S I S T E M
SMALL INFLATABLE SPACE TANKS ENGINEERING MODEL

FINAL REVEW (FR)

OCTOBER 19TH 2021

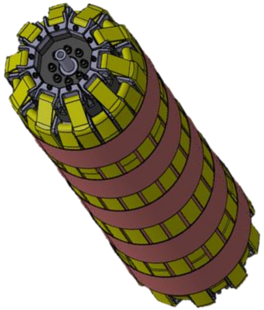
AGENDA

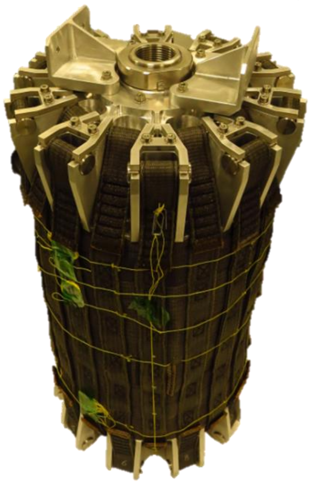
- Recap SISTEM Objectives
- SISTEM consortium
- SISTEM work logic
- Main events: RR, BDR , TRR , PTR outcomes
- SISTEM deliverables
- SISTEM development wrap up
- SISTEM integration and test campaign
- SISTEM test campaign evidences
- Critical area identification for TRL increasing path
- Conclusions and way forward

SISTEM TECHNICAL SOLUTION

/// Main objectives from SoW:

- Design, develop and test a **prototype** for **inflatable gas and cryogenic liquid storage** solutions for long duration manned missions, that **optimizes the volume** (possible launch of tanks in **compacted configuration**) whilst satisfying safety and design requirements.





The technical solutions is based on a **12 liters tank prototype** to fly in compacted configuration and then used on-orbit for high pressure storage of gases or cryogenic fluids or water/urine.

/// Key Aspects:

- High-perfomance ribbon net as structural restraint
- Fluoropolymers bladder
- Flexible Cryo-insulation (SoA)

ThalesAlenia Space

SISTEM ORGANIZATION

Thales Alenia Space in Italy (Prime Contractor)

- Overall program management
- Technology Survey & Tank Concept Selection
- Requirements & Performances Review
- Candidate Materials Trade-off and Selection
- Materials Test Plan & Tank Development Plan
- Tank Prototype Detailed Design & Modelling
- Tank Prototype Metallic Parts (Domes & Fluid Port) Manufacturing
- Tank Prototype Assembly & Testing

SABELT (Sub-Contractor)

- Tank Pressure Restraint Materials and Joints Development & Testing
- Pressure Restraint Mfg

HOLSCOT (Sub-Contractor)

- Tank Bladder Materials and Joints Development
- Bladder & Fluid Port Design Concurrency
- Bladder Mfg & Acceptance Test

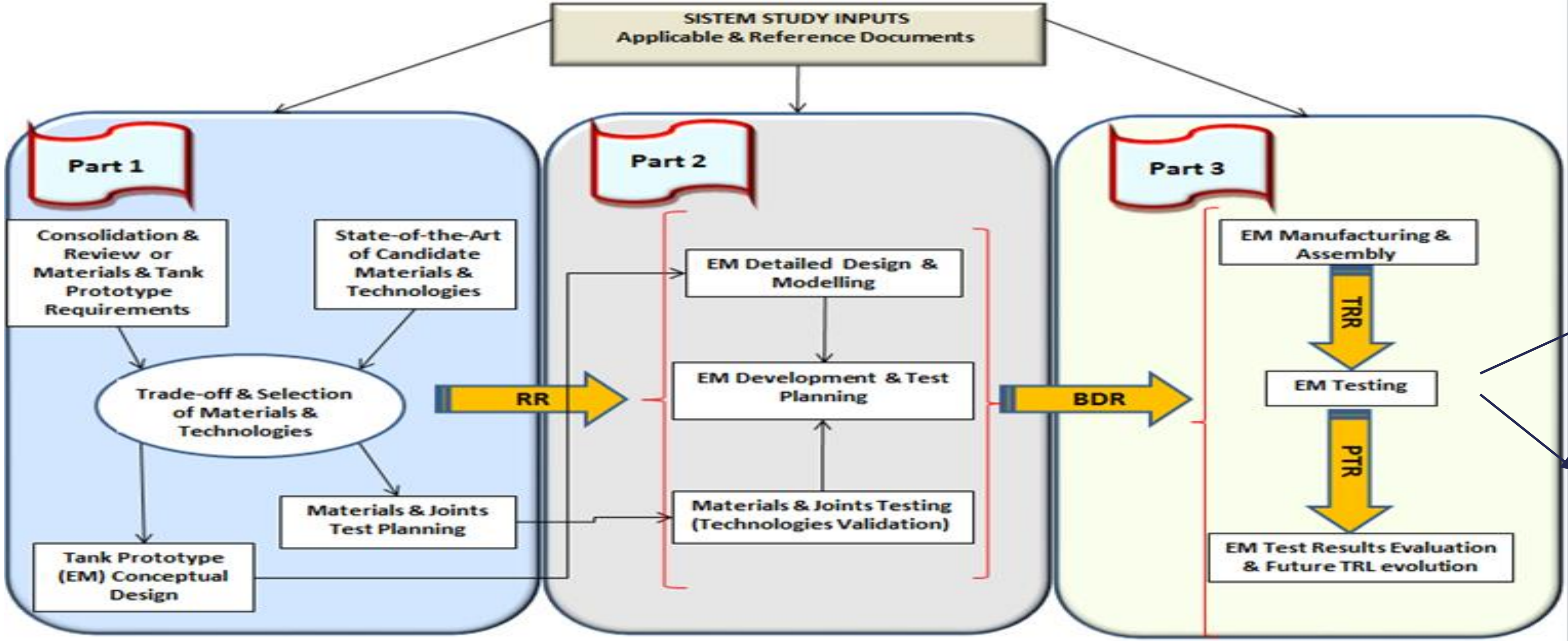
AAC-Research (Sub-Contractor)

- Bladder Basic Materials & Joints Testing

DATA PACKAGE

Event	Link	Deliverables
Requirements definition review (RDR)	TASI-SD-SISTEM-PBR-0127 - RDR2.pdf	• TN1 Definition of key requirements and design drivers • Inflatable tank concept • TN2 Materials space characterization and test plan for • Inflatable tank
Baseline Design Review BDR	TASI-SD-SISTEM--BDR part Apptx.pptx TASI-SD-SISTEM--BDR part B 13072020.pptx	• TN3 Inflatable tank development plan • TN4 Summary of space charact. of mat. selected for the inflatable tank • TN5 Detail design definition of prototype Inflatable tank • SW1 (CAD and Finite Element Model) • TN6 Manufacturing, quality and test plan for prototype inflatable tank
Test Readiness Review TRR	TASI-SD-SISTEM-TRR- 181220220.pdf	• TN7 Test for pressure and mechanical testing • HW2 (Prototype Inflatable Cryogenic Tank to be tested)
Final Review t- FR & FR		• TN8 Update detail design • HW2 (Tested Prototype Inflatable Cryogenic Tank) • TN9: “Product Validation Plan for Development • & Application of Inflatable Tank

SISTEM WORK LOGIC



RUN#1

RUN#2

RUN#3-4-5 (6 attemps)

REQUIREMENTS DEFINITION REVIEW (RDR) OUTCOMES

/// A tank concept is proposed based on an inflatable shell where the structural restraint is being realized by a narrow net of hoop and meridian ribbons while the fluid containment bladder, by a vacuum formed and welded liner compatible by literature with cryo-conditions.

/// The requirements for an inflatable tank concept for on-orbit utilization (stowed empty during launch) ware subdivided in the following as:

- *Functional Requirements*
- *Interfaces Requirements*
- *Environment Requirements*
- *Physical Requirements*
- *Product Assurance Requirements*

/// A set of requirements for new generation of high pressure gas storage tank able to cope with cryo-tank applications has been reported in the TN-1.

/// According to ESA comments, the TN-1 has been revised in two main sections, one devoted to gas and conventional fluids and the other one to cryogenic fluid that has been delivered not restricted to ESA as TASI-SD-SISTEM-TNO-0363

BDR PURPOSE

/// Main activities

- ✓Materials trade-off results and selection and the preliminary tank concept,
- ✓ Testing of the basic materials and the development of the relevant joining processes which are functional to the final manufacturing of the tank and validation testing:
  - ✓On manufactured and defected samples of FEP film and FEP welded samples and Kevlar or Zylon ribbon and on seams (S1, S2 and S3).
- ✓Detailed design and sizing of the prototype tank with the relevant FE model,
- ✓ CAD model and manufacturing drawings and the associated tank prototype test planning
- ✓ Full execution of restraint material test planning

MATERIAL TRADE-OFFS AND TEST PLAN

Based on TN 2 output following basic materials have been selected as well as relevant 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

BLADDER TEST SUMMARY – BASIC MATERIAL

The FEP sheets were supplied by Holscot Fluoroplastics Ltd UK; sample preparation (tension and circular permeability samples) was done by AAC.

Table reported the test plan for basic materials

Test	Aim	Proposed Standard (if available)	Specimens to be tested
Bladder Basic Material			
DSC Differential Scanning Calorimetry	Tg/Degree of Cure	ASTM D7426	5
DMA – Dynamic Mechanical Analysis	Viscoelastic Properties over Time	ASTM D4065	5
TMA - Thermo Mechanical Analysis	Coefficient of Thermal Expansion	ASTM E831	5
Outgassing Analysis	Thermal Vacuum Testing	ECSS-Q-70-02A	3
Permeability	Determining Gas Permeability Characteristics of Plastic Film and Sheeting	ASTM D1434 - or equivalent	5
Chemical compatibility of material solutions	Analysis to be conducted post immersion	ASTM D543	5
Tension	Tensile Strength	ASTM D882/D368	10

Details are collected in AAC 097 2019-20 Report V1.0

BLADDER TEST SUMMARY – JOINT MATERIAL

Joints			
Tensile strength	Test joints between material	ASTM D882/D368	20 at RT
			5 at Low T (e.g. 77 K)
			10 as defected (porosity and cracking)
			5 post repair
Permeability	Gas Permeability Characteristics	ASTM D1434 or equivalent	3
Residual strength	Tension test after mechanical fatigue loading	ASTM D882/D638	10 as pristine, 5 as defected
Performance after repeated folding/ unfolding cycles	Residual strength (tension test after folding cycles)	ASTM D882/D368	10

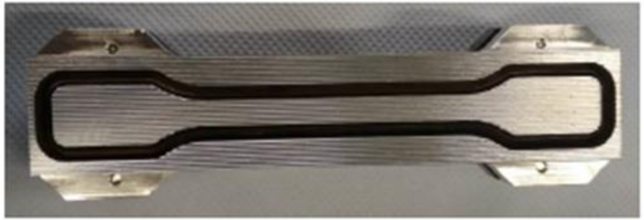
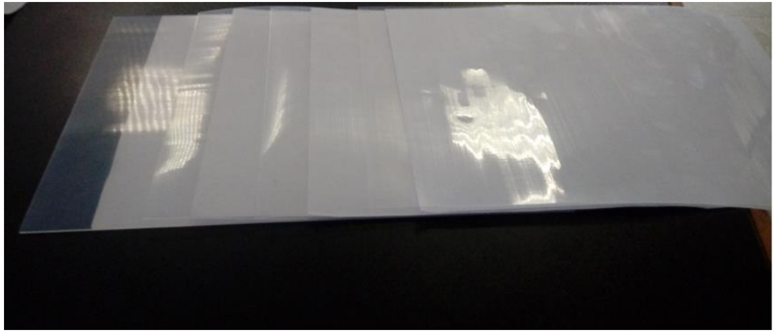


Figure 13. Cutting-die for tensile samples



AAC ACTVITIES

Contract No. 1550006426

aerospace & advanced composites

For the supply of: Small, Inflatable, High Pressure Composite Tanks for Human Spaceflight
Date: 10/04/2020

REPORT

Confidential

Contract No. 1550006426

Fluid Containment Bladder Basic Material & Joints Testing

FINAL REPORT

M. Scheerer
Z. Simon

Aerospace and Advanced Composites GmbH (AAC)

April 2020

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Commercial Register Court: Landesgericht Wiener Neustadt I FN: 350472a I UID-Number: ATU65923539 DUNS Number: 300635302
Bank account: Raiffeisenregionalbank Wiener Neustadt I Kto. Nr. 000-05.029.145 Bank code: 32937 I IBAN: AT 903293700005029145 I BIC: RLNWATWWWRN

BLADDER WELDED MATERIALS RESULTS

/// Tensile mechanical properties of welded FEP material

- No major difference was observed between the original and the clean welded material, the yield strength and the tensile strain vales were lower in case of welded samples.

→ Joint efficiency 0.7

- In comparison to clean welds, the dirty welds showed slightly lower mechanical properties
- The ‘weld repaired’ samples showed very similar results to the ‘clean weld’ samples.
- Fatigue and/or folding did not negatively influence the mechanical properties of welded samples.

BLADDER MATERIALS RESULTS

- /// Welded FEP material showed some plastic behaviour at liquid nitrogen temperature
- /// The LN2 exposure did not result in a change of mechanical properties.
- /// No visible changes were observed on the samples during and after fatigue loading and after folding/unfolding loading.
- /// Fatigue and/or folding did not negatively influence the mechanical properties of welded samples.
- /// The helium gas permeability properties of as received (without welds) and welded samples are very similar
- /// Tensile moduli and yield strengths are on the same level for both as received and welded samples.
- /// The original thin foil material showed high strains at break.

RESTRAINT TEST SUMMARY

/// Ribbon basic materials

Hoop and meridian belts based on PBO (Zylon®) treated with FKM-Viton, showed a mechanical performance capability of 55000 N.

At beginning two different ribbons have been evaluated :

- one for the hoop assy based on already qualified belts (Cygnus program)
  - Width = 49,5 mm
  - Thickness = 1,0 mm
  - Mass = 38 g/m
- and one developed at hoc

RESTRAINT TEST PLAN

/// Basic ribbon

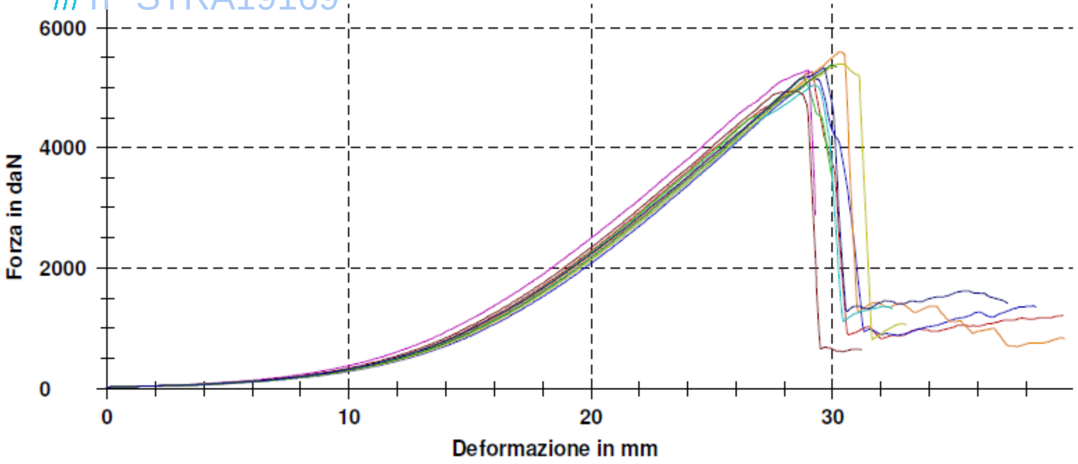
ID code	Test	Aim	Standard	Sample State	#Specimens to be tested
R1	**Monoaxial tension**	Ultimate Tensile Strength (UTS) Testing	FIA 8853/98	As-received	10
R2	**Monoaxial tension**	Ultimate Tensile Strength (UTS) Testing	FIA 8853/98	With defects(*)	5
R3	**Light ageing**	Evaluate detrimental effect on ribbon material	Internal procedure (Sabelt)	As-received	5
R4	**Monoaxial tension**	Residual strength after UV irradiation	FIA 8853/98	After irradiation	5

ID code	Test	Aim	Standard	Sample State	#Specimens to be tested
R5	**Monoaxial tension**	Ultimate Tensile Strength (UTS) Testing	FIA 8853/98	As-received	3

Meridian- new configuration

RESTRAINT BELT SELECTION

/// n° STRA19169



Advantages:

- good reproducibility,
- high load capability
- dimensionally compatible with CAD reqs
- predictable failure mode
- available in Sabelt

MODIFIED TEST PLAN

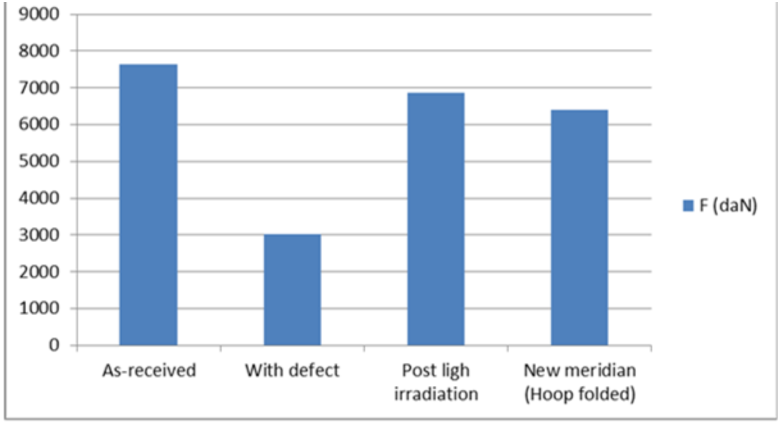
ID code	Test	Aim	Standard	Samples	Specimens to be tested	Note
S9	Monoaxial tension	Ultimate Tensile Strength (UTS) Testing	FIA 8853/98	As-received	10	
S11	Fatigue loading	Evaluate detrimental effect after 100 cycles	Internal procedure (Sabelt)	/	3+3	
S12	Folding cycle	Evaluate detrimental effect after 10 folding/unfolding	Internal procedure (Sabelt)	/	3+3	
S13	Long term loading	Evaluation of permanent deformation	Internal procedure (Sabelt)	/	3+3	
S14	Monoaxial tension	Residual strength after fatigue loading	FIA 8853/98	Post S11	3	
S15	Monoaxial tension	Residual strength after folding cycles	FIA 8853/98	Post S 12	3	
S16	Monoaxial tension	Residual strength after endurance cycle	FIA 8853/98	Post sS3	3	
S17	Monoaxial tension	Residual strength after combined cycles	FIA 8853/98	Post (S13+S12+S11)	3	

BASIC MATERIAL RESULTS

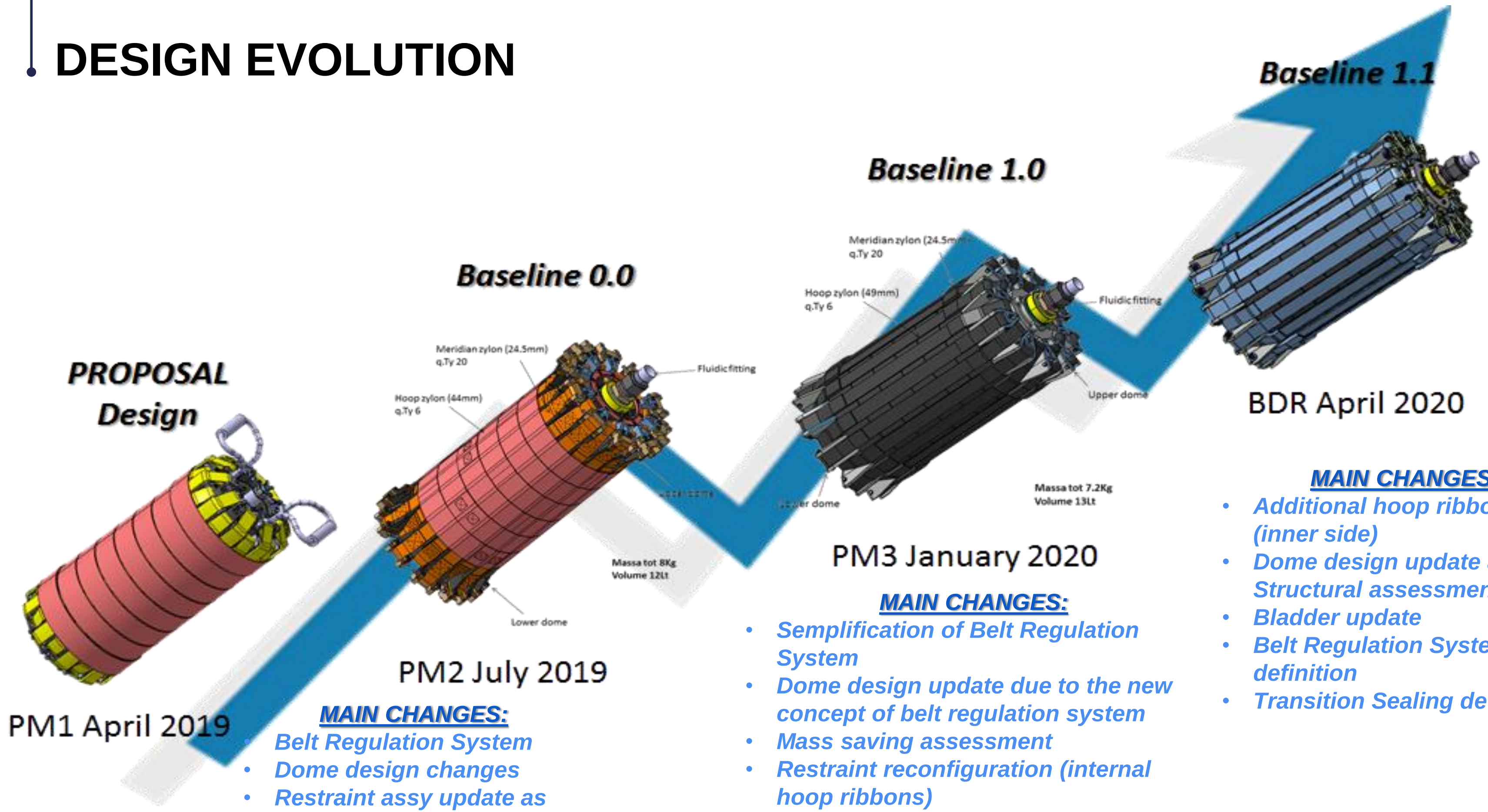
- Test campaign on basic ribbon materials highlighted a linear behavior and a good standard deviation of tested specimens, the failure mode is the webbing rupture.

- Effect of defects (transverse cut of 24.5 mm) is about 40% of the load capability and a slight reduction (about 10%) takes place on samples after irradiation, confirming the excellent effectiveness of Viton as protective coating for PBO-based ribbon.

- The meridian new configuration (w=25.4 mm) showed good performance in terms of linearity and rupture mode and finally the load capability is up to 85% of the hoop basic ones



DESIGN EVOLUTION



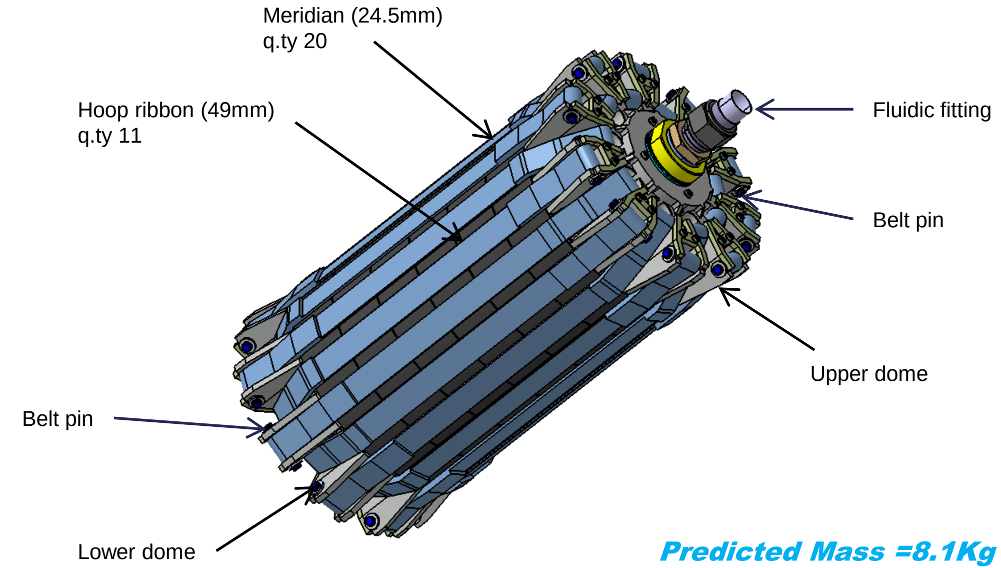
MAIN CHANGES:
- *Belt Regulation System*
- *Dome design changes*
- *Restraint assy update as per SABLET input*

MAIN CHANGES:
- *Semplification of Belt Regulation System*
- *Dome design update due to the new concept of belt regulation system*
- *Mass saving assessment*
- *Restraint reconfiguration (internal hoop ribbons)*
- *Bladder definition*

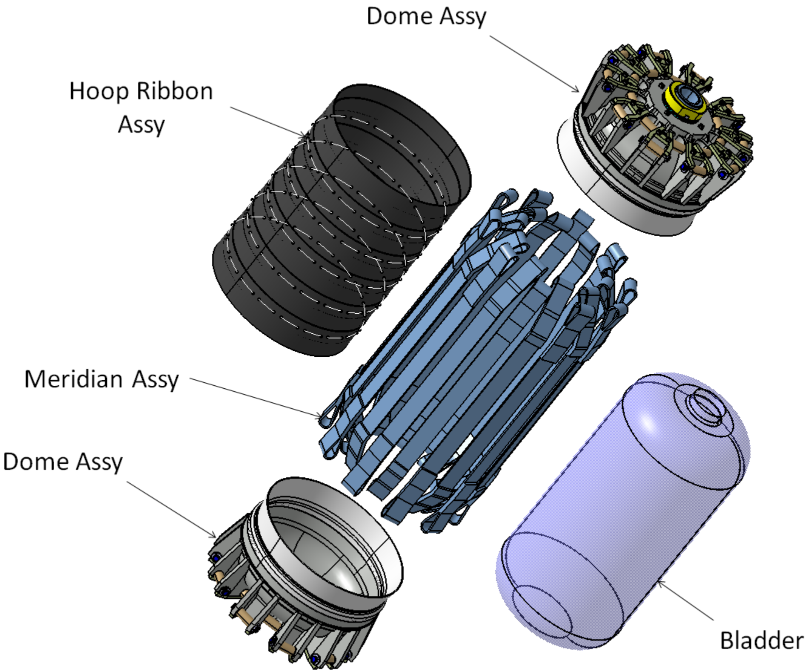
MAIN CHANGES:
- *Additional hoop ribbon layer (inner side)*
- *Dome design update as per Structural assessment results*
- *Bladder update*
- *Belt Regulation System definition*
- *Transition Sealing definition*

BASELINE DESIGN

The final configuration (BASELINE 1.1) has been selected considering the FEM analysis outputs, the manufacturing, mass and flexibility aspects,.



Predicted Mass =8.1Kg
Vol= 13 lt

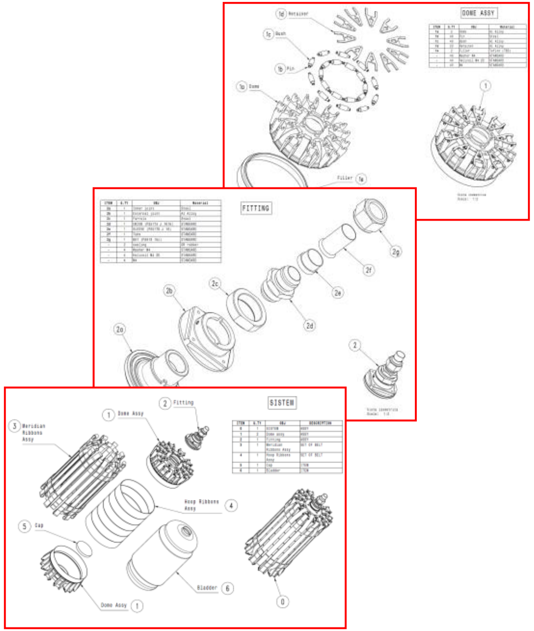


EXPLODED VIEW

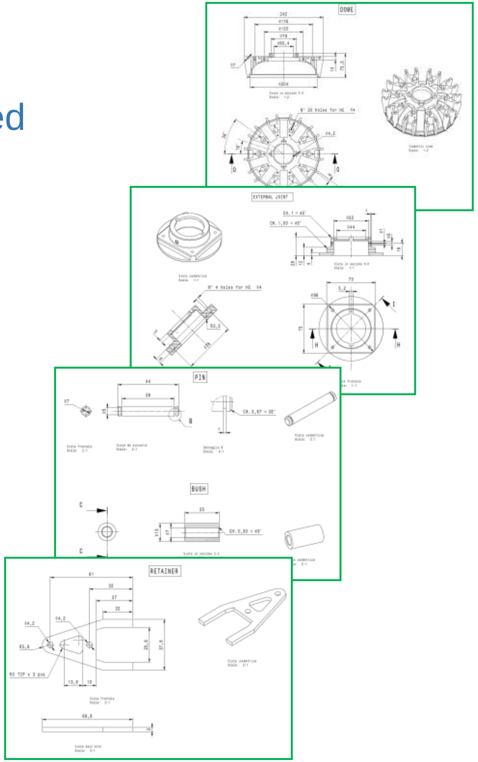
BASELINE DESIGN

The metallic parts and assembly drawing under TAS responsibility are listed hereafter:

- ASSY DWG
  - Upper Dome assy
  - Lower Dome assy
  - Fluidic fitting assy
  - Retain system assy
  - Tank system assy
  - Fasteners part list
  - Bush VS meridian map
- ITEM DWG
  - Dome
  - Cap
  - Belt Pin
  - Pin Bush
  - Retain
  - Bladder
  - Transition profile
  - Fluidic fitting ferrule
  - External joint
  - Internal joint
  - Test retainer



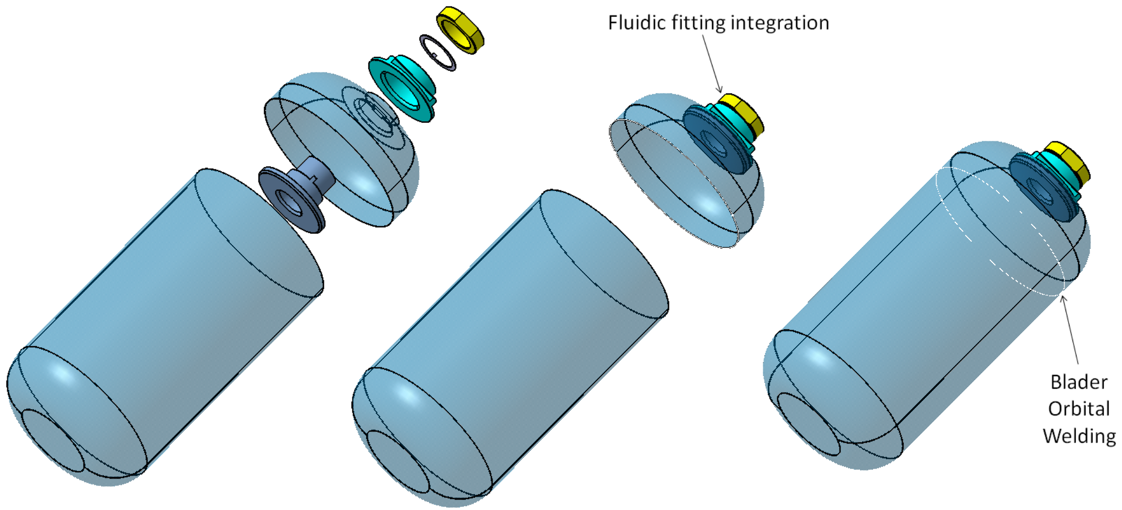
… ASSY DWG



… ITEM DWG

BASELINE DESIGN

The integration sequence of bladder and fluidic fitting has been defined in accordance with the suppliers, the inner & the external joints shall be delivered to Holscot in order to be integrated just before to perform the last welding of the bladder as shown in the picture below:

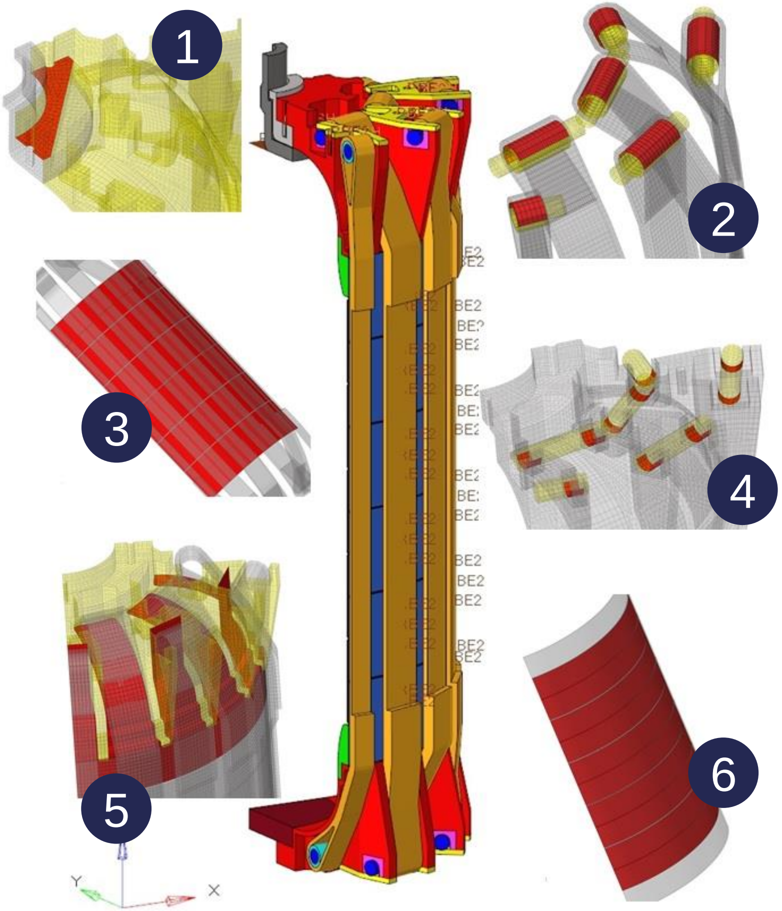


CONTACT CONSTRAINTS

The contact body pairs are listed below and the contact surfaces are showed in following figure marked in red.

The contact algorithm used is: segment to segment.

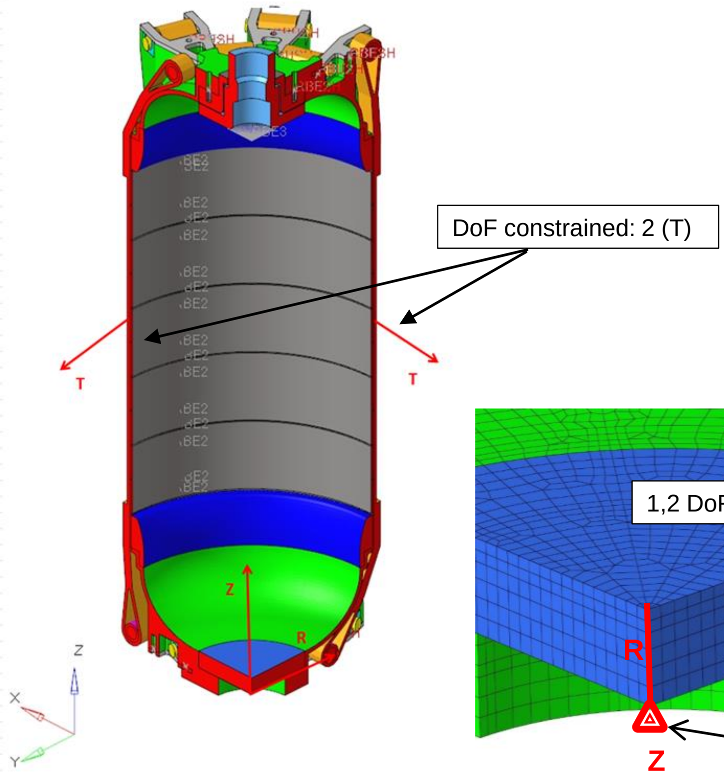
1. Upper dome – fluid fitting
2. Pins – Meridian belts
3. Meridian belts - external hoop belts
4. Pins – Inserts
5. Meridian belts – domes (upper and lower)
6. Internal-External Hoop belts

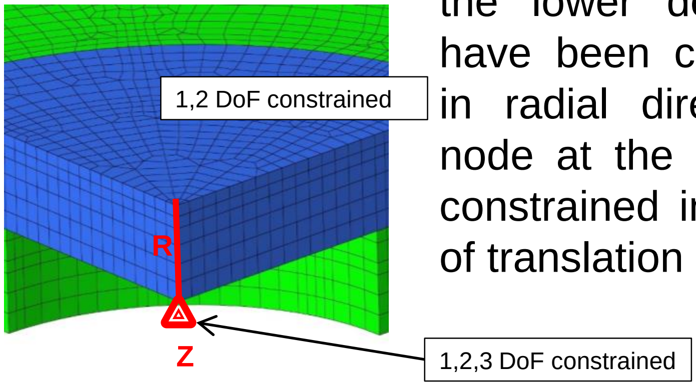


BOUNDARY CONDITION

Applied pressure in FE analysis is equal to

$$1.25 * MDP = 60\ bar$$

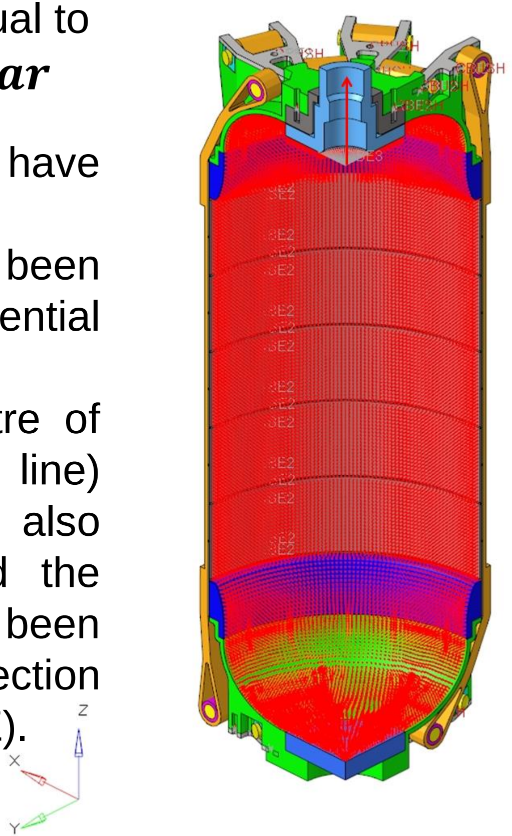




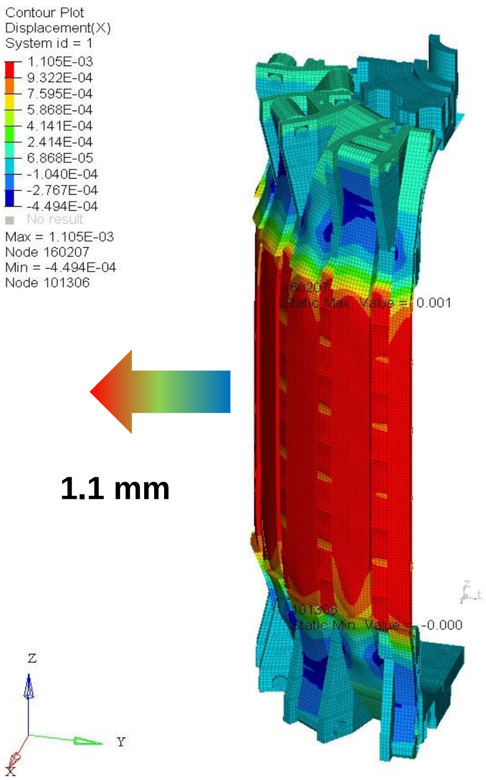
Symmetry constraints have been adopted.

The model have been constrained in tangential direction.

The nodes at the centre of the lower dome (red line) have been constrained also in radial direction and the node at the base has been constrained in all 3 direction of translation (R,T and Z).

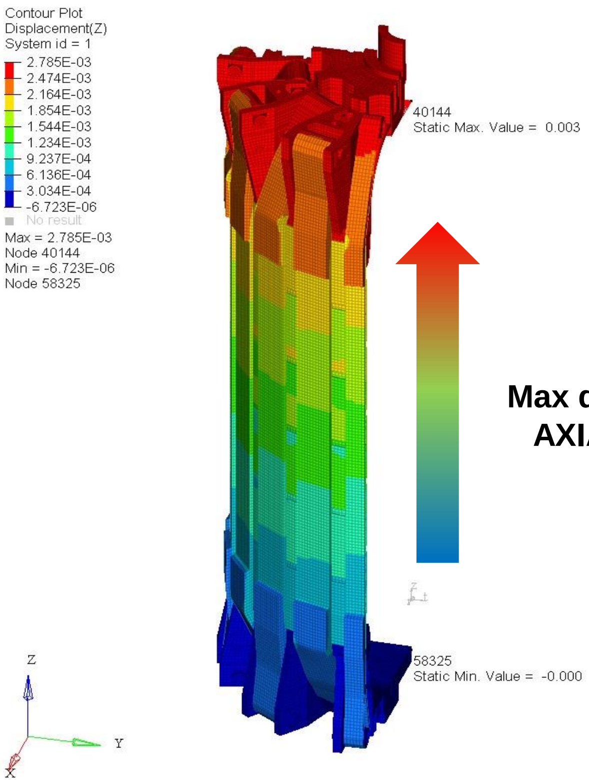


ANALYSIS RESULTS – DISPLACEMENTS -



Max disp. RADIAL

1.1 mm



Max disp. AXIAL

2.8 mm

SISTEM
Small Inflatable Space Tank Engineering Model
Analysis Report

Written by	***Responsibility*** + handwritten signature if no electronic workflow tool
Miriana Valentino	Author
Verified by	
Marina Bellini	Checker
Approved by	
Antonia Simone	Study Manager
Released by	
Rosetta Cavaglià	Documentation Manager

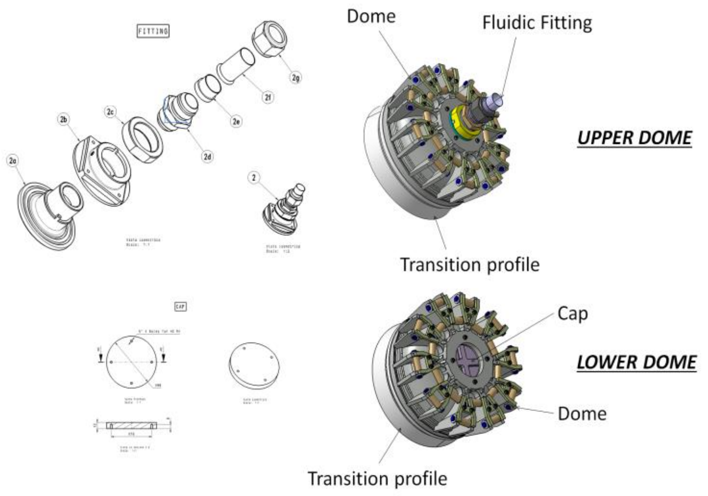
Approval evidence is kept within the documentation management system.

BASELINE DESIGN

Inflatable tank made from the following parts:

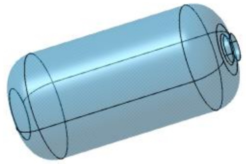
- Machined Dome assy: Common design (Al 7075-T7351)
- Lower cap (Al 7075-T7351)
- Transition Profile (elastomeric)
- Retainer System (Al 7075-T7351)
- Pins (Inconel® 718)
- Hoop Ribbon assy (PBO-Zylon)
- Meridian assy (PBO-Zylon)
- Bladder (Fluorinated Ethylene Propylene – FEP)

Under TASI responsibility

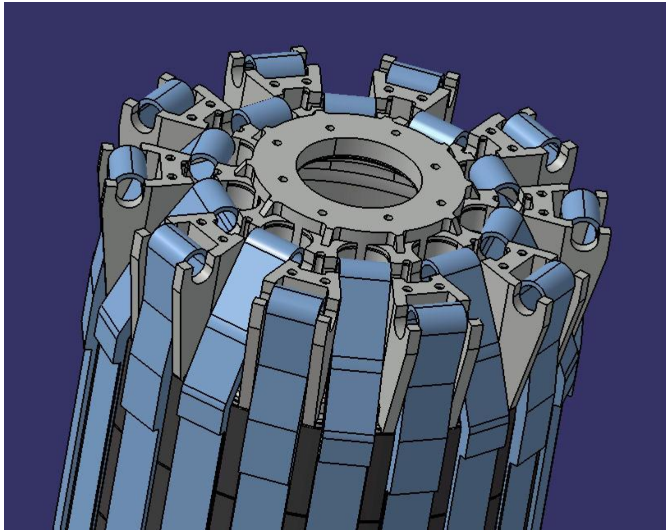


Under SABELT responsibility

Under HOLSCOT responsibility



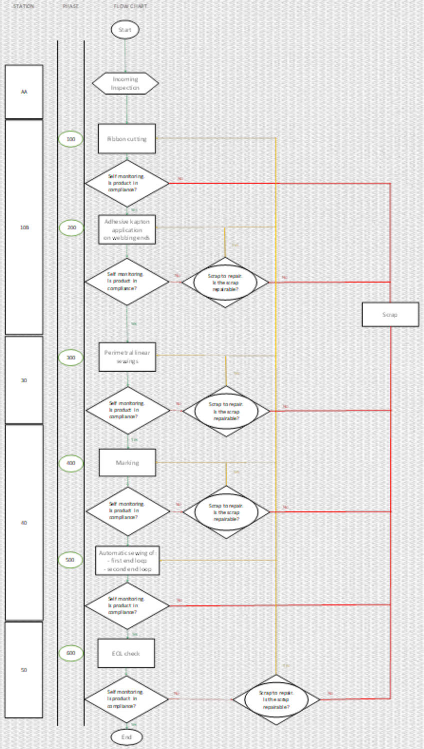
SISTEM -Restraint



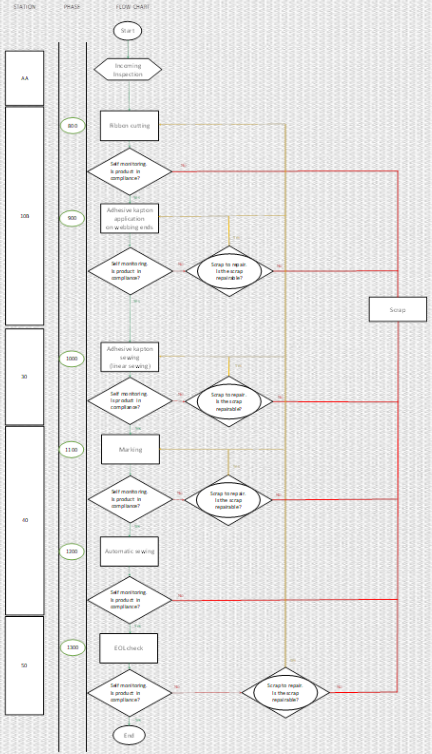
SISTEM – Small Inflatable Space Tanks Engineering Model

- PROTOTYPE PROCESS CYCLES AND PRODUCTION PLAN -

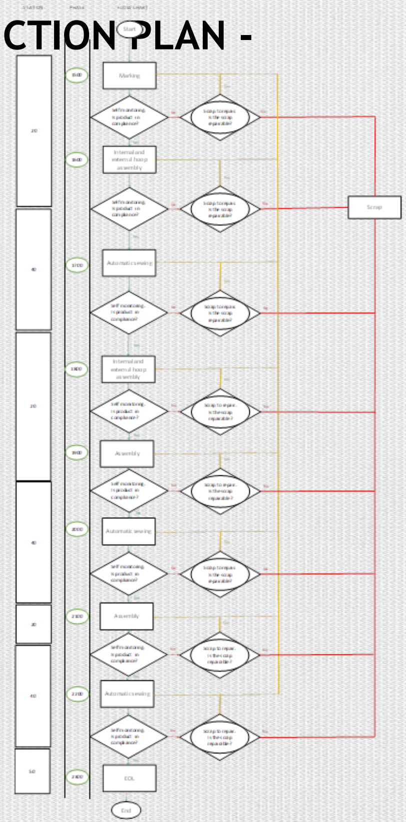
- 3 main process steps
  - Meridian belts
  - Hoop belts
  - Restraint assembly



Typical flow chart for
the meridian manufacturing process



Typical flow chart for
the hoop manufacturing process

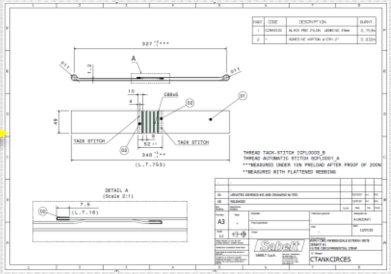


Typical flow chart for
the assembly manufacturing
process

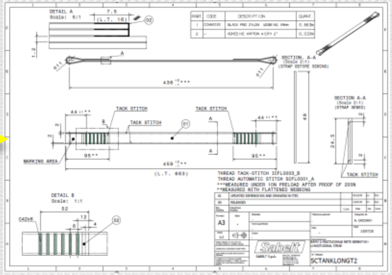
SISTEM – Small Inflatable Space Tanks

- DESIGN -

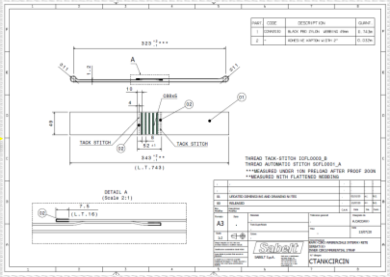
Longitudinal strap

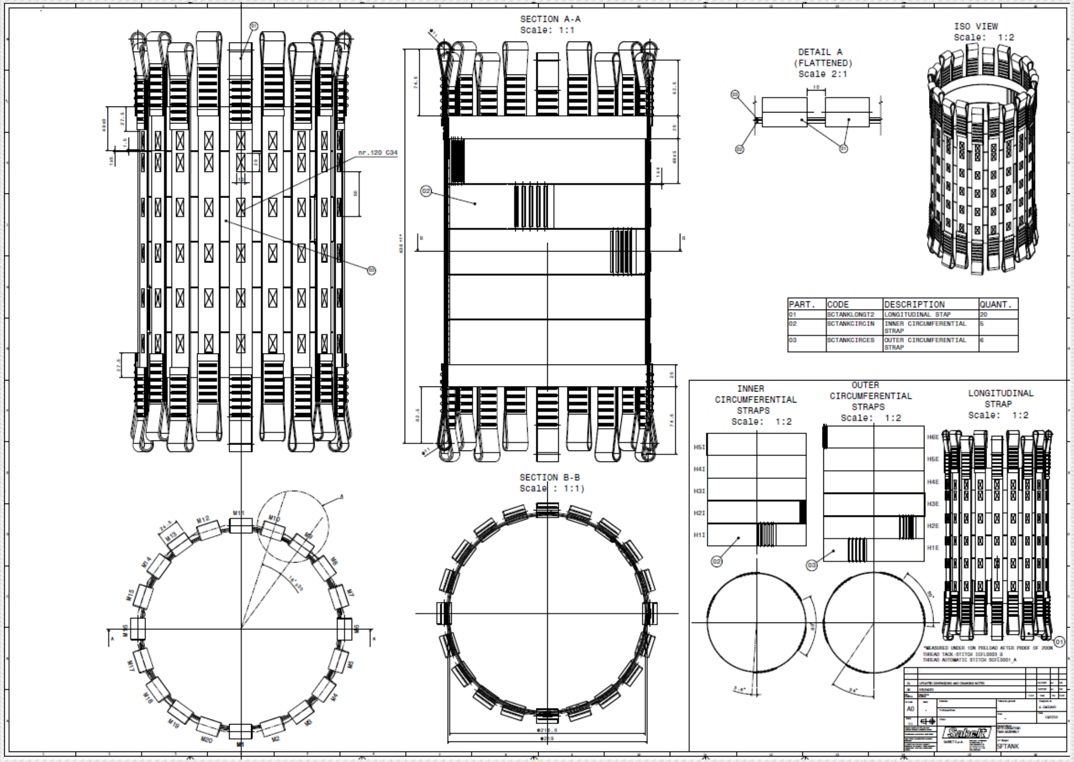


Outer Circumferential strap



Inner circumferential strap

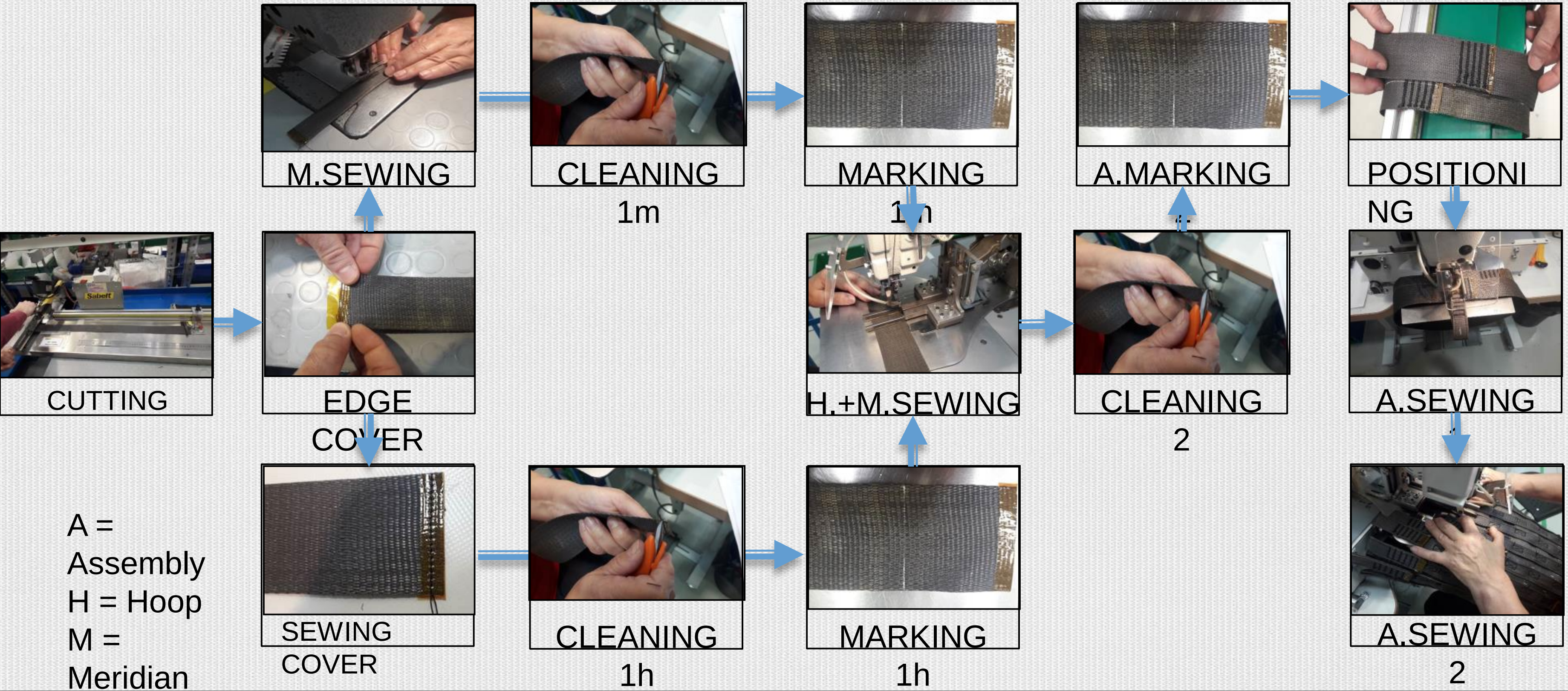




Tank assembly

SISTEM – Small Inflatable Space Tanks Engineering Model

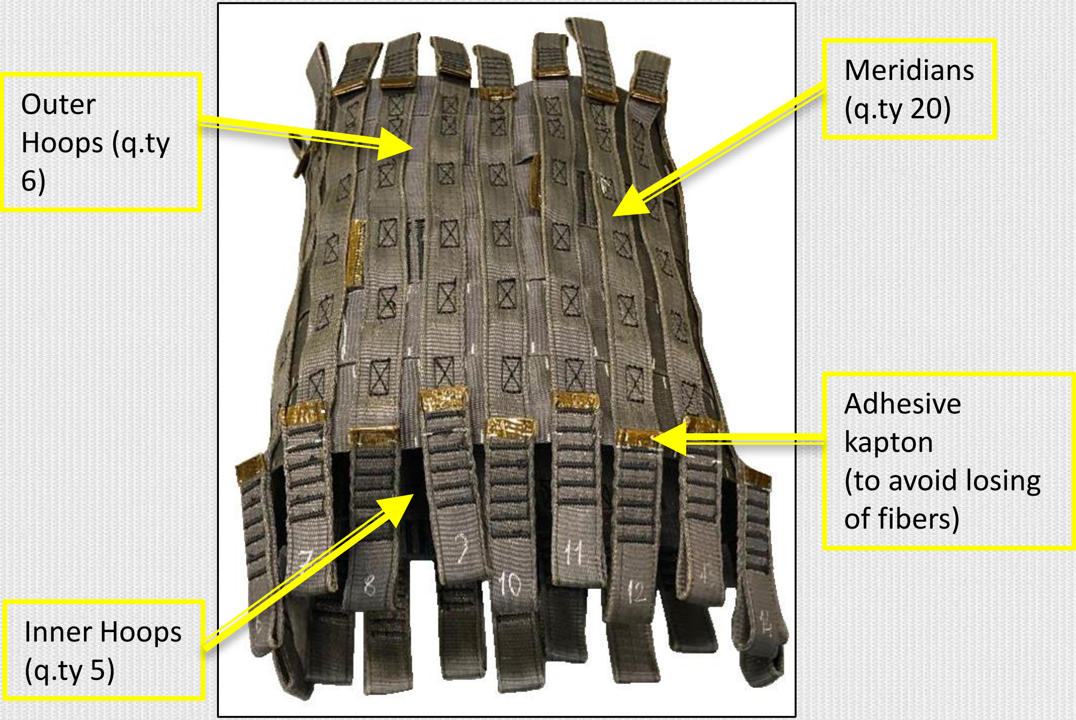
- PROTOTYPE PROCESS CYCLES AND PRODUCTION PLAN -



A = Assembly
H = Hoop
M = Meridian

SISTEM – Small Inflatable Space Tanks

- CONFIGURATION AND FEATURES -



- Lightness (about 0,89 kg)
- High flexibility and foldability

HOLSCOT™

50 YEARS

1970 - 2020

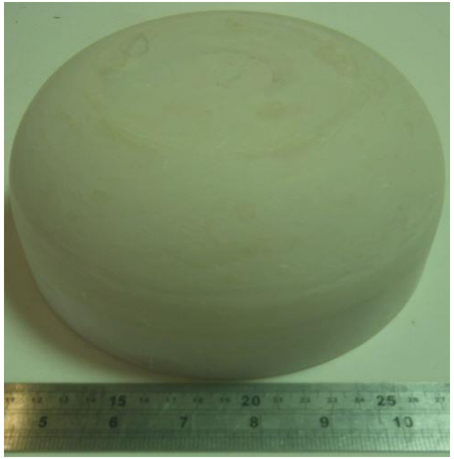
OF DIVERSITY IN FLUOROPOLYMERS

Activities

- Manufacture of mould tools to produce vacuum formed endcaps
- Manufacture of vacuum formed endcaps
- Receipt of inlet port assembly
- Manufacture of jigs for welding endcaps to bladder body
- Manufacture of bladder central body

Manufacture of mould tools to produce vacuum formed endcaps

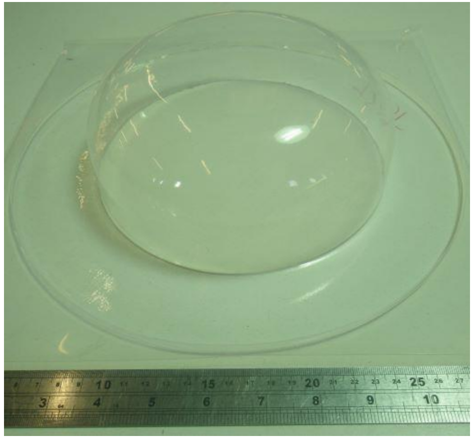
Mould tool for open end



Mould tool for closed end

Manufacture of vacuum formed endcaps

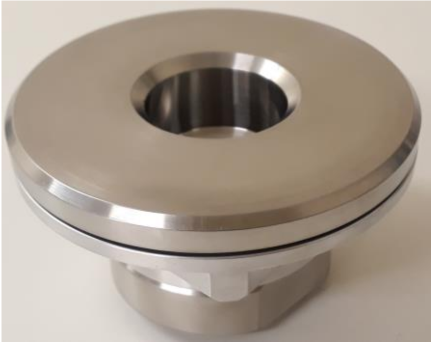
Vacuum formed endcap for open end (before trimming to size)



Vacuum formed endcap for closed end (before trimming to size)

Receipt of inlet port assembly

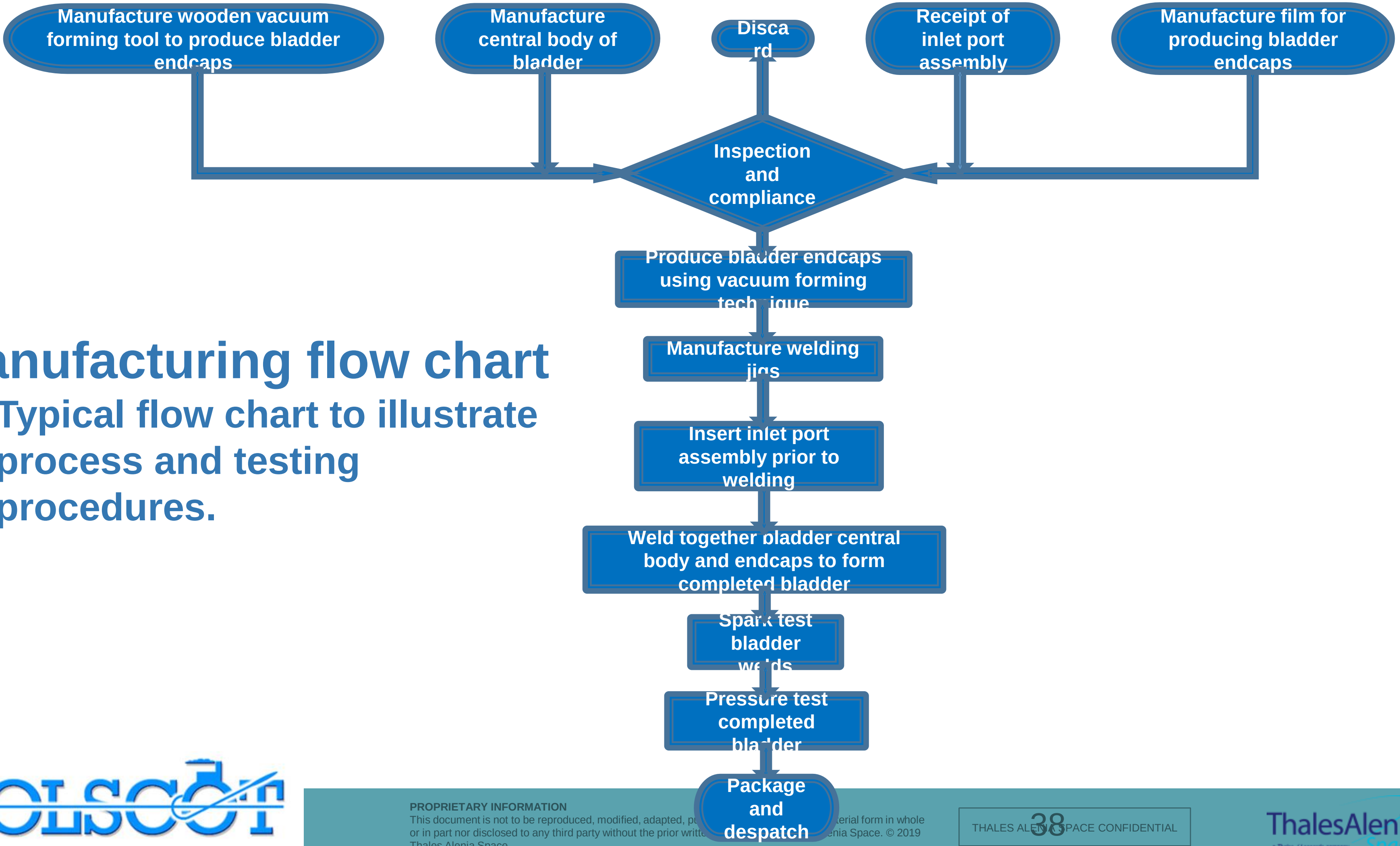
Top profile



Bottom profile

HOLSCOT

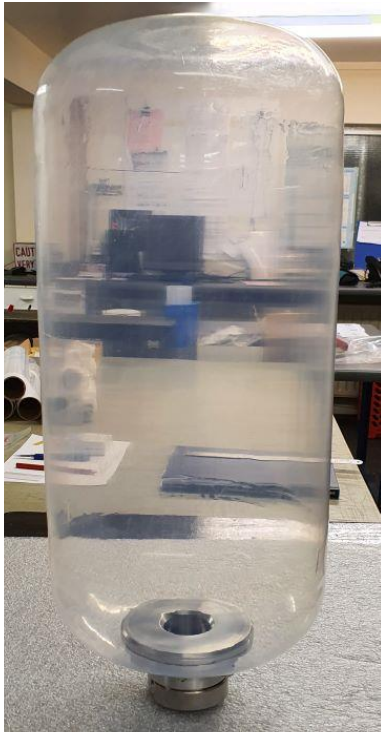
ThalesAlenia Space



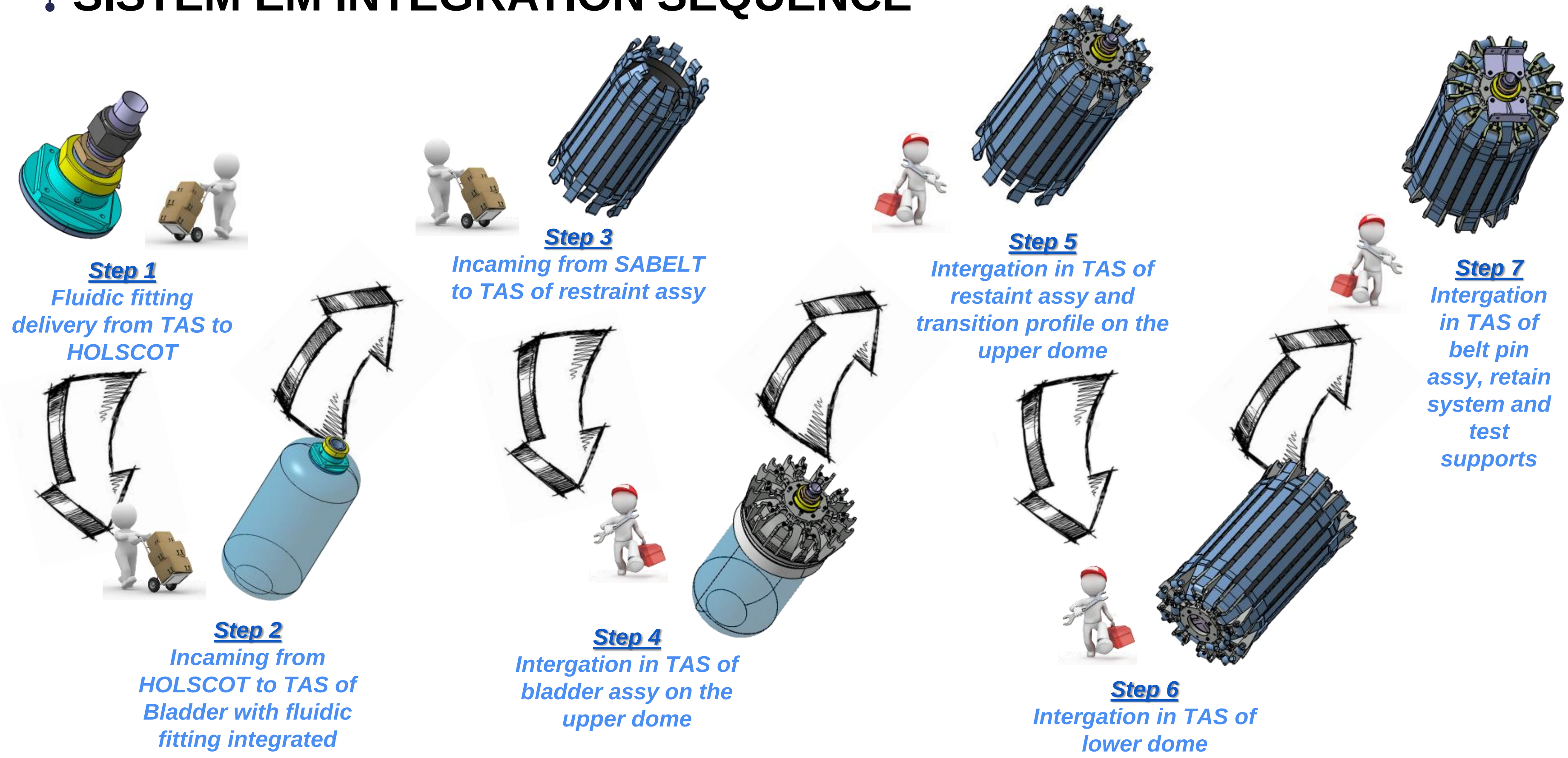
Manufacturing flow chart

- Typical flow chart to illustrate process and testing procedures.

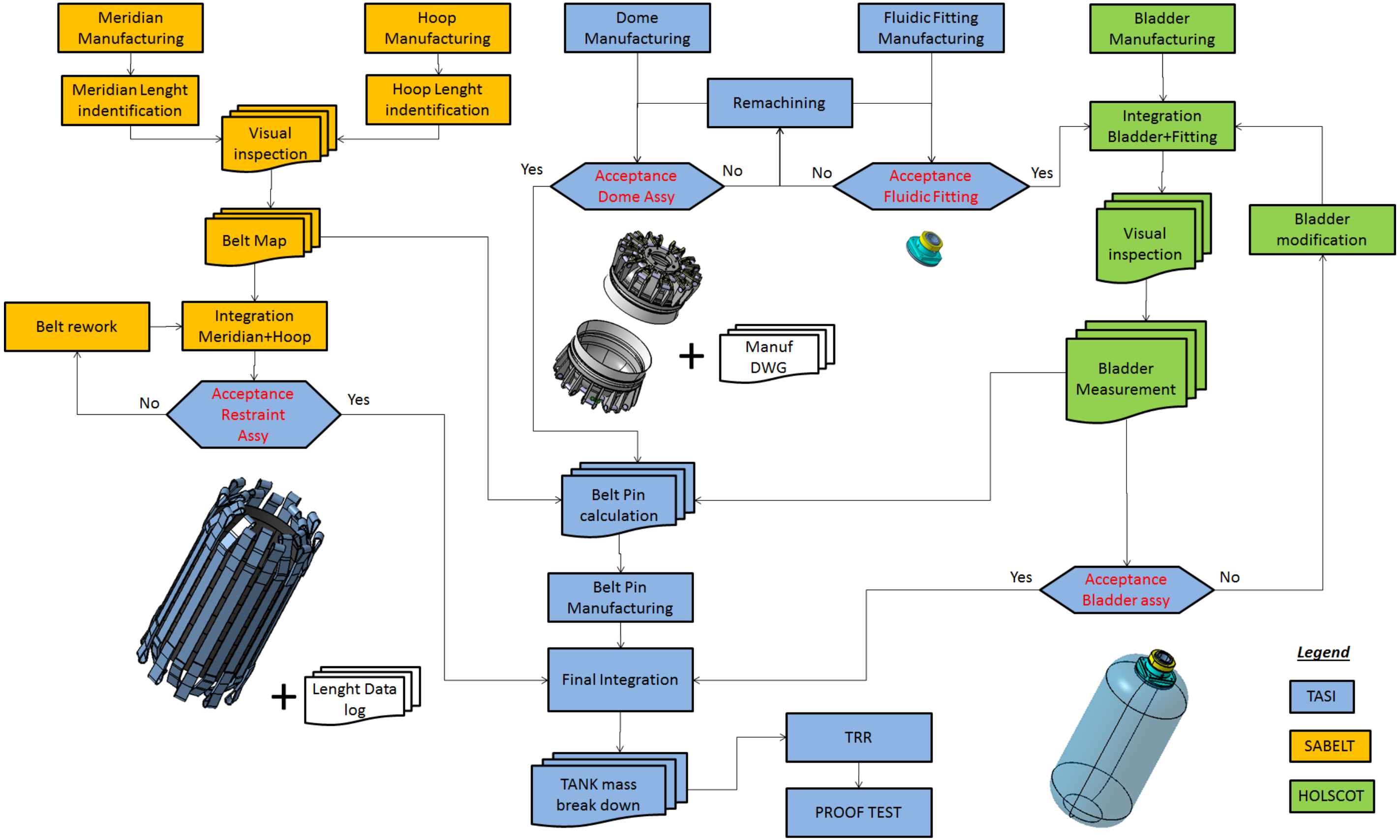
Completed bladder



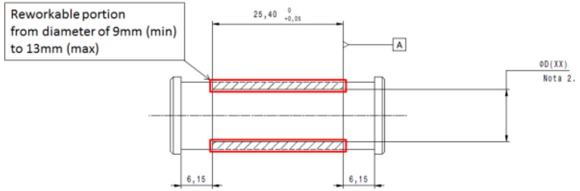
SISTEM EM INTEGRATION SEQUENCE

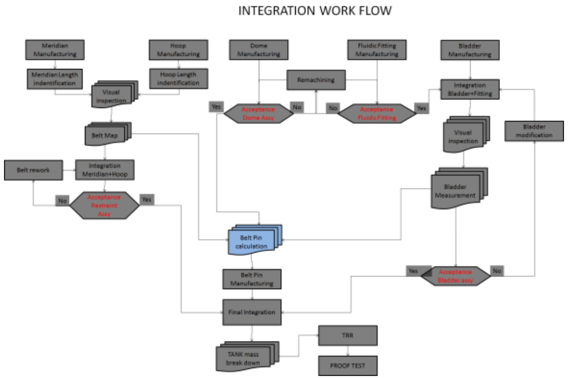


INTEGRATION WORK FLOW

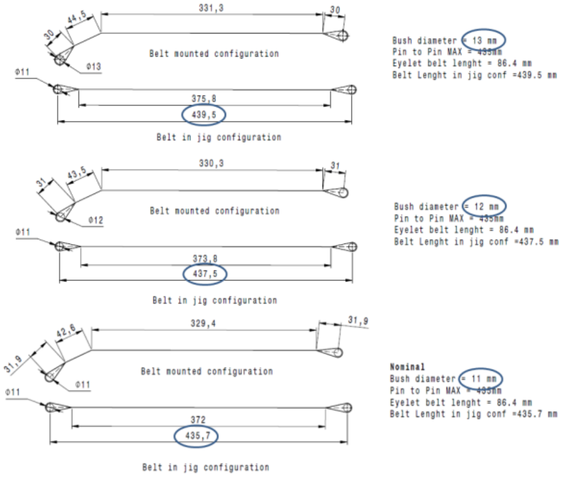


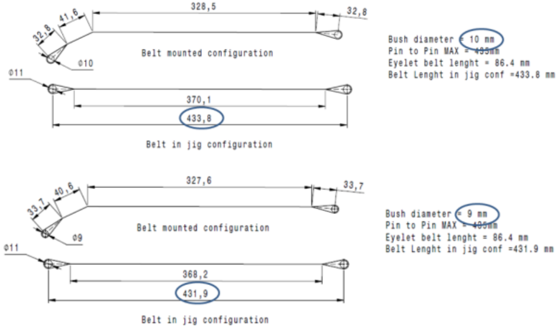
INTEGRATION WORK FLOW





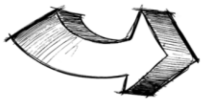
CALIBRATION ASSESSMENT





Belt

Pin Calibration



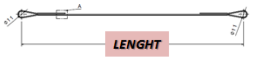
Φbush	L belt	
13	439.5	Δ2mm
12	437.5	Δ1.8mm
11	435.7	Δ1.9mm
10	433.8	Δ1.9mm
9	431.9	

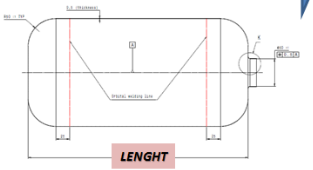
Calibration Matrix

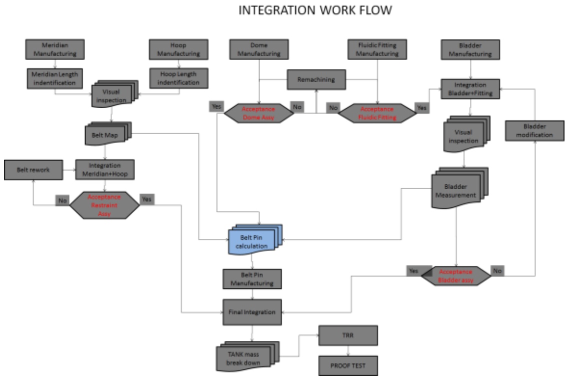
INTEGRATION WORK FLOW

Meridian	Lunghezza	Max/min	Meridian Nominal lenght	Δ con il nominale	Rilavorazione approssimata a 0.5mm	SHORT bladder				NOMINAL bladder	LONG Bladder	
M1A	435.04		436	1.0	1.0	12.5	12	11.5	11	10.5	10	9.5
M2A	434.93			1.1	1.0	12.5	12	11.5	11	10.5	10	9.5
M3A	434.37			1.6	1.5	12.5	12	11.5	11	10.5	10	9.5
M4A	434.60			1.4	1.5	12.5	12	11.5	11	10.5	10	9.5
M5A	435.17			0.8	1.0	12.5	12	11.5	11	10.5	10	9.5
M6A	434.86			1.1	1.0	12.5	12	11.5	11	10.5	10	9.5
M7A	435.78			0.2	0.0	13	12.5	12	11.5	11	10.5	10
M8A	435.02			1.0	1.0	12.5	12	11.5	11	10.5	10	9.5
M9A	435.36			0.6	0.5	13	12.5	12	11.5	11	10.5	10
M10A	435.64			0.4	0.5	13	12.5	12	11.5	11	10.5	10
M11A	434.19	Max		1.8	2.0	12	11.5	11	10.5	10	9.5	9
M12A	435.44			0.6	0.5	13	12.5	12	11.5	11	10.5	10
M13A	435.34			0.7	0.5	13	12.5	12	11.5	11	10.5	10
M14A	434.72			1.3	1.0	12.5	12	11.5	11	10.5	10	9.5
M15A	435.16			0.8	1.0	12.5	12	11.5	11	10.5	10	9.5
M16A	436.07	min		-0.1	0.0	13	12.5	12	11.5	11	10.5	10
M17A	435.44			0.6	0.5	13	12.5	12	11.5	11	10.5	10
M18A	434.60			1.4	1.5	12.5	12	11.5	11	10.5	10	9.5
M19A	435.00			1.0	0.0	12.5	12	11.5	11	10.5	10	9.5
M20A	434.86			1.1	1.0	12.5	12	11.5	11	10.5	10	9.5
					BLADDER LENGHT HYPOTHESIS	396	397	398	399	400	401	402

MERIDIAN LENGHT



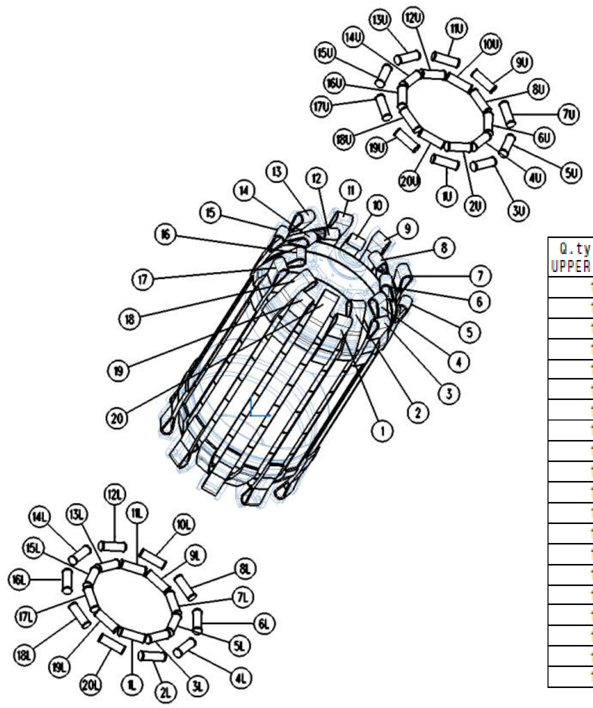


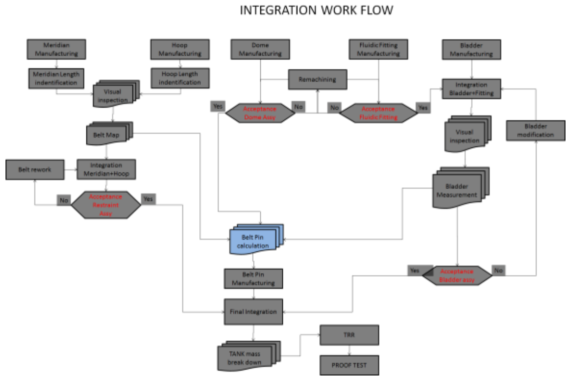


Belt

Pin Calibration

INTEGRATION WORK FLOW





BELT PIN MAP

Q.ty PIN UPPER DOME	Cod. Tank	Cod. Pin	Diam [D]
1	1U	B	10.5
1	2U	B	10.5
1	3U	B	10.5
1	4U	B	10.5
1	5U	B	10.5
1	6U	B	10.5
1	7U	C	11
1	8U	B	10.5
1	9U	C	11
1	10U	C	11
1	11U	A	10
1	12U	C	11
1	13U	C	11
1	14U	B	10.5
1	15U	B	10.5
1	16U	C	11
1	17U	C	11
1	18U	B	10.5
1	19U	B	10.5
1	20U	B	10.5

Q.ty PIN LOWER DOME	Cod. Tank	Cod. Pin	Diam [D]
1	1L	B	10.5
1	2L	B	10.5
1	3L	B	10.5
1	4L	B	10.5
1	5L	B	10.5
1	6L	B	10.5
1	7L	C	11
1	8L	B	10.5
1	9L	C	11
1	10L	C	11
1	11L	A	10
1	12L	C	11
1	13L	C	11
1	14L	B	10.5
1	15L	B	10.5
1	16L	C	11
1	17L	C	11
1	18L	B	10.5
1	19L	B	10.5
1	20L	B	10.5

BELT PIN SPARE

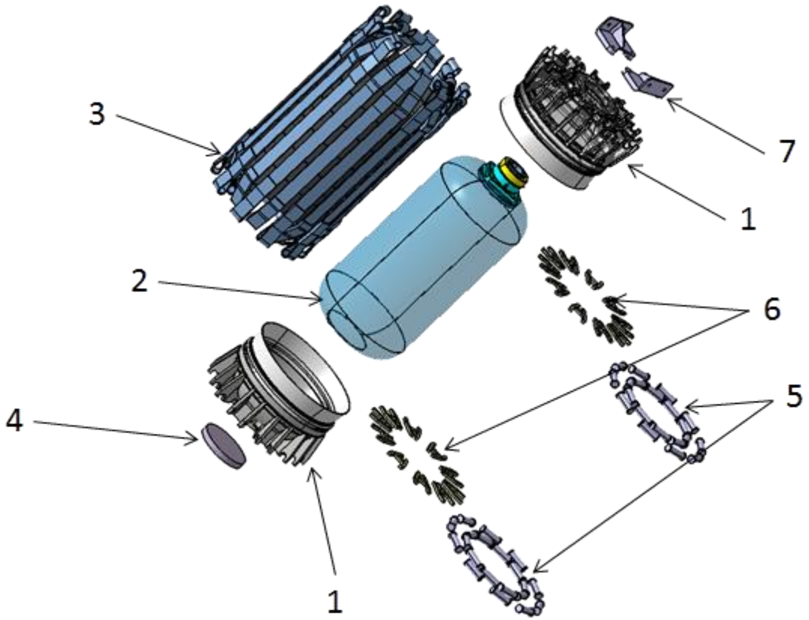
Q.ty PIN SPARE	Cod. Pin	Diam [D]
1	A	10
1	B	10.5
1	C	11

Belt Pin Calibration

MASS BREAK DOWN

ID	ITEM		Q.ty	Mass [kg]	Total mass [kg]
1	Dome		2	1.765	3.53
2	Bladder Assy		1	1.763	1.763
3	Restraint		1	0.892	0.892
4	Cap		1	0.165	0.165
5	Pin set	Pin A	2	0.036	0.072
		Pin B	24	0.037	0.888
		Pin C	14	0.039	0.546
6	Retainer set		1	0.214	0.214
7	Test support		2	0.078	0.156

Tot mass= 8.05 Kg



INTEGRATION SEQUENCE

PHASE 0: Pre-integration and items Check

PHASE 1: Dome assy integration

PHASE 2: Bladder Inspection

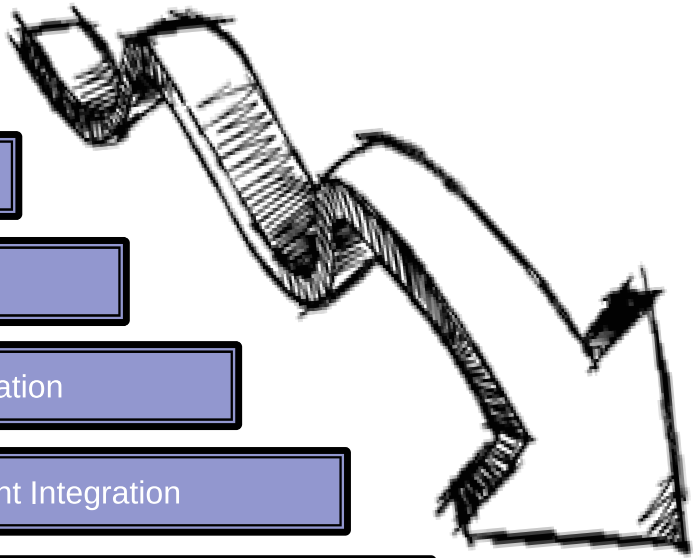
PHASE 3: Restraint Preparation

PHASE 4: Bladder Integration

PHASE 5: Restraint Integration

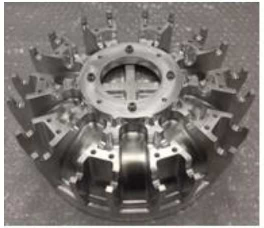
PHASE 6: Retainer Integration

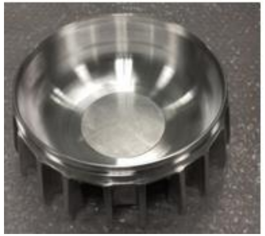
PHASE 7: Test support Integration



INTEGRATION SEQUENCE

Phase 0: Dry-run and items fits check



Activities

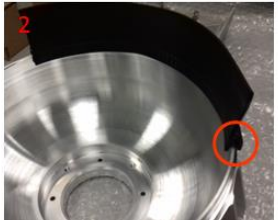
- Dome visual inspection
- Dome Cleaning
- Cap Inspection
- Cap Cleaning
- Helicoil Check
- Belt Pin Check
- Lip Sealing preparation (cut to fit)
- Items weigh

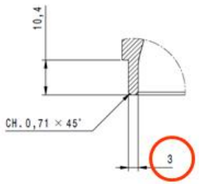
Activity results:

1. One HC failure
2. Lip sealing I/F problem

Recovery Action:

1. Use as is because this location is not used
2. Reworking of the dome rib from 3mm to 2mm





INTEGRATION SEQUENCE

Phase 1: Dome assy integration

Activities

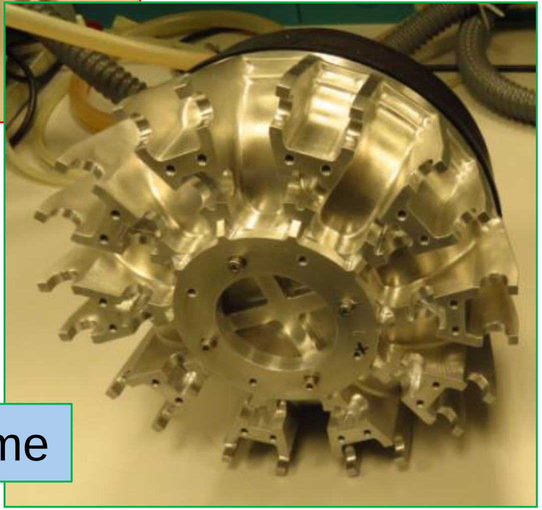
- Cap integration on lower dome
- Lip Sealing integration on lower dome
- Lip Sealing integration on upper dome
- Filler deposition (silicone-based paste)
- Lubricant deposition on inner surface

Activity results:

1. None

Recovery Action:

1. None



INTEGRATION SEQUENCE

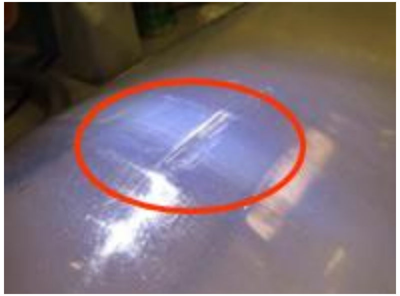
Phase 2: Bladder Inspection

Activities

- Bladder visual inspection
- Bladder Cleaning
- Fluidic fitting Inspection
- Fluidic fitting Cleaning
- Helicoil Check

Activity results:

1. Bladder discontinuity highlighted and marked

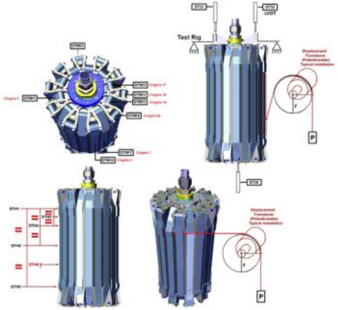


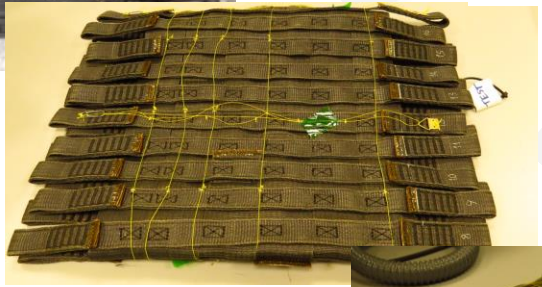
Recovery Action:

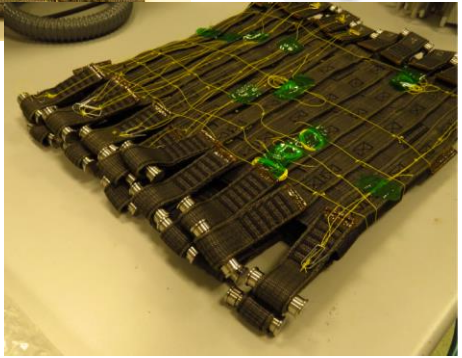
1. Use as is

INTEGRATION SEQUENCE

Phase 3: Restraint Preparation







Activities

- Restraint visual inspection
- Test device integration
- Pin Integration
- Restraint Cleaning

Activity results:

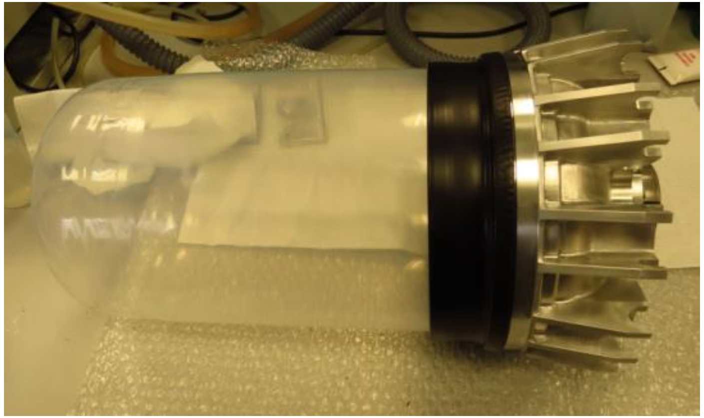
1. None

Recovery Action:

1. None

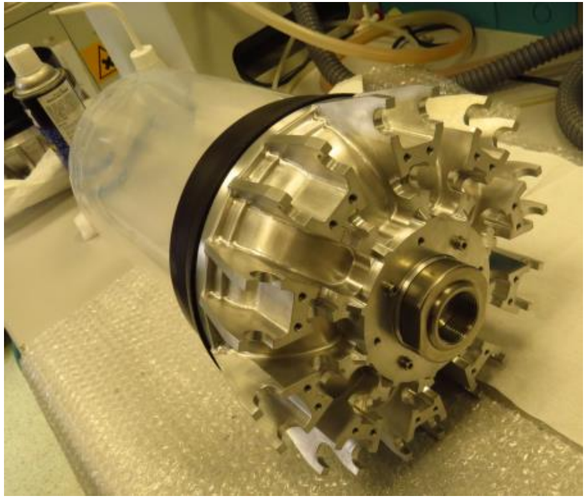
INTEGRATION SEQUENCE

Phase 4: Bladder Integration



Activities

- Fluidic fitting connection
- Visual Inspection
- Assembly Cleaning



Activity results:

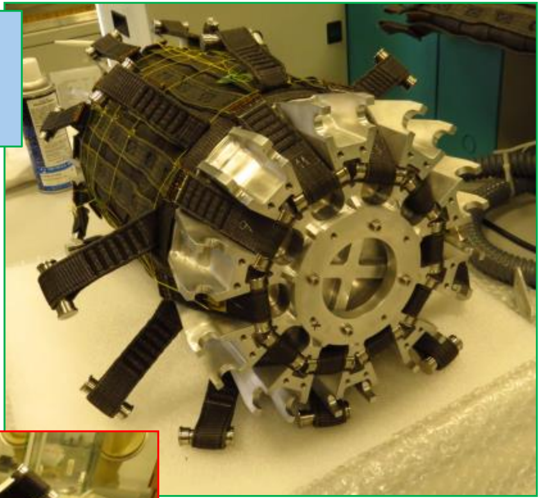
1. None

Recovery Action:

1. None

INTEGRATION SEQUENCE

Phase 5: Restraint Integration (step 1)



Activities

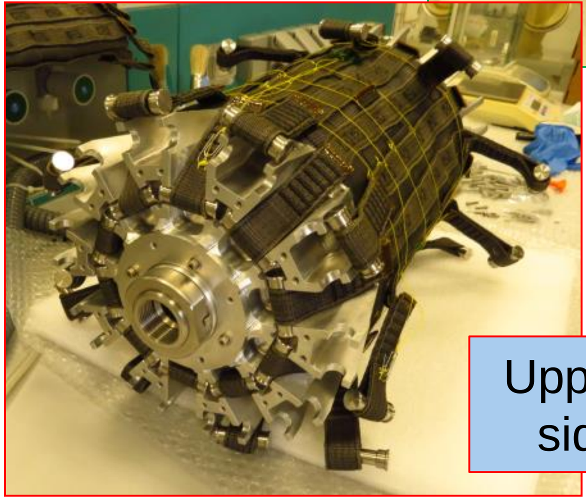
- Inner Belt Pin Connection on lower dome
- Inner Belt Pin Connection on upper dome
- Visual Inspection
- Assembly Cleaning

Activity results:

1. None

Recovery Action:

1. None



INTEGRATION SEQUENCE

Phase 5: Restraint Integration (step 2)

Activities

- External Belt Pin Connection
- Visual Inspection
- Assembly Cleaning

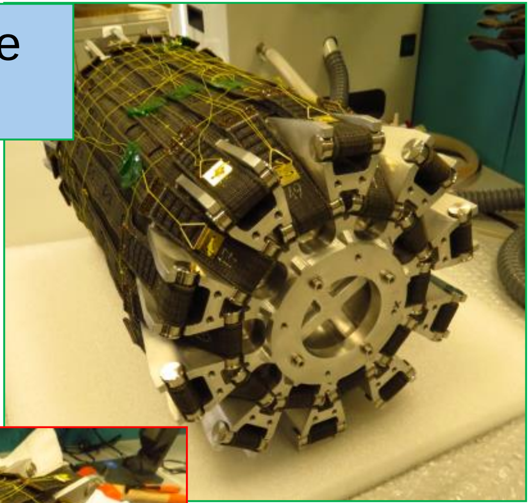
Activity results:

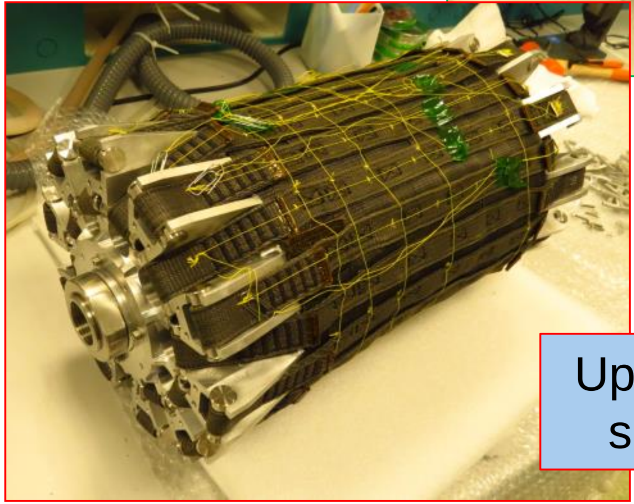
1. None

Recovery Action:

1. None

Lower dome side view

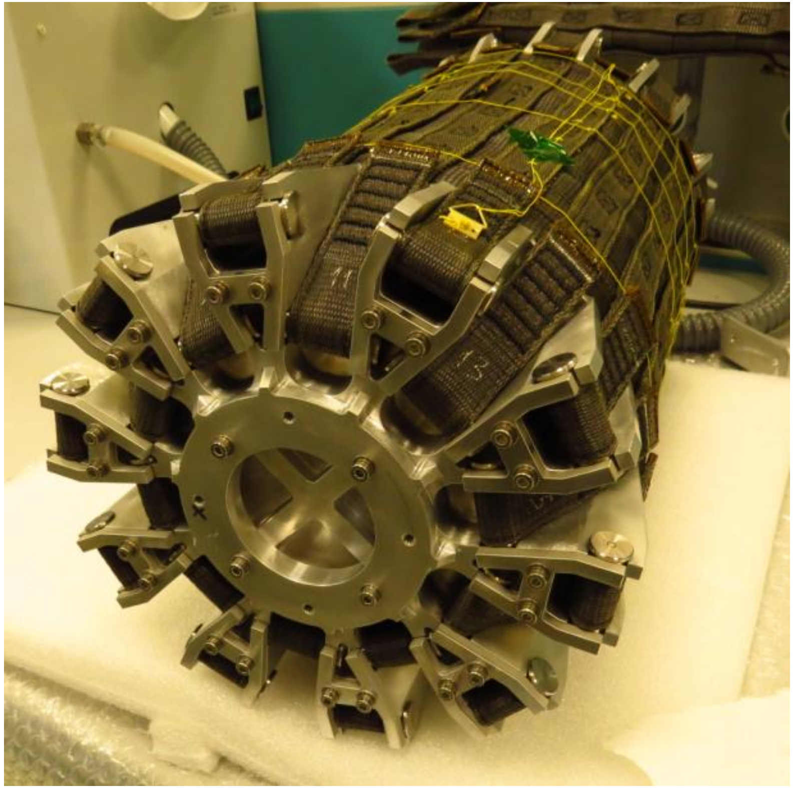




Upper dome side view

INTEGRATION SEQUENCE

Phase 6: Retainer Integration



Activities

- Retainer Integration on lower dome
- Retainer Integration on upper dome
- Visual Inspection
- Assembly Cleaning

Activity results:

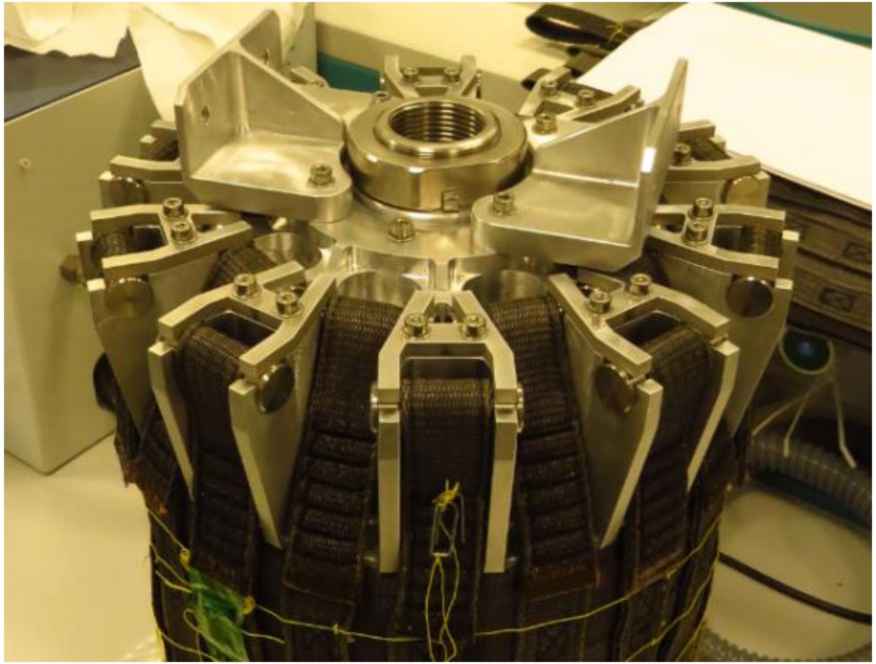
1. None

Recovery Action:

1. None

INTEGRATION SEQUENCE

Phase 7: Test support Integration



Activities

- Test support integration on upper dome
- Visual Inspection
- Assembly Cleaning

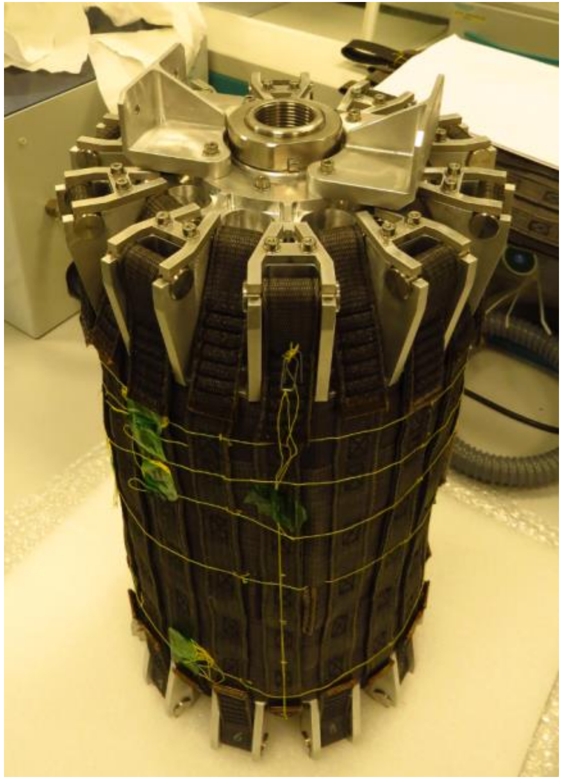
Activity results:

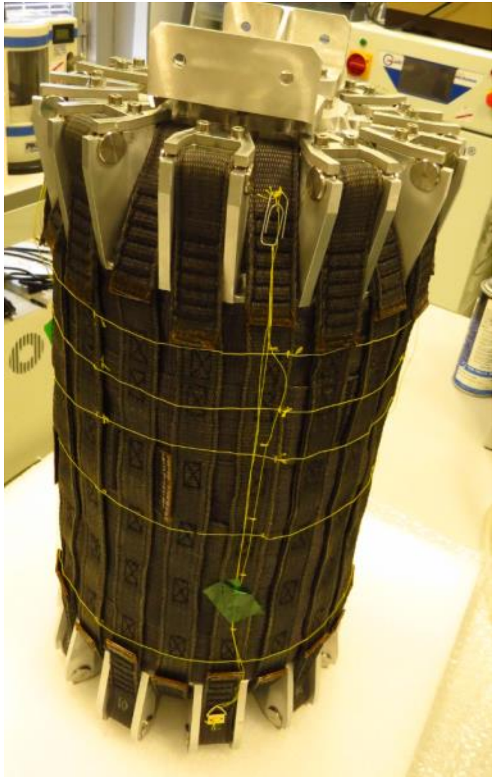
1. None

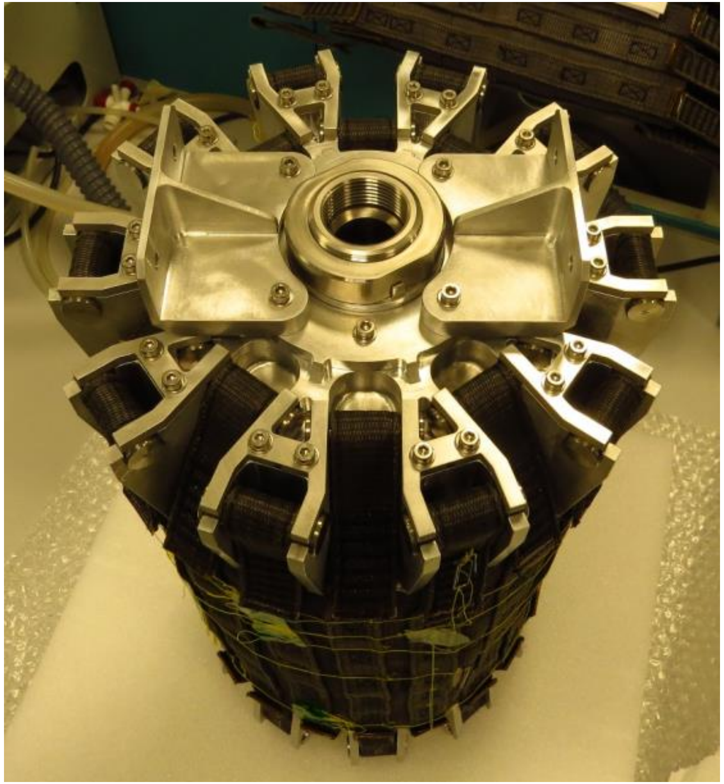
Recovery Action:

1. None

SMALL INFLATABLE SPACE TANK ENGINEERING MODEL







LEAK, PROOF, LEAK
SERVICE LIFE & BURST PRESSURE TEST REVIEW

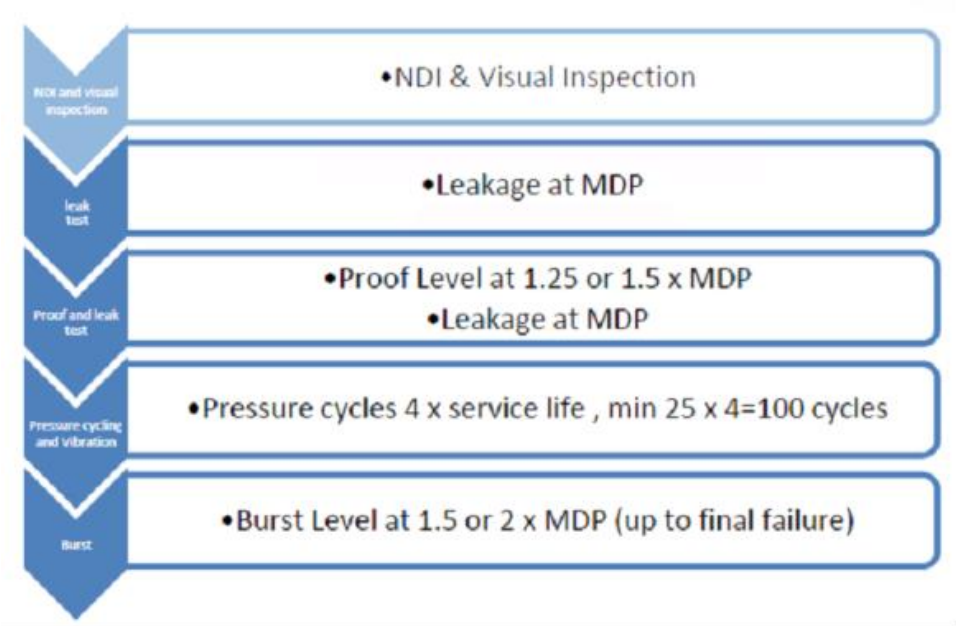
TEST PURPOSE

In the frame of Small Inflatable High Press & Comp Tank (System) Verification, the development approach, required by pressure vessel standards: (Pressurize Hardware, ECSS-E-ST-32-02) & (Fracture Control for Space Application, ECSS-E-ST-32-01C), shall be applied.

This mean that, the test campaign shall consist of validate the tank prototype (EM) and demonstrate that the chosen technology is able to withstand the targeted pressure during its service life.

TEST APPROACH

The test approach will consists of to fix, on one (top) side, the Sistem Tank to a rigid fixture, without any constraint against dynamic behaviour during pressure test.
A dedicated test set-up shall be responsible to apply the several test, here below, reported.



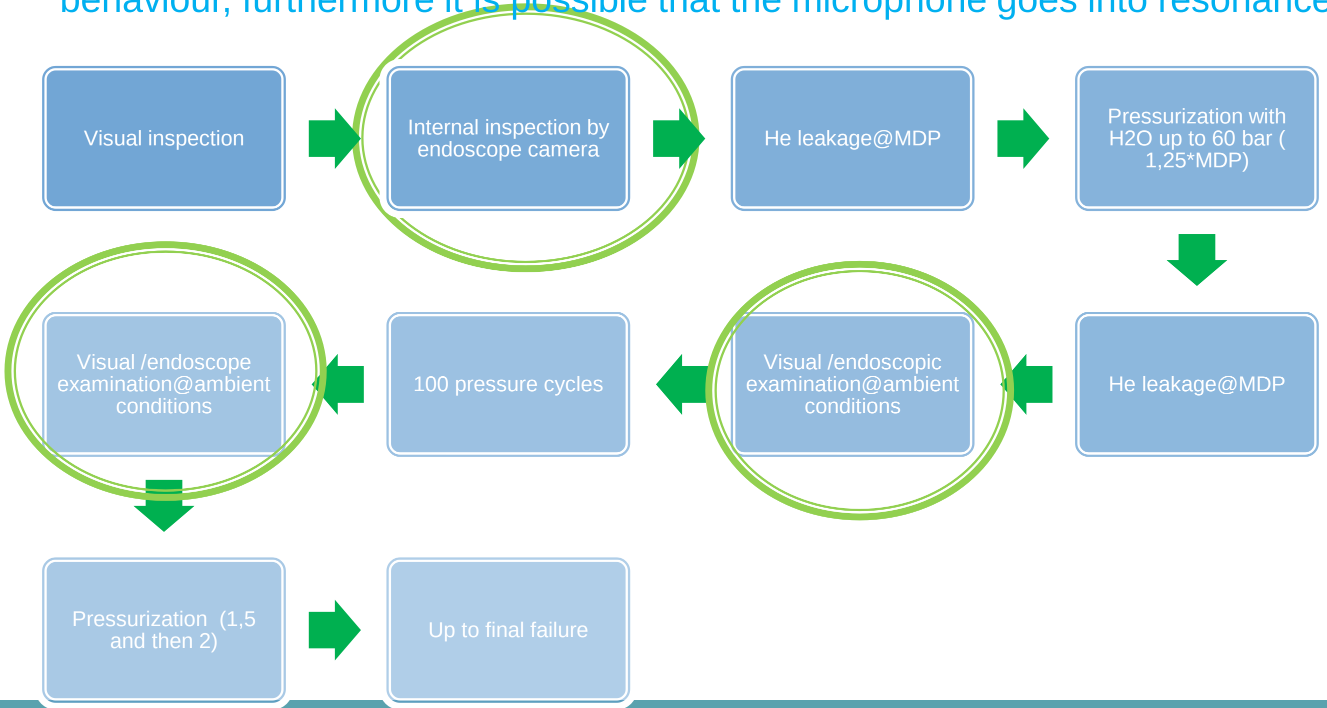
Note:

- the tank will be pressurized, ever, with water except for leak test pressurized with Helium) and draining (pressurized with Nitrogen);
- the MEOP (*) is equal to 48 BARG;
- the Proof factor shall be 1.25
- the Burst factor shall be 1.5.

(*) MEOP=MDP

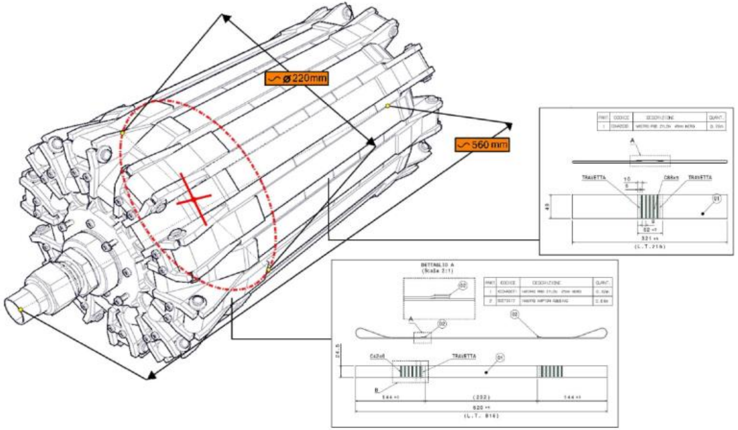
TEST FACILITY CONT'D

Additional inspection points have been added to detect bladder issues, if any as well as a webcam system will be installed inside the safety chamber to check the tank behavior. Regarding the sound, it could be possible that the sound / noise, coming from the pressurization system, is higher than the test article sound behaviour, furthermore it is possible that the microphone goes into resonance and becomes saturated.



TEST ARTICLE

The test article, as describe (better) before, consist of a bladder (fluid containment) surrounded by a structural cylindrical shape (composed of straps) with two elliptical (metallic) dome.



TEST FACILITY

Test facility (Bulding 69 b) shall consist of:

- Test Area

Every test concerning the pressurization of the tank will be performed inside a dedicated test building that meets the safety requirements about such kind of tests. Inside this building a safety box, having enough room to accommodate the hoisting fixture with the tank, has been realized.
This building is provided by the following utilities: electrical power source 220 V single phase and 380 V three phase; pressurized service air; air heating plant.
This area has an external safety wall composed by concrete blocks.

TEST FALCILITY CONT'D

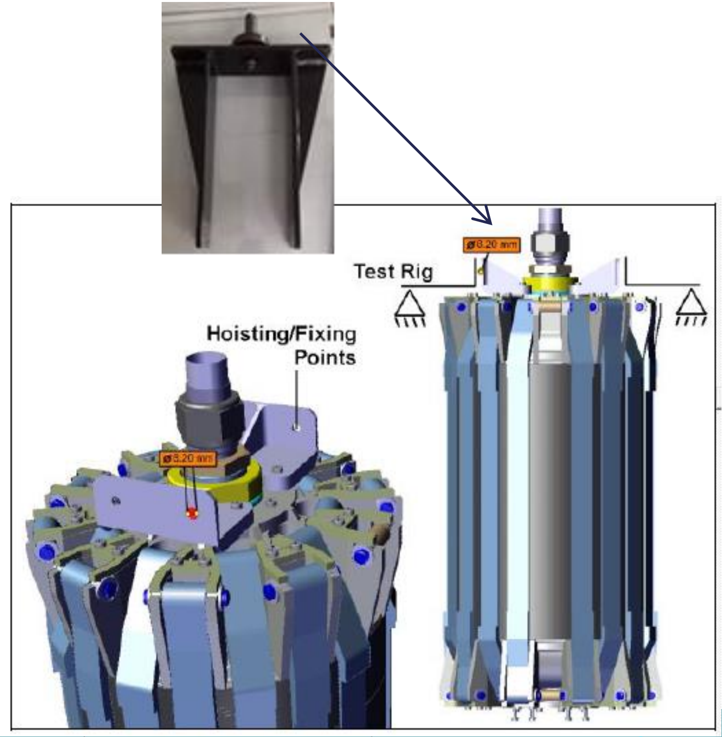
- Test Rig

A dedicated test rig will be used in order to allow the test execution in safety condition for the involved items and personnel.

It will consist of a simple trestle, capable to simple supported the TA in vertical position (by means of 4 holes per M6 bolts) during the filling and pressurization activities.

The test rig will be able to allow any test article deformation that occurs during the pressurization.

A protective cover could be fitted, to the frame, in order to avoid pollution of the testing area in case of burst



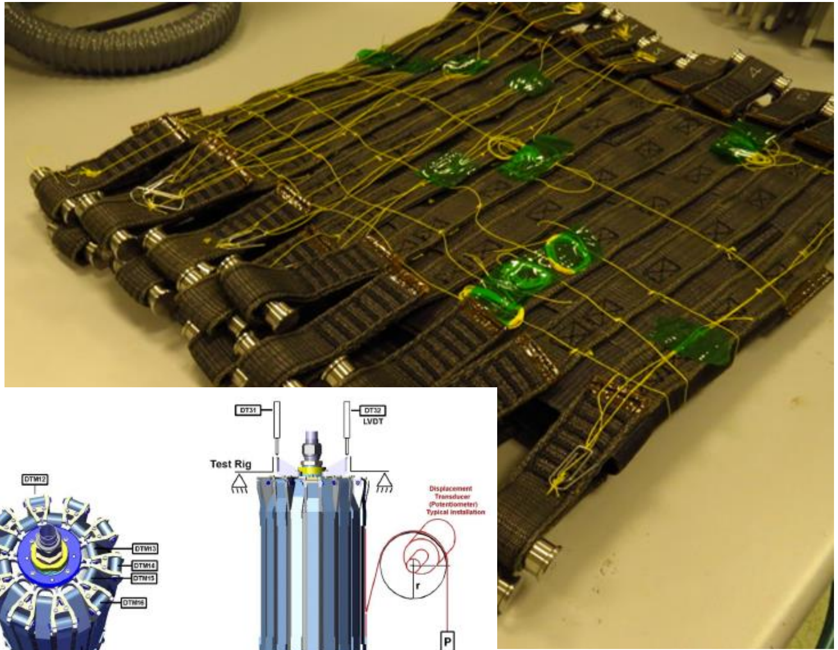
TEST FACILITY CONT'D

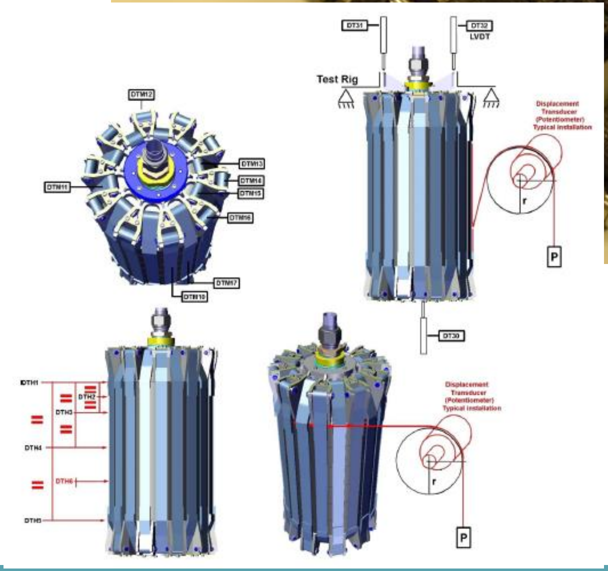
- Test Instrumentation

In order to monitored the load of the strap, two wire for each (monitored meridian) strap shall be sewed on it, a slipknot between them shall permit, by one side of the wire, connected to a displacement transducers, to detect the strain of the strap,

Note:

- DTM x = Meridian Displacement transducers
- DTH x = Hoop Displacement transducers
- the hoop direction (monitored outside the tank) will measure the tank deformation only. No load shall be derived, from this system, because affected from the overall deformation/contribution of hoop and meridian strap. However a tentative to place a wire (DTH6), on hoop strap, below the meridian, shall be done.



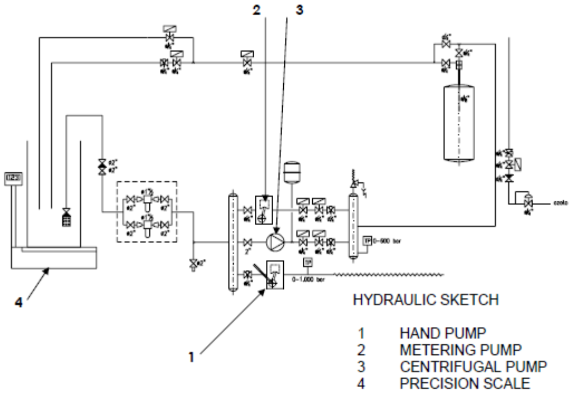


TEST FACILITY CONT'D

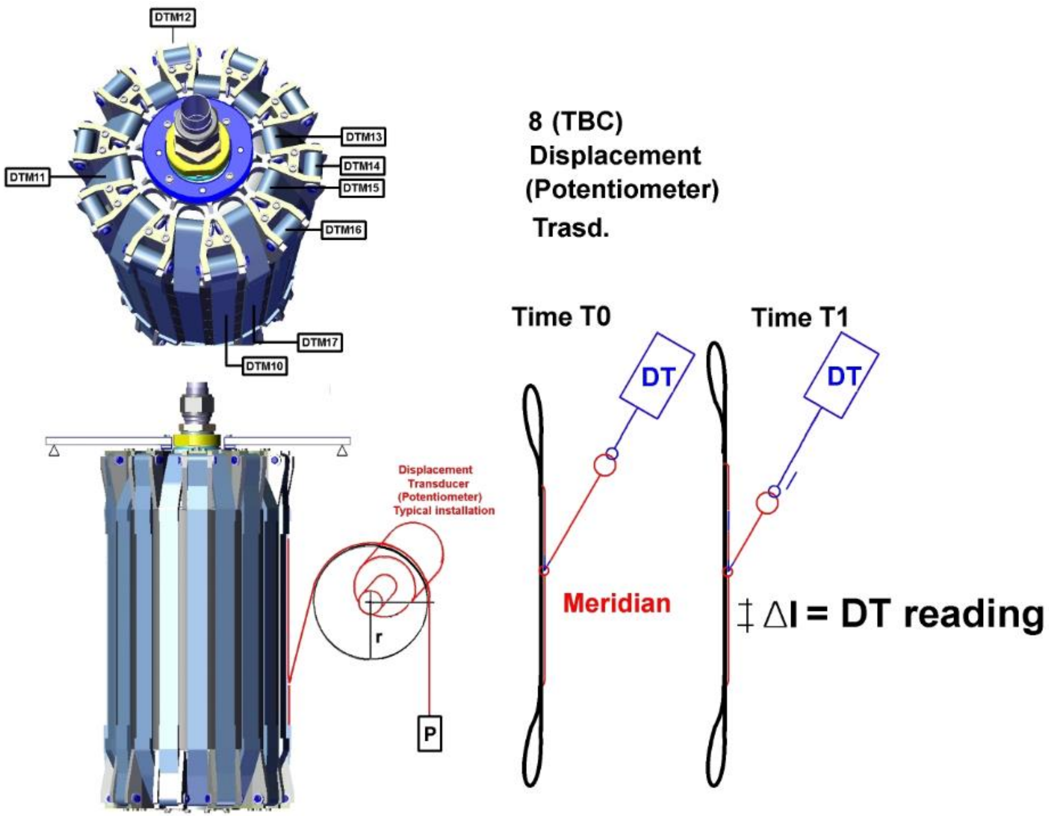
- Pressurization Apparatus

a. the centrifugal horizontal jetpump with a max flow of 5 m3/h and a max pressure of 6 bar used to fill the tank.
b. the metering pump, with regolable stroke of the piston that allows the control of the flow rate. This pump allows to reach a max pressure of 450 bar used to perform Proof Test, Pressure Cycling & Burst Test and it has also a safety valve set to 72 bar.
c. the hand pump with a max pressure of 220 bar used to reach the tank burst
d. the precision scale with a full scale value of 30 kg and accuracy of 90 g (0.9 l) used to evaluate the volume and the changes of it during and after the tests.
e. the trends of pressure of different tests are managed by opening and closing a set of solenoid valves controlled by software. In all the lines with high pressure the valves are twice to have more reliability.

The first phase of all tests is the filling of the hydraulic circuit. Then the zero point on scale is done and the filling of the tank can start with the connection port in up position. When the tank is filled (water comes out from line without air) the volume (reduced from the end pipe connection volume) can be recorded.
Now it is possible to start with the specific test. At the end of the test, with the tank in the same position the charging pipe of water must be disconnected and in the same position the nitrogen pipe will be connected and the drain phase can start.

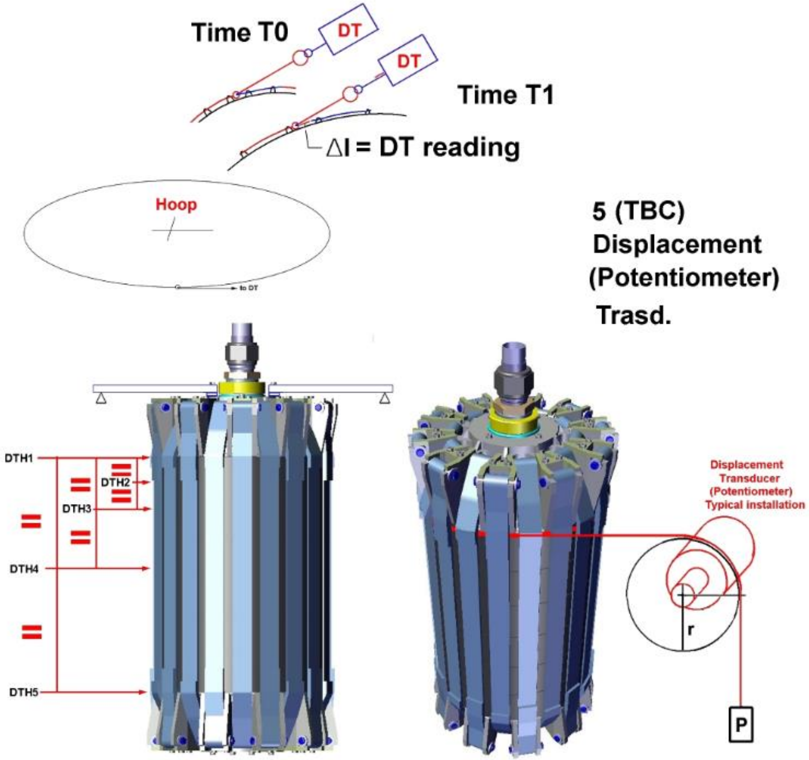


SISTEM EM INSTRUMENTATION LOGIC: MERIDIAN ASSY



+ Strain gauges: measurement of stress level on metallic parts (e.g. domes)

SISTEM EM INSTRUMENTATION LOGIC: HOOP ASSY



To be positioned on the innermost Hoop assy

TEST FACILITY CONT'D

- Video

  Even if, initially not foreseen in specification a Video Recording equipped with an audio recorder System will be implemented.

  6 webcam shall be placed (each one) at 120° between them and on top and bottom side of test article

TRR OUTCOMES CONCLUSIONS

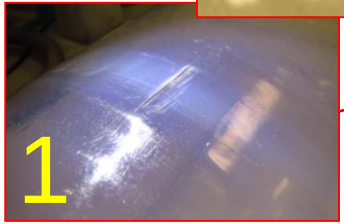
- SISTEM EM completed integrated, no deviation wrt design is occurred
- SISTEM EM instrumented to check ribbon deformation . No predictions vs. instrumentation plan are available; however the displacement coming from the strap elongations, submitted to a pressure test, shall be compared with the belts calibrating curve, the comparison between them shall be done in real time.

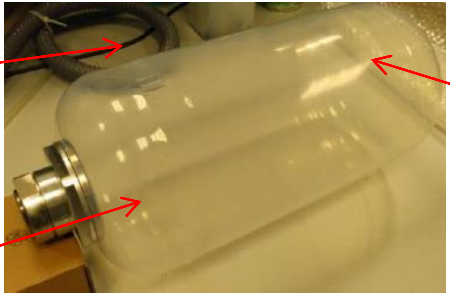
RUN#1

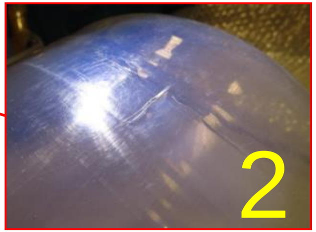
INSPECTION REPORT

During the acceptance inspection of the bladder the following discontinuities have been detected on the bladder. From a visual inspection the flaws seems only a superficial discontinuity. They have been marked directly onto the bladder and reported into the TRR presentation held on DICEMBER, 18TH 2020

Upper dome area welding line







Lower dome area welding line

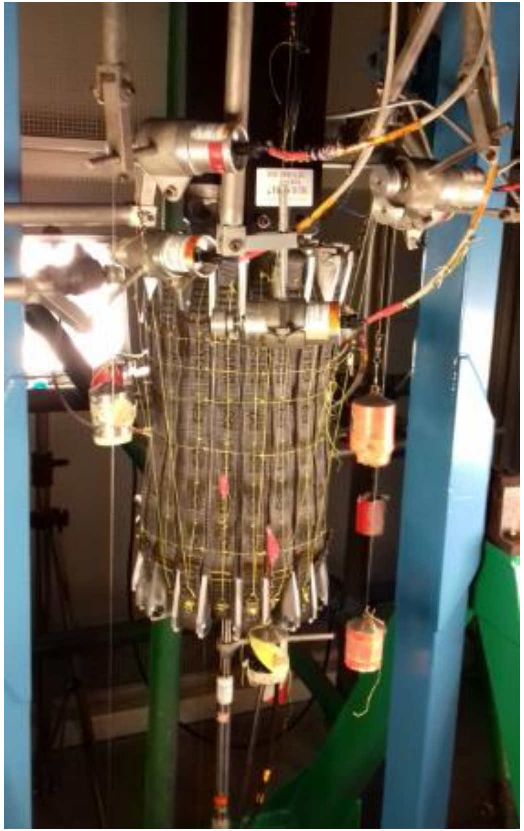
From HOLSCOT report, the pressure test (with low positive pressure 30KPa) and Spark test (voltage 850V about) didn't highlight any non-conformance, for this reason, the bladder has been integrated as it is

INSPECTION REPORT

A dry-run test has been performed in TASI on the last week of January 2021 (test facility is shown in the picture) with a step-by-step pressure rate.

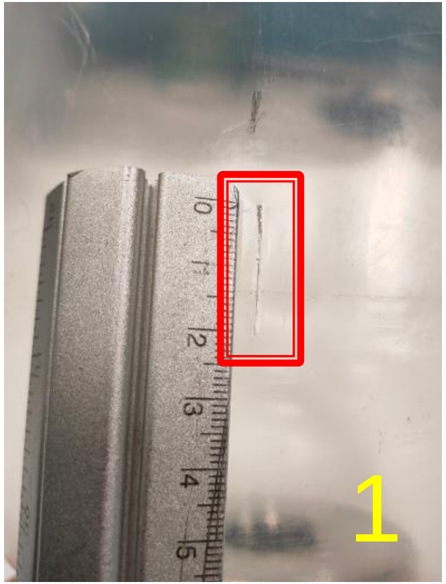
The test has been stopped soon due to the leakage appeared at few bars (1bar <Ptest< 2bar) .

The leakage area has been marked (see the movie) and the tank has been disassembled in order to evaluate the problem.

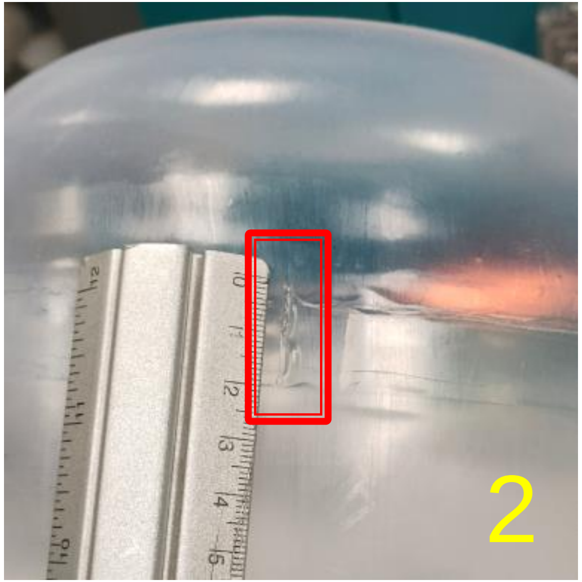


INSPECTION REPORT

Fissures appeared on the areas marked during the acceptance inspection, in particular the damage n°1&2, which are pass through crack. The n.3 instead seems to be not affected by the pressure test.



Upper dome zone welding line area

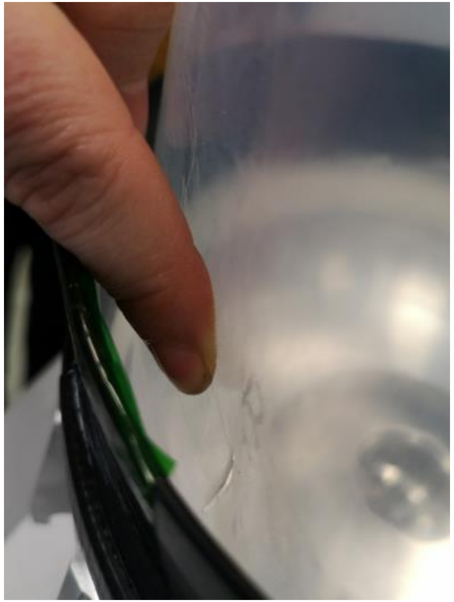


Lower dome zone welding line area

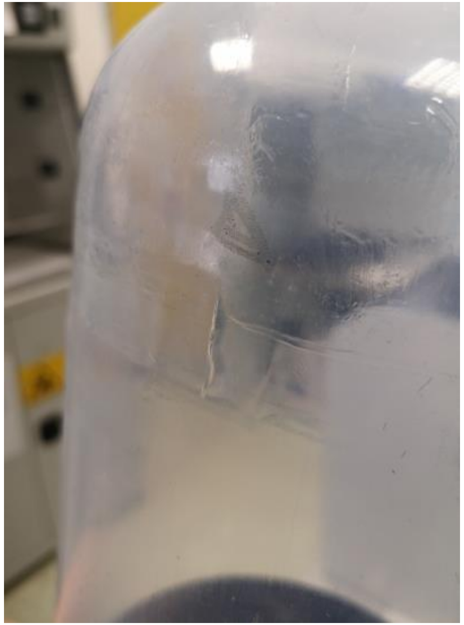
Upper dome zone welding line area

INSPECTION REPORT

After the test, in order to verify the leak areas it has been needed to disassembling of the tank assy. After that, the following majors flaws have been detected on the bladder:



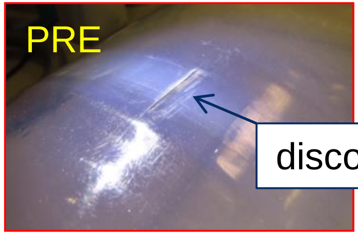
Upper dome portion



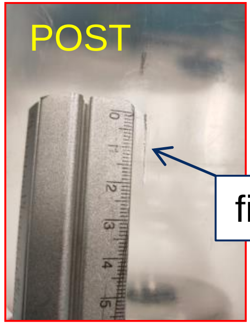
Lower dome portion

INSPECTION REPORT

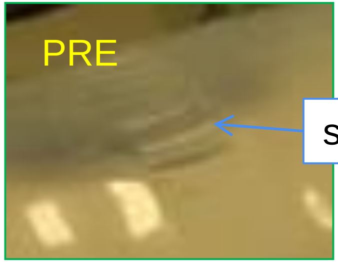
The comparison between the discontinuity pre and post test are hereafter reported:



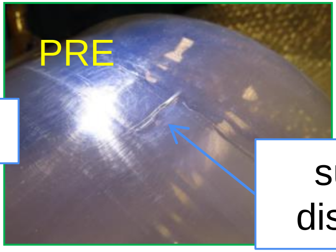
discontinuity



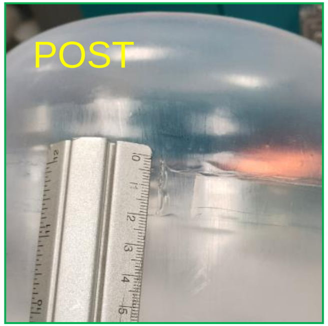
fissure



superficial ripple



superficial discontinuity



change pre and post

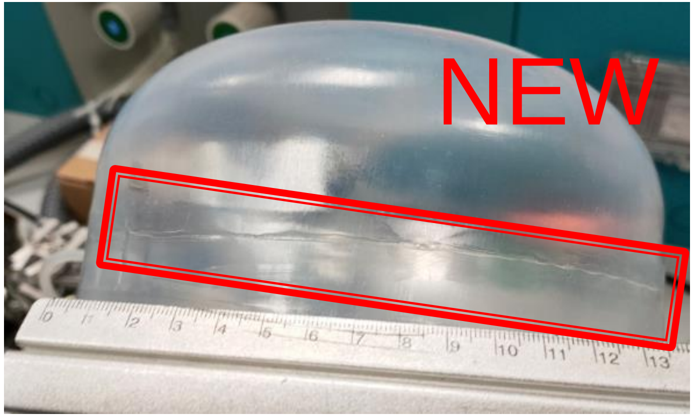
no changes pre and post

INSPECTION REPORT

A deeper examination after full disassembly, showed new discontinuities (details on L and R images):

Upper dome zone welding line area

Upper dome area (created during the tank disassembling)



Lower dome zone welding line area

RUN#1 OUTCOMES

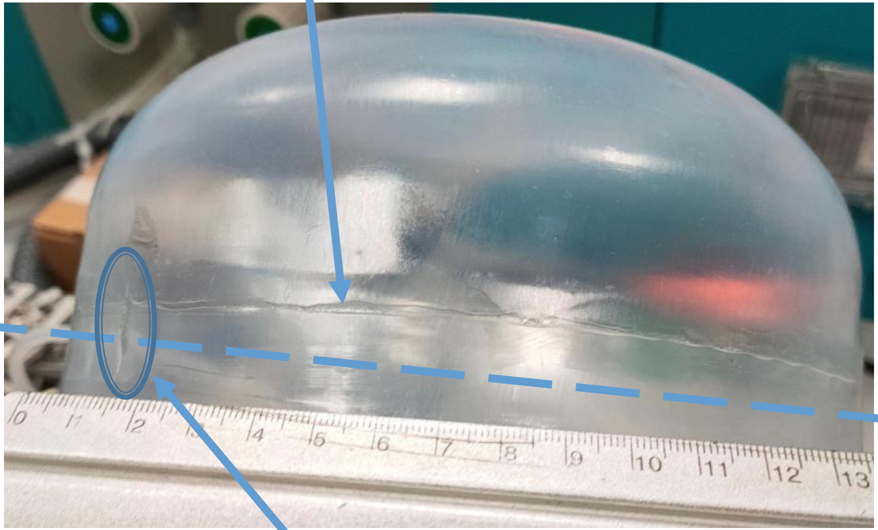
- From visual inspection, the bladder is not-deformated, as expected due to very low pressure reached during the test.
- Both major damages are located on the welding line areas (upper and lower) in the area marked during the acceptance inspection. The bladder has been sent to Holscot on the first week of February for deeper investigations to understand possible root causes (e.g end closure welding point…) and recovery actions

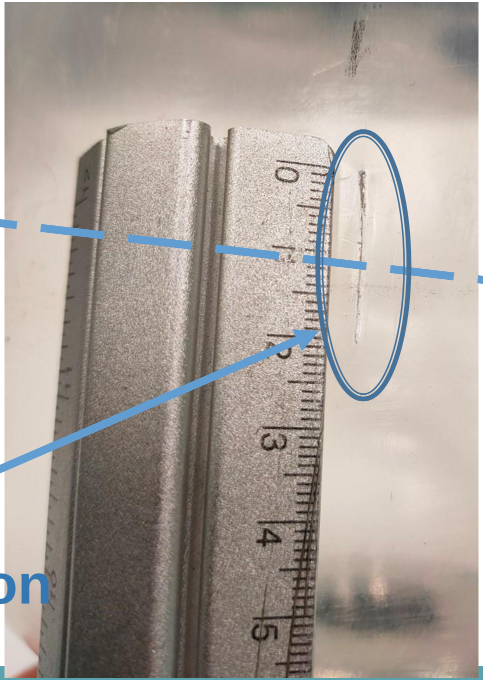
→ Repair process (assessed at sample level) application to bladder model to be evaluated by HOLSCOT

Repairs

Witness line resulting from welding process

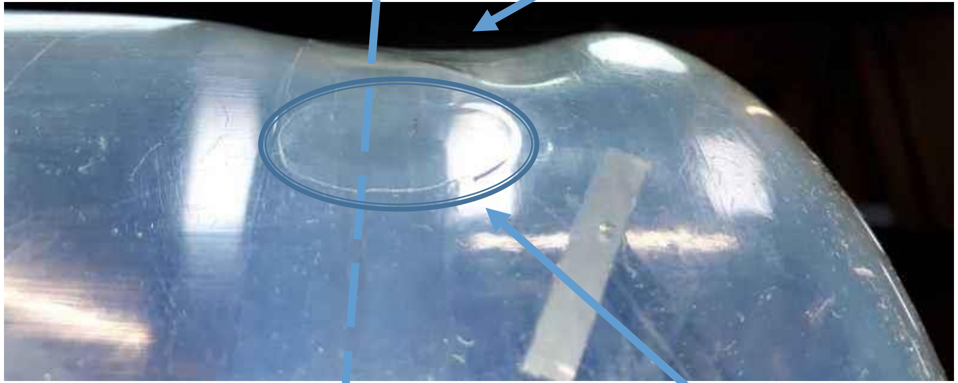
Approximate centre line of weld



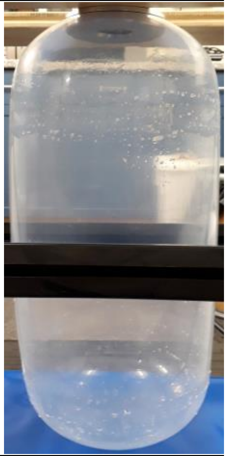


Split across weld during integration

Repairs cont...



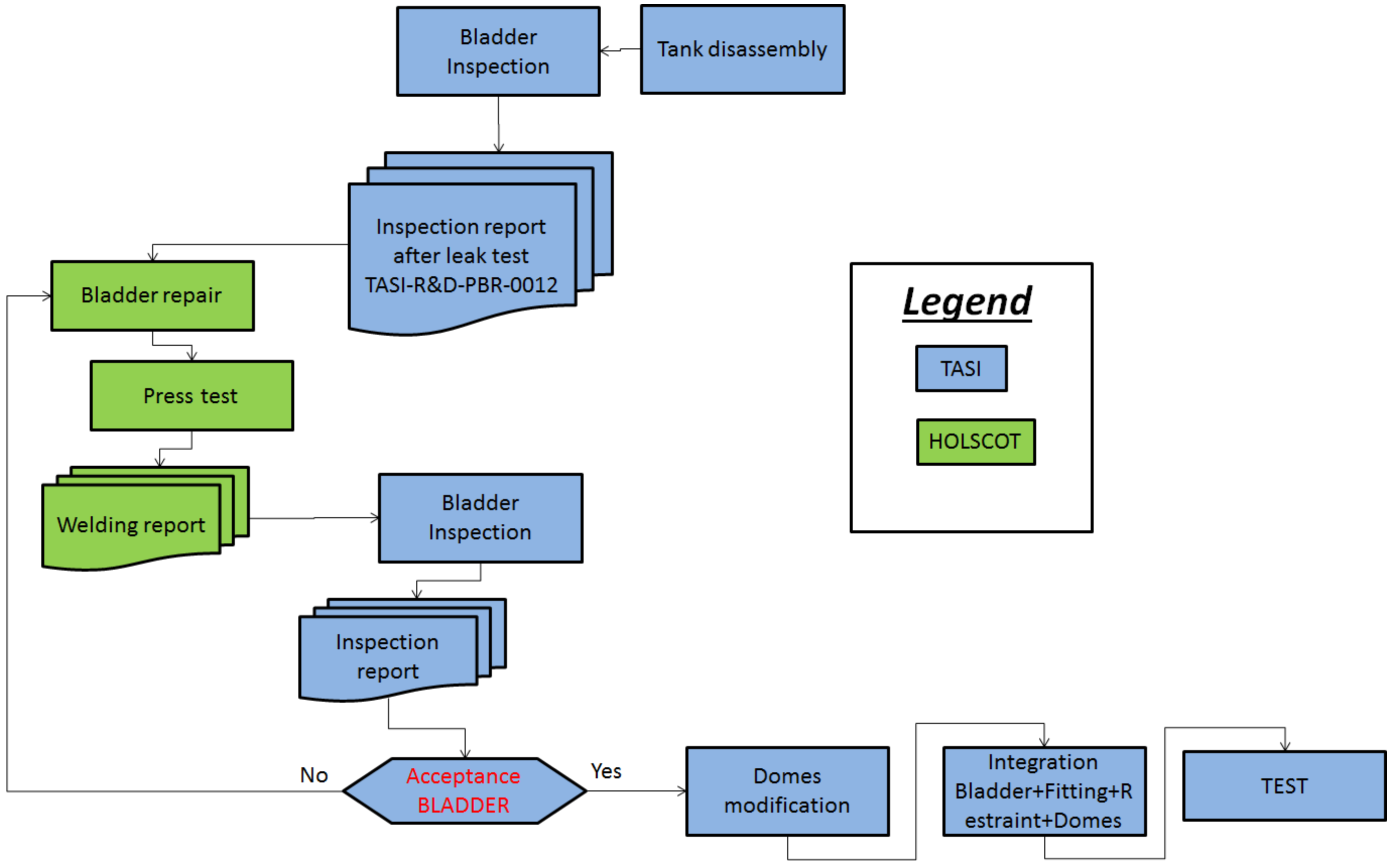
Pressure test

Internal pressure/bar	0.0	0.4	0.6	0.8	1.0
Diameter of bladder at centre line/mm	198	200	202	204	208
Distance between centre of welds/mm	252	252	254	254	252
Image during test					

Conclusions

- FEP bladder c/w metal inlet port adaptor
- Nominal weld width 20 mm
- Bladder distortion post welding
- Spark testing (850 V)
- Pressure testing (0.3 bar)
- Dimensions Ø196 mm x 0.5 mm wall x 400 mm length x Ø50 mm inlet
- Air leakage during integration up to 2.0 bar
- Bladder weld repairs and retested 0.0 bar to 1.0 bar

BLADDER REPAIR WORK FLOW



INTEGRATION SEQUENCE AFTER BLADDER RAPAIR

PHASE 0: Pre-integration and items Check

PHASE 1: Dome assy integration

PHASE 2: Bladder Inspection

PHASE 3: Restraint Preparation

PHASE 4: Bladder Integration

PHASE 5: Restraint Integration

PHASE 6: Retainer Integration

PHASE 7: Test support Integration

PHASE 1.1: Bladder Inspection

PHASE 2.1: Dome corrective actions

PHASE 3.1: Bladder modification

PHASE 4.1: Bladder Integration

INTEGRATION SEQUENCE

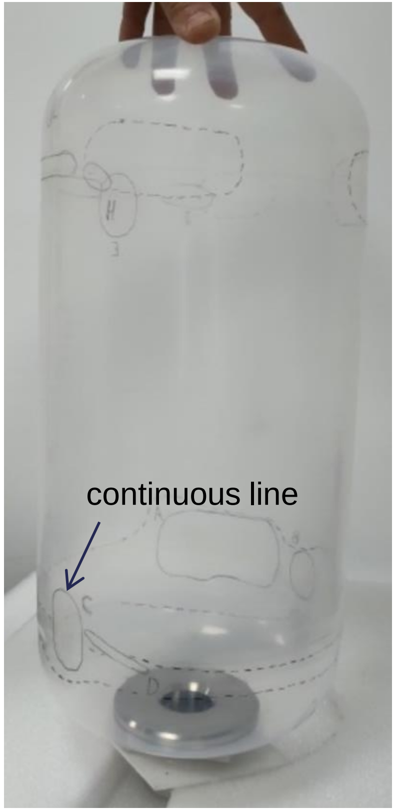
Phase 1.1: Bladder Inspection

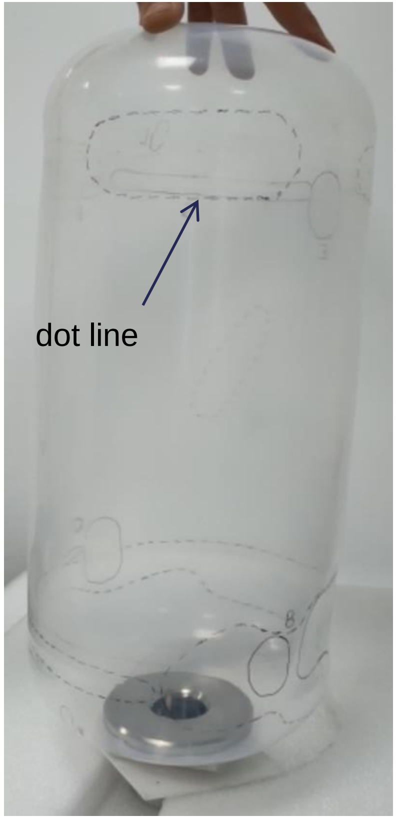
Activities

- Bladder visual inspection

Activity results:

1. Bladder discontinuity highlighted and marked:
    - continuous line = discontinuity
    - dot line = deformation





INTEGRATION SEQUENCE

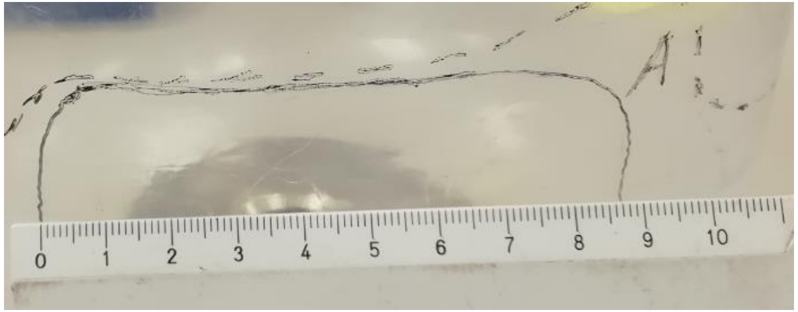
Phase 1.1: Bladder Inspection

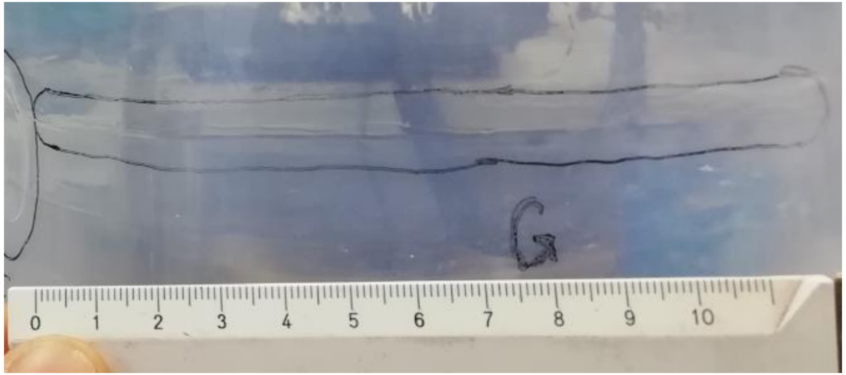
Activity results:

N° 10 Bladder discontinuity (continuous line) have been detected and marked with a letter from A to L.

They have been classified in 2 categories:

- Big (Length>5cm) : A & G
- Small (Length>5cm) : B, C, D, E, F, H, I & L



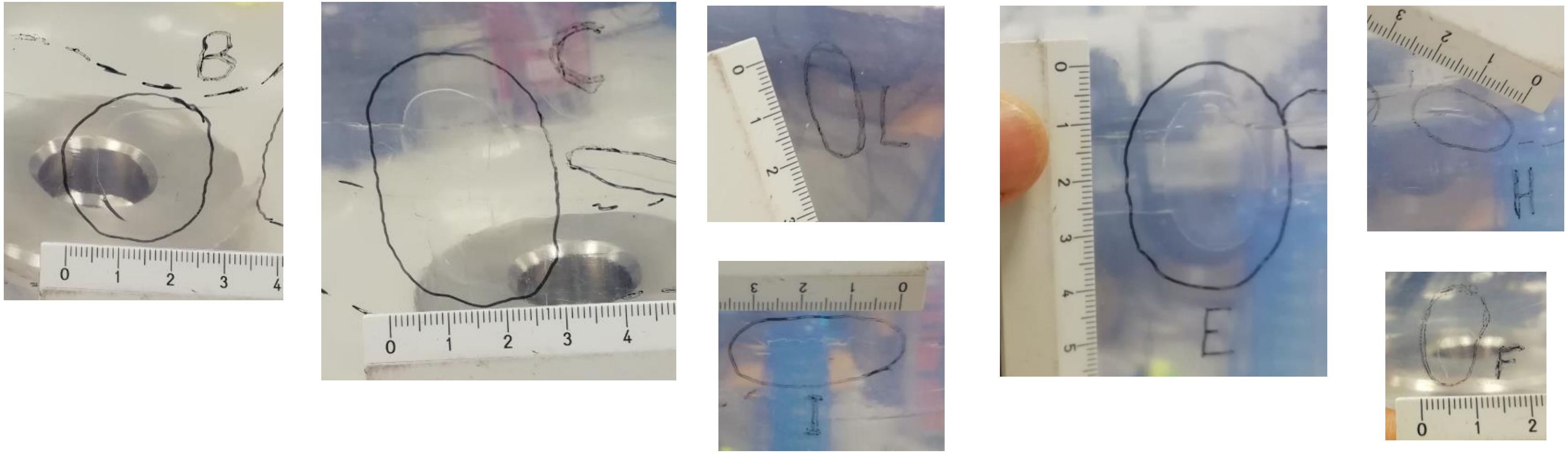


Discontinuity >5cm

INTEGRATION SEQUENCE

Phase 1.1: Bladder Inspection

Activity results:

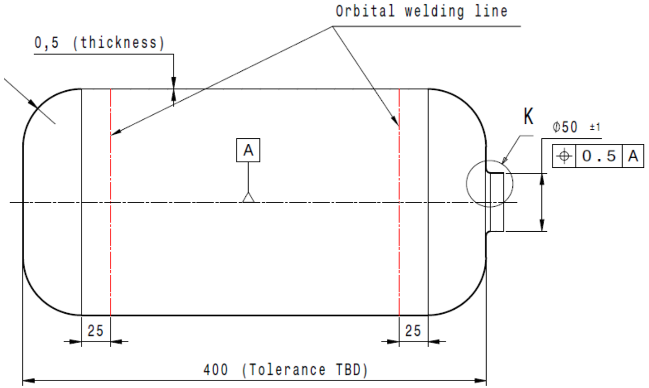


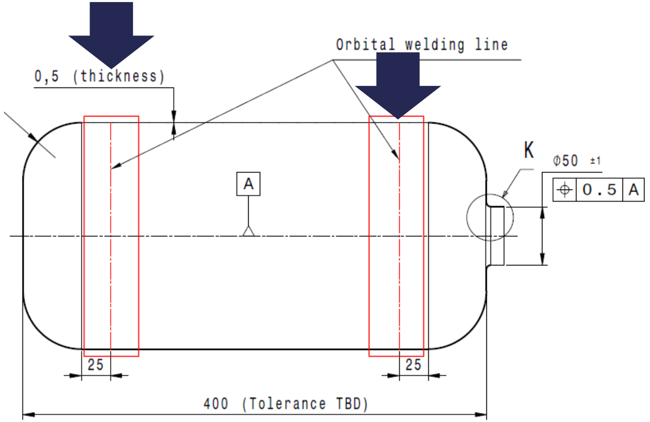
Discontinuity <5cm

Phase 2.1: Dome modification

Risk mitigation activities:

Transition zone mitigation: The bladder inspection put in evidence that the area affected by the Welding repair is larger than expected, in fact it is not limited to an orbital line (red dot lines) but it shall be considered a large band (red areas).



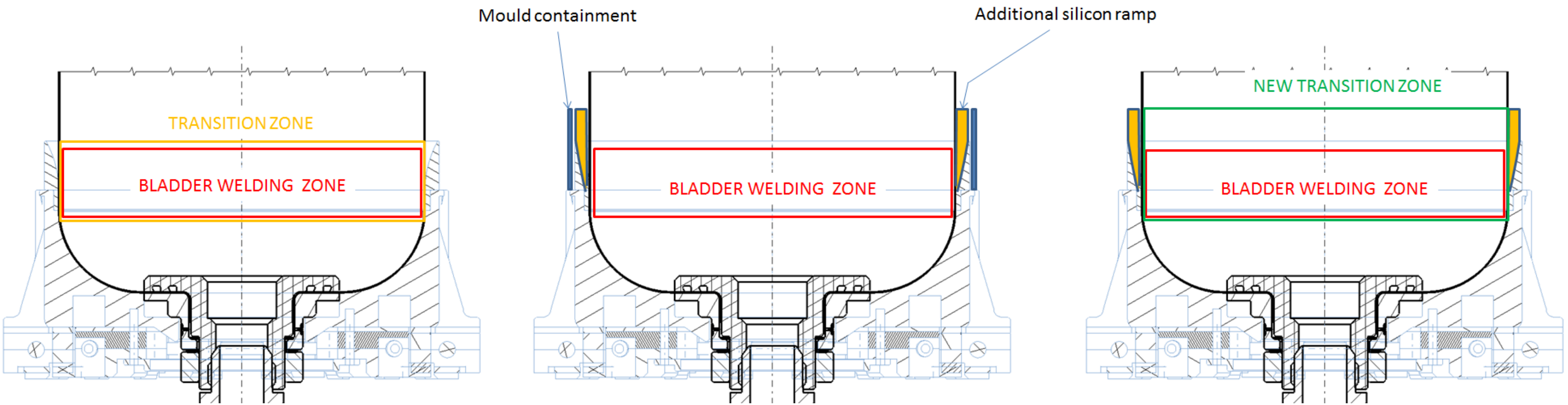


INTEGRATION SEQUENCE

Phase 2.1: Dome modification

Risk mitigation activities:

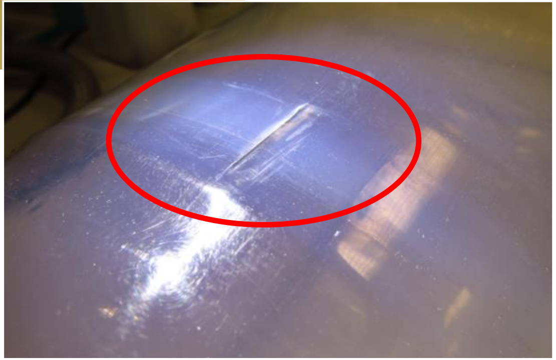
This means that the transition zone, considered a critical area from bladder stiffeners point of view, shall be enlarged (from yellow area to green area) to improve the bladder support with an additional silicon ramp (orange volume).



S.I.S.T.E.M.
SMALL INFLATABLE SPACE TANKS
TEST CAMPAIGN PROGRESS REPORT

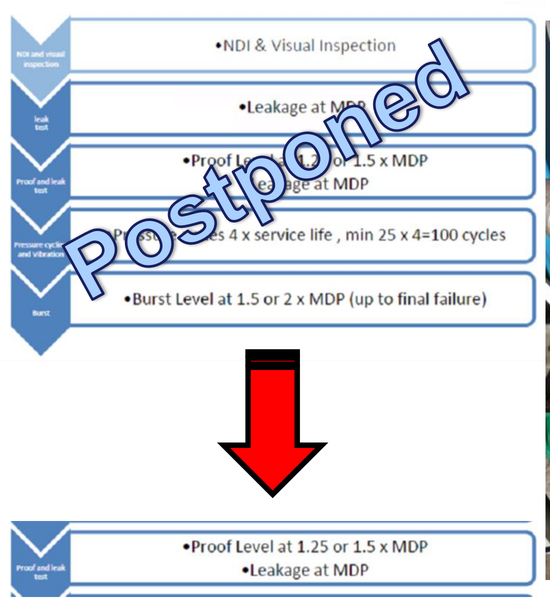
PREVIOUSLY ON SISTEM

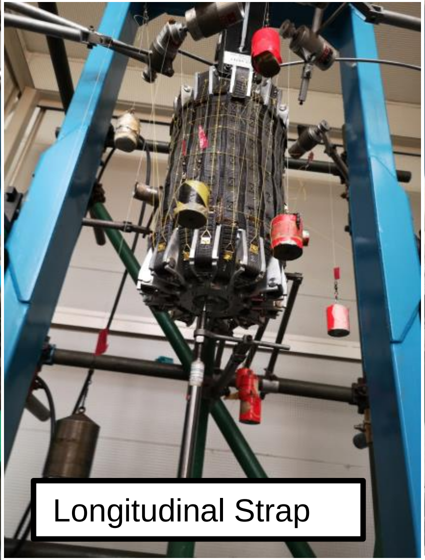
As you remember, at the beginning of test campaign, on the liner of test article, several discontinuity, on circumferential welding, were highlighted and marked.

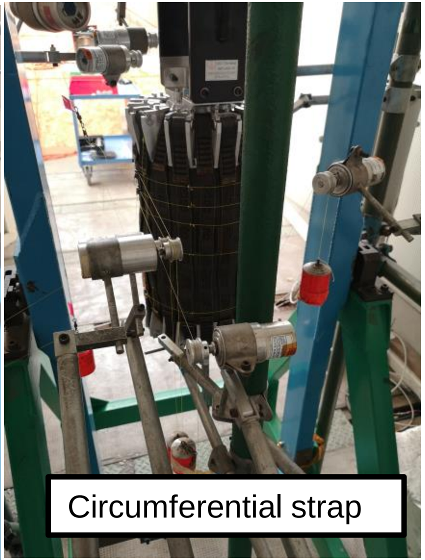


PREVIOUSLY ON SISTEM

Taking into account this boundary condition it was decide to perform, prior to start the entirely test campaign, a proof test. Furthermore, based on TASI heritage and the inflatable unpredictable behaviour, it was decided to totally instrumented, as foreseen on test spec TASI-SD-SISTEM-TSP-0015, the test article.



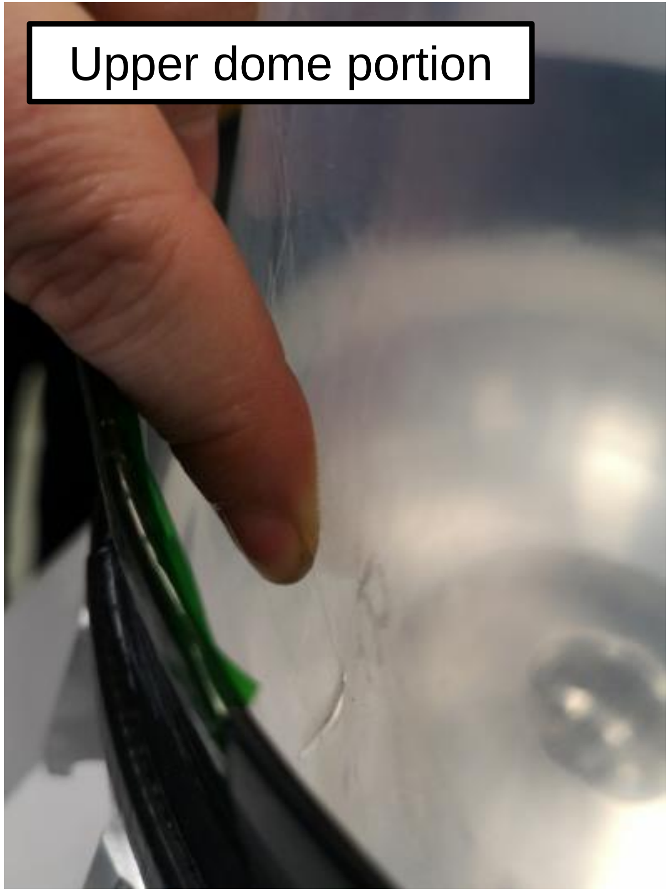




PREVIOUSLY ON SISTEM

FIRST PROOF TEST (28/1/2021 - FAILED)

- Pressure (N_2) level reached <= 1 barg
- 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.
- The Bladder was sent to the manufactured for the repair



PREVIOUSLY ON SISTEM

1ST RECOVERY ACTIONS

Two parallel ways were defined:

1. The Bladder was sent to the manufactured for the reparation,

2. After liner, return back, a silicon based filler (Shore 15) has been casted into the gap between the bladder and Metallic domes in order to recover any gap between bladder and dome.

PREVIOUSLY ON SISTEM

SECOND PROOF TEST (14/05/2021 - FAILED)

- Pressure (N2) level reached <= 2 barg
- The test set-up was disassembled and the visual inspection on the demated test article put in evidence a failure (2cm about) in correspondence of the lower dome welding line (between discontinuity G & E).

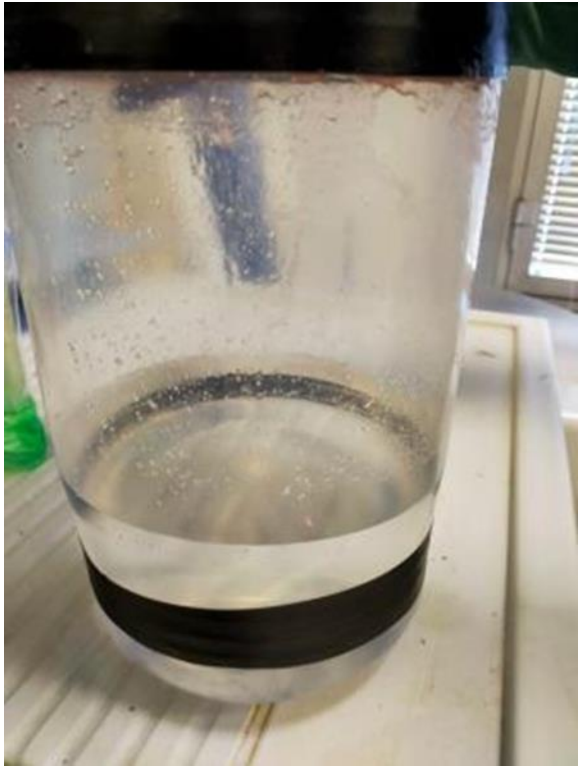
PREVIOUSLY ON SISTEM

2ND RECOVERY ACTIONS

The previous test have consolidate that, in the liner part, there is an underlying problem related to the design & manufacturing conception .
So it was decided to go beyond the liner limitation (i.e. accept the leakage) in order to verify the restraint loading capability.
Also in this case two parallel ways were defined:

1. The Bladder was repaired by (air thigh) simple tape

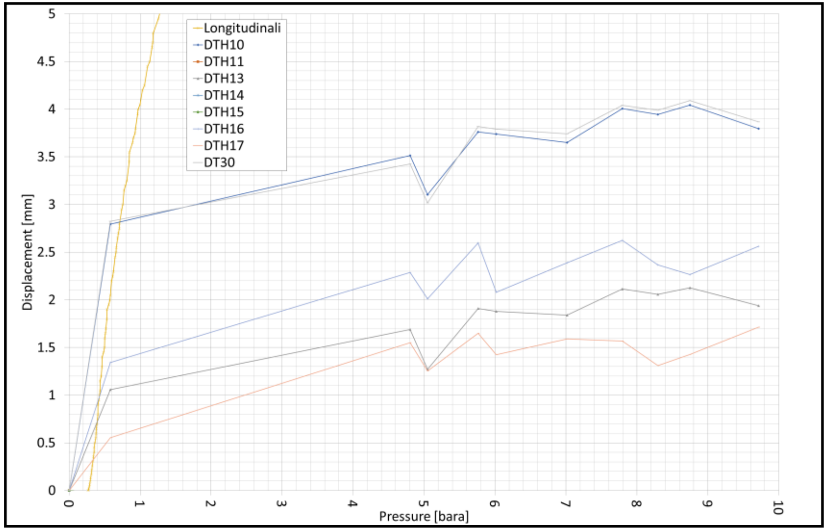
2. The test will be performed in water in order to reduce, as minimum, the leak de-contribution to the test.



PREVIOUSLY ON SISTEM

THIRD PROOF TEST (19/07/2021 - FAILED)

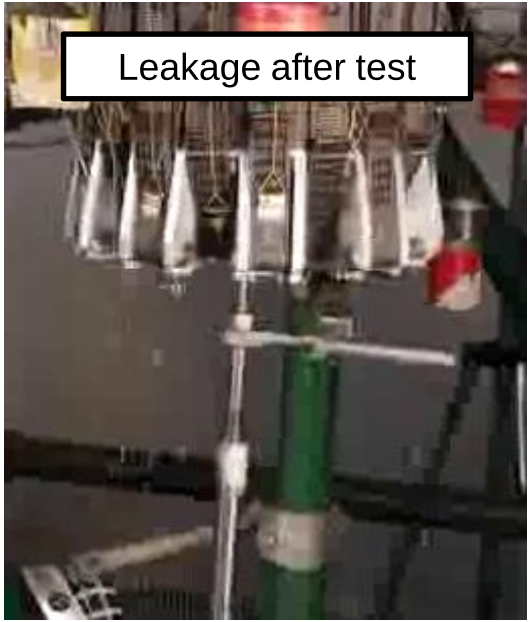
- Pressure (H_2O) level reached <= 10 barg
- Even if the leakage still there, a pressure close to 10 bar was reached.
  After that, the pressure was not increased due to the water pump limitation.
  It was, due to its nature (alternative motion), not capable to maintain a constant & continue water flux inside the tank.
  The displacement results, coming from test article, put in evidenced the asymptotic behaviour reached by the pressure system.



PREVIOUSLY ON SISTEM

THIRD PROOF TEST (19/07/2021 - FAILED) CONT'D

A further result, coming from visual inspection of the water leak (detected much more than beginning), it is evident a crack propagation.

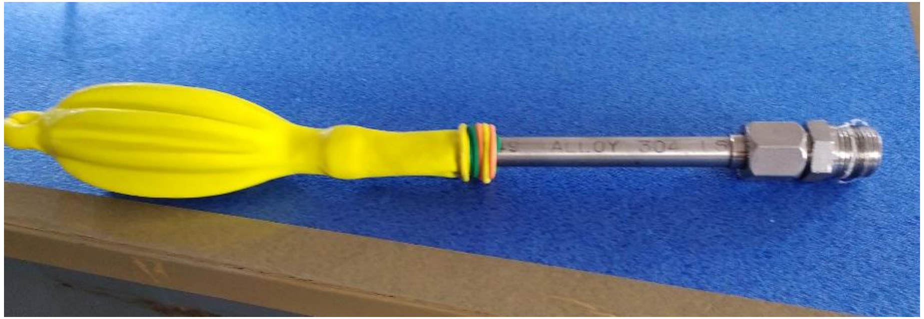


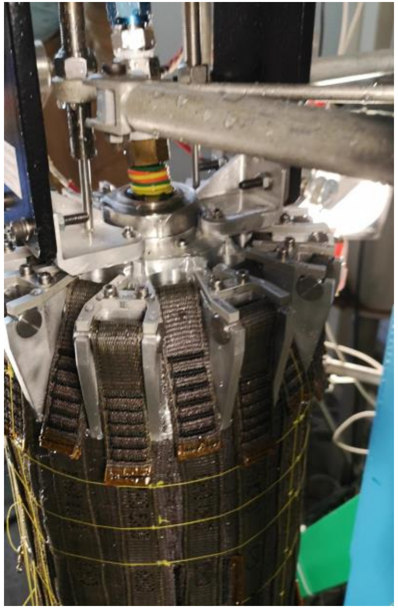
PREVIOUSLY ON SISTEM

FOUR PROOF TEST (17/09/2021 - FAILED)

The fourth proof test has been done inserting 6 overwrapped, between them, child balloon in the bladder.

At the beginning, the leakage seems to be solved, but at pressure, close to 2 bar, the balloons were broken and the water was pull out from the upper interface.





FOUR PROOF TEST (17/09/2021 – FAILED) CONT’D

To verify this aspect the assembly was dismounted and one balloon only (identical to the one involved in the proof test) was inserted in to the bladder and pressurized up to 1 bara, no rupture was detected.

Considering what emerged from the above verification, with the single balloon, it would seem that the use of encapsulated balloons (to protect the inner most balloon from the bladder defect) was deleterious rather than useful.

It is suspected that the friction between the various layers, of the individual balloons, have contributed negatively to the pressurization.

So it was decide to repeat, once again, the proof test inserting one balloon only.

FOUR PROOF TEST (17/09/2021 – FAILED) CONT'D

To verify this aspect the assembly was dismounted and one balloon only (identical to the one involved in the proof test) was inserted in to the bladder and pressurized up to 1 bara, no rupture was detected.

Note:

unfortunately due to the several mounting a dismounting activities the lower silicon cap was damaged so the bladder has been installed without it.

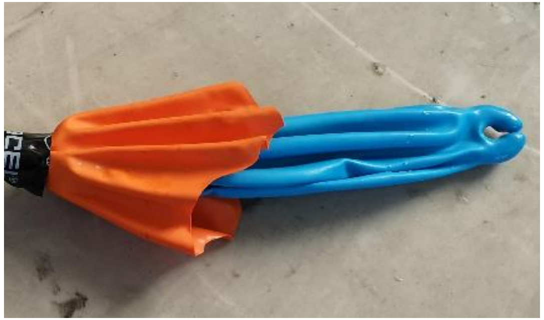
It would seem that the use of encapsulated balloons (to protect the inner most balloon from the bladder defect) was deleterious rather than useful.
It is suspected that the friction between the various layers, of the individual balloons, have contributed negatively to the pressurization.
So it was decide to repeat, once again, the proof test inserting one balloon only.

FIFTH (11/10/2021 FAILED BUT WITH TEST DATA) PROOF TEST

The fifth proof test was consisted into six attempts:

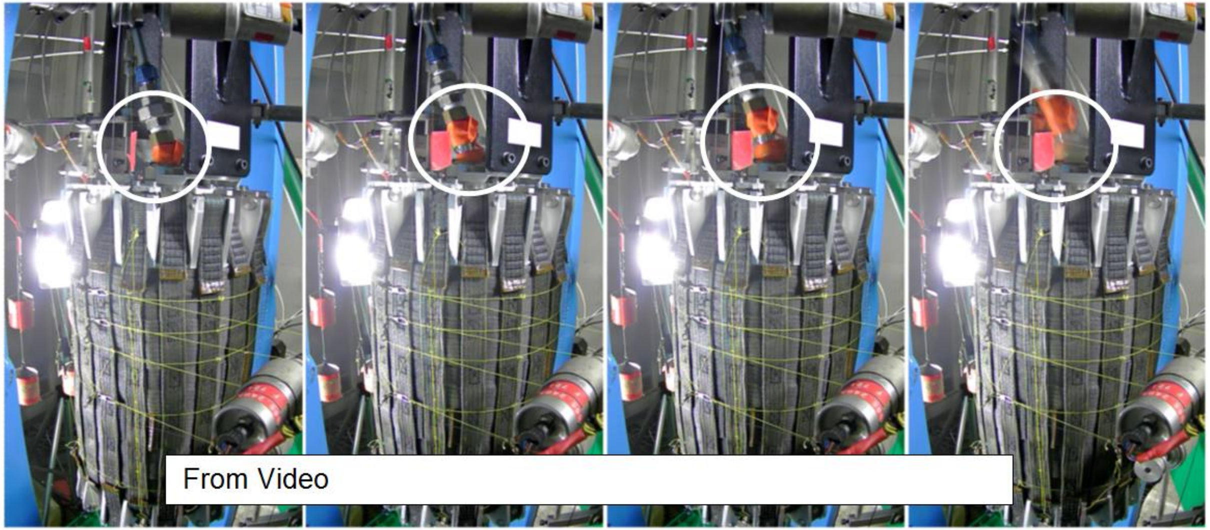
1) Balloon filled by Water.
   Broken on neck due to water weight.
   No Test Data available

2) Balloon pressurize by N2.
   Broken due to longitudinal cut.
   No Test Data available.
   Broken Picture Missing



FIFTH (11/10/2021 FAILED BUT WITH TEST DATA) PROOF TEST COND'T

4) Balloon pressurize by N2.
   Exploded due to hernia that was arisen, as before, during the push out of inlet from interface area.
   No Test Data available

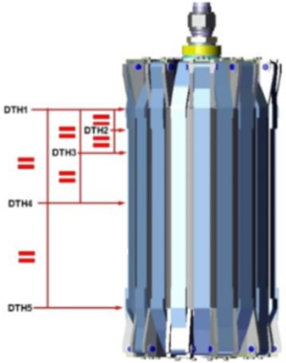


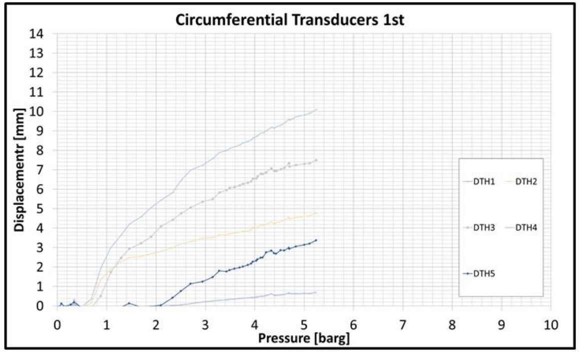
FIFTH (11/10/2021 FAILED BUT WITH TEST DATA) PROOF TEST COND'T

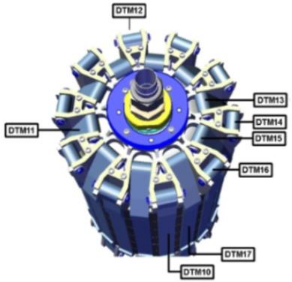
5) Balloon pressurize by N2.

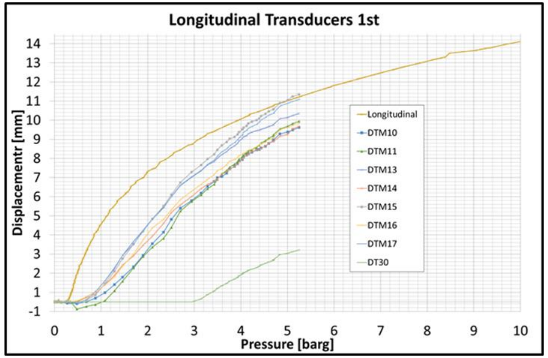
Broken due to a cut on the edge of the hose connector.

Data available up to 5.2 Barg







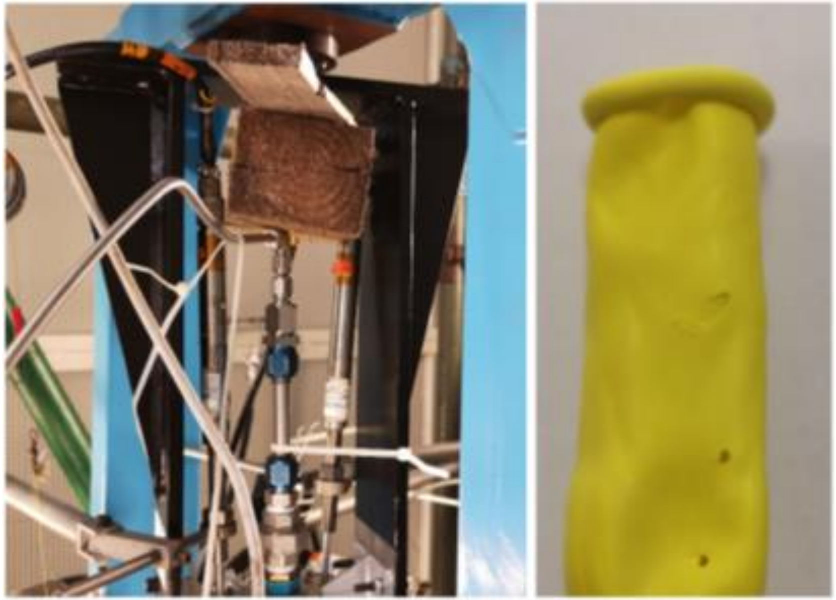


FIFTH (11/10/2021 FAILED BUT WITH TEST DATA) PROOF TEST COND'T

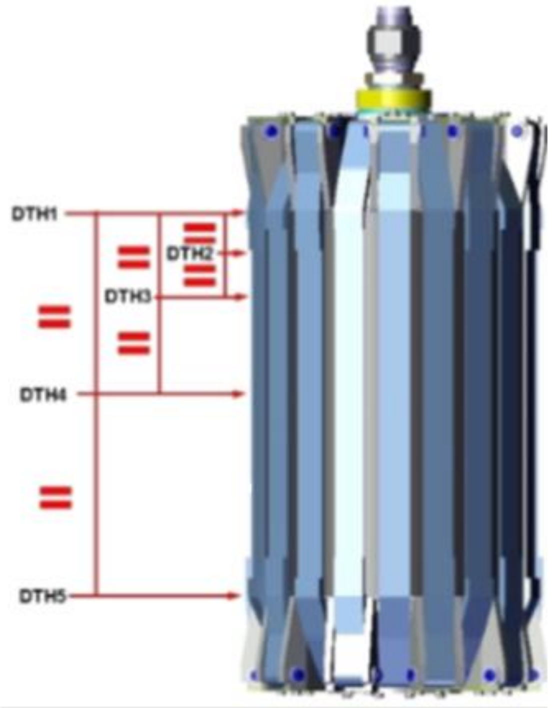
6) Balloon pressurize by N2 two times:
the first was stopped up to 4.26 Barg due to hernia occurred.
Test Data available up to 4.2 Barg.

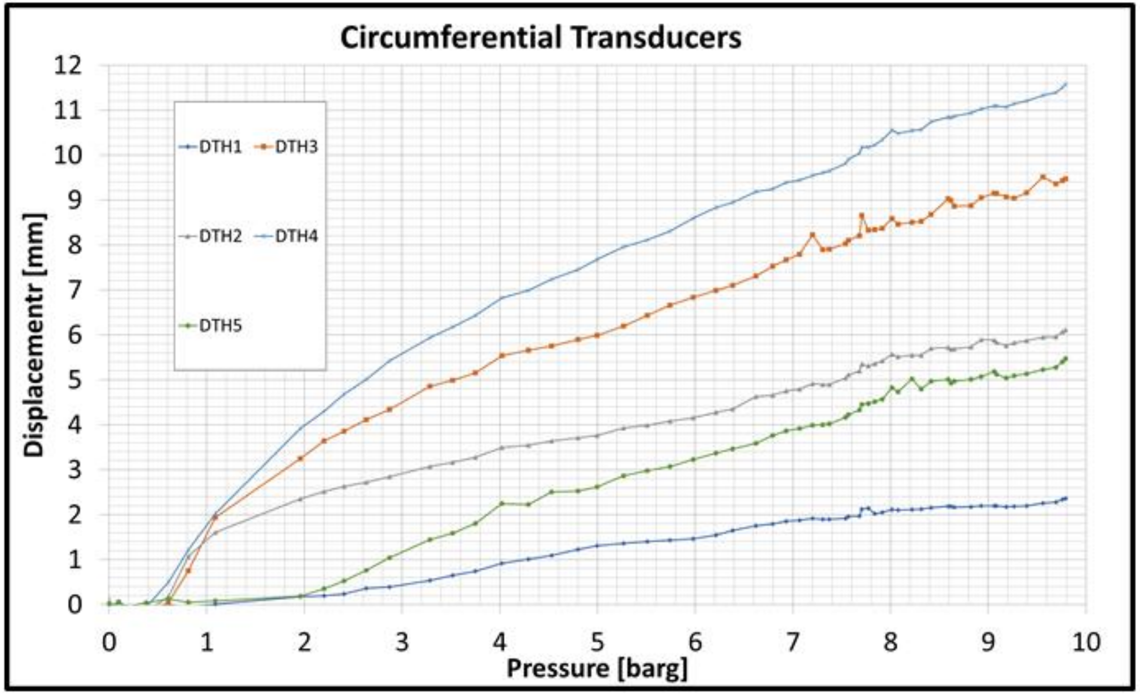
The second (with the inlet blocked and properly aligned with the through hole), broke due to a cut on he edge of the hose connector (plus two holes just before the cut)

But finally at least some test data up to 9.7 Barg have been obtained

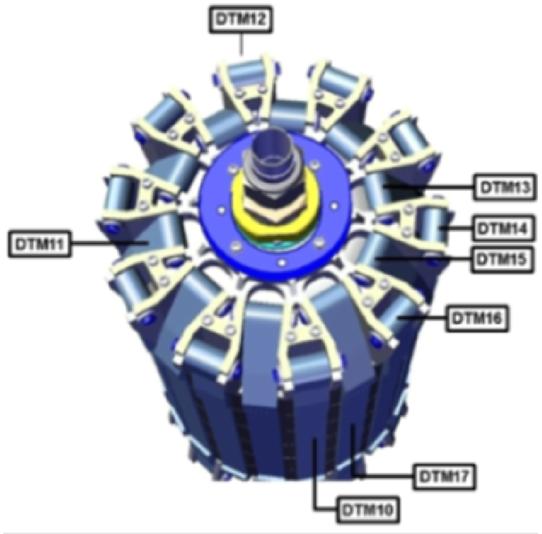


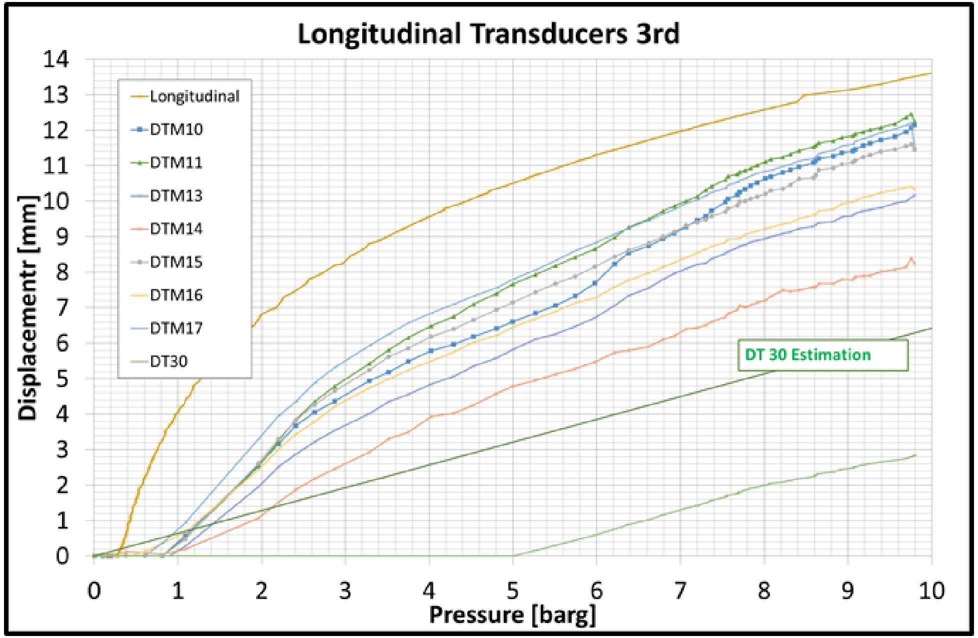
FIFTH (11/10/2021 FAILED BUT WITH TEST DATA) PROOF TEST COND'T





FIFTH (11/10/2021 FAILED BUT WITH TEST DATA) PROOF TEST COND'T



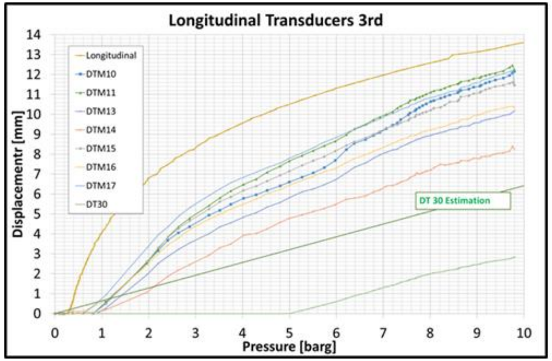


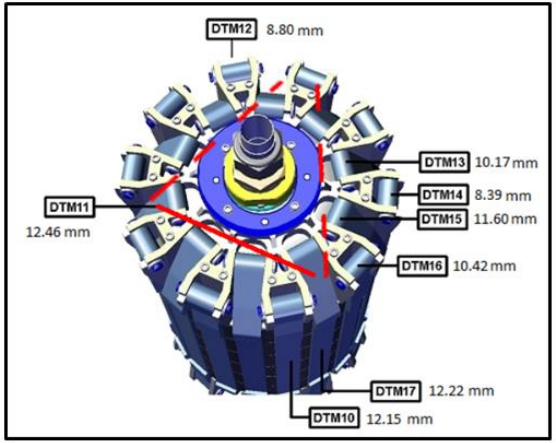
Note: the plunger of Transducers DT30 was found blocked, probable due to the friction and several "explosive" test; so the line reported, in the graph, has been estimated taking into account the value detect on 2nd & 3rd tests (2.8+2.7= 5.5 mm) and the trend showed in the last one.

EVALUATION

Analysing the graphs of the longitudinal straps vs. strap calibration curve (called, in the graph, longitudinal), when submitted to pressure loads, it is evident that:

- the load, on it, are well below the characterization curve (Called "Longitudinal").
- The maximum displacement detected on the belts testifies that the shorter ones are the first straps responsible for supporting the main load.
- It is interesting to note the trend of the belt/transducer DTM10 which, during it stretches, begins to contribute to supporting the load of the adjacent belt DTM17
- Considering the dome, as a planar surface, it can be assumed that the third belt, more loaded, is in the area between DTM12 and DTM13
- The max load reached along the longitudinal strap is about 521 N.



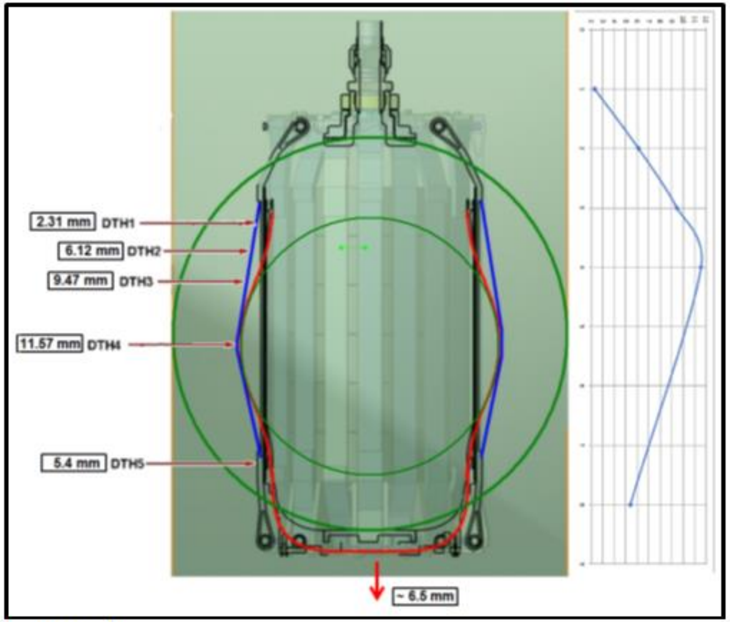


EVALUATION CONT'D

The hoop direction (monitored outside the tank) have been used to graphically measure the tank deformation only.

No loads have been derived, from this system, because affected from the overall deformation/contribution of hoop and meridian strap.

In fact, the reading of DTH1 & DTH5 shown a difference of 3 mm (however symmetrical); difference induced from the previous contribution and the overall tank elongation of about 6.5 mm



LESSON LEARN

Based on these preliminary test data it is evident that the structural part has been adequately designed to support its containment role, however the bladder remains the weak link in the chain and needs further development. .

Despite the huge test campaign devoted to characterize the mechanical properties of the several material involved in SISTEM , only one test campaign, on overall assembly, were foreseen.

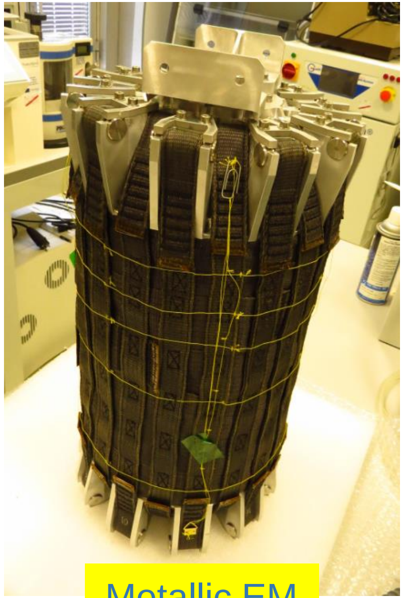
For the future inflatable tank design and verification campaign, two main aspects will be better consider:

- the fluid chamber SISTEM must be made in one single piece, intermediate welding is absolutely not recommended if not forbidden.
- Before designing the housing / interface / dome, it is highly recommended to check the behaviour of the bladder itself, before being wrapped, when submitted to pressure, and then start designing the wrapping system in accordance.

FOLDING BB DESCRIPTION

A full scale polymeric breadboard has been realized by TASI in FDM technology, with internal additive manufacturing printer (3NTR SPECTRAL 30), devoted to perform the foldability test campaign in parallel to the metallic EM tank involved in the pressurization test.

Polymeric BB



Metallic EM

The polymeric BB (white ABS) made from the following parts:

- 2 domes
- 40 simplified pins (without extra reworkable diameter)
- 20 “H” shape retainers
- 2 caps

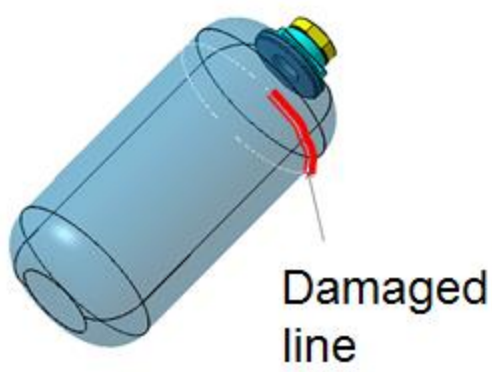
For this test has been utilized the DM restraint and the first bladder DM released by HOLSCOT.

FOLDING BB DESCRIPTION

The restraint used is fully similar to the EM restraint in term of dimension and quality, whereas the bladder utilized for this test is a DM bladder characterized by a linear damaging on the welding line as shown in the picture below and it is not equipped with fluidic fitting

The damaged area has been repaired with tape.

SABELT RESTRAINT (DM version)



HOLSCOT Bladder (prototype version)

FOLDING TEST CAMPAIGN

The foldability campaign held in TASI laboratory in 22nd September 2021 has been planned with the following test:

- **Folding BB without bladder inside**
  - *Packaging factor*: single folding measuring the final envelope (H and Ø) in folded and unfolded configuration
  - *Cycling*: n°10 folding and unfolding cycling to evaluate the effect on the restraint
- **Folding BB with bladder inside**
  - *Foldability*: way to folding
  - *Packaging factor*: single folding measuring the final envelope (H and Ø) in folded and unfolded configuration
  - *Cycling*: n°10 folding and unfolding cycling to evaluate the effect on the restraint

FOLDING BB WITHOUT BLADDER INSIDE

Packaging factor:

Only one longitudinal folding has been performed with the aim to detect the contribute of the restraint only on the final envelope (H and Ø) in folded and unfolded configuration

Unfolded configuration

H=43 cm

Folded configuration

H=24 cm

FOLDING BB WITHOUT BLADDER INSIDE

Packaging factor (cont'd):

$H_{unfolded}$ = 43cm

$Ø_{unfolded}$ = 24cm

H_{folded} = 24cm

$Ø_{folded}$ = 26cm

Packaging longitudinal =44%

Unfolded configuration
Ø=24 cm

Folded configuration
Ø=26 cm

FOLDING BB WITHOUT BLADDER INSIDE

Cycling:

n°10 folding and unfolding in longitudinal direction has been performed to evaluate the effect on the restraint.

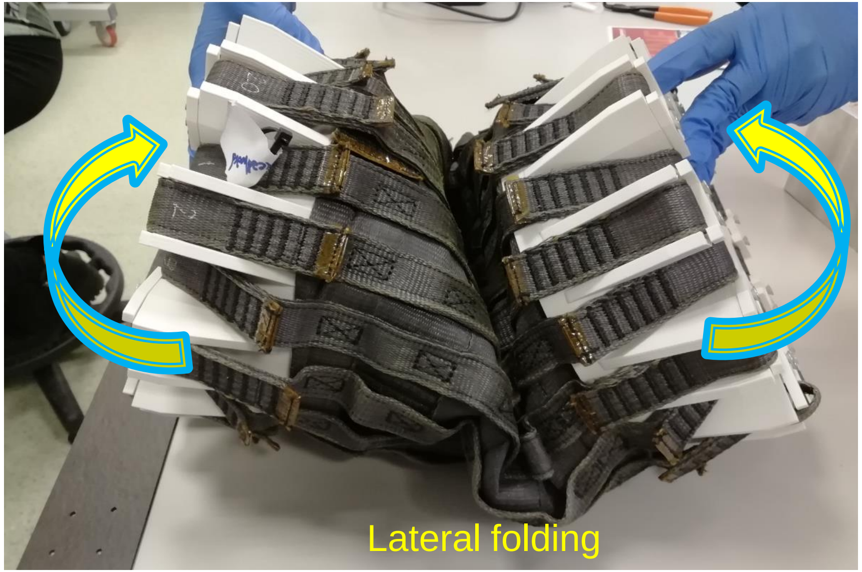
No effect on the restraint has been detected after the cycling test.

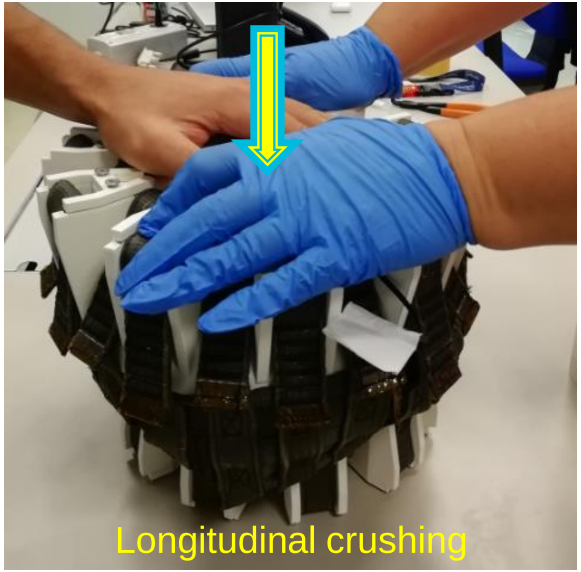
FOLDING BB WITH BLADDER INSIDE

Foldability:

2 different folding could be applied with the bladder inside:

- lateral folding
- longitudinal crushing (best packaging factor)

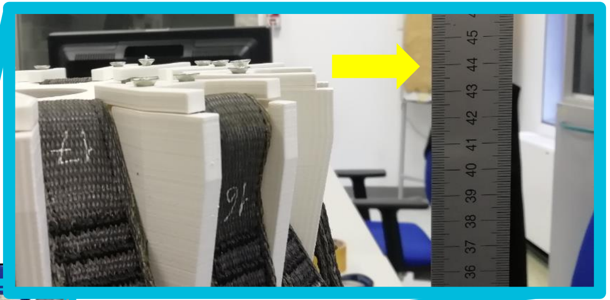


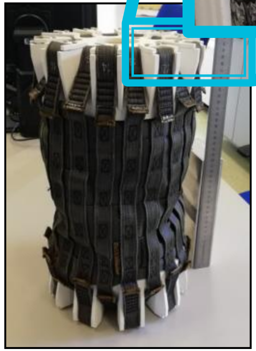


FOLDING BB WITH BLADDER INSIDE

Packaging factor:

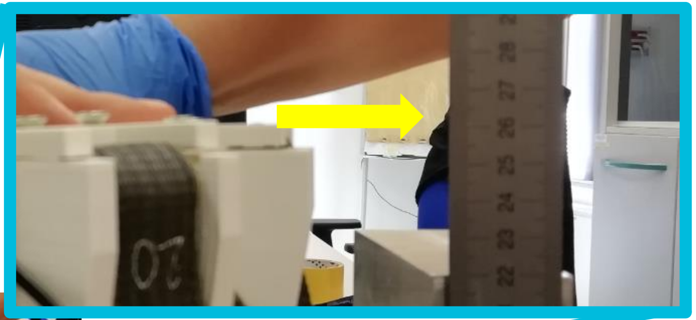
Only one longitudinal folding has been performed with the aim to detect the contribute of the restraint with the bladder inside on the final envelope (H and Ø) in folded and unfolded configuration

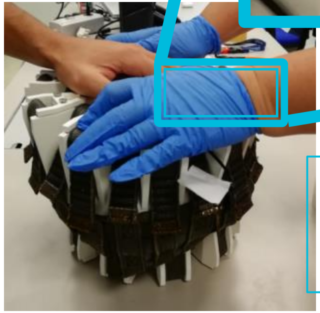




Unfolded configuration

H=44 cm





Folded configuration

H=26 cm

FOLDING BB WITH BLADDER INSIDE

Packaging factor (cont'd):

$H_{unfolded}$ = 44cm
Ø$_{unfolded}$ = 24cm

H_{folded} = 26cm
Ø$_{folded}$ = 28cm

Packaging factor =41%

Unfolded configuration
Ø=24 cm

Folded configuration
Ø=28 cm

FOLDING BB WITH BLADDER INSIDE

Cycling:

n°10 folding and unfolding in longitudinal direction has been performed to evaluate the effect on the restraint and on the bladder.

No effect on the restraint has been detected after the second cycling test.

AFTER 23 cycle

After the cycling test any visible findings is detected and the existing crack doesn't increase its extension

AFTER 11 Cycle

ThalesAlenia Space

DEVELOPMENT AREAS (1/2)

LEVEL	Development area
Bladder Material	The fluid containment layer is one of the most critical in the foldable tank design, the selection of materials should be refereed to one specific applications taking into account temperature and pressure example elastomeric based bladder to be used at RT while fluoropolymers one to be used at low temperatures
Bladder Material	Application to cryogenic environment requires specific test campaign as cryogenic temperature helium leak test, mechanical testing in temperature
Restraint strap	The mechanical properties are not significantly affected by aging treatment (residual strength up to 85%) , even if unexpected behavior is observed on the meridian strap after folding and fatigue, this suggest to increase number of tested specimens for the KDF determination as lesson learnt for the future since the values are a little bit scattered, probably influenced also by the sewing process of the meridian one.
Technological process	Welding and /or bonding should be limited as much as possible a seamless component have to be preferred
Technological process	In case of welding , the welding line have to be continuous avoiding multiple start and go points
Development logic	Adding Bladder DM dedicated to characterize the effect of the welding line and the reproducibility of manufacturing parameters

DEVELOPMENT AREAS (2/2)

Level	Development area
Development logic	Add characterization test on the aforementioned "starting points" foreseen biaxial test on critical joints and performed testing also extracting samples from DM
Development logic	Adding Bladder DMs to be pressurized up to burst
Design	Belt Regulation System→ a fine regulation system based on elliptical pin can be foresees in order to have a fine preload regulation of each longitudinal belt Transition profile _-> reduce the step between the metallic domes and restraint assy Avoiding inlet to be internal inserted (this implies a dome to be welded)
Recommendation from FEP bladder in case of welding	• minor variation in wall thickness between body and endcap to be improved where possible • improvement to collapsible welding jigs to reduce witness lines • satisfactory weld first time to aid reduction in shrinkage/distortion • high stress area around weld might be eased by an alternative weld position • it is recommended to support the bladder above 1.0 bar pressure
Methodology	Improve methodology for serviceability, characterization and specification of design factors to ensure proper long-term performance
Methodology	Existing standards / codes don't provide design guidance sufficient to characterize serviceability and/or properly select a design factor for inflatable tank subjected to changeable operational exposure.
Modelling	Even if Bladder is a "passive" layer, it should be included in the model phase

CONCLUSIONS (1/3)

- 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.
- In the frame of ESA technology research programs AO/1-9397/18/NL/LvH an innovative tank concept based on ribbon net and polymeric “bladder” able to cope with a wide variety of fluids (gas and liquids) storage and temperatures has been designed to withstand a pressure in the 50-100 bar range.
- The tank design is based mainly on high pressure capability assembly (structural restraint) and a fluid containment layer (bladder). Metallic domes and pins bush are added to avoid the local deformation.
- The high pressure will require the accurate selection of the structural restraint material and of the stitching processes to achieve the required performances in terms of load capability.
- The restraint based on Zylon strap has been fully characterized also on repaired and defected samples.

CONCLUSIONS (2/3)

- /// 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.

- /// 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. A 360° video/audio recorder system will also installed

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

- /// 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.

- /// Holscot provided to repair both cracks and then, the repaired bladder has been re integrated in the EM for the second pressure run. In this case, higher pressure has been reached but failure occurred again in the welding line (along the circumference at that time)

CONCLUSIONS (3/£)

- The major findings on bladder are linked to the circumferential welding line, that has been performed on sectors each positioned at 120° → 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
- 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, ribbons→ the restraint could be refurbished for future test campaign
- The foldability of the SISTEM has been assessed successfully on 3D printed parts, a high compaction level (> 40%) has been reached

WAY FORWARD

- Refurbishment of structural restraint, metallic dome and retention systems
- Different bladder material solutions: coated eng. fabrics , multilayer, coated –PBO fabric (Sabelt)
- Bladder design modification using a seamless part e.g. coextrusion blow moulding technology.
- Design modification for the fluidic IF
- Realization of new fluidic Ifs compatible with the manufacturing process of bladder.