QUALIFICATION AND TESTING OF PROPULSION SUBSYSTEM OF AMAZONIA-1 SATELLITE

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ABSTRACT

In the mid-2000's the Brazilian National Institute for Space Research – INPE began a program of medium-sized satellites based on Multi-Mission Platform. The MMP is comprised of the Service Modules. Among other subsystems, these modules contain: batteries, solar panels with rotating devices for alignment with the Sun, propellant tank, thrusters, onboard computers, sensors and actuators for attitude control, etc. In this paper we present an outline of the Amazonia-1 Satellite, the first in the series that will employ the MMP, with special emphasis on welding and qualification testing of the propulsion subsystem, consisting of components and pipes made from commercially pure titanium (Grade 2) and Ti-6Al-4V titanium alloy (Grade 5). Programs and results are presented for different welds together with different wall thicknesses, using orbital welding equipment with inert gas (GTAW). Details of procedures adopted by the Integration and Tests Laboratory - LIT where the activities were performed are shown too.

1 – INTRODUCTION

In the 2000s the National Institute for Space Research – INPE began a space program, based on a modern concept in terms of satellite architecture [1]. The Multi-Mission Platform – MMP consolidates together, on one platform, all equipment that perform functions necessary for the survival of a satellite, regardless of the type of mission, orbit, or pointing, within wide limits. It is what is called "Service Module" of the family of satellites that may compose this space program.

The major subsystems that comprise those service modules are: structure, propulsion, power, attitude control, communications, on-board computers, thermal control and wiring.

In the following sections it will be presented characteristics of MMP Program, as well as the Amazonia-1 satellite, the first to use the MMP as their service module. Special emphasis will be given to the integration and qualification of the propulsion subsystem, performed at the Integration and Testing Laboratory – LIT.

2 – METHODOLOGY

2.1 – Multi-Mission Platform MMP

The MMP is a generic platform for satellites in the 500 kg Class. With a mass of about 250 kg, it provides the necessary resources, in terms of power, control, communications and others, to operate in orbit a payload of up to 280 kg.

With external geometry similar to a cube, its structure has outer dimensions of approximately 1 m × 1 m × 1 m. It contains two solar panels positioned on opposite sides.

Figure 1 shows exploded views of the MMP service module.

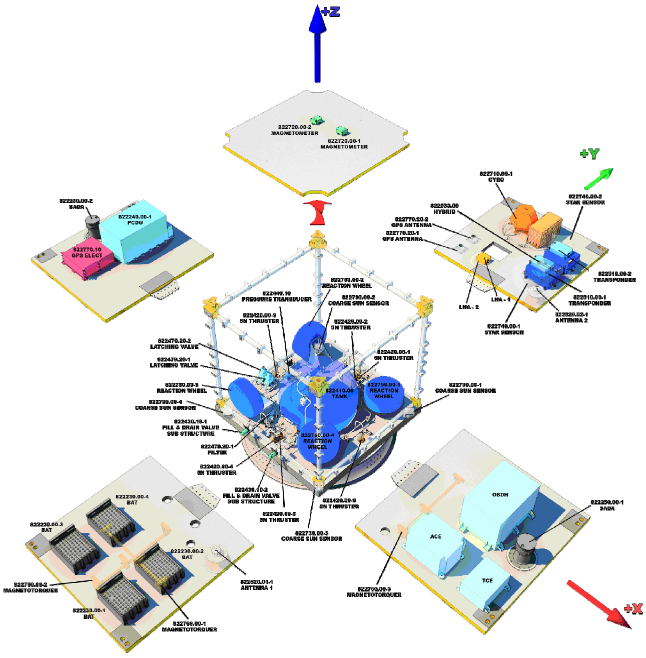

Figure 1 – Exploded views of the MMP.

At the center of Figure 1 one can see the bottom panel (-Z face) with the adaptation ring to the launch vehicle set underneath. In each corner of the "cube" there are columns of aluminum which, together with the side panels, form the structure. A great ball in the center corresponds to the propellant and pressurizing tank. Four reaction wheels are positioned at each corner of the bottom panel. Six 5-N thrusters are present, pointing towards -Z. The whole propulsion subsystem is contained in the lower panel.

The upper panel of Figure 1 (+Z side) contains two magnetometers oriented within the structure. The coupling to the satellite payload module is done through this face (Figure 2).

The panel positioned on the upper left side of Figure 1 (-X side) contains the PCDU unit (Power Conditioning and Distribution Unit), GPS receivers, and one SADA device (Solar Array Drive Assembly), rotating equipment to which one solar panel wing is fixed. The SADA permits to position the solar panel so as to achieve a better energy captation.

The panel positioned on the upper right side of Figure 1 (face +Y) contains transponders, gyroscope, gyro unit electronics, LNA amplifiers, GPS antennas, star sensor and S-band antenna.

The panel on the bottom left side of Figure 1 (face -Y) contains four sets of batteries, an S-band antenna and two magnetotorque bars.

The panel positioned on the bottom right of Figure 1 (face +X) contains the units OBDH (On Board Data Handling), ACE (Attitude and Control Electronics), TCE (Thrusters Electronics Control), magnetotorque bar and another SADA device corresponding to the other solar panel wing.

2.2 – Amazonia-1 Satellite

Scheduled to be launched in 2016, Amazonia-1 is a polar orbiting satellite that will generate images of the planet every 5 days. For this, it has an optical imager of wide target AWFI (Advanced Wide Field Imager). This camera has three bands in the VIS spectral range and one in the NIR band, able to observe a range of 750 km with 40 m resolution.

Its rapid revisit feature will allow improvement in deforestation warning data of the Amazon region in real time, by maximizing useful image acquisitions when the region is cloudy. The Amazonia-1 will also provide frequent images of Brazilian agricultural areas.

Being the first satellite of the MMP Program, the Amazonia-1 is being developed and undergone extensive qualification tests, along with its MMP service module. Figure 2 shows a view of what will be the Amazonia-1 Satellite, with the MMP service module (bottom) coupled to the payload module.

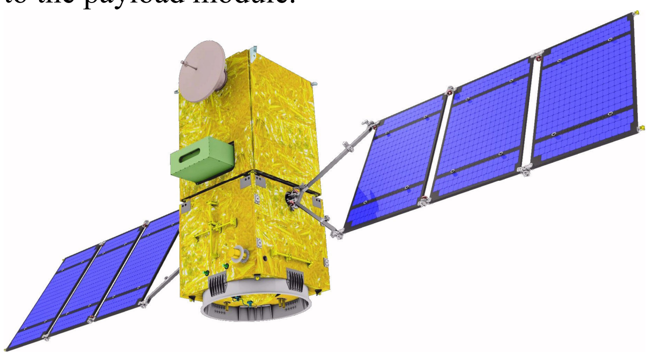

Figure 2 – Amazonia-1 Satellite composed of MMP service module and payload module.

2.3 – Laboratory of Integration and Tests – LIT

The Integration and Testing Laboratory – LIT of INPE was specially designed and built to meet the needs of the Brazilian Space Program [2].

Opened in 1987, LIT has been operating for more than 25 years in qualifying satellites and other space systems, their subsystems, equipment and components. Besides developing activities in the space branch, LIT is currently considered one of the most sophisticated and powerful in qualifying industrial products requiring high reliability. Figure 3 shows a panoramic photo of the LIT facilities in Sao Jose dos Campos – SP.

Figure 3 – Panoramic photo of LIT.

This laboratory provides means and skills to qualify products of the national industry and participates in programs of International Cooperation in the Space Sector, generating constant innovation and fostering the integration of human resources with the most modern and sophisticated technological means.

The first satellite fully assembled, integrated and tested at LIT was the SCD-1, which is a Data Collect Satellite, from the MECB Program (Brazilian Complete Space Mission), successfully launched in the U.S. in 1993, which still remains in activity.

There are twenty thousand square meters of constructed area which house clean areas, control rooms, data acquisition rooms, support labs, offices, training rooms and meeting rooms, engine rooms and workshops, a modern auditorium with two hundred seats and an exclusive circuit for visits.

In LIT are brought together within the same installation, all the means necessary for the complete sequence of assembling, integration and testing (AIT) of satellites up to three tonnes.

2.4 – LIT test facilities

Among the means of testing existing in LIT, we can highlight: acoustic and vibration tests, electromagnetic compatibility tests, climatic tests, thermal shock tests, space simulation tests by thermal-vacuum chambers, mass properties measurements and optical alignments, physical metrology, electrical metrology, laboratory for contamination analysis, laboratory for electronic components qualification and laboratory of titanium welding.

In most cases, the testing environments are located in ISO-8 Class clean areas (equivalent to the old FED.STD.209E Class 100,000), and ISO-7 Class (Class 10,000) [3]. Figure 4 shows a photo of the LIT's Hall of Tests.

Figure 4 – ISO-8 Class LIT's Hall of Tests.

2.5 – Welding Laboratory

LIT has a space systems piping welding laboratory, suitable for conducting welding of stainless steel and titanium [4]. The environment is ISO-7 Class. It is equipped with an Arc Machine Model HP-207a welding system (Fig. 6), with a 9AF-750-HP orbital head model (Figure 9). This orbital head allows welding pipes from 3/16" (4.76 mm) to 3/4" (19.04 mm). It has instruments, tools, and accessories for use and handling of inert gas used in the autogenous GTAW (Gas Tungsten Arc Welding) [5] titanium welding process. The gas used is the 99.999%-purity argon. Figure 5 shows a photo lab welding of LIT.

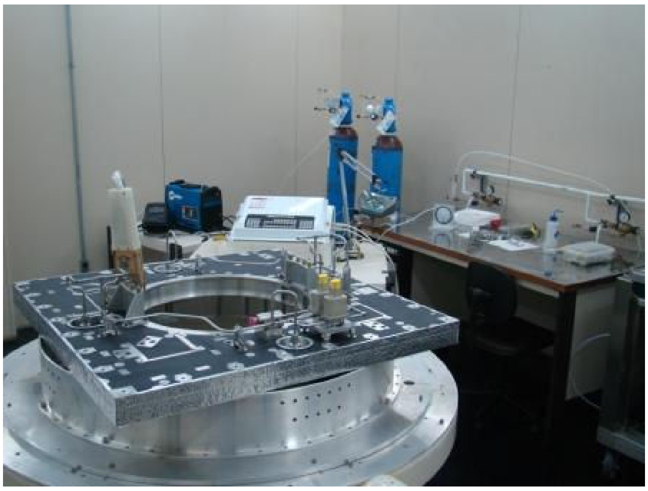

Figure 5 – ISO-7 Class Laboratory for spatial systems piping welding at LIT.

Figure 6 shows computerized equipment for GTAW orbital welding, present in the LIT's welding laboratory.

Figure 6 – Computerized equipment of LIT's titanium welding laboratory.

Prior to being welded, the pipes and components are subjected to a pickling process. Then, the titanium tubing must go through a cleaning process, which uses a pumping system which employs isopropyl alcohol filtering. The circulation of alcohol inside the pipe drags the particles that detach from the interior of the pipes and components. The cleaning process is monitored by counting the released particles up to a number which is below the acceptable limit. Figure 7 shows the cleaning equipment used in LIT's welding laboratory.

Figure 7 – System for cleaning titanium piping by circulation of isopropyl alcohol.

3 – DEVELOPMENT

The MMP qualification process includes the development and testing of the various constituent parts of the system, from its structure to the integration and testing of the flight model. In this work, in a particular way, some details of the propulsion subsystem qualification process will be presented and discussed, with special attention to the welding of pipes and components manufactured in commercially pure titanium (Ti-cp Grade 2) and titanium alloy with 6% aluminum and 4% vanadium (Ti-6Al-4V Grade 5).

3.1 – MMP Propulsion Subsystem

The MMP employs titanium pipe of external diameter equal to 6.35 mm and a thickness of 0.889 mm. Some components have edges having the same outer diameter but with reduced thicknesses of 0.508 mm and 0.425 mm. Therefore, we identified 5 different combinations of joints of parts, as summarized in Table 1.

Table 1 – Types of solder joints in titanium.

Type	Union (∅ = 6.35 mm)	Thickness (mm)
1	Ti Grade 2 with Ti Grade 2	0.889
2	Ti Grade 2 with Ti Grade 5	0.889
3	Ti Grade 5 with Ti Grade 5	0.889
4	Ti Grade 2 with Ti Grade 5	0.508
5	Ti Grade 5 with Ti Grade 5	0.425

The major components of the propulsion subsystem are:

- Tank of propellant and pressurizing gas;
- Fill and drain valves;
- Flow control valves;
- Pressure transducer;
- Fuel filter;
- Piping;
- Thrusters;
- Wiring and connectors;
- Thermal insulation and heaters;
- Mounting panel and structural parts.

Figure 8 shows a 3D view of the design of the propulsion subsystem of MMP. This project is in charge of the company Fibraforte Eng. Ind. e Com. Ltda., partner of INPE in this Space Program.

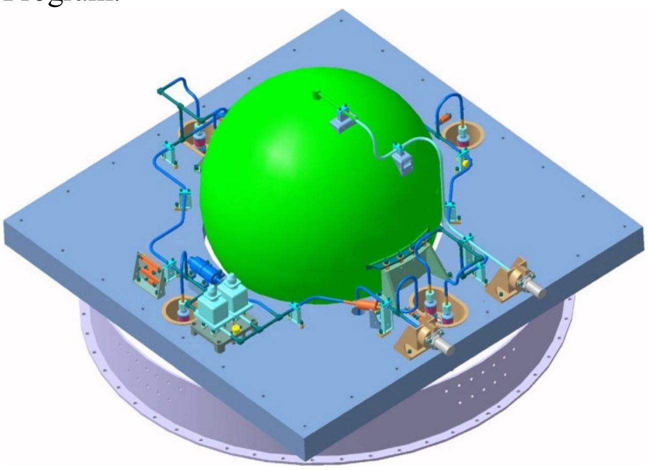

Figure 8 –3D view of the propulsion subsystem of MMP.

The tank has an internal volume of 60 liters. It consists of two environments separated by a flexible membrane. One of the environments contains the “hydrazine” propellant – N2H4 [6]. The other environment contains pressurizing gas (nitrogen). The amount of hydrazine may depend on the mission of the satellite, being foreseen an initial volume up to 45 liters. The internal pressure at the beginning of life (launch phase) is 22 bar.

The tank is made of titanium alloy Grade 5, with two ends of 6.35 mm diameter and a thickness of 0.508 mm. Similarly to endings of certain tanks like the CBERS[1] satellites series, these terminations are not threaded, but welded to the titanium Grade 2 pipes. This increasing in reliability with respect to the possibility of leaks imposes significant difficulty and attention to welding the tank, since no rework is admitted in the welding process.

The valves that control the flow of hydrazine are also made of Ti Grade 5. The thickness of its ends is 0.425 mm, the smallest present in the propulsion subsystem.

3.2 – Titanium pipe welding

The titanium tube joints to be welded should be located in rectilinear regions of the parts involved, at least 2 cm apart from any bends, folds or components, depending on the need for insertion of orbital welding head. The weld is autogenous, that is, there is no participation of compounds other than titanium and elements present in its alloy.

Argon is injected inside the tubes, and in the region that surrounds the joint to be welded. Pressures and flow rates must be well controlled to obtain weld beads without imperfections (convexities, concavities, etc.).

The ends to be fused must be previously made even to obtain perfect fit. Parts should be immobilized by fixation devices. To ensure that no misalignment happens during assembly and operation of the orbital head, they receive at least two welding spots manually, run in diametrically opposed positions of the joint.

Figure 9 shows photos of the orbital head model 9AF-750HP, used in the GTAW welding process.

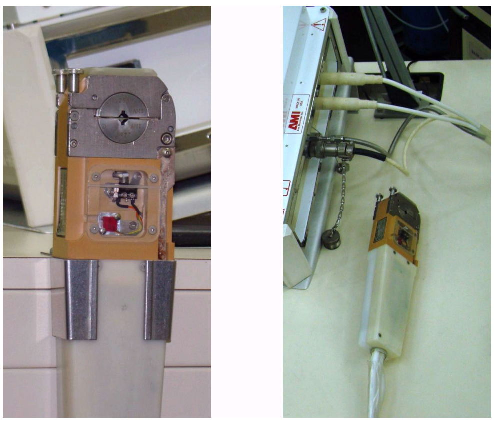

Figure 9 – Orbital head model 9AF-750HP, used in the GTAW welding process.

[1] China-Brazil Earth Resources Satellite.

For welding pipes with different thicknesses, it is necessary to provide a transition in the wall of the thicker tube, so as to enable that the weld bead formed by the fusion of parts occur as flat as possible, as recommended by welding Standards [7] [8] and LIT procedures [9].

Figure 10 illustrates the strategy adopted by LIT to match the extremities of 0.889 mm thickness with flow control valves ends of 0.425 mm to be welded together. A smoothed transition region at the thicker side was adopted, in order to avoid sudden variations in pressure and increasing in losses.

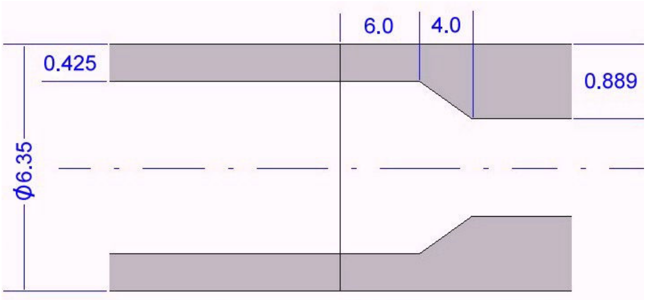

Figure 10 – Detail of transition zone between parts of different thicknesses to be welded.

It is important to mention that after the welding of pipes and components clean, it is not recommended to introduce any objects that may cause some kind of damage or contamination to the interior. Even the use of borescopes and endoscopes should be avoided.

Figure 11 shows a rigid rod endoscope used for inspections in LIT's welding laboratory.

Figure 11 – Rigid Rod endoscope used in LIT's welding laboratory.

3.3 – Standard test bodies

The welded joints should instead be represented by standard test bodies (STBs), which will undergo several tests. The amount of STBs should be sufficient to allow the completion of all required tests. Furthermore, it is recommended to manufacture additional STBs to allow extra tests or re-testing, if necessary.

For the standard test body, the thickness "t" of the material should be the same of the tubes and components to be welded. The shape and minimum dimensions of the STB are specified by ISO 15614-5 [10]. Figure 12 shows how the STBs should be.

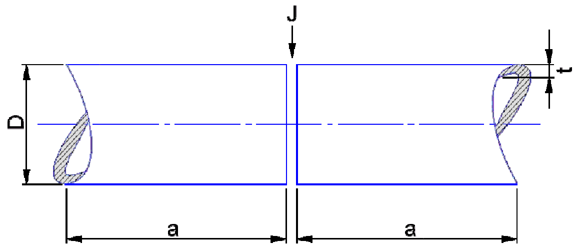

Figure 12 – Standardized dimensions for STBs.

The lowest value of the length "a" for STBs of thicknesses up to 1.6 mm is 50.8 mm [9] [11]. For thicknesses greater than 1.6 mm, the minimum value of "a" is 76.2 mm.

The preparation of the joint "J" of STBs must follow guidelines contained in [12], in accordance with PWPS (Preliminary Welding Procedure Specification) [9], and under the general conditions of welding, which should provide welding positions and limitations for angles of tilt and rotation, so that the specimens remain in compliance with EN ISO 6947 [13].

The welding procedure and testing of STBs must be witnessed by a competent examiner from the welding and applicable testing area.

Welding is considered qualified if the discontinuities of the weld beads are within the limits established for the class of quality of the specimens in question. In our case it is a Class A, referring to projects that require high demands, because if the weld fails, there may be failure in the main system and consequent loss of the project. This class is intended for projects of high pressure vessels, aerospace vehicles, pressure tubes, pipes steam turbine, shown in AWS D17.1: 2001 [7] [8].

All STBs should undergo non-destructive testing and some of them, later, destructive tests. Non-destructive tests are:

- Visual inspection;
- Measure of the width of the weld bead;
- Checking for concavities or convexities;
- Determination of thickness variation in the region of the weld;
- Determination of surface pores or other defects (internally using boroscope);
- X-ray by at least two images with rotated STB;
- Leakage test, using helium leak detector equipment;
- Pressure test;
- Inspection of the coloration of the weld.

With respect to destructive tests, the most important one is the tensile essay where STB is pulled until runoff and rupture.

Figure 13 shows a set of eight STBs type "1" according to Table 1. This series was welded in order to better evaluate the acceptable time between the pickling and cleaning process of the tubes, its long-term storage and later welding.

Figure 13 – Additional set of STBs for evaluation of late soldering after storage.

After pickling and cleaning the tubes with acid attack, they were placed in plastic bags, filled with argon and sealed. The last subset of these STBs was welded 20 days after they have been packaged in argon. The welds were perfect, given the non-occurrence of contamination and oxidation in an inert atmosphere, proving that, if necessary, pickled and clean tubes can wait several days to be welded without any harm to a successful welding. No additional stripping must take place in order to avoid the thickness reduction that occurs in these processes.

3.4 – Welding programs

To carry out the welding of various types of joints described in Table 1, four different welding programs were qualified, each defining over 50 parameters. Basically those parameters are related to currents, voltages, pressures, times, electrode specification (composition, spacing and angle), flows, and operating modes. The set of all these parameters will determine the good result of the welding, the bead width, coloration, absence of dimples, porosity, convexities, cracks, etc.

3.5 – Inspections with digital X-Ray

LIT has a digital X-ray system, that allows radiographic inspection of STBs and welded parts of dimensions compatible with the access window of the device. This test medium was very valuable during the process of obtaining the welding programs mentioned above.

It is possible to change, in real time, the intensity of the X-ray beam, the angle of incidence, the zoom level and other parameters of the apparatus, enhancing the images obtained,, coloring them artificially, and improving contrast in regions of interest.

Figure 14 shows the image of Ti Grade 2 tubes that were welded for preliminary tests with the purpose of validation of images. They have original thickness of 0.889 mm, with reduction of 50% in the welded region. One of them has a through hole of 0.6 mm. The other has a 0.2 mm punch (not through) in the region of the weld bead. It is possible to investigate the lack of pores and imperfections in the region of the weld.

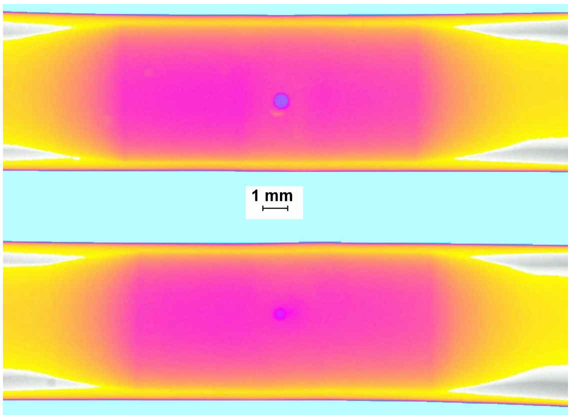

Figure 14 – Digital X-ray image (reduced thickness welded tubes with reference holes).

The various images thus obtained helped in the preparation of different welding programs. Once established these programs, it was made STBs with all combinations of joints to be welded. Final approval of the welding was performed by a company specialized in obtaining x-ray images and analyzing them, contracted to issue reports concerning welded joints. This company has experts, qualified and certified by the AWS-Brazil (American Welding Society) and the SNQC (National System of Qualification and Certification), for Non-Destructive Testing.

Four programs were configured to attend to the five types of joints to be welded. Table 2 shows the association of these programs to unions to be welded.

Table 2 – Welding programs × types of solder joints in titanium.

Union (∅ = 6.35 mm)	Thickness (mm)	Program
Ti Grade 2 with Ti Grade 2	0.889	P-18
Ti Grade 2 with Ti Grade 5	0.889	P-18
Ti Grade 5 with Ti Grade 5	0.889	P-19
Ti Grade 2 with Ti Grade 5	0.508	P-23
Ti Grade 5 with Ti Grade 5	0.425	P-17

4 – CONCLUSIONS

The propulsion subsystem of the qualification model of PMM was fully integrated and successfully tested. The tank was filled with 45 liters of deionized water and passed through test pressure of 33 bar for 10 minutes. This pressure corresponds to 1.5 times the working pressure. Burst pressure tests, with peaks of 88 bar, were also performed in a subset of the propulsion subsystem.

Global leak tests were performed, with the subsystem filled with helium and placed inside a space simulation chamber at high vacuum ($\leq 1\times10^{-5}$ mbar) and room temperature. Leakage measuring was performed through the mass spectrometer installed in the vacuum chamber. The reading, measured in mbar·ℓ/s, was below the allowable limit of 1×10^{-3}, proving the tightness of the subsystem.

Shot tests of the thrusters were carried out, with the tank filled with hydrazine and nitrogen, in the Combustion and Propulsion Laboratory of INPE, located in Cachoeira Paulista. The thrust of the thrusters have reached 5 N under pressure of 22 bar as specified. The tests were successful.

Figure 15 shows a photo of the qualification model of the propulsion subsystem developed and tested at INPE. Skin heaters for thermal control as well as wiring and electrical connectors are already installed.

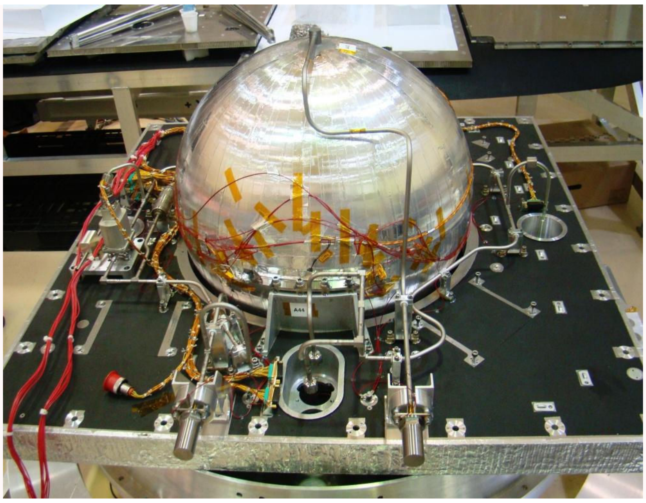

Figure 15 – Photo of the Qualification Model of the MMP propulsion subsystem, assembled and tested at INPE.

5 – AKNOWLEDGEMENTS

Since the phase in which it was built its Titanium Welding Laboratory, firstly used to welding the propulsion subsystem of Satellite CBERS-2, LIT had expert advice. In the welding campaign of the qualification model of the propulsion subsystem of the MMP, LIT could again count on the valuable advice of two experts from the Institute of Aeronautics and Space – IAE, of the Department of Science and Aeroespacial Technology – DCTA. Thus, the authors of this article thank Dr. Jose A. Orlowski Garcia [14] [15] and the welding technician Wilson D. Bocallao Pereira for their assistance during this process of welding and qualification of MMP propulsion subsystem.

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