Executive summary

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SISTEM

Executive summary

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Change Records

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2 SCOPE AND PURPOSE

This document is issued in the frame of the ESA TRP "SISTEM -Small, Inflatable, High Pressure Composite Tanks for Human Spaceflight" (Ref.: AO/1-8798/16/NL/KML) contract /AD1/ and summarizes the whole SISTEM development encompassing the outcomes of test campaign, highlighting the critical areas to be finalized before to complete the development phase.

2.1 Applicable documents

Internal code / DRL	Reference	Title
AD1	ITT ESA AO/19397/18/NL/LvH	Invitation to Tender "Small, Inflatable, High Pressure Composite Tanks for Human Spaceflight"
AD2	DESI-TASI-PRO-0521	Proposal: SISTEM -Small Inflatable Space Tanks Engineering Model

2.2 Reference documents

Internal code / DRL	Reference	Title
RD 01	TASI-SD-SISTEM-TNO-0353	TN 1. Definition of key requirements and design drivers Inflatable tank concept
RD 02	TASI-SD-SISTEMTNO- 0363	Extract of Key Requirements Inflatable Tank
RD 03	TASI-SD-SISTEM-TNO-0352	TN2: Materials Space Characterization & Test Plan for Inflatable Tank
RD 04	TASI-SD-SISTEM-PLN-0040	TN3. Inflatable tank development plan
RD 05	TASI-SD-SISTEM-TNO-0403	TN4: Materials Space Characterization and Test report for Inflatable tank
RD 06	TASI-SD-SISTEM-ORP-0132	TN 5: Detail Design Definition of Prototype Inflatable Tank
RD 07	TASI-SD-SISTEM-ARP-0034	Small Inflatable Space Tank Engineering Model Analysis Report
RD 08	TASI-SD-SISTEM-TNO-0423	TN.6 Manufacturing, quality and test plan for prototype inflatable tank
RD 09	TASI-SD-SISTEM-TSP-0015	TN 7. - Leak, Proof, Leak, Service Life & Burst Pressure Test Spec
RD 10	TASI-SD-SISTEM-ETR-0008	Leak, proof, leak service life & service life & evaluation
RD 11	TASI-SD-SISTEM-ORP-0271	TN8 - Update detail design report
RD 12	TASI-SD-SISTEM-PLN-0099	TN 9. Product validation

3 SISTEM - Small Inflatable Space Tanks Engineering Model

Next future exploration medium and long term manned space missions will necessarily require transportation and storage of a considerable amount of fluids to support human life and propulsion systems both in the form of gases and liquids. These fluids, which could be either transported from Earth or produced exploiting in-situ resources, will require a wide variety of tank sizes able to work at different operative pressures and to cope with both low temperature and aggressive environments.

The main advantages of inflatable tank typology is not only related to their potential for mass saving but above all to the possibility of flying in packaged configuration (e.g. in storage bags or inside foam shells) not seeing in this way significant flight loads. The limited mass and the compaction capability (low volume) gives furthermore the possibility to launch several tanks of different sizes as needed inside a cargo module.

The inflatable technology applied to tanks will require dedicated functional layers to accomplish functions like fluid containment (named Bladder), pressure containment and insulation for the specific of cryogenics applications.

This new type of tanks could provide a valid alternative to rigid tanks both from a mass perspective and from a compaction capability point of view, being able to fly in compacted configuration and be deployed/inflated once on-orbit. As simple storage tanks they could also adapt their shape to the contained waste fluids so optimizing the occupied volume.

The inflatable technology applied to tanks will require dedicated **functional layers** to accomplish functions like **fluid containment** (named Bladder), **pressure containment** and i**nsulation** for the specific of cryogenics applications.

The Structural Restraint layer is a cylindrical shape thick net made of high-strength ribbons (PBO based) arranged along meridional and hoop directions [RD 05].

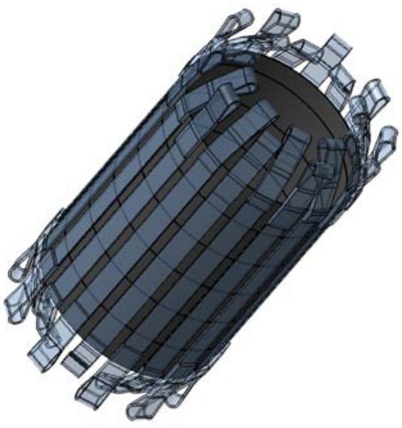

Figure 6-1: Structural restraint in the SISTEM tank

The material selected is a 100% Zylon weave ribbon coated with VITON elastomer in order to protect the fiber from UV degradation. It is supplied by Sabelt and was appositely upgraded for the space application from an already commercial available product used as for automotive safety belts (same type but less performing) in order to meet the tensile strength requirement. Test campaign on basic ribbon materials highlighted a linear behaviour and a good standard deviation of tested specimens, the failure mode is the webbing rupture.

Each assembly is composed of a certain number of equal ribbon opportunely sewn together in order to create connecting joints and desired shapes. The seams represent the connection elements between the ribbons. For all the seams type a dedicated testing has been foreseen. Detail of test campaign to be conducted as sample level are collected in [RD04].

Table 3 5: Restraint Seams location

ID code	Denomination	Purpose
S1	Stitching of Eyelets	Meridian ribbons fixation to the metallic pins
S2	Stitching of Hoop Lap-Joints	Hoop ribbons closure on the circumference of the tank
S3	Stitching for Position	Keep position the hoop ribbons with respect to the meridian ribbons

Due to possible cryogenic application the fluid containment bladder is a single **FEP monolith sheet, vacuum formed** and then welded between dome and seamless cylindrical body and equipped with a fluid port.
Details on material specification and process will be reported in RD [046]. Based on the outcomes reported in [RD04] the table reports materials and relevant technologies:

Table 3-1: SISTEM materials & technologies

Layer	Functions	Main requirements	Materials	Technologies
Restraint	Structural element	Load capability, long term stability	PBO (PolyBenzOxazole)	Webbing Sewing
Bladder	Fluid containment	Flexibility, tightness, fluid compatibility	FEP (Fluorinated Ethylene Propylene)	Vacuum forming Hot welding

~~3.1.1.1~~

The design of the Engineering Model is based on the data derived from both basic material properties and the shape is based on cylindrical barrel configuration with elliptical domes, targeting on operative pressure of 60 bar considering a maximum design pressure of 48 bar with a Proof Factor of 1.25 with a capability of about 13Lt.

This design has been conceived keeping in mind the manufacturing constraints in primis to the manufacturing of the bladder versus fluidic fitting integration and after to the integration of the assy composed by bladder+fitting into the upper dome, the manufacturing sequence is skecthed in the picture below:

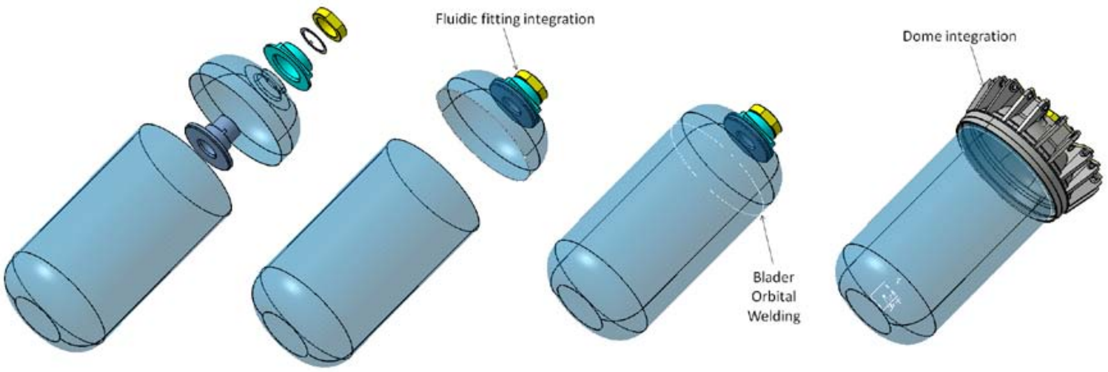

Figure 7-2: Integration sequence between Upper Dome and Bladder

The main components of the SISTEM project are the following:

- Dome Assy (common design)
- Hoop ribbon assy
- Meridian assy
- Bladder
- Fluidic Fitting

To assure the integration of the bladder inside the structural restraint a regulation system based on a parametric study, has been conceived to recovery any "out-of-tolerance". The final assembly will assure a fine balance pretensioning in order to avoid any unverified deformation during the pressurization cycles

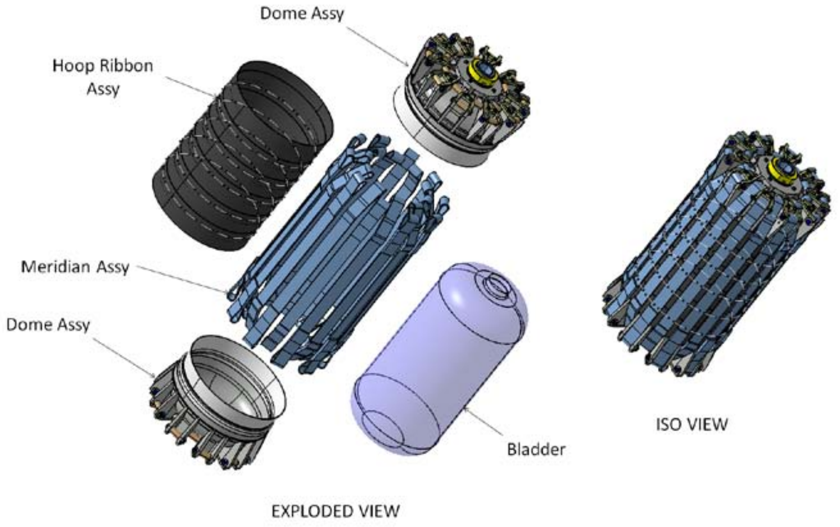

Figure 7-3: Inflatable Tank Design (Section View)

A flexible monitoring system has been also proposed to be connected to a displacement transducers in order to detect the strain of the strap during the pressurization cycles. The EM integration encompassing flexible wires has been achieved with success:

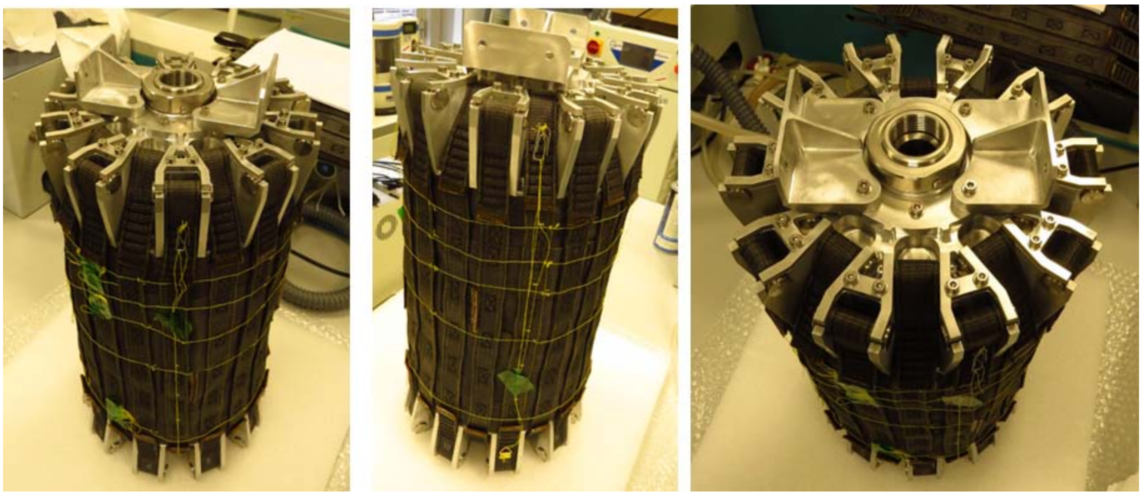

Figure 9-4: Inflatable tank fully integrated

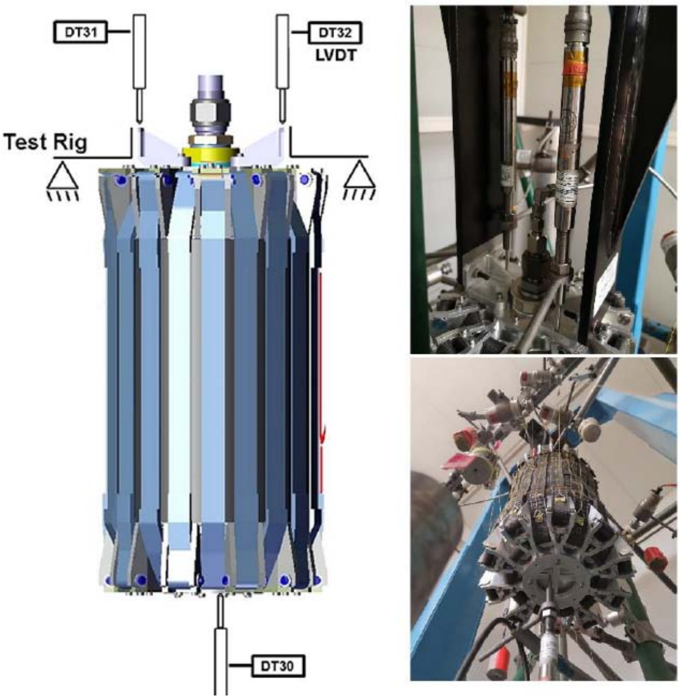

Figure 10-5 Instrumentation (LVDT) Layout

During TRR on the liner of test article, several discontinuity, on circumferential welding, were highlighted and marked. Unfortunately during the Pressure (nitrogen level reached 1 barg) a failure occurred .

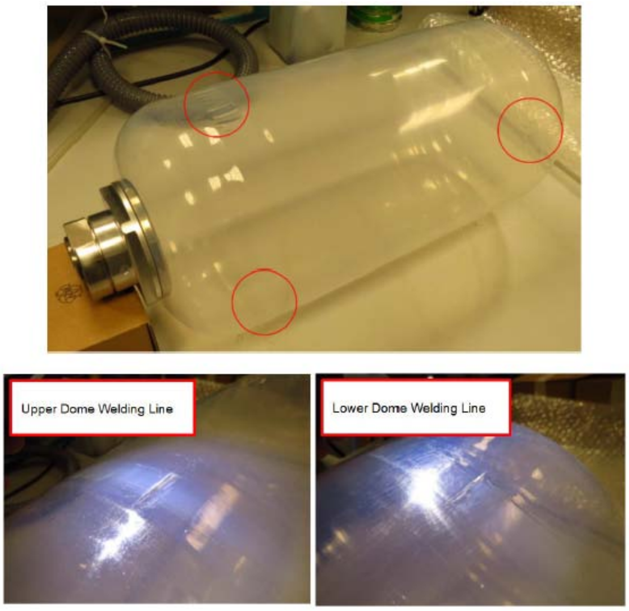

Figure 10-2 Bladder discontinuities

The test set up was disassembled and the visual inspection on the demated test article put in evidence that the majors flaws have been detected on the bladder (Upper dome portion), in an area (called R) already detected as critical.

Figure 10-6: Cracks after first pressurization test

Holscot provided to repair both cracks and then, the repaired bladder has been re-integrated in the EM for the second pressure run. Despite the repair, the bladder still shown discontinuities areas; here below some of them hereafter reported.

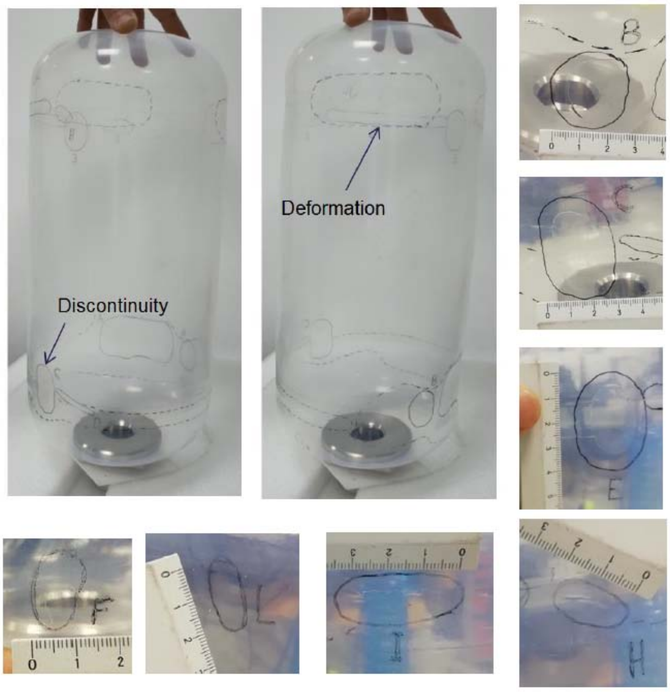

Figure 10-7: Discontinuites on the repaired bladder

In this case, higher pressure during test has been reached but failure occurred again in the welding line along the circumferential welding line. The major findings on bladder are linked to the circumferential welding line, that has been performed on sectors each positioned at 120° meaning that a dedicated development should be put in place to increase reliability and to obtain a correlation between manufacturing process and material test results.

In order to test the structural restraint at higher loads, several recovery actions (overwrapping repairs, balloons , air chamber…) , had put in place and pressurization test (up to 8 trials) performed. Inside the damage liner, 6 inflatable balloons (each one in capsulated to the other in order to protect the internal one from the defect already present on the original bladder) have been inserted. An adapter capable to pressurize the balloon with water and to interface with SISTEM edges complete the overall assembly.

Figure 10-8: Balloon as “ bladder up to six tentative

Finally, a pressurization up to 10 barg has been reached and the test data recordered by the ad-hoc flexible monitoring system. Experimental data are in line with the expected curves in terms of observed displacements and stress, demonstrating that the structural restrains would be able to sustain the design loads.
After test, any findings have been noticed on the structural restraint, in terms of defects on sewing and the restraint could be refurbished for future test campaign.

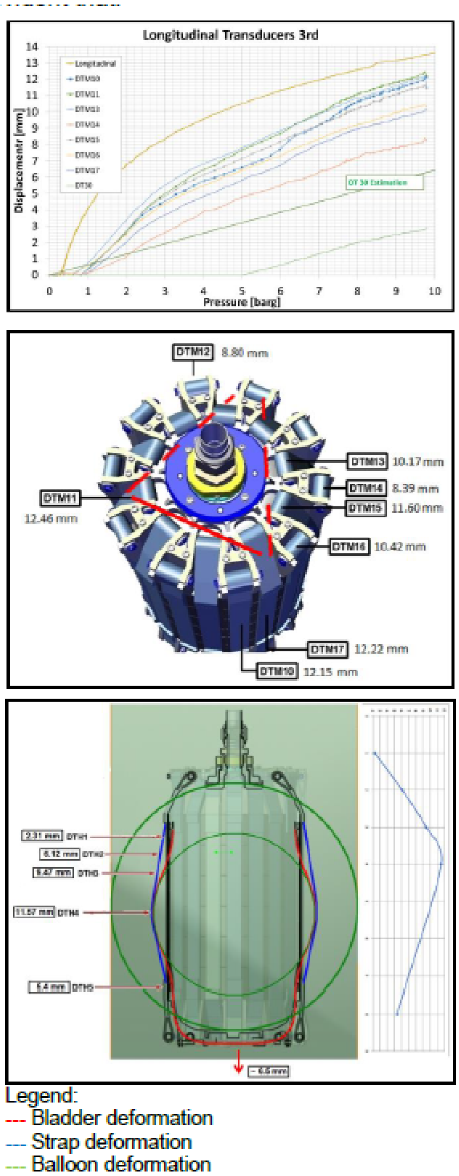

Figure 10-9: Data collected during the final test up to 10 barg.

A full scale polymeric breadboard has been realized by TASI in, with internal 3D printer devoted to perform the foldability test campaign utilizing the DM restraint and the first bladder DM.

Figure 10-10: 10 Cycles Folding BB with bladder inside

A key parameter is also represent by the foldability of the proposed concept, that has been assessed successfully on 3D printed parts, a high compaction level (> 60%) has been successfully reached.

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