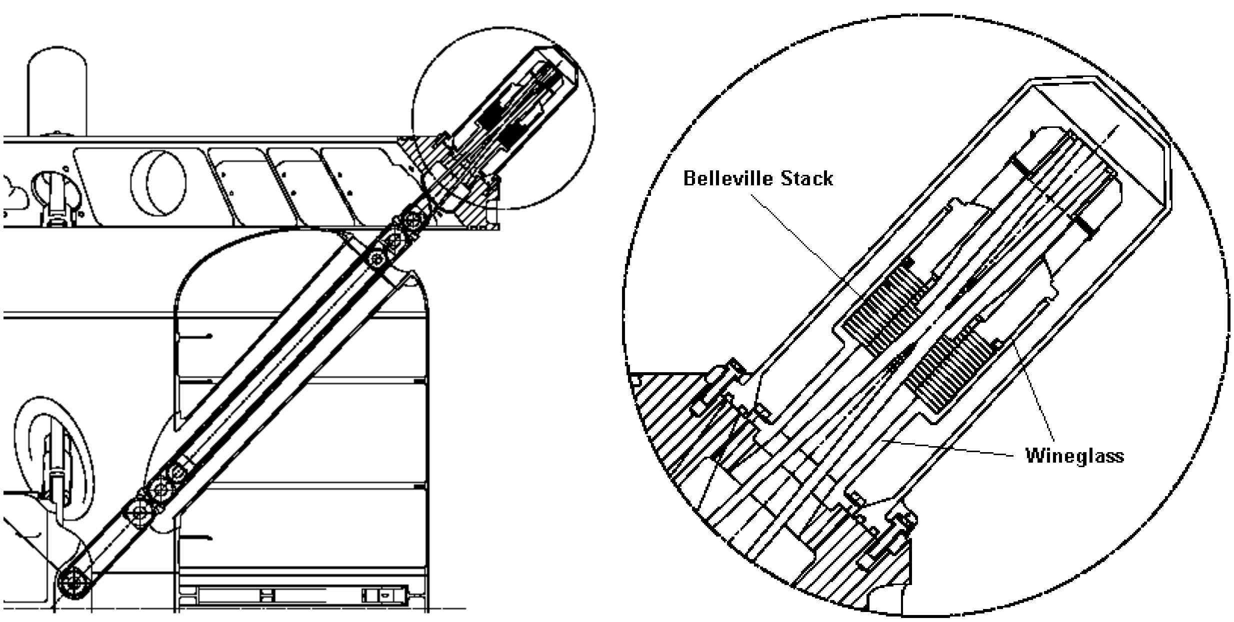


Figure 3.3.1.2.1-3 Wineglass Fitting

The magnet coils must be kept at a temperature of 4 K or less in order to remain super-conductive. Not only must the temperature be maintained for the life of the mission, but the magnet must also be able to be recharged after an on-orbit quench without EVA support. Helium becomes a superfluid when normal liquid helium is cooled below 2.17 K and serves as the cooling medium for the Cryomag.

The AMS-02 cryogenic system schematic is shown in Figure 3.3.1.2.1-4. Heat is removed from the magnet coils through the Superfluid Cooling Loop, which then conducts the heat into the main Helium tank. This tank is at 1.8 K and is the ultimate heat sink for the entire system. As the Helium slowly boils away, vapor is removed from the system and flows through a series of four vapor cooled shields operating between 1.8 K and 60 K which surround the magnet assembly. Small thermal connections run between these shields and the metallic fittings on the support straps to further reduce the heat leak into the main tank from the structural supports. The outermost vapor-cooled shield is thermally attached to four cryocoolers, which further reduce the overall temperature and slow the rate of helium loss.

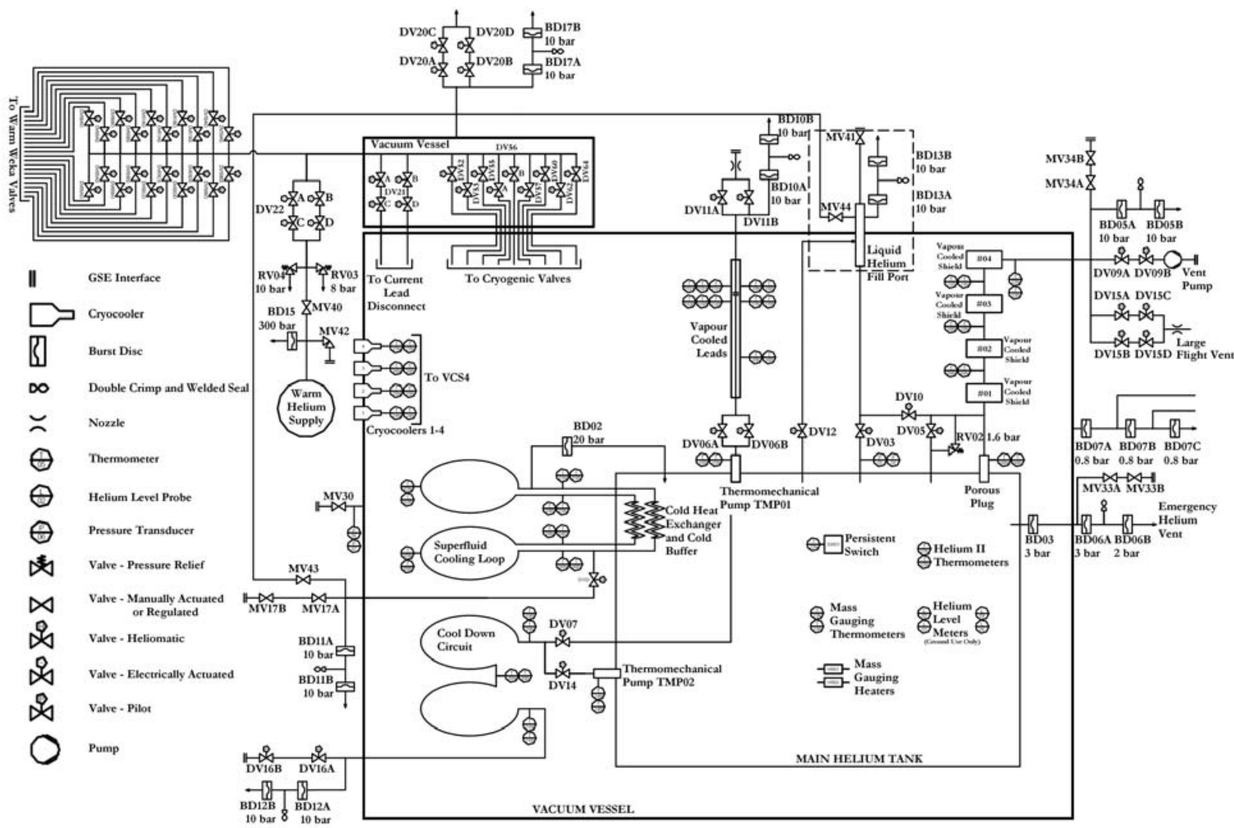


Figure 3.3.1.2.1-4 Cryogenic Cooling System

Each magnet coil has two thermal shunts attached to the Superfluid Cooling Loop, which runs along the top and bottom of the magnet. The loop is a copper pipe filled with superfluid helium at 1 bar pressure. Heat in the coils is conducted through the shunt into the liquid inside the loop. The cooling loop in turn extends into the main Helium Tank where a serpentine heat exchanger dissipates the heat into the superfluid helium. Cooling the magnet by means of a thermal bus and external tank provides AMS-02 the ability to recover from a quench.

The SFHe Tank is a 2500 liter toroidal vessel which contains the cryogen used by AMS-02. The tank consists of a central support ring attached to two rib-stiffened cylinders. The inner cylinder has a radius of 0.96 meters and the outer cylinder has a radius of 1.29 meters. The tank is made up of Al 5083 forgings and all interfaces are welded. The construction technique used to fabricate the tank optimizes the ability of the tank to withstand helium permeation of the aluminum by careful control of the material "grain" orientation.

Sixteen through-tubes are included in the tank to allow the strap assemblies to pass through tank. Structural analysis has shown that these tubes are wide enough to prevent the strap from contacting the side of the tank. The remainder of the ports seen in the figure are thermal and electrical interfaces with components inside the tank or ports designed to support filling and venting operations.

As heat is dissipated into the SFHe Tank, the vapor generated is separated from the liquid by means of a porous plug. This vapor then flows into small tubes inside a series of four Vapor Cooled Shields (VCS). These shields surround the magnet and helium tank assembly and are connected via small thermal shunts to the metallic portions of the support strap assemblies.

The final stage of the magnet thermal control system is four Stirling-cycle cryocoolers which attach to the outermost VCS. Together they remove approximately 12W of heat from the system. This additional temperature drop has been calculated to reduce Helium consumption by a factor of four. After this final cooling stage, the helium gas is allowed to vent to space from a zero-thrust vent aligned with the ISS Y-axis.

3.3.1.2.2 Transition Radiation Detector and associated Gas System (TRD)

The role of the TRD (Figure 3.3.1.2.2-1) is to discriminate between electrons/anti-protons (e^-/p^-) and positrons/protons (e^+/p^+) over the Energy (E) range E = 3 – 300 GeV. This is accomplished by detecting X-ray photons emitted by electrons and positrons when they pass through a radiator. Heavier particles do not emit such radiation. The radiation is detected in tubes filled with Xe and CO_2 gas in an 80:20 ratio. Xenon gas ionizes very easily and is thus very sensitive to the passage of photons.

The TRD detector is composed of 5248 proportional tubes which are made from a multi-layer wound composite structure. The composite includes layers of polyurethane, carbon-polyimide, aluminum, and Kapton. The straw tubes are grouped into 41 separate segments which are connected through gas manifolds. The straws have an inner diameter of 0.24 inch (6.02 mm), a wall thickness of 0.003 inches (72 microns), and vary in length from 31.5 inches (0.8m) to 78.7 inches (2.0m).

A straw module consists of 16 straws glued together with 6 stiffeners running alongside the straws. Every 3.94 inches (10 cm), additional stiffeners are glued across the module for extra rigidity. The straw ends are glued into polycarbonate endpieces. The endpieces contain the wire fixation pieces (wire: gold plated tungsten, 0.001 inch (30 microns) diameter; wire fixation pieces (Cu/Te alloy), the gas distributor, and the gas seal.

The TRD is constructed with 20 layers of the straw modules where a gap of 0.91 inch (23 mm) between the layers is filled with a radiator material (polypropylene fleece). The upper 4 layers (72 modules) and the lower 4 layers (56 modules) are oriented in the X-direction and the 12 middle layers (200 modules) in the Y-direction

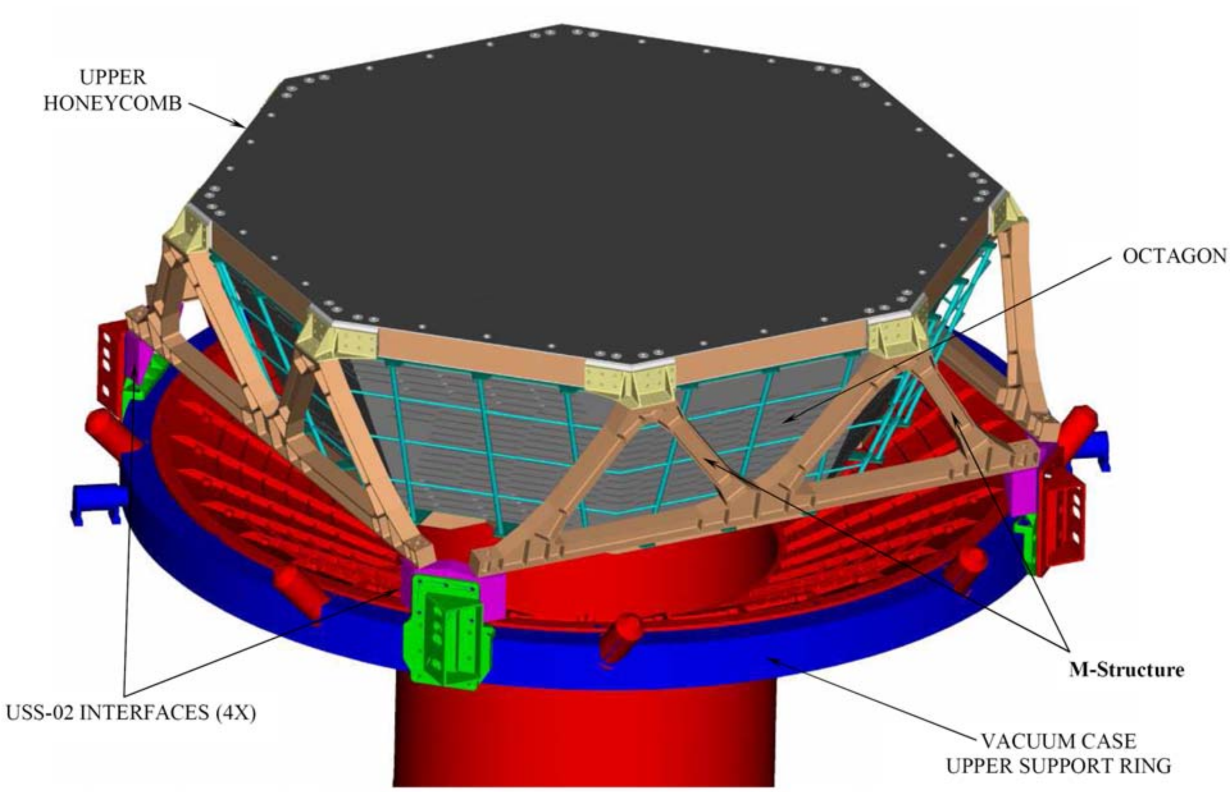


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Figure 3.3.1.2.2-1 – Transition Radiation Detector Structure

The 20 layers of straw modules and radiators are mounted in an octagon structure which consists of 8 honeycomb side panels [1.18 inches (30 mm) thickness], a lower honeycomb support plate, and an upper honeycomb plate. The size of the octagon structure is 91 inches x 24.5 inches (height) (2.3 m x 0.6 m). The combined weight of the TRD is 728 lbs (303.4 Kg). Inside the octagon structure, the straw modules are further supported by 4 bulkheads (0.1 inch (3 mm) thick), 2 in the Y-direction and 2 times 2 smaller ones in the X-direction.

The TRD is located at the top of the experiment stack above the Upper TOF. The Octagon Structure is supported by the M-Structure, which is mounted to the USS-02 at four locations, just above the Vacuum Case interface. The TRD corner joints are hard-mounted to the corner joints on the upper USS-02 (Figure 3.3.4-1).

The front-end readout electronics and the High Voltage (HV) distribution boards are mounted on special boards close to the module end pieces. The gas distribution system is also mounted close to the ends of the modules on the opposite side of the electronics.

The TRD Gas Supply System (Figure 3.3.1.2.2-2) supplies a mixture of 80% Xenon (Xe) and 20% Carbon Dioxide (CO_2) to the straw tube modules. The density and purity of the gas mixture is monitored and adjusted to ensure efficient photon detection. The gas supply system (Box S) includes three tanks, one for the Xe, one for the CO_2, and one mixing tank. These tanks are mounted to a support bracket and covered by shields to protect them from orbital debris.

The Xe tank is a composite over-wrapped stainless steel tank that is designed and built by Arde, Inc. It has a maximum design pressure (MDP) of 3000 psid with a minimum temperature rating of –60°F and a maximum temperature rating of 150°F. The tank was designed with a proof test factor of 1.5 x MDP and a minimum burst factor of 3.1 x MDP. It has an outside diameter of 15.4 inches (390 mm) and a volume of 1680 cubic inches (27.5 liters). It carries 109 lbs (49 Kg) of Xe at launch and has been tested to 8.9 G_{rms} at 0.08 g^2/Hz.

The CO_2 tank is also a composite over-wrapped stainless steel tank designed and built by Arde, Inc. This tank has a maximum design pressure of 3000 psid with a minimum operating temperature of –100°F and a maximum operating temperature of 300°F. The tank is designed with a proof test factor of 1.5 x MDP and a minimum burst factor of 2.125 x MDP. The outside diameter is 12.4 inches (315 mm) and it has a volume of 813 cubic inches (13.3 liters). The tank weighs 9.5 lbs (20.9 kg) and it can hold a maximum of 11 lbs (5.0 kg) of CO_2. A vibration test has been performed to 8.9 G_{rms} at 0.07 g^2/Hz axially and 4.5 G_{rms} at 0.02 g^2/Hz laterally.

The small mixing tank is also manufactured by Arde, Inc. It has a nominal operating pressure of 200 psia, a normal operating temperature of 77°F and an MDP of 300 psid established by dual pressure relief devices and the source gas supply control. A proof test factor of 1.5 x MDP and a minimum burst factor of 4 x MDP will be used. The volume will be 61 cubic inches (1 liter).

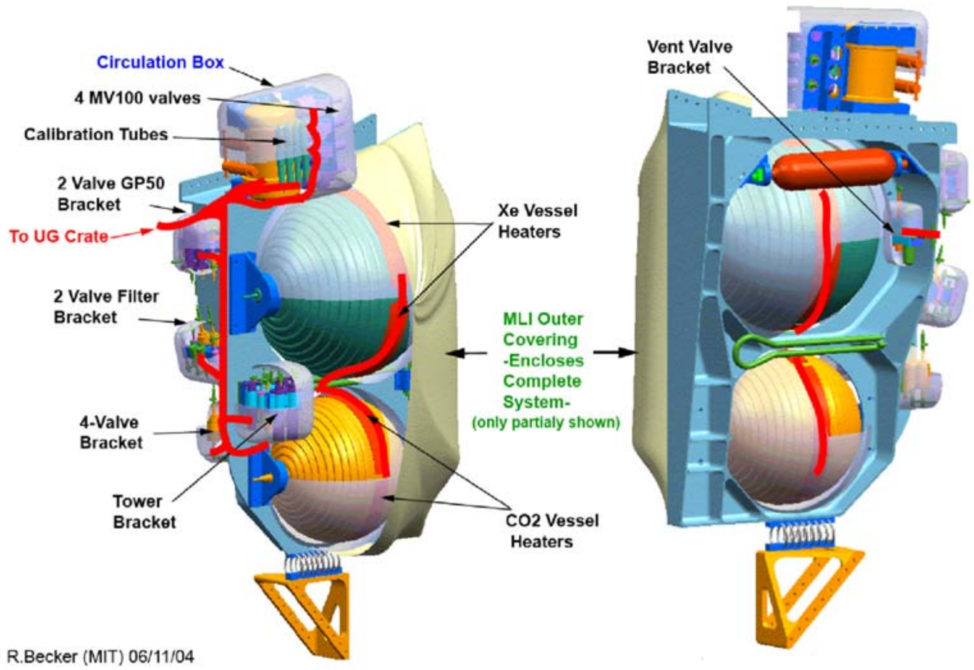

Figure 3.3.1.2.2-2 – TRD Gas Box S (Calibration Tubes represent older design)

The fittings and connections in the gas system include stainless steel tubing, welded joints, and numerous gas manifolds. The stainless steel tubing ranges from 0.06 - 0.25 inch (1.6 - 6 mm) outer diameter. Connections are made with welded joints or metal sealed fitting could be used). The connections between the gas manifolds and the TRD segments are made with 0.04 inch (1 mm) inner diameter stainless steel tubing and metal connectors.

The TRD straw tubes have a maximum design pressure of 29.4 psid. The minimum design temperature is –4°F and maximum design temperature is 95°F. The relief valves will be set to 30 psia. Each of the 41 separate segments contains 244 – 427 in^3 (4 – 7 liters) of gas, for a total gas volume of 8.1 ft^3 (0.23 m^3). The nonflammable gas mixture is circulated through these tubes in a continuous loop. The density and purity of the gas mixture is monitored and corrected.

The 41 TRD segments are connected through manifolds to Box C, containing controls, monitors, and recirculation pumps. Box S provides Box C with pre-mixed gas from the gas supplies in a limited transfer volume (approximately 1 liter). A feed control between Boxes S and C is activated by computer approximately once a day. Mounted inside the Gas Supply System Box C are 4 calibration tubes (Reference Figure 3.3.1.2.2-1), which monitor the gas gain changes of the circulating mixture. The calibration tubes have an inside diameter of 0.24 inch (6 mm) like the straw tubes; however, they are milled inside a stainless steel structure (Figures 3.3.1.2.2-6, 3.3.1.2.2-7). On the inner wall is a 0.2 microCurie deposit of Fe^{55}.

Box C, shown in Figure 3.3.1.2.2-4, contains the two KNF Neuberger UNMP30 pumps for the primary TRD gas circuit. By causing the gas to flow continuously throughout each of the TRD's

41 straw modules, the gas is not able to separate into pockets and uniform properties are ensured. Box C is mounted on the USS-02 just above the main TRD Gas Supply.

From Box C, 3 mm stainless steel gas lines run to the top rim of the TRD, where input and output manifolds are located. The 5248 tubes of the TRD are grouped into 41 separate segments, each separately attached to input and output manifolds (Figure 3.3.4-5). Each manifold is connected to the 41 TRD segments via pressure controlled isolation valves. 0.06 inch (1.6 mm) steel tubing runs from the isolation valves to the segment inputs and outputs, where it is joined to the straws via RWTH Aachen designed special connectors. Where other connections need to be made, Cajon VCR fittings are used.

The isolation system is designed to protect the TRD against gas loss in order to maximize efficiency. Leakage of the Xe/CO_2 gas cannot produce a safety hazard, but can cause the gas supply to be used at a faster rate than anticipated and reduce the operational life of the TRD.

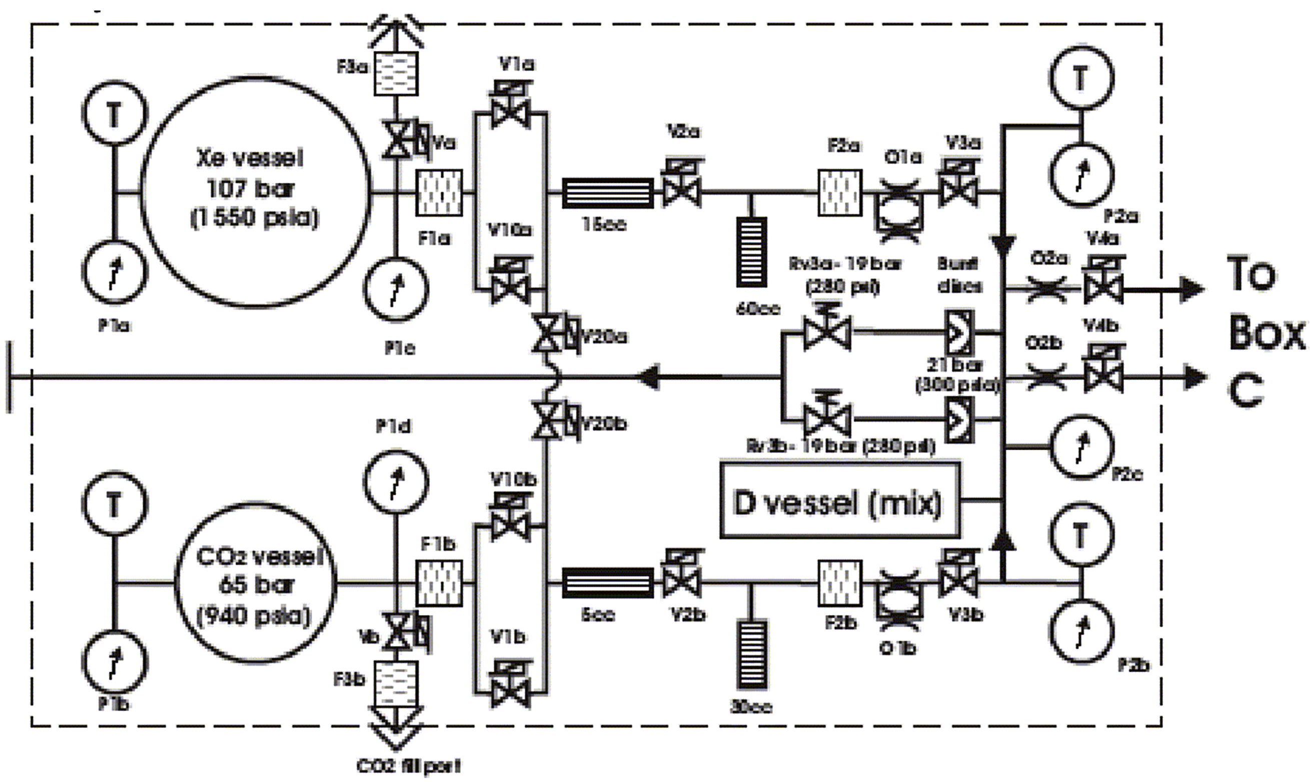

Figure 3.3.1.2.2-3 – Box S Schematic

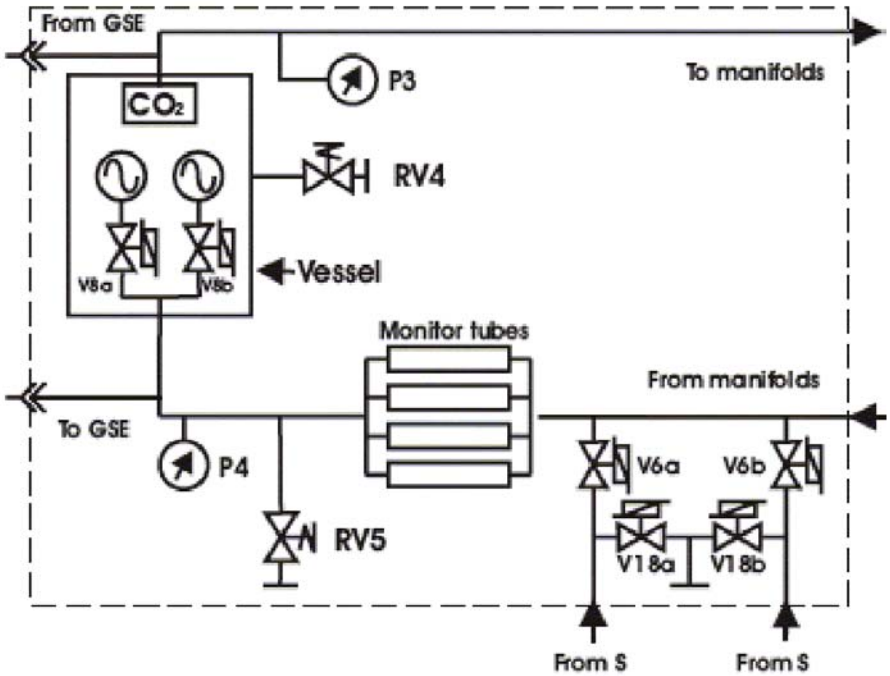

Figure 3.3.1.2.2-4 – Box C Schematic

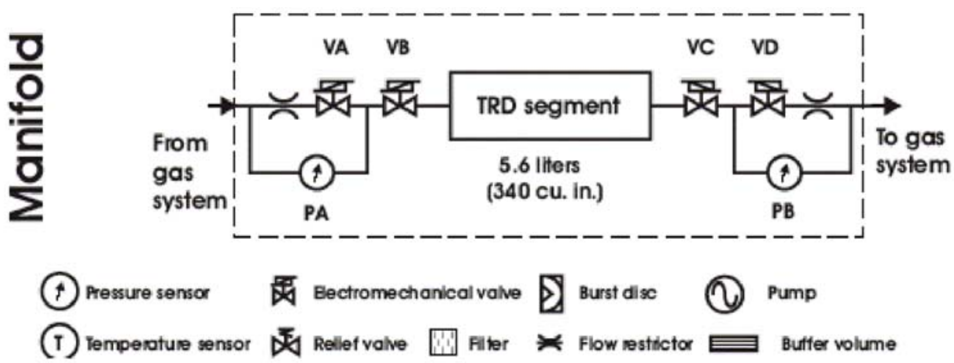

Figure 3.3.1.2.2-5 – TRD Straw Manifold Schematic (Example)

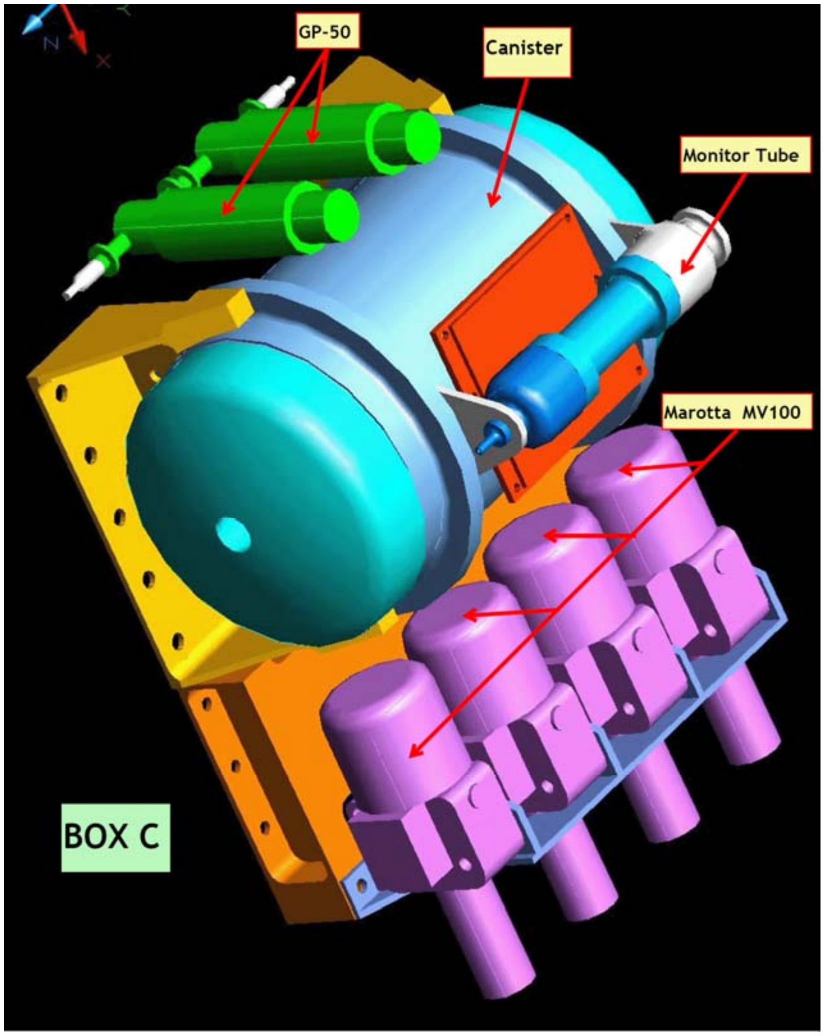

Figure 3.3.1.2.2-6 – Calibration Tube (Radiation Source) Location

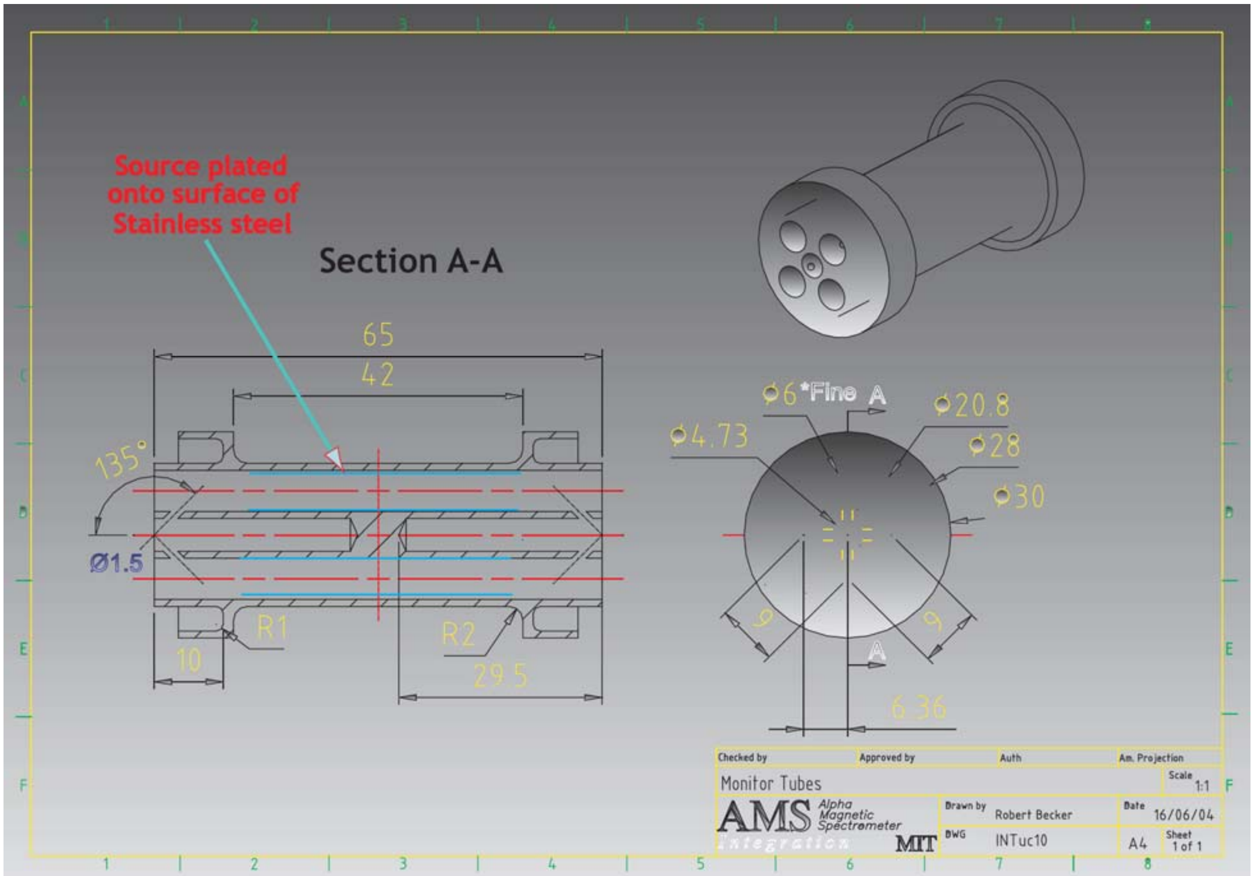

Figure 3.3.1.2.2-7 – Calibration Tube Radiation Source Location

The electronics that control the gas system will be located in the UG-crate. This crate contains a Universal Slow Control Module (USCM) computer that manages the monitoring and control tasks, as well as maintaining communication with the AMS-02 Main DAQ Computer (JMDC). The USCM provides interface electronics to the transducers and actuators scattered throughout the gas system. The USCM and interface electronics perform the following tasks:

1. Close or open emergency isolation valves in the manifolds.
2. Provide housekeeping data (temperature of valves, pressure vessels, etc.)
3. Store calibration constants.
4. Condition and perform analog to digital conversion for over 100 pressure sensors and approximately 500 temperature sensors distributed around the TRD and gas system.
5. Control two recirculation pumps.
6. Provide logic control for approximately 200 gas valves.
7. Provide HV for the calibration tubes in Box C.
8. The interface electronics will provide the power electronics to drive valves, etc.
9. Read out digital signals from the gas analyzer (spirometer) and calibration tube MCA.
10. Have control logic to switch the gas system to “Safe Mode” (for mission success) in case of communication failure.

The USCM, interface electronics, and calibration tubes are doubled to provide single fault tolerance for mission success.

The TRD HV system consists of HV generation cards (UHVG) with six each located in the two U-crates controlled by the crate interface cards (JINF). Each UHVG card drives seven HV lines with twofold internal redundancy to provide single fault tolerance for mission success. Each line is connected via shielded HV cabling to a HV distribution board (UHVD) mounted on the octagon in the vicinity of the readout cards to distribute the HV to four modules (64 tubes). Each unit provides +1600V (control range: 700-1750V) with current limited to <100 microamps.

3.3.1.2.3 Time-of-Flight (TOF) Scintillator Assemblies

The TOF serves to a) be a fast trigger to the experiment for traversal of a particle across the bore of Cryomagnet and Silicon Tracker, b) measure the particles traversing the detector to a resolution sufficient to distinguish between upward and downward traveling particles and c) measure the absolute charge of the particle. Particles that pass through the scintillators generate photons as they pass through the counter paddles, these events detected by groups of two or three sensitive photomultiplier tubes (PMT) on either end of the detector element, the counter paddles. The TOF is composed of four planes of detectors, two atop the AMS tracker, two below as shown in Figure 3.3.1.2.3-1. Numbered from the top down, detector assemblies 1, 2 and 4 have eight detector paddles per plane and detector assembly 3 has ten. The pairs of detector assemblies are oriented 90° to each other, shown in Figure 3.3.1.2.3-2. This configuration gives a 12 x 12 cm2 resolution for triggering particle events over the 1.2 m^2 area the TOF covers.

Each individual detector paddle is made of polyvinyl toluene (a Plexiglas-like material) that is 12 cm wide and 10 mm thick. End paddles of each layer are trapezoidal with a width of 18.5 to 26.9 cm. Each detector paddle is wrapped in aluminized Mylar and enclosed in a cover made of carbon fiber and includes a depressurization pipe to allow for pressure equalization. In the center of each detector is an LED that is used for calibration and testing. At the ends of each panel are light guides which direct the light of scintillation to photo multipliers. These light guides are curved to orient the photomultiplier tubes within the AMS-02 magnetic field for minimum impact to photomultiplier operations.

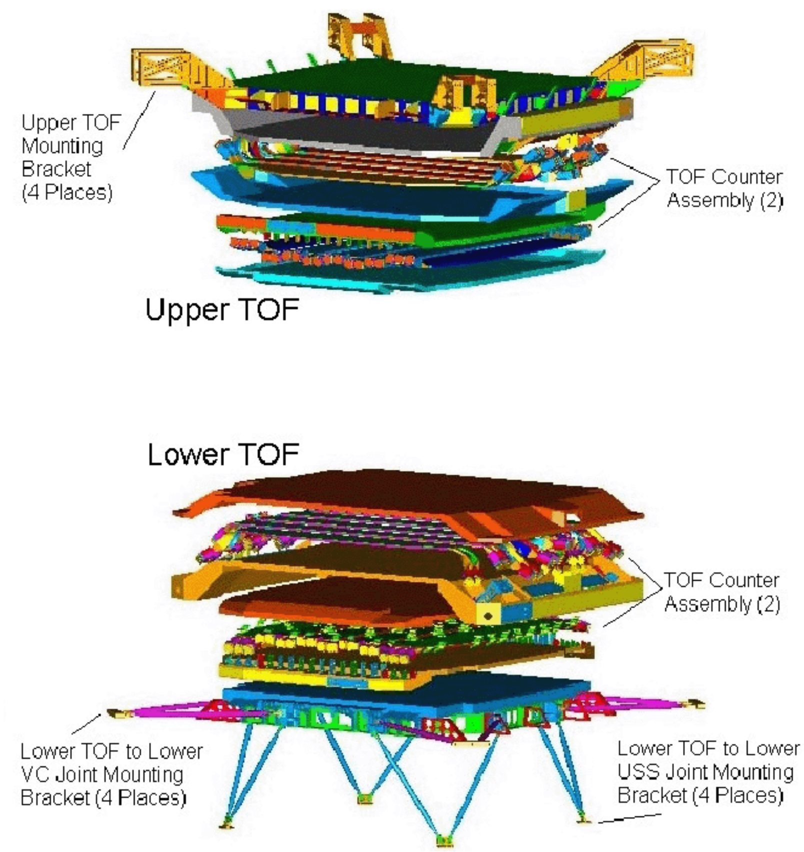

Figure 3.3.1.2.3-1 Time of Flight Counter Construction

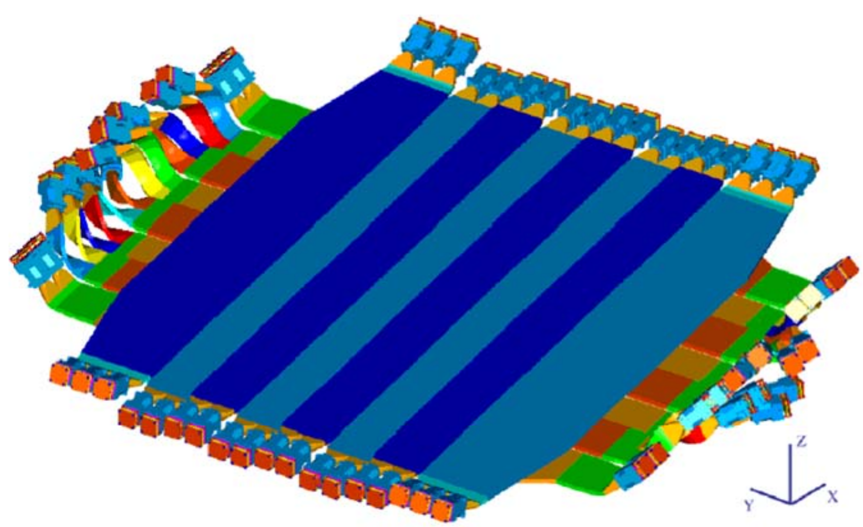

Figure 3.3.1.2.3-2 TOF Detector Paddles Orientation

The TOF is instrumented with 144 Hamamatsu R5946 photomultipliers, used to detect the scintillating light. The PMT operated with a 700-750 Vdc voltage that is supplied by the SHV Crates. The output from the PMTs on each end of the TOF detectors are summed to provide the necessary triggering signal that is provided to the four S Crates for data processing.

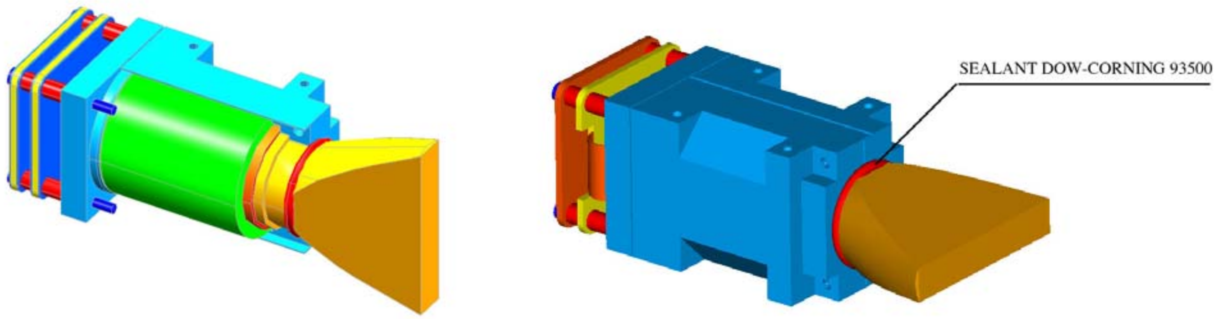

Figure 3.3.1.2.3-3 TOF PMT Construction

The Hamamatsu R5946 PMT is within a PMT housing, shown in Figure 3.3.1.2.3-3.

The PMTs are mounted to the TOF structure at orientations that minimize the impact of the magnetic fields on the PMT operations. Light guides have complex curves to orient the light from the paddles into the carefully oriented PMTs.

Two large flat aluminum honeycomb panels are used to support the scintillator counters. The upper TOF attaches via brackets to the TRD corner joints which hard-mount to the USS-02 upper corner joints. The lower TOF honeycomb is supported to the lower USS-02. The honeycomb panels are roughly circular with a 60.6 inches (1540 mm) equivalent outside diameter. The thickness of the honeycomb aluminum core is 1.97 inches (50 mm) and the aluminum skin is 0.04 inch (1 mm) thick. Figure 3.3.1.2.3-4 shows the mounting of the TOF Upper and Lower units.

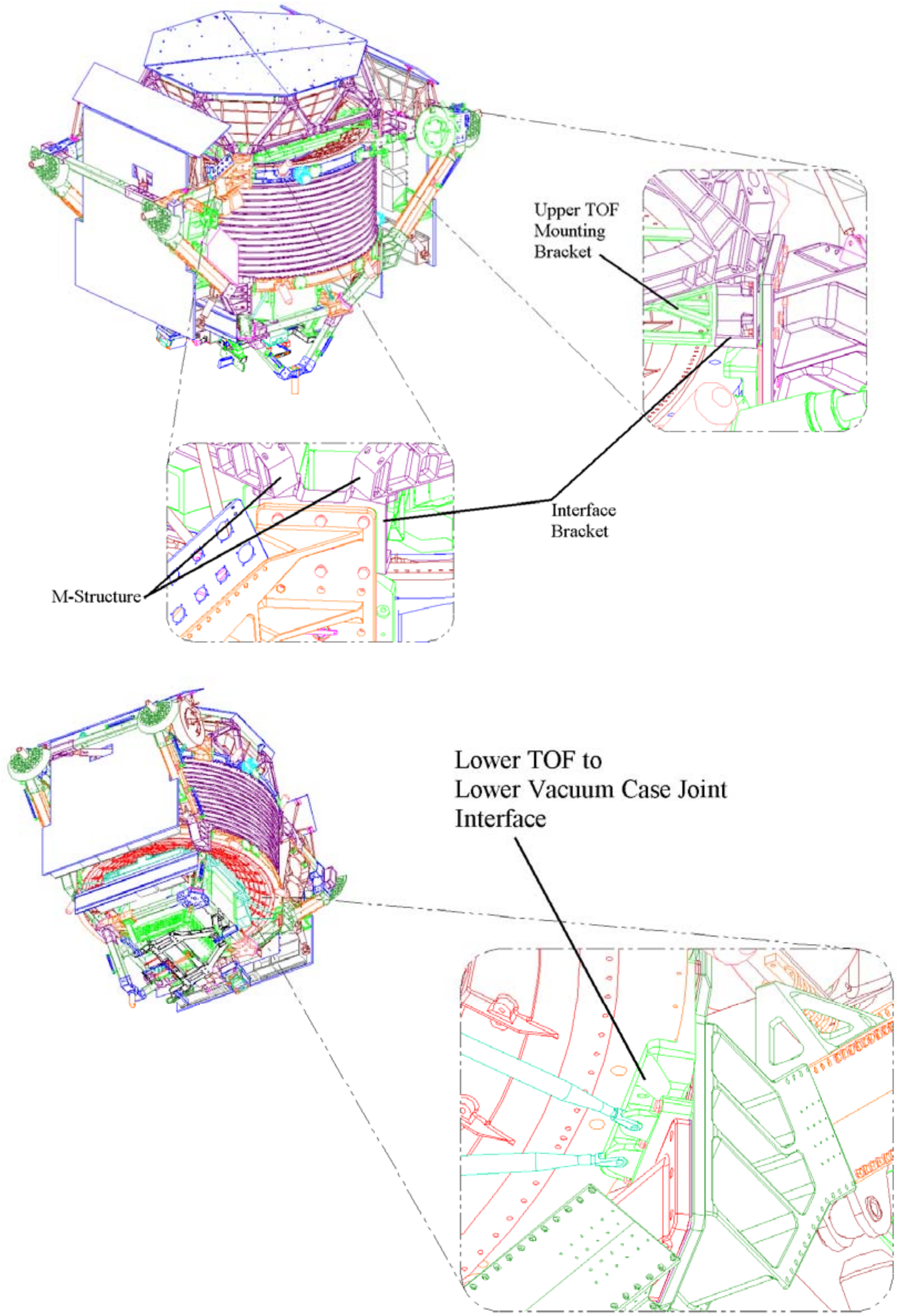

Figure 3.3.1.2.3-4 Structural Interfaces for the Upper & Lower TOF