Aquarius Main Structure Configuration

Alexander Eremenko
Jet Propulsion Laboratory, California Institute of Technology / NASA
4800 Oak Grove Drive, M/S 303-422, Pasadena, CA 91109-8099
+1 818 354-1070
Alexander.E.Eremenko@jpl.nasa.gov

Abstract – **The Aquarius/SAC-D Observatory is a joint US-Argentine mission to map the salinity at the ocean surface. This information is critical to improving our understanding of two major components of Earth's climate system - the water cycle and ocean circulation. By measuring ocean salinity from space, the Aquarius/SAC-D Mission will provide new insights into how the massive natural exchange of freshwater between the ocean, atmosphere and sea ice influences ocean circulation, weather and climate.**

Aquarius is the primary instrument on the SAC-D spacecraft. It consists of a Passive Microwave Radiometer to detect the surface emission that is used to obtain salinity and an Active Scatterometer to measure the ocean waves that affect the precision of the salinity measurement.

The Aquarius Primary Structure houses instrument electronics, feed assemblies, and supports a deployable boom with a 2.5 m Reflector, and provides the structural interface to the SAC-D Spacecraft.

The key challenge for the Aquarius main structure configuration is to satisfy the needs of component accommodations, ensuring that the instrument can meet all operational, pointing, environmental, and launch vehicle requirements. This paper describes the evolution of the Aquarius main structure configuration, the challenges of balancing the conflicting requirements, and the major configuration driving decisions and compromises.[1]

TABLE OF CONTENTS

1. INTRODUCTION

The Aquarius/SAC-D (Satelite de Aplicaciones Cientificas) Observatory, collaboration between NASA and Argentina's space agency, Comision Nacional de Actividades Espaciales (CONAE), launched from Vandenberg Air Force Base on June 10th, 2011 aboard a Delta II Launch Vehicle. Aquarius/SAC-D Spacecraft inside Delta II Fairing is shown on Figure 1. Aquarius Instrument will make global space observations of the salinity, or concentration of salt, at the ocean surface. The Aquarius science goals are to observe and model the processes that relate salinity variations to climatic changes in the global cycling of water and to understand how these variations influence the general ocean circulation. By measuring salinity globally and synoptically every month for 3 years, Aquarius will provide an unprecedented new view of the ocean's role in climate. The Aquarius investigation will address these processes on the seasonal cycle as a basis for understanding interannual climate variations.

Figure 1. Aquarius/SAC-D inside Delta II Fairing

The Aquarius science instruments include a set of three identical radiometers that are sensitive to salinity (1.413

---

[1] This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

978-1-4577-0557-1/12/$26.00

GHz; L-band) and a scatterometer that corrects for the ocean's surface roughness. The radiometers and scatterometer share a common antenna system, which includes a 2.6 m reflector and three RF feeds. Aquarius is mounted on the top of the SAC/D spacecraft platform, and is shielded from direct Sun illumination by a sunshade. An artist's concept of the Aquarius/SAC-D spacecraft is shown in Figure 2.

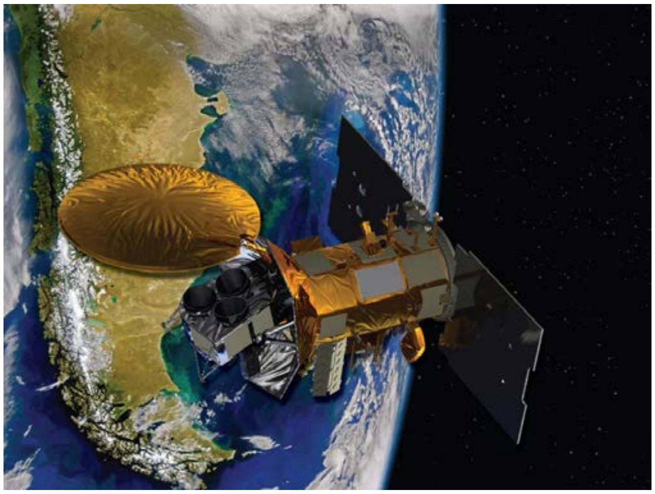

Figure 2. Aquarius/SAC-D Spacecraft artist's concept

Commissioning of the Aquarius Instrument was completed and regular data collection began on August 24, 2011. The first global map of the oceans salinity was completed on September 11, 2011 and shown in Figure 3.[2]

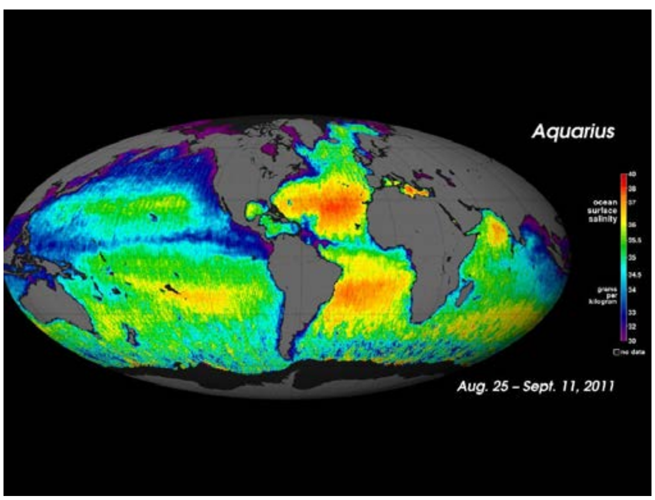

Figure 3. First Aquarius ocean salinity map.

2. AQUARIUS INSTRUMENT CONFIGURATION EVOLUTION

From the earliest stages of development, the Aquarius instrument was planned to be mounted on top of the spacecraft bus. This configuration was driven by the launch vehicle (LV) fairing geometry. This approach also simplified the mechanical interface, integration, and testing between the instrument and spacecraft bus.

The initial Aquarius design was based on a composite frame main structure and a single-point hinged reflector with one launch restraint point. This configuration is shown in Figure 4.

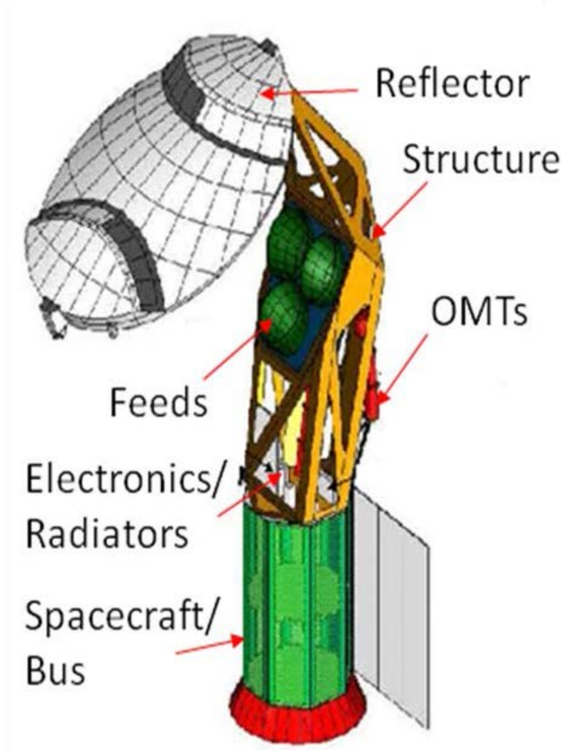

Figure 4. Initial Study/Proposal Aquarius Instrument Configuration

Subsequent pre-phase A studies led to major configuration changes. The reflector size was significantly increased, driving reflector design, deployment schematics, and main structure design. The reflector dish was composed of three components – a center section and two deployable flaps. Reflector deployment required a deployable boom. Multiple restraint points were required to keep the reflector in its stowed configuration. A sunshade was added to minimize Earth radiation effects to the most sensitive instrument components. The main structure design was adapted to support the reflector, boom, feeds, electronics boxes, and sunshade. The pre-phase A Aquarius configuration is shown in Figure 5. This preliminary configuration significantly improved instrument performance, but made the mechanical configuration more complicated, having added a large number of mechanisms, which increased instrument cost. The baseline plan was to utilize composite materials for the reflector, a truss structure deployable boom, and the main instrument structure. The large reflector size drove tighter alignment requirements as well.

The aforementioned complications, especially the projected cost increase, lead to additional major configuration trades and the final Aquarius configuration concept. Reflector size was reduced in order to eliminate deployable flaps, the

[2]http://www.nasa.gov/mission_pages/aquarius/main/index.html

deployable truss boom was replaced by a single boom design, the number of required mechanisms and restraints was reduced, and the composite instrument main structure was replaced by a more cost-effective metallic structure. Sunshade size was increased to provide better protection for sensitive instrument components. The instrument was mounted to the spacecraft bus by a set of three bipods. This revised Aquarius configuration becomes the Project baseline for PDR, with very minor changes and adjustments thereafter.

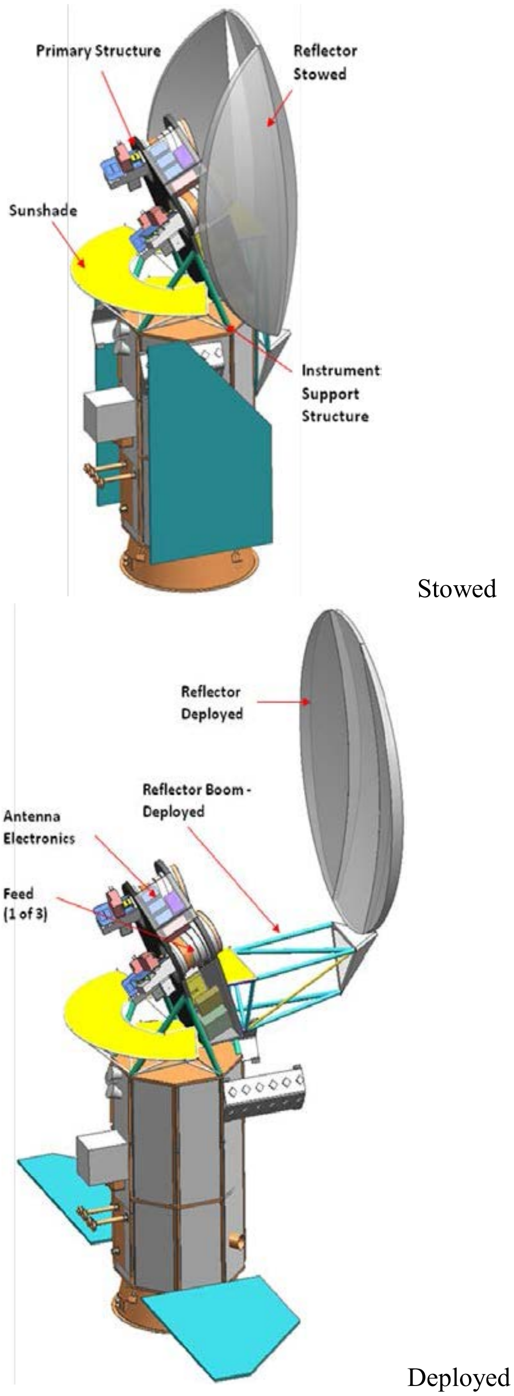

Figure 5. Pre Phase A Aquarius/SAC-D stowed and deployed Configurations

The Aquarius Instrument stowed and deployed final configurations as shown in Figure 6, are the result of a balanced compromise between instrument performance parameters, cost, complexity, functional and implementation risks, and interface to the SAC-D service platform.

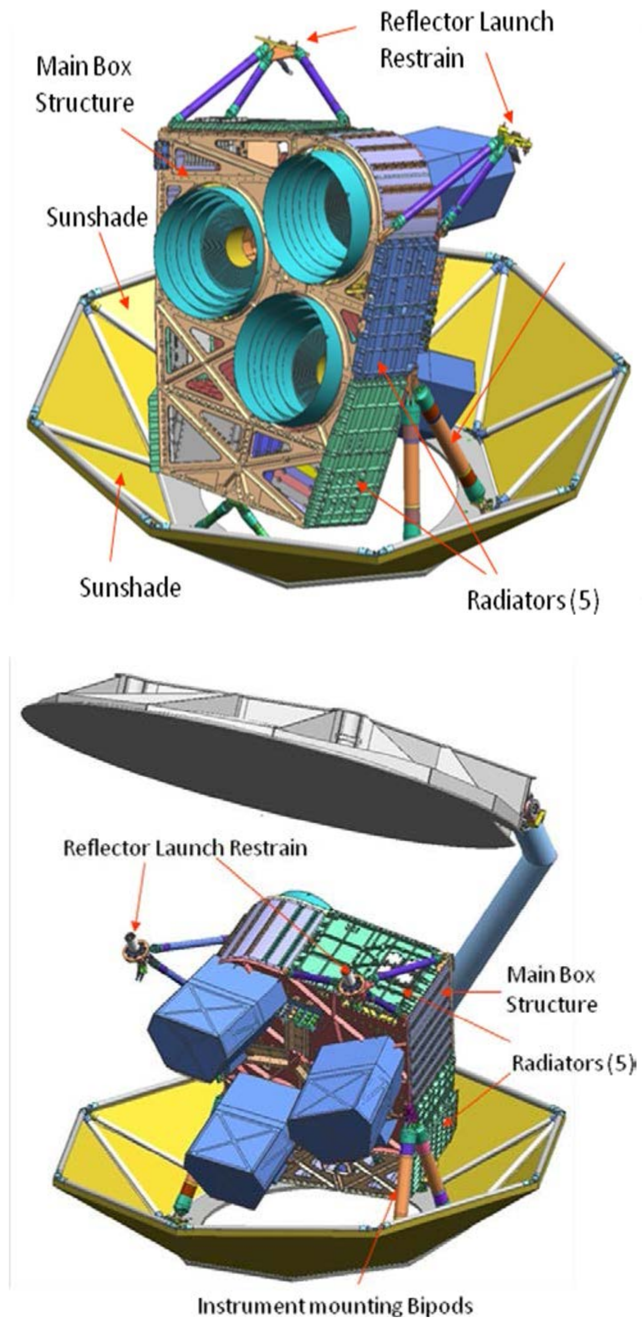

Figure 6. Aquarius final Configuration

The Aquarius/SAC-D Spacecraft on orbit operational final configuration is shown in Figure 7, and the stowed Aquarius/SAC-D Spacecraft accommodation inside the Delta II LV Fairing is shown in Figure 8, respectively.

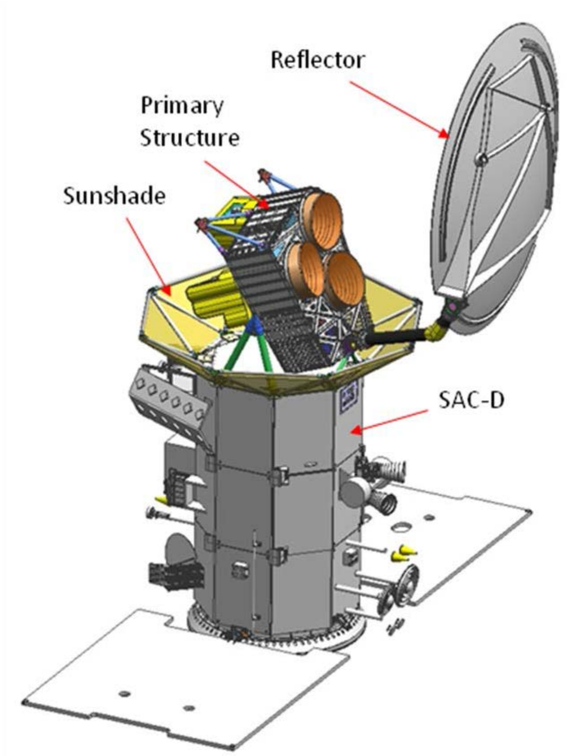

Figure 7. Aquarius/SAC-D Spacecraft final Configuration

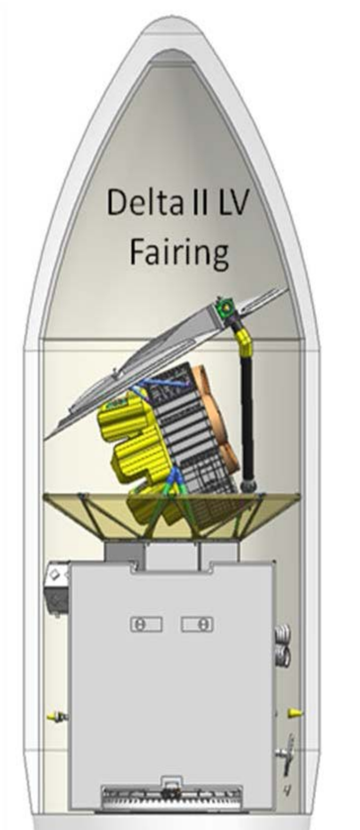

Figure 8. Aquarius/SAC-D Spacecraft accommodation inside of the Delta II LV Fairing

3. Aquarius Main Structure Primary Requirements

The Aquarius main structure requirements came from three major sources – Launch Vehicle, SAC-D service platform, and instrument accommodations. More specifically, this included the need to:

- accommodate three feeds, the reflector boom, several instrument electronics boxes, the reflector launch restraint, and thermal and cabling hardware;
- comply with instrument antenna system pointing, alignment and FOV requirements;
- interface with the SAC-D Service Platform, including the provision for enough clearance and access for cables running from the instrument to the SAC-D Service Platform, and between electronics boxes, separation devices, and thermal hardware;
- satisfy instrument first-mode frequency requirements;
- provide required radiator areas for radiometer electronics boxes, scatterometer electronics boxes, control and data handling, power control electronics boxes;
- provide radiometer, scatterometer electronics boxes radiator, and instrument cabling thermal isolation from the main structure.

One of the key and driving main structure requirements was instrument alignment requirements between the RF feeds and the deployable boom, and between the instrument and SAC-D service platform. The range of tolerance was from +/- 0.1 mm (0.005’’) to +/- 0.25 mm (0.010’’).

The set of the typical requirements includes requirements to accommodate GSE handling and lifting points, accessibility for electronics boxes, cabling, and thermal hardware installation.

4. Aquarius Main Structure and Sunshade Design Overview

The Aquarius primary structure accommodates radiometer and scatterometer electronics, 3x feed assemblies, the deployable boom with 2.5m Reflector, and provides structural interface to the SAC-D Spacecraft / Service Platform.

The Aquarius mechanical structure includes front and back main panels, five side panels/radiators, close-out panels, and internal structural components forming a “Cage” or “box” shaped structure. All Aquarius components, including the reflector/boom subassembly, feed horns, feed isolators, ortho-mode transducers (OMTs), instrument electronics boxes, and thermal control hardware are mounted on the two main panels or side panel/radiators. The “box” is kinematically attached to the spacecraft bus (SAC-D service platform) by three bipods. The reflector is attached to the main structure by the reflector launch restraint (in the stowed configuration). The OMTs interface to the feed horns through titanium thermal isolators. Feeds are mounted to the real Main Panel. Most of the 0.1C thermal stability instrument components (diplexers, couplers and noise diodes, radiometer front ends) are mounted on the OMTs with individual thermal radiators for each radiometer front end. The scatterometer front end, back end and radiometer back end boxes are mounted directly to the dedicated thermal panel/radiator, and isolated from the main structure by fiberglass thermal isolators. Both feed radiators and scatterometer/radiometer radiators utilize active closed-loop thermal control in order to achieve their required thermal stability (ranging from 0.1C to 2C). The rest of the instrument components are mounted inside the "Cage" structure. The configuration of the Aquarius main structure with bipods and reflector launch restraint is shown in Figure 9.

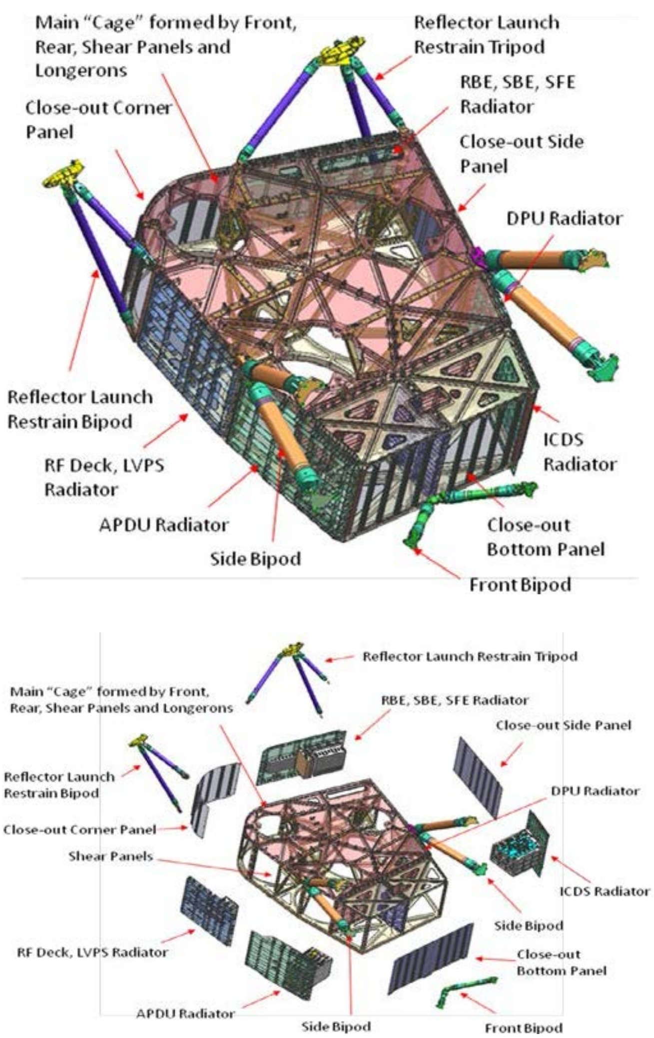

Figure 9. Aquarius Main Structure with Bipods and Reflector Launch Restrain

The main structure "Cage" is formed by front and rear 38.1 mm (1.5'') hogged-out aluminum panels, five 25.4 mm (1'') hogged-out aluminum radiators, three close-out 1.0 mm (0.040'') aluminum sheet metal panels with U-shape stiffeners, aluminum hogged-out shear panels, "L" OR "T" shape aluminum hogged-out longerons/beams. Cabling brackets and a cabling tray are mounted to the cage and isolated from cage structure by fiberglass isolators. The radiators/panels are painted on their outside with white paint in order to provide required thermal properties. Two removable access panels provide access to APDU and ICDS electronics boxes without removing or de-mating cabling from APDU and ICDS boxes. An all-aluminum instrument main structure provides the required thermal and structural properties for instrument component accommodations, fabrication/assembly/test friendliness, conventional fabrication/assembly processes, and cost effectiveness.

The cage structure with removed panels/radiators is shown in Figure 10.

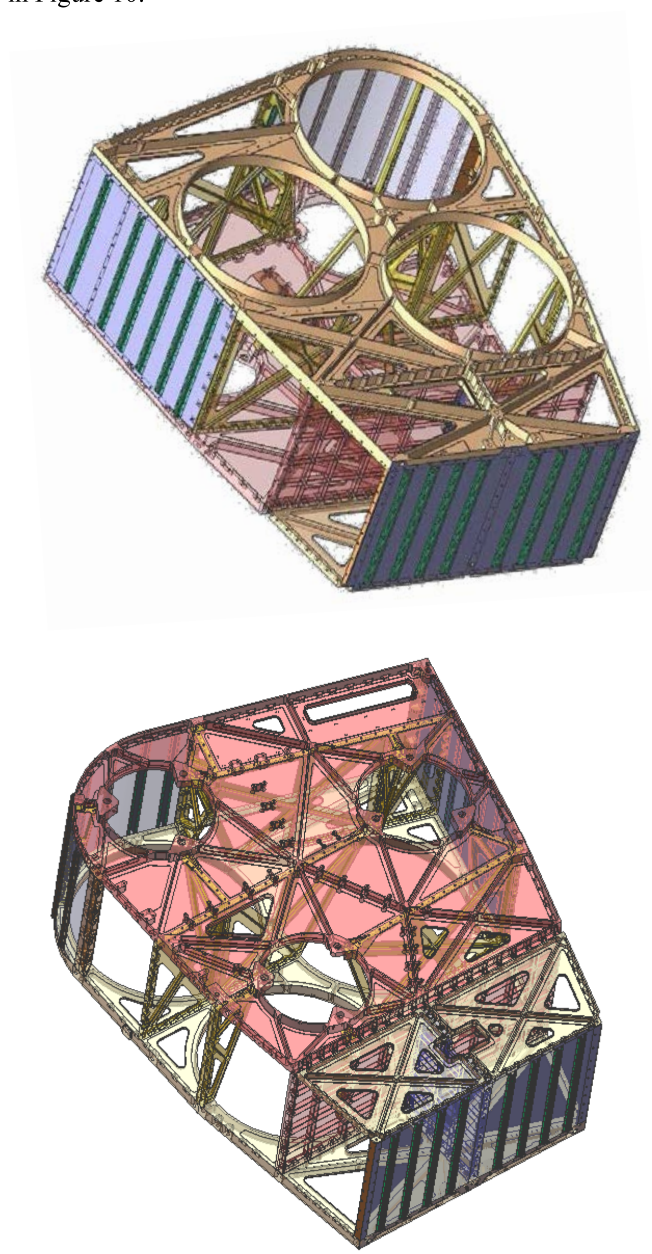

Figure 10. Cage structure with removed Panels/Radiators

Three bipods mount the instrument to the SAC-D service platform (Figure 11). Composite bipod struts provide the required combination of instrument structural stiffness and thermal isolation between the Aquarius main structure and

SAC-D service platform. Non-moment-carrying interfaces are based on spherical bearings and a compensated CTE difference between the composite bipod struts and aluminum SAC-D service platform top deck. Titanium clevis end fittings reduce thermal stresses between the composite tubes and end fittings.

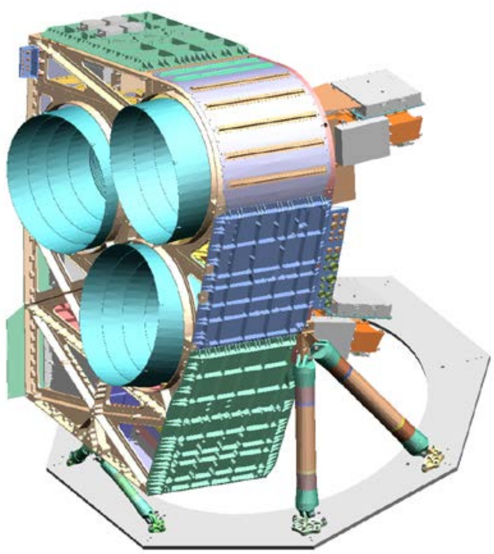

Figure 11. Three Bipods Instrument interface to SAC-D Service Platform

The front bipod and two side bipods are shown in Figure 12.

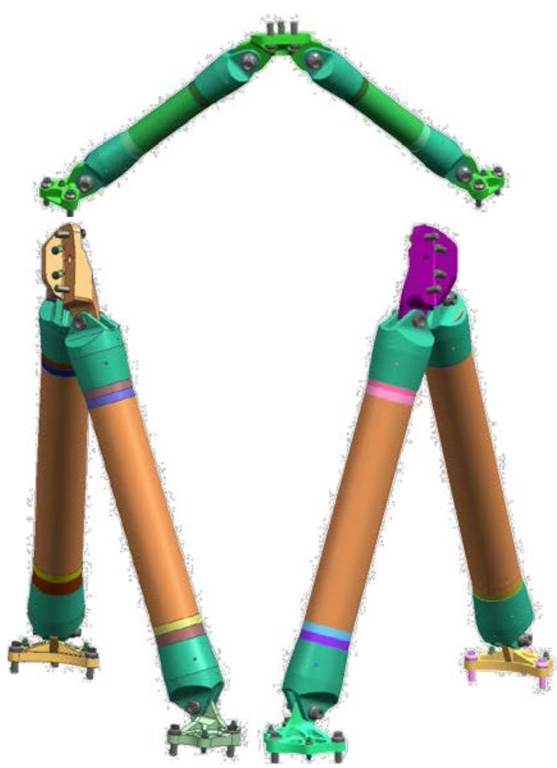

Figure 12. Front Bipod and two Side Bipods

The reflector launch restraint provides the required structural support to the reflector in the launch (stowed) configuration. The instrument stowed configuration with reflector launch restraint supporting the reflector is shown in Figure 13.

The reflector launch restraint includes the reflector restraint bipod and tripod. Both bipod and tripod utilize composite struts with titanium end fittings. Due to thermally-induced loads, the reflector restraint design includes both non-moment carrying (via spherical bearings) and moment carrying attachments to the main structure and top end fittings / SEP hardware supports.

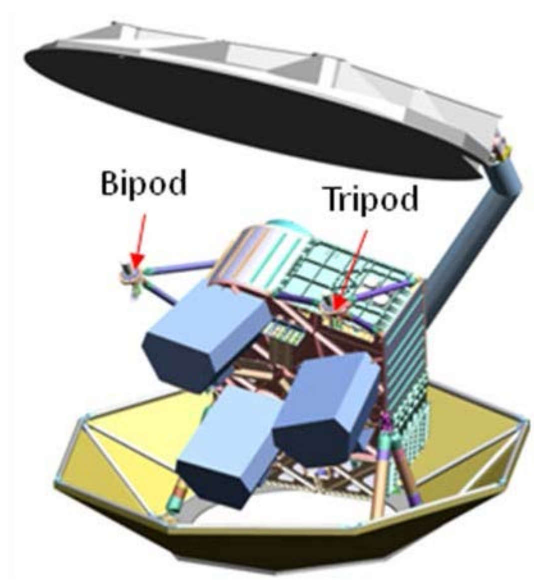

Figure 13. Reflector in stowed configuration supported by Reflector Launch Restraint.

Flexures are used to support the bipod after reflector deployment. Shear Bushings are used to take shear loads at main structure interfaces. The reflector restraint bipod and tripod are shown in Figure 14.

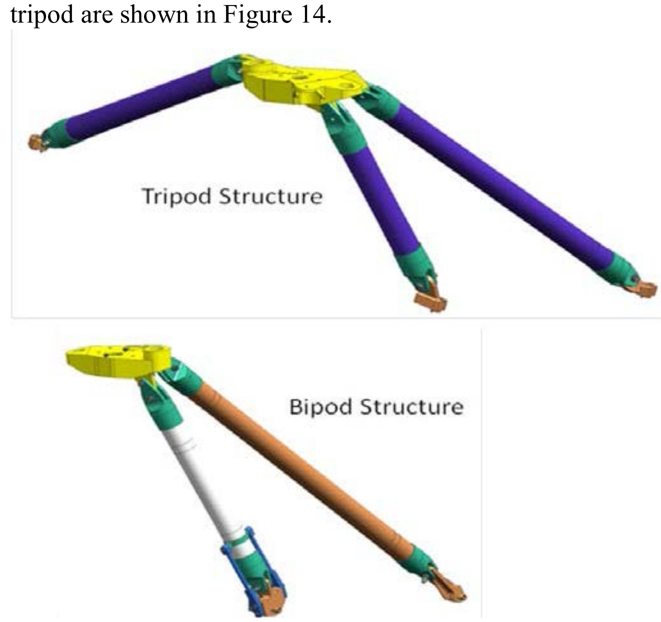

Figure 14. Reflector Launch Restraint Bipod and Tripod

The sunshade is designed to shade/isolate the instrument from direct solar radiation (Figure 15). The sunshade structure utilizes an all-aluminum tubular structure with a MLI "tent". The sunshade structure is attached to the SAC-D service platform in 8 places through fiberglass thermal isolators. The MLI "tent" has removable sections to support spacecraft lifting operations.

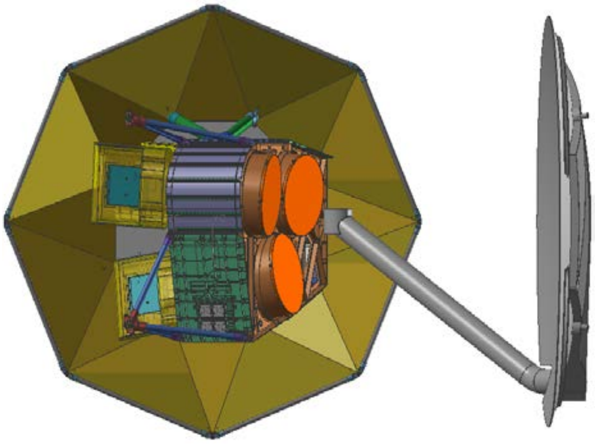

Figure 15. Observatory FOV and stay-out-zones requirements

The sunshade is designed to be split into two halves for transportation, and does not require any special jig or tooling for assembly/disassembly. Sunshade frame design details are shown in Figure 16.

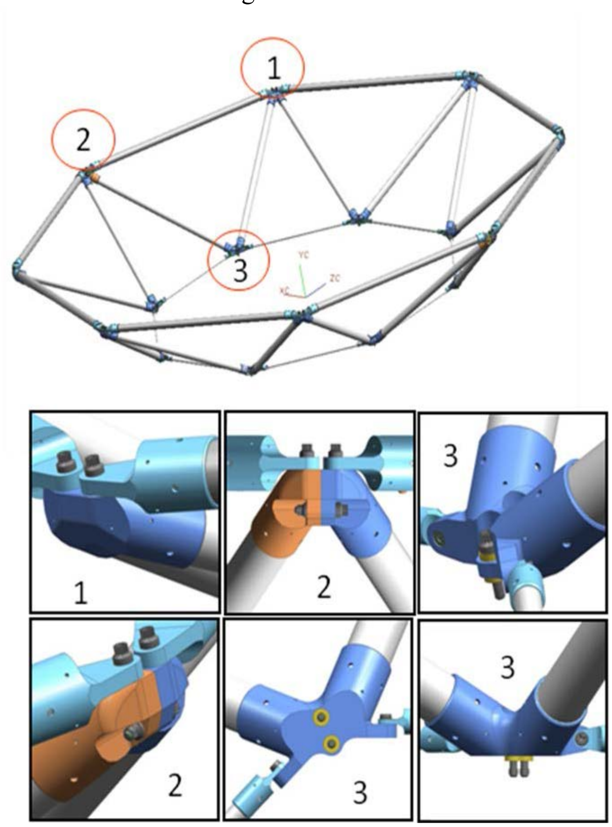

Figure 16. Sunshade frame design

5. AQUARIUS MAIN STRUCTURE AND SUNSHADE FABRICATION AND ASSEMBLY

The main structure components were machined aluminum, aluminum sheet metal, and fiberglass machined parts. Fabrication required standard CNC machining processes and tolerances with intermediate thermal stress relief steps for large machined parts – front and back cage panels. The cage was assembled on a granite table without the use of any special assembly jigs or tools. Figures 17-19 show the cage assembly progress.

Figure 17. Cage initial assembly steps

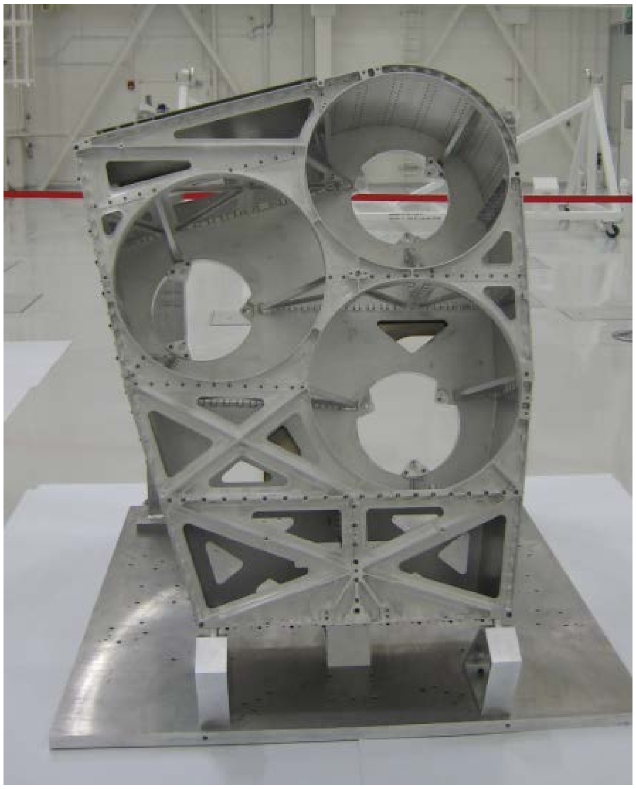

Figure 18. Cage is fully assembled

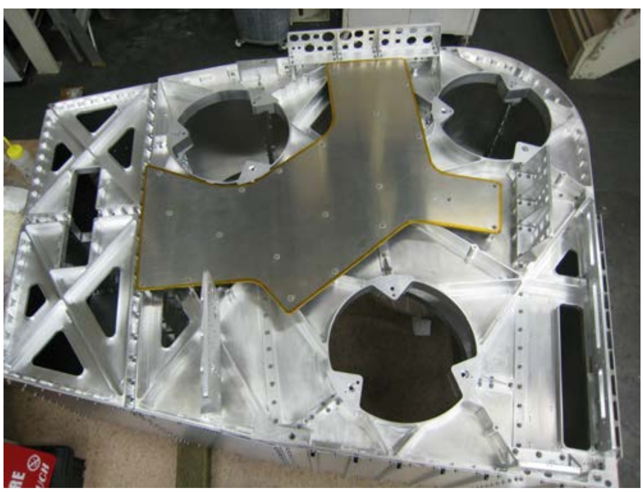

Figure 19. Cabling Tray is mounted to the Cage

After initial cage assembly, the radiators/panels were replaced by GSE panels while the radiators/panels were painted. GSE protective covers were subsequently used during instrument integration in order to protect the painted surfaces.
Cage assembly process is shown on Figure 20.

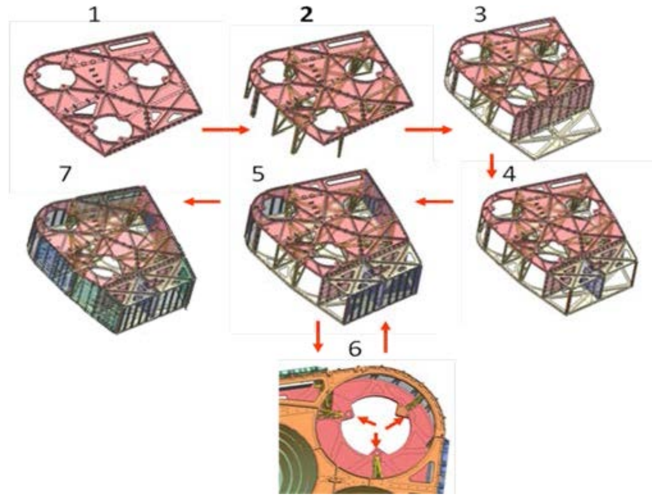

Figure 20. Main Structure Cage assembly process

Due to alignment requirements between feed mounting interfaces and the deployable boom mounting interface, final machining of those interfaces was performed after the cage was fully assembled. To accomplish this step, the cage was covered by a protective cover, exposing only those areas that would be machined (Figures 21-23).

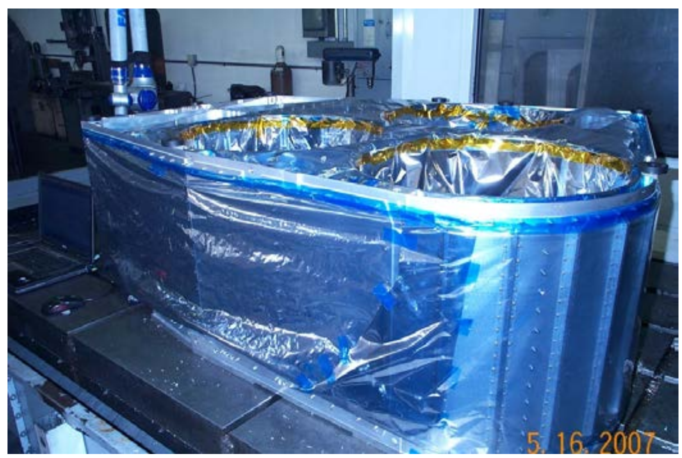

Figure 21. Cage is ready for Feed's and Boom interfaces final machining

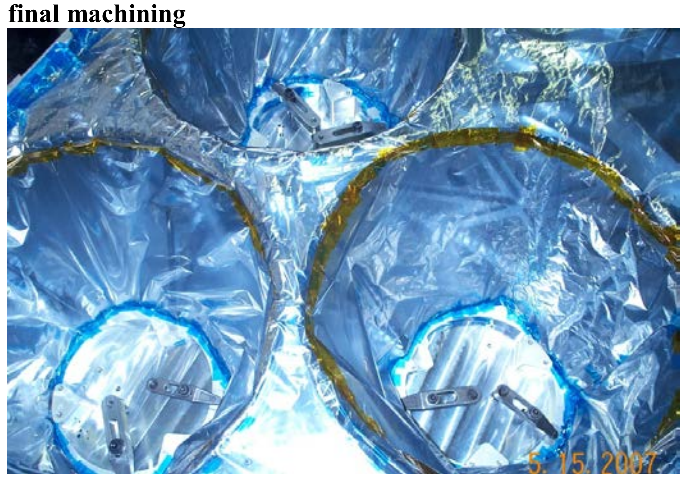

Figure 22. Feed's interfaces at final machining

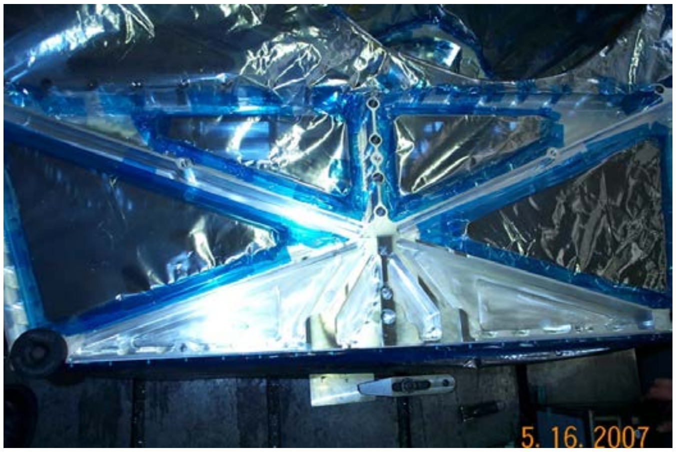

Figure 23. Boom interface at final machining

After final machining of the feed and deployable boom interfaces, the main structure cage and radiators/panels were cleaned and delivered for instrument assembly.

In parallel with cage fabrication was fabrication of the bipods and reflector launch restraint components. The composite tubes for the main bipods and reflector launch restraint utilized three types of graphite composite and E-glass as a thermal stress buffer between the composite tubes and metallic end fittings. The main bipod struts were assembled in a jig. All bipod struts passed workmanship static tests.
Figure 24 shows a pair of bipod struts being assembled to the cage through spherical bearings utilizing the Main Structure Assembly Plate.

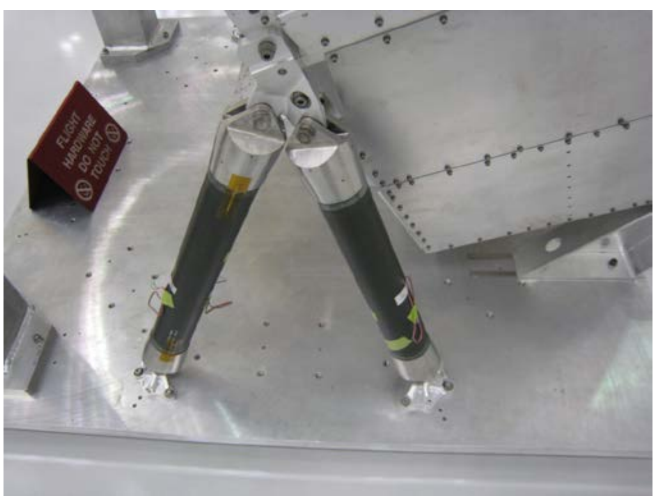

Figure 24. Main Bipod mounted to the Cage and Main Structure Assembly Plate

The reflector launch restraint was built utilizing instrument main structure/cage and reflector restraint tooling as a bonding fixture. The reflector launch restraint's top end fitting interfaces were then aligned to the boom interface (Shown in Figures 25-26).
Tripod and bipod components were dry assembled. After check-outs, adhesive was applied to all reflector launch restraint bonded joints in order to finish the reflector launch restraint assembly.

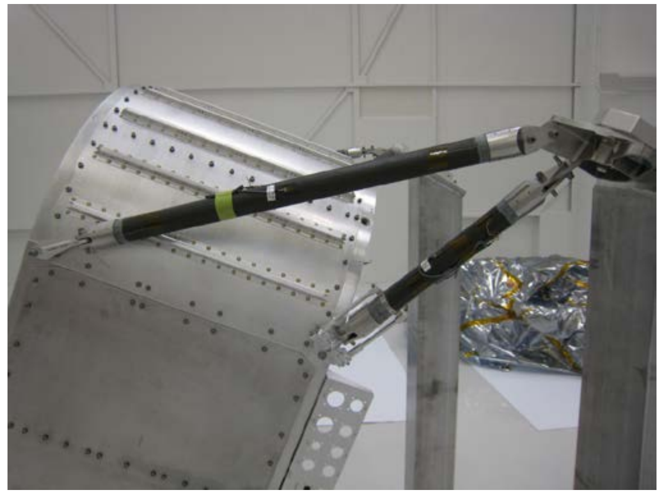

Figure 25. Reflector Launch Restraint Bipod assembly

Figure 26. Reflector Launch Restraint assembly and Tooling

Sunshade components included aluminum tubes, aluminum machined end fittings, and fiberglass thermal isolators.
The sunshade was assembled as two identical halves utilizing the Sunshade assembly tooling shown in Figure 27.

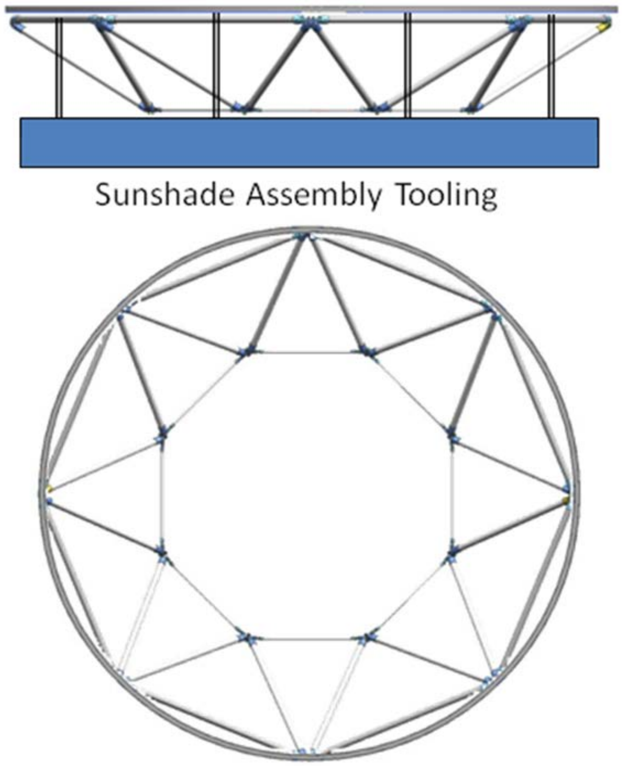

Figure 27. Sunshade Assembly Tooling

Sunshade struts were dry assembled to their top end fittings, and adhesive was applied to all bonded joints. After curing for one week at room temperature, all end fittings were riveted to their corresponding tubes.
Finally, two sunshade structure halves were assembled together and delivered to instrument integration. The fully assembled sunshade structure is shown in Figure 28 The sunshade MLI tent was fabricated and integrated with the sunshade structure at a later stage of instrument integration.

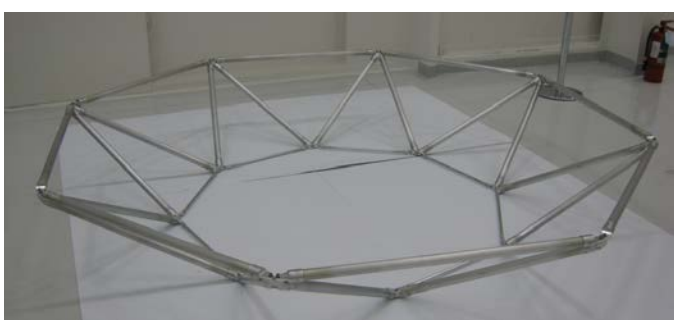

Figure 28. Sunshade Structure Assembly

6. SUMMARY

A number of major configuration trades were performed for the Aquarius instrument main structure. Three major instrument configurations were designed and analyzed. The Aquarius main structure was designed, analyzed, fabricated, assembled and tested, meeting all requirements, cost and risk constraints. The main structure and sunshade structure were cost effective, robust, and straightforward to integrate and test. Aquarius/SAC-D was successfully launched, commissioned, and has begun science observations. The instrument main structure has not shown any anomalies and is performing per expectations. Figures 29-30 show Aquarius at the test facility and ready to be shipped for integration to the SAC-D service platform.

Figure 29. Aquarius Instrument fully integrated and ready for testing

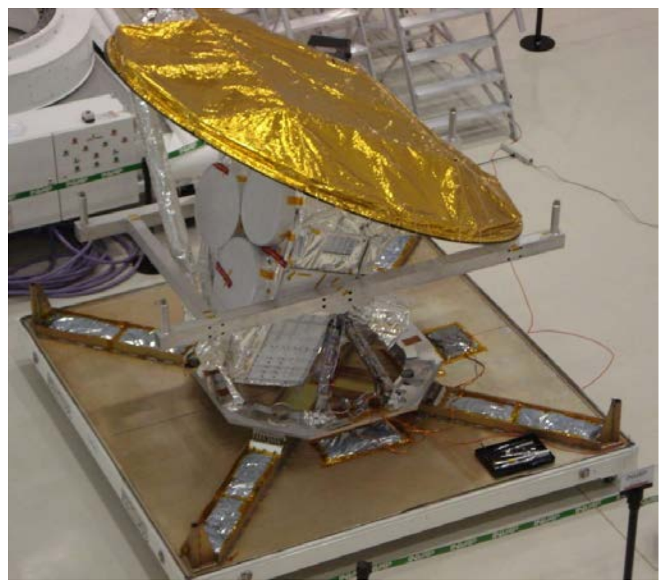

Figure 30. Aquarius is ready to be shipped for integration to the Spacecraft

REFERENCES

[2] http://www.nasa.gov/mission_pages/aquarius/main/index.html

BIOGRAPHY

Alexander Eremenko *received his Masters degree in Aerospace Engineering from the Moscow Aviation Institute, Moscow, USSR (Russia) in 1984. He was* *working for Lavochkin Science & Production Association, Moscow, Russia for 11 years developing a variety of the planetary and astrophysical missions. For the last 15 years Alexander is working at NASA's Jet Propulsion Laboratory developing a variety of deep space missions including Ice&Fire, Solar Probe, Europa Orbiter, Pluto Kuiper Express, Mars Exploration Rover, and Mars Science Laboratory. He is currently the Mechanical Systems Engineer for SMAP spacecraft.*