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NEW INFLATABLE HABITATS GENERATION

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Abstract. *A new generation of inflatable/expandable modules has been developed in the frame of STEPS2 (Project co-funded by EU on the "Misura Piattaforme Innovative" - Phase 2 of POR ERDF 2007/2013). As a matter of fact this innovative module concept relies on a 2D expansion/compaction which allows launching in "tandem" configuration of a stacking of modules and will be also easily exploitable either as on-orbit habitats or surface habitats for Moon/Mars manned outposts, where the expansion could be horizontally driven by a rails system laying on the ground. The currently designed, manufactured and tested prototype has furthermore raised to a full scale level the inflatable technology: the actual ISS crew lock has been replicated in size showing how a metallic design could be fully converted in an inflatable/expandable solution reaching a compaction capability slightly exceeding the initially allocated target of 50 %. All the functional layers required for space manned habitats have been implemented with their challenging interfacing to the prototype metallic bulkheads: high development effort is mostly relevant to the internal "smart barrier" providing monitoring and lighting capability to the habited volume, to the air containment chamber minimizing the leakage performance and to the high strength capability of the pressure containment restraint. The internal metallic structure, based on frames and foldable longerons, has then specifically designed to assist and drive the inflatable shell packaging and deployment. A dedicated testing campaign has then been conducted on breadboards and prototype to demonstrate the maturity level of the developed technologies. From an assembly point of view, the dimension of the prototype has furthermore allowed validation of the assembly procedures for a full scale structure. A valuable advance has so been reached putting the basis for further ground testing and on-orbit validation of the inflatable technology.*

I. INTRODUCTION

The Inflatable Technology for Space applications is clearly indicated by the Space community as one of the enabling capabilities that will play a fundamental role in the next future manned Exploration Missions, with particular reference to Planetary Transfer and Moon/Mars Habitats for surface outposts. As a matter of fact, huge habitable volumes for long-term Interplanetary missions and permanent settlements on Moon and Mars, will be only achievable with inflatable modules providing the required volume after deployment but still maintaining, in packaged configuration, the required compatibility with the fairing accommodation in existing and next generation launchers. The inflatable technology in the European context is currently at ground demonstration level with the aim to progressively increase its TRL. Further consistent efforts have still to be made prior to be ready for on-orbit demonstration.

II. METHODOLOGY

The most recent development is relevant to the work package dedicated to "***Inflatable & Environmental Protection***" in STEPS2 (*Project co-funded by EU on the "Misura Piattaforme Innovative" - Phase 2 of POR ERDF 2007/2013*), where an Inflatable Crew Lock, fully replicating in size the metallic Crew Lock of the ISS (International Space Station), has been designed, manufactured and tested by a team having TAS-I as project coordinator, traditional partners like Aero Sekur and academic entities like Politecnico di Torino. The concept which has been investigated, is based on the linear compaction and deployment of the inflatable shell. The linear expansion gives the possibility to launch 2-3 modules in "tandem" configuration (see Fig. 1) and can also represent a winning solution for surface habitats in which the linear expansion could be assisted by a rail system anchored on Moon or Mars soil. It furthermore allows a straightforward packaging of the structure in launch configuration which does not require any workmanship intervention but can be easily operated with a bridge crane. The module compaction and deployment being guided by an internal metallic structure given by foldable longerons and frames: the foldable longerons creates valleys (see Fig. 2) in which the inflatable shell naturally enters as the packaging process proceed.

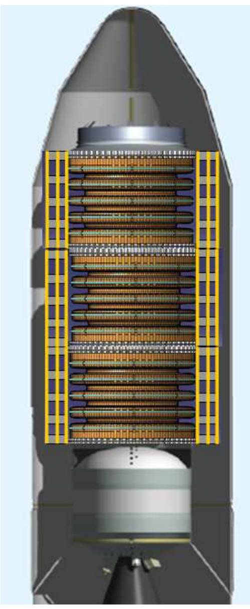

Figure 1 - Launch in "Tandem"

The developed Crew Lock prototype is 2 m in diameter and 3 m in length and implements the most critical functional layers given by the ***internal barrier***, which has been made "smart" by the insertion of cables during the very same weaving process to feed sensors for internal pressure, volume and humidity monitoring and LED spotlights. The air containment bladder which is based on a multi-layer polymeric barrier and the pressure containment layer which relies on high strength ribbons and on a complex manufacturing involving 4 stitching typologies. The MMOD (Micro Meteoroids & Orbital Debris) and MLI (Multi-Layer Insulation) have been inserted, for the time being, as single but fully representative panels as future modules shall in any case require a modularity approach for these kind of protections: the astronaut in EVA (Extra Vehicular Activity) shall be able to replace only a damaged panel of the entire MMOD and MLI covering. The main purposes of the current development has so been related to evolve the inflatable functional layers, perform deep investigation of interfaces with bulkheads, realize an internal deployable system to drive packaging/deployment guidance and providing internal attachment points for secondary structures.

Figure 2 - Folded Shell (Inside View)

The prototype principal functions are: provide habitable volume of about 8 m^3 after deployment, assure packaging efficiency in launch configuration in the range of 50 %, provide 1 bar pressure environment, provide outstanding air tightness performance, and implement a sensorized "smart" internal barrier for the habitat monitoring.

In synthesis, the Crew Lock prototype main components (system breakdown) are so given by: the inflatable multi-layer shell, the metallic bulkheads with closure caps, the internal frames with extendable longerons. Equipment and tooling have then been provided to support mounting and testing activities with mechanical, fluidic, electrical and data exchange interfaces.

II.I The Crew Lock

The complete ISS Airlock (see Fig.3) consists of two segments, the "Equipment Lock" that stores spacesuits and equipment, and the "Crew Lock" from which astronauts can exit into space.

Characteristics

- Material: Aluminium Alloy
- Length: 5.5 meters
- Diameter: 4 meters
- Weight: 6,064 kilograms
- Overall Volume: 34 m^3 (including Equipment Lock & Crew Lock)

The Crew Lock, in particular is the pressurized compartment from which astronauts and cosmonauts exit the ISS and step into space, while the Equipment Lock is used for storing gear and for overnight "campouts."

This Crew Lock is currently a metallic based design; the idea within this project has been to develop a prototype reproducing the same shape and sizes and providing the same internal habitable volume as a first evolution to full scale design for the inflatable technology.

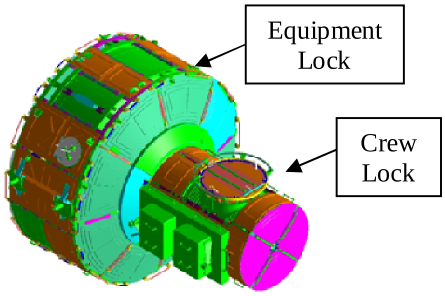

Figure 3 - ISS Airlock

II.II The Inflatable Layers

The Crew Lock has so been taken as reference for the prototype design in terms of volume and dimensions but the developed technologies are widely applicable to inflatable manned space modules with different sizes.

As mentioned above, the technological core and major effort of the design is therefore focused on the inflatable shell of the prototype which is currently given by 3 complete layers plus 2 representative portions of the most external layers as follows:

- Smart internal barrier
- Air containment bladder
- Pressure containment restraint
- MMOD (representative portion only)
- MLI (representative portion only)

The typical functional layering for a manned inflatable structure is here represented for the Crew Lock:

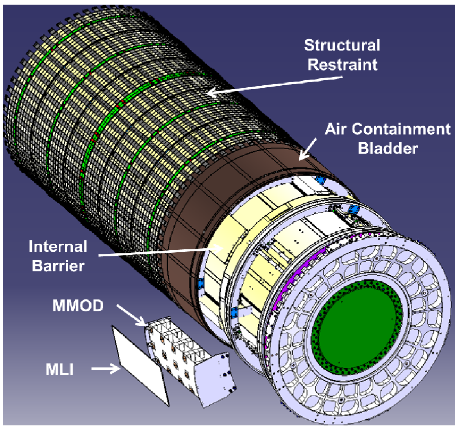

Figure 4 – Crew Lock Functional Layering

Internal Barrier

The internal barrier is the first layer from the inside of the module and it is in direct contact with the crew. Its primary functions are therefore related to prevent crew accidental damaging of the polymeric bladder during on board activities and to act as a flame barrier. To these purposes the adopted material is a Aramidic fabric which can assure high perforation strength matched with outstanding fire containment capabilities. Since STEPS project, additional functions have been added to this barrier with the introduction of cables in the very same weaving process of the Kevlar fabric (see Fig.5). The barrier can so additionally perform a capillary distribution on the entire internal module surface, of small electrical power to feed both a sensors' network and LED spotlights. This new concept provides a "smart internal barrier" which can perform with dedicated sensors: environmental monitoring and control (pressure, temperature & humidity) as well as damage detection, so providing health monitoring capabilities and rapid tracing of air bladder damaged areas (e.g. based on the acoustic emission of the air exiting from perforations).

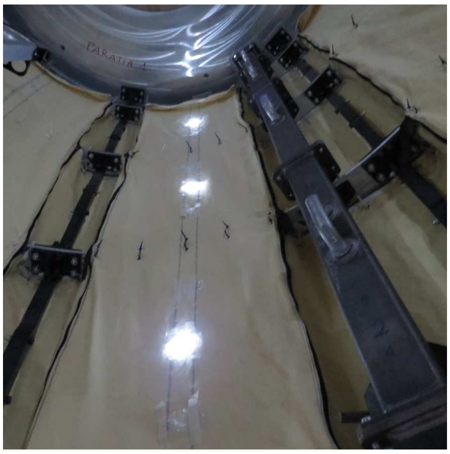

Figure 5 - Smart Internal Barrier Breadboard with Cables & Spotlights (STEPS)

In the prototype barrier the insertion of environmental control and spotlights has so been foreseen.

The Internal Barrier Configuration is based on 3 panels' typology:

- Small size panels dedicated to cover the longerons' areas
- Intermediate and big size panels dedicated to cover the areas in-between longerons

The panels are discretely fixed to the frame via dedicated eyelets.

Each internal barrier panel is then joined to the 2 adjacent panels via zip closures: this eliminates the presence of discontinuities through which accidental damaging of the bladder can occur and, on the other hand, allows fast access to the bladder in case some area needs to be inspected or repaired.

The internal barrier configuration design is shown in the next picture:

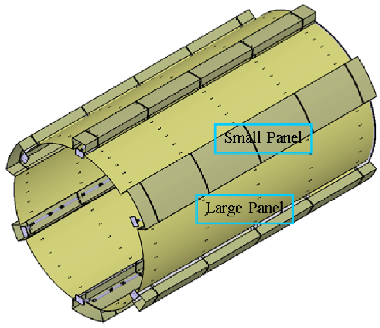

Figure 6 - Internal Barrier Panels

The TPH (Temperature, Pressure and Humidity) sensors and spotlights distribution is reported in Figure 7 on a prototype internal barrier panel:

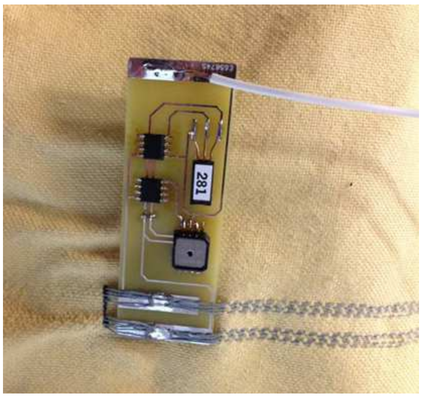

Figure 7 – PHT Sensors Card Detail

Air Containment Bladder

The air containment bladder is based on a polymeric multilayer or an engineered coated fabric: 2 materials typologies are currently being subjected to final testing and bladder-to-bladder joining process evaluation to select the best performing material.

The bladder is slightly oversized to follow the structural restraint deformations. The selected material is a polymeric multi-layer having a thickness of 0.7 mm which provides the following main properties:

- Density = 915 g/m2
- Tensile Strength = 27.8 N/mm
- Air Permeability = 9.2 ml/(m^2*24 h*atm) for 1 mm thickness

Figure 8 - Air Bladder Polymeric Multi-Layer

The selected material exhibits good tensile strength and air tightness; it is also very versatile in terms of joints manufacturing as, being symmetric, it is straightforwardly weldable on both sides with most of the available techniques.

After final material selection the bladder has been manufactured in longitudinal gores (whose number has been driven by the available roll width):

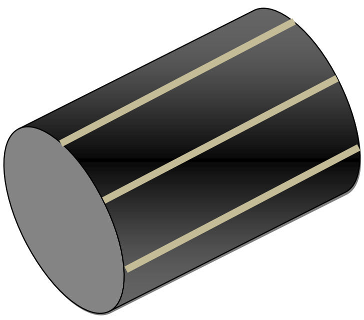

Figure 9 - Air Bladder Longitudinal Joints

The air bladder has been shaped and slightly oversized to take into account the deformation of the structural restraint under pressurization. Both the bladder and the joints exhibits however a high elongation at break.

The air bladder interface with the metallic bulkheads has been based on the folding of the free edges of the bladder around an L-shaped flange which has been then encased, sealed and bolted onto a counter-flange. Their assembly is finally bolted and sealed to the upper and lower bulkheads.

Structural Restraint

The design and structural sizing of the structural restraint has been performed based on the available test data on ribbons and ribbons stitching. Based on the performed calculations, 2 ribbons' typologies have been selected to maximize the structural performances and to obtain a continuous ribbons' net: maximum number of the ribbons in both longitudinal and hoop directions

The following data have been used for the structural sizing of the restraint:

- Burst pressure level of 0.4 MPa (Safety Factor of 4 with respect to the operative pressure level of 0.1 MPa)
- Cylinder Diameter of 2020 mm
- Cylinder Length of 3260 mm
- Safety factor: 4

The load fluxes have been evaluated in hoop and longitudinal directions under the applied pressure at burst level.

A dedicated FE model (see Fig.11) has been prepared and run using LS-DYNA software, taking into account the 2 different ribbons typologies and the stitching typologies involved in the final assembly of the restraint (see Figg.10-11):

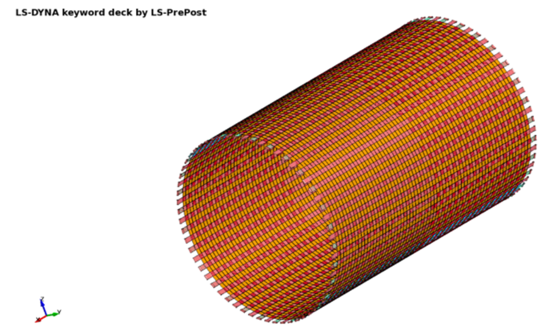

Figure 10 - Structural Restraint Detailed FE Model

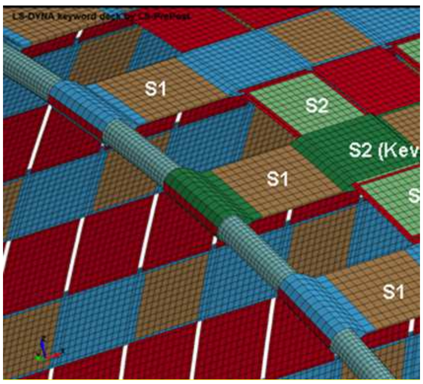

Figure 11 - Structural Restraint Detail of Ribbons and Stitching

An axial displacement of about 58 mm and a radial displacement of 14 mm have been detected and used for the air containment bladder oversizing to follow the structural restraint deformations.

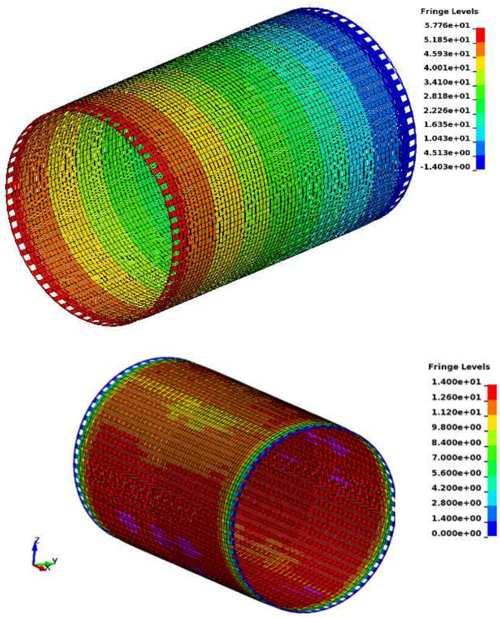

Figure 12 - FE Model Axial & Radial Displacement

The maximum detected stress on longitudinal ribbons and circumferential ribbons have resulted fully compatible with the tested ribbons' capability.

The local structural analyses performed on stitching have also confirmed the compatibility with the test results.

MMOD & MLI

The MMOD of the final prototype is based on an individual panel in accordance with a modular configuration which allows replacement of a damaged panel in EVA (Extra Vehicular Activity) including the most external MLI thermal protection. The MMOD is currently based on a 2 bumpers' configuration based on previously performed design and hypervelocity testing campaign:

Figure 13 - MMOD Panel Prototype

The 2 first bumpers provide projectile fragmentation while the additional ballistic restraint forming a 3rd layer prevents any damaging of the structural restraint (pressure containment layer) in case the impacting particle succeeds in the perforation of the first two bumpers.

The interposed foam block contribute to the ballistic performances maintaining the required bumpers spacing for which the ballistic performance is achieved. Their discretization allows compaction of the MMOD during packaging operations of the inflatable module.

The design has then been implemented in the CAD model and the single MMOD panel is here shown:

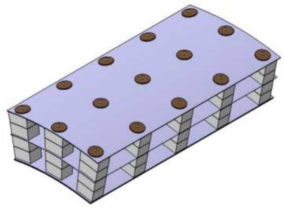

Figure 14 - MMOD Single Panel CAD Model

The MMOD single panel has then been interfaced with the external side of the Crew Lock prototype structural restraint layer and with the bulkhead. This single panel, as shown in the first picture, is as currently implemented in the final prototype while the full implementation of MMOD panels as it could look like in future flight HW has been included in the CAD model of the second picture hereafter:

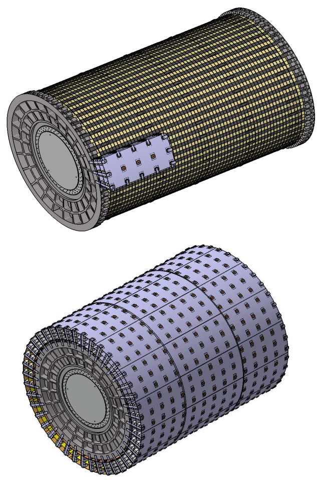

Figure 15 – MMOD Single Panel (on Prototype) & Full MMOD (on Future Flight HW)

The MLI is derived from a piece of standard flight HW taken from current ISS space modules (TAS-I heritage). As a matter of fact, the MLI applied to current metallic modules is in any case already flexible and could be straightforwardly implemented in the next generation of inflatable modules.

II.III The Metallic Parts

The metallic parts are given by the following items:

- Bulkheads (including Manhole Closures, Bladder I/F Flanges, Structural Restraint I/F and MMOD panel I/F)
- Internal Foldable Longerons
- Frames

These parts are only intended to provide interface, support and correct deployment/inflation of the inflatable parts, so they will have a relevant importance from a functional point of view for the complete assembly but not representing a critical technology as ordinary mechanical parts, their manufacturing is therefore based on commercial Al alloys which are not specific for aerospace applications leaving the use of aerospace Al alloys on future flight HW. From a technological point of view it is however important how the mechanical parts interface and interact with the inflatable parts during packaging and deployment operations and this aspect is fully covered by the metallic parts.

- **Bulkheads**

The bulkhead design has been based on the Inflatable Airlock diameter of 2 m, to sustain internal pressure and to provide the required internal and external interfaces. An orthogrid waffle design has been adopted to enlighten the structure maximizing its structural efficiency. The bulkhead is based on commercial Al alloy but implements a design and interfaces that can be reproduced on a flight configuration. The bulkhead is completed by a bolted and sealed closure cap providing access to the inside of the module.

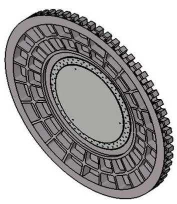

Figure 16 - Prototype Metallic Bulkhead with Closure Cap

- **Internal Structure**

The internal structure is formed by frames and foldable longerons:

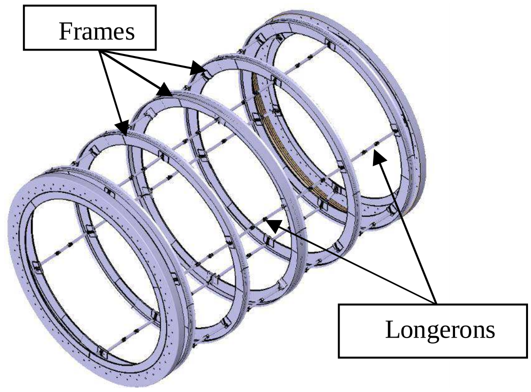

Figure 17 - Internal Metallic Structure (Frames & Longerons)

- **Longerons**

The internal longerons are 6 and are designed to act as a guiding system for the inflatable shell during ground packaging operations as well as attachment elements for secondary structures after on-orbit deployment, in order to allow outfitting of the pressurized compartment. The longerons segments perform also frames connection. Each longeron segment between 2 adjacent frames is composed of 3 hinged beam segments: during packaging the 3 beams create a valley (U-shape) for accommodation of the flexible layers.

- **Frames**

The frames are obtained by the assembly of curved sectors; they provide segmentation for the longerons and support to the inflatable layers during ground assembly and packaging operations.

II.III Development Activities

The System Development Logic for the target inflatable layers, has been based on an incremental approach starting from basic materials testing and technological processes set-up (e.g. bladder gores joining & restraint stitching), then evolving to the manufacturing and validation testing of breadboards for the bladder I/F sealing and the bi-axial restraint structural capability and ending up with the final prototype inflation and packaging/deployment testing activities.

As a first step, a considerable testing campaign has therefore been conducted on both the air containment bladder and the structural restraint basic materials to evaluate their key properties (i.e. tear, tensile, permeability, flammability, abrasion, puncture, fungus susceptibility for the air containment bladder and tensile for the ribbons considering also UV ageing).

Then, the joining processes for the bladder and the structural restraint layers have been investigated.

- **<u>Bladder joints</u>**

The technological processes for the polymeric bladder have been mainly related to its cold bonding for bladder repair and the joining to metallic flanges and to the welding of the bladder adjacent gores.

These joints typologies which are present in the final prototype layer, have been tested by lap shear and T-peel testing.

The welding process for adjacent gores has been set-up using HF (High Frequency) welding technique. This technology, which takes advantage of the dielectric properties of a material submitted to a variable electric field, allows joining of the polymeric material without using any interposed adhesive but through a "controlled local fusion" of the material.

As a further advantage, the HF welding does not create the dangerous annealing zones that are common in hot-welding techniques.

Butt-Strap Joint (Double Layer)

The joint configuration which has been considered is the single butt-strap, the process parameters set-up (on 50 and 40 mm joint width) have been evaluated and the 40 mm joint has been selected considering the overall bladder configuration and the achieved performance.

Figure 18 - Welded test trials (50 mm) front (L) and back side of Polymeric Bladder

In particular, the joint configuration and process parameters have been considered satisfactory when breaking of the joint has reached a less than 15% with respect to the basic material tensile strength:

Figure 19 - Welded Samples Testing & Test Apparatus

The air transmission rate have been assessed for comparison both on basic material (as received) and after joining with HF technique, as reported in the table below no significant detrimental effect has been detected in particular for the double layer configuration, practically showing the same performance of the basic material. The double layer configuration is relevant to the longitudinal welding lines of the bladder adjacent gores. The triple layer joint configuration is more relevant to future applications in which, due to the size of the modules, circumferential welding lines could be needed in addition to longitudinal welding lines and implying a triple layering welding at their crossing points.

Figure 20 - Air permeability transmission (ml/(m^2*24 h*atm) on Polymeric Bladder as received, double and triple welded joints

- **<u>Structural Restraint Joints</u>**

The structural restraint joints are based on stitching which have to maximize the structural performances when compared with the basic ribbons tension properties. Different stitching patterns have been taken into account in combination with different stitching tows to find the best performing combination. The main stitching typologies are here reported for the Longitudinal and Circumferential Ribbons:

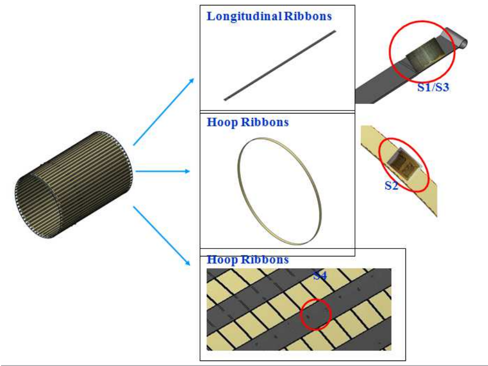

Figure 21 – S1 to S4 Stitching Typologies

In particular for S1 & S3 stitching in Longitudinal Ribbons, the here shown Ferrari-like pattern from Sabelt has been selected.

Figure 22 - Ferrari-like pattern for S1

For S2 stitching in Hoop Ribbons, the snake seam shows a higher (almost 17%) breaking load in comparison with the diamonds seam.

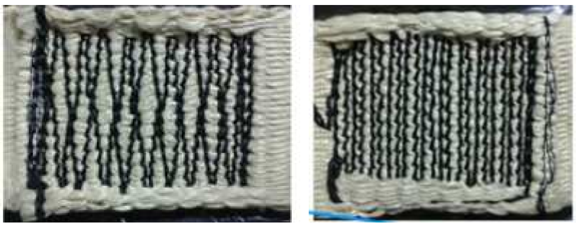

Figure 23 – Diamonds (L) and Snake (R) pattern for S2

The extended development campaign has allowed reaching of strength properties practically in line with the basic ribbons structural capabilities.

- **Bladder Breadboards**

The maturation process of the HF welding has allowed the realization of 2 bladder breadboards.

The first breadboard having a height of 0.8 m, full 2 m diameter and including all the 16 welding lines, in order to assess the manufacturing process steps prior to implement them on the final bladder:

Figure 24 - Bladder Breadboard Welding Lines

The second breadboard dedicated to evaluate the bonding and sealing of the bladder through a leakage test.

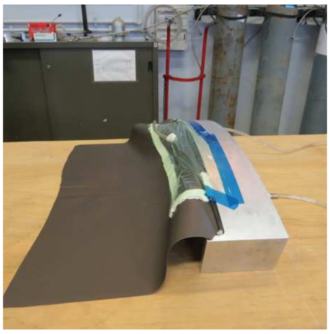

Figure 25 - Bladder Breadboard for Leakage Test

This is a fully representative bladder interface sector with the same curvature radius of the final prototype.

The test procedure has consisted in the main following steps:

- Installation of the inflation bag on the Bladder sealed I/F
- Inflation with Helium gas
- Detection of the He amount passing through the sealed joint through a leak check port and the use of a He leakage detector

- **Structural Restraint Breadboards**

After validation through testing and FE modelling of the structural restraint configuration, the manufacturing of the 1st breadboard has been developed based on a specifically designed tooling which allows the exact positioning of the hoop and longitudinal ribbons during stitching operations. The stitching operations are performed with a numerical control stitching machine which has to complete all the ribbons joining inside the tooling provided matrix. The first manufactured breadboard, which has been based on PES ribbons in order not to waste costly final prototype ribbons, is a manufacturing trial to validate both the tooling and the numerical control program for automatic stitching. The first breadboard has been successfully manufactured:

Figure 26 – 1st Manufacturing Breadboard

The tooling and the automatic stitching program have then been considered ready for the implementation onto the real ribbons' configuration with the real stitching tow and including all the stitching typologies. The 2nd manufacturing breadboard has been manufactured and made available for the subsequent testing campaign. The number of 4 ribbons in both directions has been limited by the bi-axial loading machine capability of 150kN at Politecnico di Milano (the most performing in Europe).

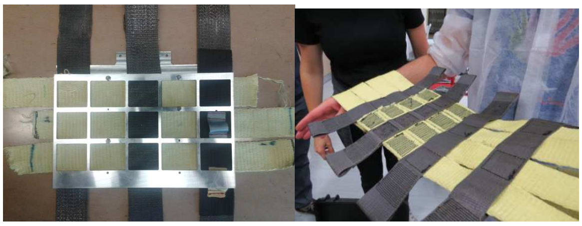

Figure 27 - 2nd Breadboard Manufacturing

The test has verified the design and shown the structural integrity of the restraint after biaxial testing. Digital Image Correlation (DIC) has been applied to monitor markers' deformation during test execution.

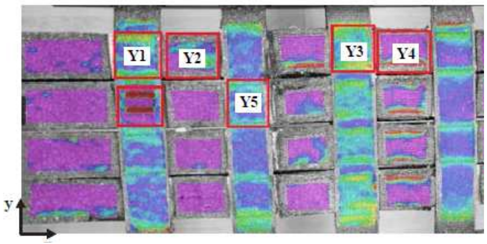

Figure 28 - DIC Deformation Distribution

The structural restraint breadboard has been tested for burst loading simulation at 4 bar (burst pressure level). The breadboard's attachment system to the bi-axial testing machine has been designed to provide the required interfaces with the stitched eyelets of the ribbons.

Figure 29 – 2nd Breadboard Bi-axial Testing

At the end of the test, all the ribbons and the relevant stitching were perfectly integer. The manufacturing processes have so been considered ready for the implementation in the final prototype.

II.IV Prototype Assembly & Testing

A considerable work has been performed to design an efficient mounting and testing equipment and to establish the related procedures. The vertical mounting has been finally identified as the most suitable to manage the insertion and sliding of the functional layers onto the metallic structure, exploiting the available workshop bridge crane but the dimensions of the prototype have nevertheless made very challenging the whole activity.

Assembly

The assembly of the internal metallic structure has been obtained by mounting up frames and foldable longerons, a 120 degrees system of spacers between adjacent frames has been used to prevent collapsing of the metallic structure due to undesired folding of the longerons system:

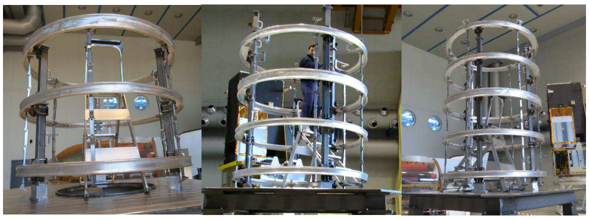

Figure 30 - Mounting Sequence for the Internal Metallic Structure

A packaging and deployment test on the naked metallic structure has then been performed to check the foldable longerons functionality prior to start the insertion of the inflatable shell layers. The operation has been performed with the use of the brigde crane:

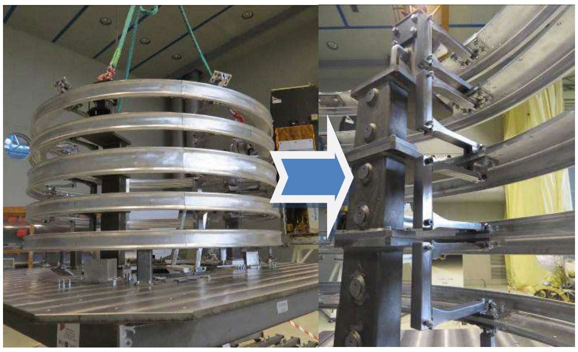

Figure 31 - Compaction of the Metallic Structure & Folded Longerons

The metallic structure in expanded configuration, has then provided the necessary skeleton to mount the inflatable shell layers.

Bladder Mounting

The air containment bladder has been added to the metallic structure after its bonding to the retention flanges of the top side. After sliding down onto the metallic structure, the bladder has then been bonded to the retention flanges of the bottom side as depicted in the next sequence:

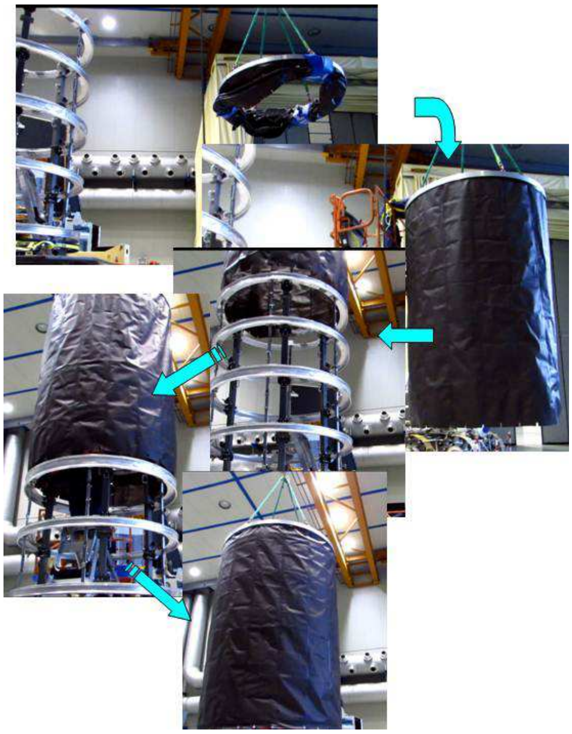

Figure 32 - Bladder Insertion on Metallic Structure

Internal Barrier Mounting

The mounting of the internal barrier with the sensors' system has been performed by attaching the panels eyelets onto the frame slots with dedicated fixation straps, this method has revealed its efficacy during the packaging tests. Adjacent panels have been then joined by zips in order to form an uninterrupted internal protection surface: in future flight hardware the zips' system will allow local fast access to the bladder for any repair need:

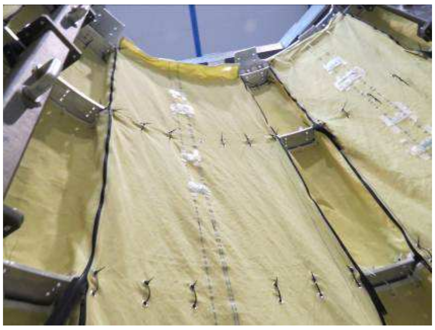

Figure 33 - Internal Barrier Mounting

Structural Restraint Mounting

The structural restraint has then been slid down on the air containment bladder and finally the upper bulkhead has been mounted on top of the assembly. The structural restraint has been fixed to both the bulkheads using the longitudinal ribbons' eyelets and a special segmented ring:

Figure 34 - Structural Restraint & Upper Bulkhead Mounting

Testing

Packaging & Deployment

The test objective has consisted in checking the correct packaging & deployment of the assembled prototype along the axial compaction direction, including a simulation for the MMOD & MLI panels:

The prototype packaging & deployment test has been assisted by an external compaction system based on pre-loaded belts and elastic chords in synergy with the internal foldable longerons system. The achieved compaction has then been measured with respect to the initial prototype length to verify the compaction efficiency.

The packaging and deployment has been performed for 5 times showing the complete repeatability and achieving the following results:

- Packaging in terms of compaction percentage of 55% (superior to 50 % requirement): initial deployed length of 3260 mm, final packaged length of 1450 mm
- Self-packaging capability (packaging and deployment can be performed by simple down/uplifting of the top bulkhead: no human intervention needed to help packaging & deployment)
- Visual inspection after test has not evidenced any damage in the inflatable layers and in the foldable longerons

One packaging/deployment cycle is shown in the picture sequence below together with the SW performed simulation for which a perfect adherence to the real HW has been found:

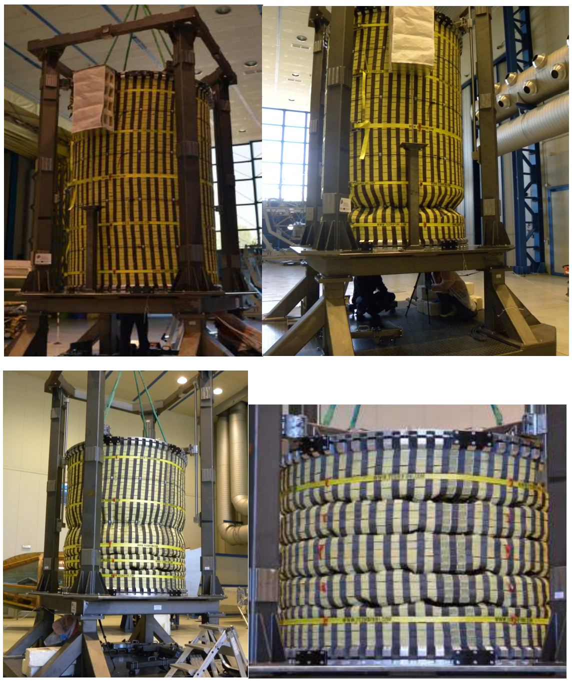

Figure 35 - Prototype Packaging Sequence

The performed SW simulations have allowed prediction of the packaging process and the final shape of the SW simulation found perfectly in line with the real HW deformed shape shown in Fig.35:

Figure 36 - Prototype Packaging SW Simulation

Environmental Monitoring

The test has been focused on checking the correct functionality of the monitoring system based on pressure, temperature and humidity sensors before and after packaging & deployment cycles: the monitoring system includes the sensors, the flexible supporting cards and the harness embedded in the internal barriers which have to follow the packaging & deployment without being damaged. The functionality of the sensors monitoring system has been checked via remote PC connection.

The sensors and LED spotlights functionality has been assessed both after 10 folding cycles on the single panels before their mounting on the prototype and after 5 cycles after mounting on the prototype. The sensors' and LED network worked perfectly after performing of all the cycles (total of 15) showing:

- 100% functionality of both sensors and LED spotlights (minimum of 70% required)
- Visual inspection after test has reported no damage of the internal barrier including sensors and LED spotlights with the relevant connections

Figure 37 - Sensors & LEDs 100% Functionality after Packaging & Deployment

II.V Conclusions

The performed development and prototype manufacturing, assembly and testing activities have allowed the evolution to full scale of the technologies for expandable/inflatable modules. The repeated packaging and deployment tests have proven the functionality of the system including the internal environmental monitoring and lighting apparatus. The structural restraint and the air containment bladder leakage performances have been demonstrated on dedicated breadboards due to the prototype test limitations imposed by the assembly facility. The achieved TRL is between 4 and 5 with the consequent need for further ground testing including the relevant environment prior to flight and performing of on orbit validation. A full size capability for future applications to Exploration Missions has so been achieved with this airlock prototype, reaching a maturity of the technological processes and of the elaborated assembly procedures which could effectively allow managing of these new generation of habitats based on inflatable technology.

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