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Alphabus Propellant Tank: Manufacturing, NDI and Damage Control

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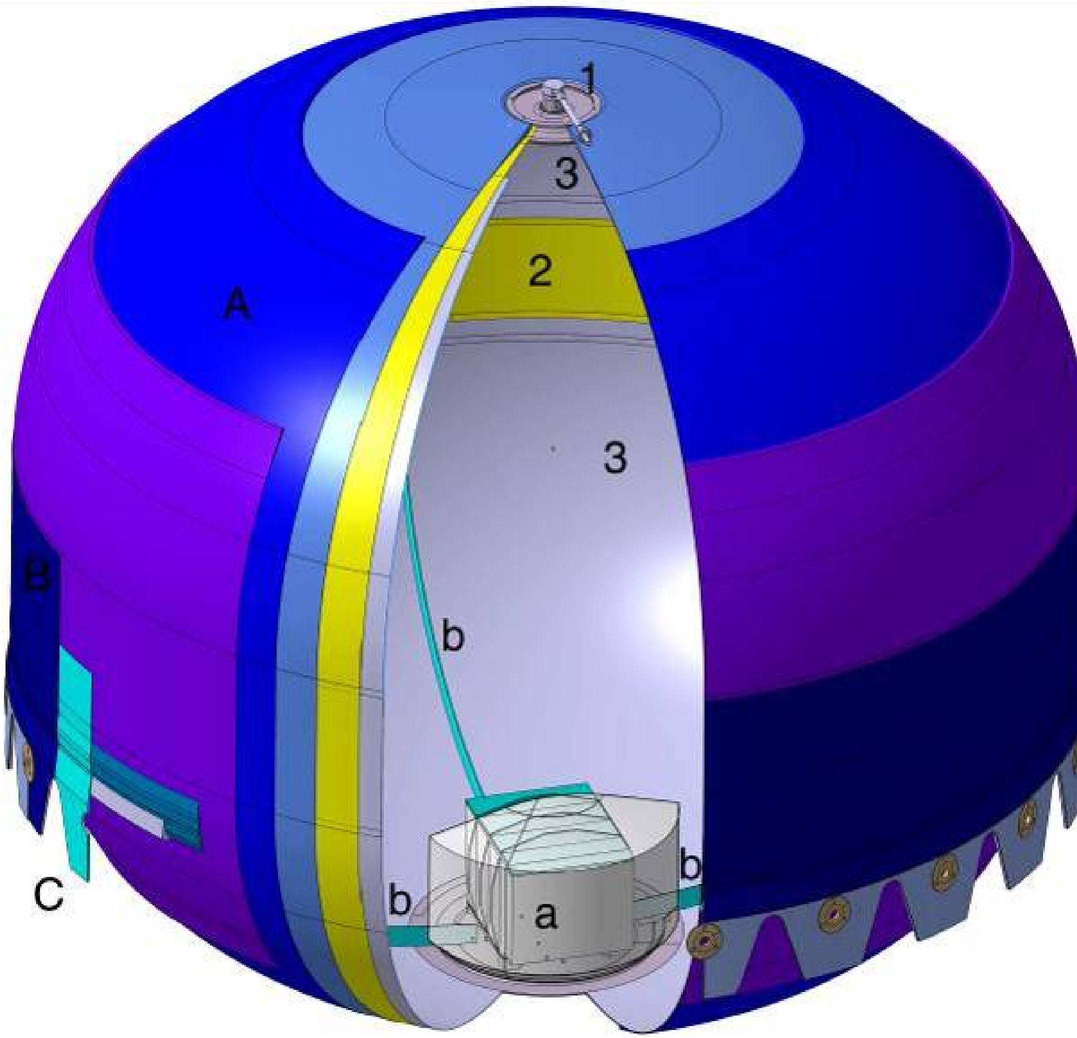
Overview

- The Alphabus Propellant Tank
- Liner Damage Tolerance Approach
- Overwrap Damage Tolerance Approach

Alphabus Propellant Tank

- For storable propellants
- Titanium liner, t ≥ 0.7 mm
- Fully wrapped, T 800
- Integrally wound CFRP skirt
- Titanium skirt insets
- Diameter ≈ 1.6 m
- Height ≈ 1.3 m
- Cassini-shaped domes
- Volume ≤ 1.9 m³
- MEOP 24 bar

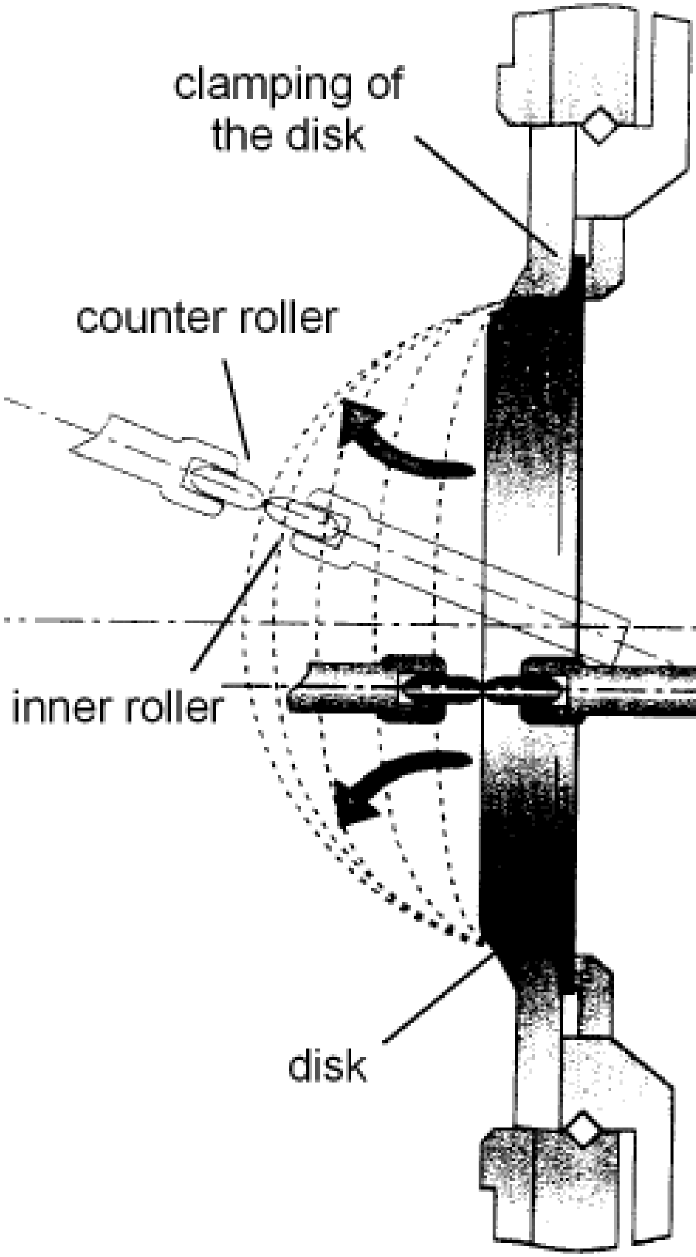
- Important mass reduction as compared to all-metal tanks



Alphabus Propellant Tank

- Liner Fabrication Approach -

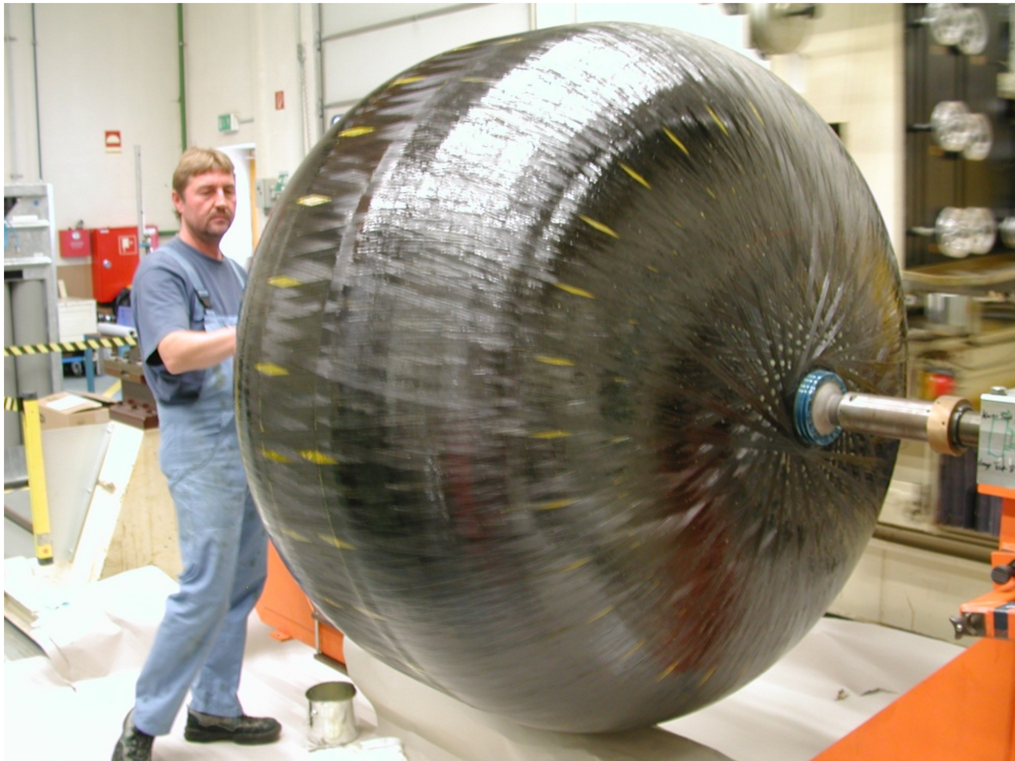
- Material base: standard mill products
- Net-shape spin-formed domes
- Sheet metal cylinder design
- TIG and EB welding (X-ray inspection)
- 100 % automatic EC inspection
- Stress relieving & aging upon welding



Alphabus Propellant Tank

- Composite Fabrication Approach -

- Bonding film between liner and overwrap
- Pressure shell wet winding
- Integrally wound skirt (wet winding & prepreg mix)
- Skirt milling
- Titanium inset assembly (satellite central tube interface)



Alphabus Propellant Tank
- Qualification Status -

- EM successfully tested to the complete qual. requirements
- QM in preparation
- PFMs in production

Alphabus Propellant Tank
– Liner Damage Tolerance Approach –

The damage tolerance approach for the titanium liner has been performed by the standard procedure for propellant tanks:

1. Safe Life Analysis
   4 x life spectrum plus a contingency of 2 for all vibration tests for the case of interrupted tests.
   - ✓ Crack growth calculation with ESACRACK (NASGRO)
   - ✓ SINTAP check for high-loaded parts (σ > 70% $R_{p0.2}$)
2. LBB
   K_c check for a 10 x t through crack for all thin walled parts
3. Sustained Load Check
   Maximum K check during operational life of 18 years w.r.t. stress corrosion cracking threshold of:
   - ✓ IPA
   - ✓ MON-1

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– Liner Damage Tolerance Approach –

- A material characterization program was performed for
  1. Ti-15V-3Cr-3Al-3Sn spin formed material
  2. Ti-15V-3Cr-3Al-3Sn TIG weld
  3. Ti-15V-3Cr-3Al-3Sn/Ti-6Al-4V EB weld

- The material characterization for all 3 material conditions included :
  1. Tensile tests
  2. Thin gauge surface crack tests (K_{Ie}) including elastic plastic evaluation
  3. da/dN curves for ESACRACK application
  4. K_{Iscc} tests for IPA, MON-1
  5. ASTM G 44 tests for cleaning fluids (IPA, Turco, Acetone, demineralized water)
  6. Fatigue tests of typical surface condition after spin-forming

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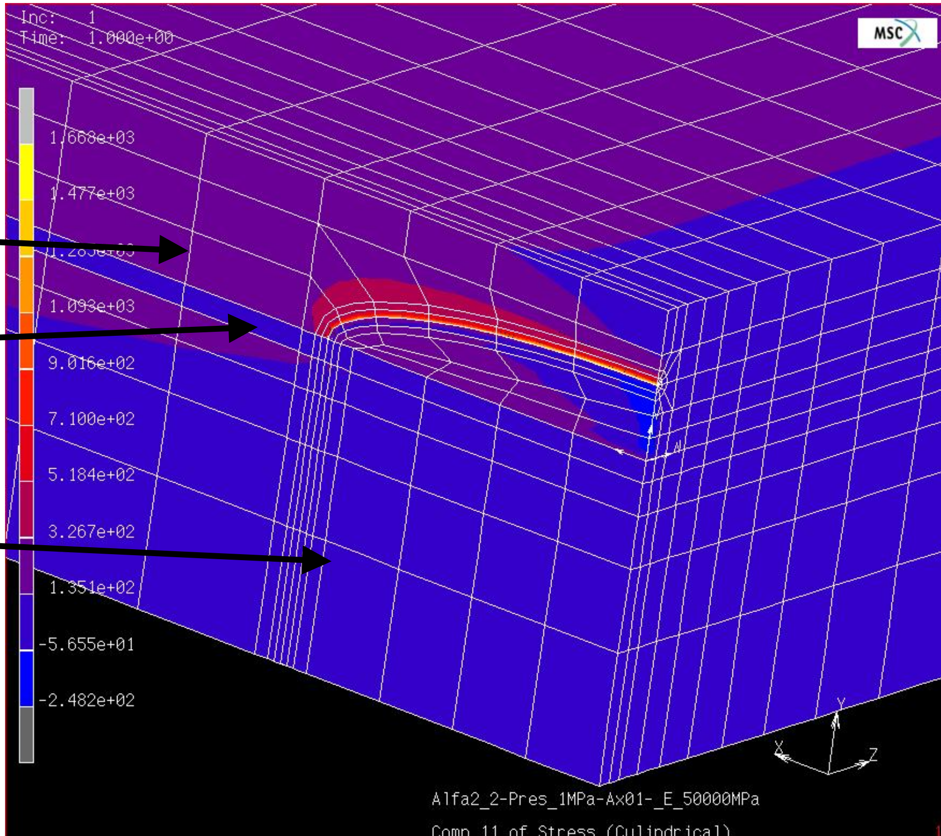
- Liner Damage Tolerance Approach –

A large numerical study was performed to study the “shielding effect” of the composite overwrap on the surface crack behaviour. The results were compared with classical K-solutions. The potential has not been applied but verified existing conservatism.

itanium Liner

Bonding

Composite Overwrap



Future application of the results
s in discussion

Alphabus Propellant Tank
DTA Requirements for the Composite -

The current damage tolerance approach of the Alphabus propellant tank composite structures is based mainly on the following applicable standards:

- ECSS-E-30-01A - Fracture Control Requirements
- ANSI/AIAA S-081-2000
  Space Systems – Composite Overwrapped Pressure Vessels (COPVs)
- ISO/DIS 14623 - Space Systems – Pressure Vessel Structural Design

The damage tolerance of the composite structures has been harmonized with the requirements of these standards in combination with MT experience gained with composite structures under consideration of

“Implementation Guidelines for ANSI/AIAA S-081: Space Systems

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DTA Requirements for the Composite -
- Damage Tolerance Approach –

The damage tolerance approach has been performed with the focus on the following most important steps:

1. Potential Defects Screening
   based on long-term MT experience with comparable materials and processes
2. Damage Threat Analysis
   based on long-term MT experience with comparable materials and processes
3. Protection Plan / Quality Assurance
   including transport containers and protective covers
4. Safe Life Demonstration
   by a full scale test with artificial defects, as analytical methods are not fully available for composite materials

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- DTA Requirements for the Composite -
- Potential Defects Screening –

The structure screening of potential defects has identified two major potential defects :

- Debonding between the metallic liner and the composite overwrap, which however is critical only during collapse test and filling operations. Debonding is not critical in the pressurized condition
- Delamination mainly in the skirt and cylinder area, where compression and shear stresses appear. The cross layers are mainly loaded by tension where delamination is not critical.
- Impact will be prevented by damage control.

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DTA Requirements for the Composite -
- Damage Threat Analysis –

Phase	Reason of Damage	Countermeasures
Manufacturing Process	Contamination (oil, grease, dust, etc.) of ➢ raw material (fibre, resin, prepreg) ➢ tools, machines, devices ➢ work shop ➢ personnel ➢ cleaning fluids	General: manufacturing of CFRP Items is ☑ performed exclusively in dedicated workshops with experienced personnel ☑ completely defined by in-house standards Justification of cleanliness by ☑ incoming inspection, material specification ☑ process control, manufacturing instruction, ☑ general instructions, cleaning instructions, maintenance of workshop ☑ briefing of qualified personnel ☑ qualified fluids, storage requirements, specifications

Alphabus Propellant Tank
- DTA Requirements for the Composite -
- Damage Threat Analysis –

Phase	Reason of Damage	Countermeasures
Manufacturing Process	Incorrect manufacturing of composite by	Strict control of manufacturing processes by
	➢ wrong application of thermal sensors	☑ regular check (and maintenance) of sensors
	➢ deviation from qualified process variables (curing temperature, fibre stress etc.)	☑ process control and record of process variables, regular checks
	➢ application of non-qualified auxiliary materials (foils, separating agents, peel ply, etc.)	☑ only application of qualified materials, preparation of applicable materials list for the workshops
	Insufficient material properties caused by	Justification of material properties
	➢ missing or wrong properties	☑ proper material characterisation
	➢ contamination	☑ control of storage and application conditions
	➢ life limiting conditions exceeded (max. storage time, temperature, UV / light / radiation)	☑ control of storage and usage limiting conditions

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- DTA Requirements for the Composite -

- Damage Threat Analysis –

Phase	Reason of Damage	Countermeasures
Storage	Delamination, cut, impact, tear by	Prevention of damaging
	➢ hoisting, handling, transport of objects in the neighbourhood	☑ definition of safe storage places with sufficient safety distance, no operation allowed at distances below, shock indicator
	➢ unauthorized contact	☑ marking of fracture critical items, contact prohibited
	➢ improper storage conditions	☑ strictly defined storage conditions (container/box, fixations, covers, drying agents)
Internal and External Transport	Delamination, cut, impact, tear by	Prevention of damaging
	➢ improper fixation during transport	☑ specified fixation conditions for transport
	➢ missing protection	☑ no transport without protective cover(s)
	➢ shock loads	☑ damped fixation, shock indicators
	➢ foreign impact	☑ appropriate protection cover(s)
	➢ moisture by unprotected outdoor transport	☑ specified outdoor transport conditions
	➢ moisture caused by improper sealing of container	☑ specified sealing of transport container, drying agent

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DTA Requirements for the Composite -

- Damage Threat Analysis –

Phase	Reason of Damage	Countermeasures
Hoisting and Handling	Delamination, cut, impact, tear, indentation by	Prevention of damage by
	➢ uncontrolled drop of the manufactured item	☑ clear definition of hoisting and handling operations
	➢ drop of tools, crane on the structure	☑ controlled areas for operation, no operations above the COPV are allowed, protective cover(s)
	➢ wrong hoisting operations, hoist points	☑ clear definition of hoisting operations (user's manual), clear marking of hoisting points
	➢ too fast operations	☑ slow operations
	➢ wrong hoisting device(s)	☑ application only of specified hoisting device(s)
	Contamination of composite with	Prevention of contamination by
	➢ water, moisture	☑ protective cover(s), operation only during absence of fluids
	➢ non-qualified fluids (cleaning etc.)	☑ application only of specified fluids (cleaning, US inspection, proof test, etc.)
	Liner buckling and/or de-bonding caused by	Prevention of liner buckling and/or de-bonding by
	➢ collapse pressure	☑ hoisting/handling only with pressurized COPV
	➢ shock loads	☑ slow operations

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- DTA Requirements for the Composite -
- Protection Plan / Quality Assurance –

All critical points, which have been identified in the damage threat analysis are considered in the

- Manufacturing instructions
- Training of personnel
- Definition and design of protective covers and transport containers
- Definition of workshop conditions
- Definition of lifting and handling devices and hoisting points
- Log book
- User's manual
- Quality assurance plan

This applies especially to impact damage which has to be prevented during all operation phases.

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DTA Requirements for the Composite -
- Safe Life Demonstration –

- Currently no generally qualified analytical method for failure prediction of composite structures with defects exists. New methods like VCCT (virtual crack closure technique) are more and more introduced in aircraft structures but need high computational and experimental effort.
- Although first experience at MT Aerospace exists also with these tools and methods, the decision has been taken to demonstrate the safe life requirements of the composite structure by test.
- Defects with size above the NDI detection limit have been introduced artificially in the engineering model at critical locations of the Alphabus composite structure.
- These locations have been determined in numerical analysis. Most of them are located in the skirt attachment area of the vessel.

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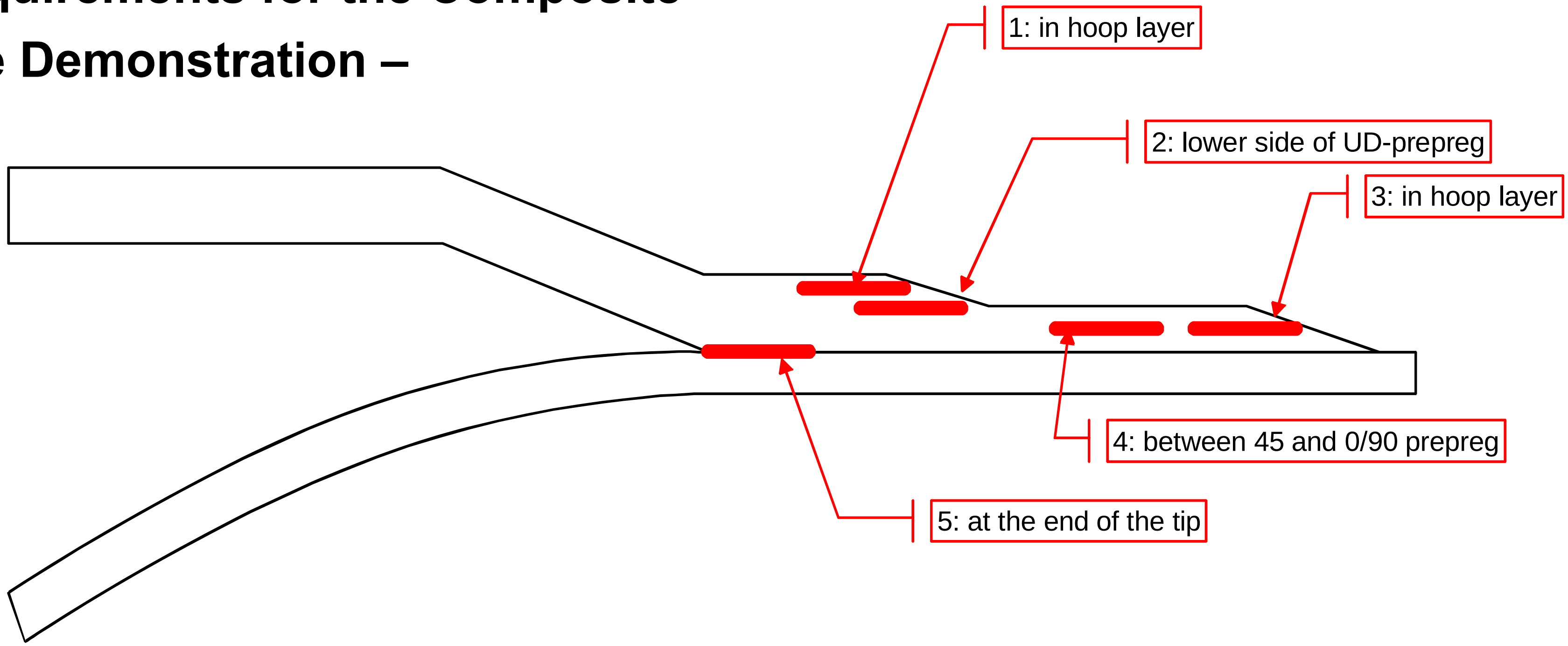
DTA Requirements for the Composite -

Safe Life Demonstration –



he damage tolerance of the composite structures has been demonstrated by showing that these defects will not lead to instability during all tests.

lone of the artificial defects showed crack extension during pressure cycle and vibration test of the development model.

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DTA Requirements for the Composite -
- Impact Tests –

In order to get information concerning the general behaviour/reaction of the vessel regarding impact damage and to determine the limits for a barely visible impact damage (BVID), a test program has been performed:

- Impacts have been introduced in all areas of the vessel: dome, cylindrical area and skirt (> changing stiffness in meridian direction).
- The energy of the impacts has been varied in the range of 5 to 25 Joule (> increasing energy in circumferential/hoop direction).

For this program an impactor according to the standards has been used.

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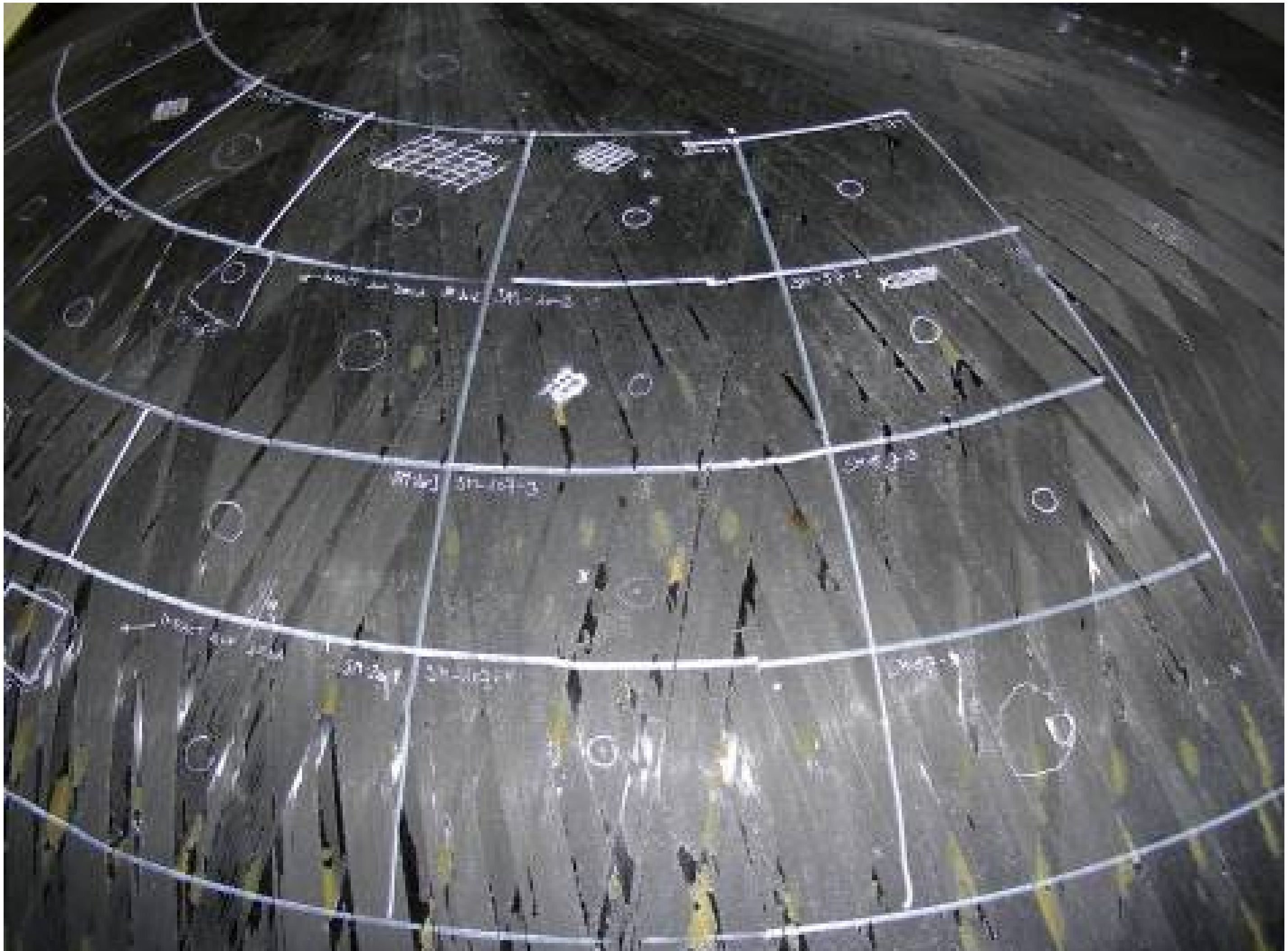
- DTA Requirements for the Composite -
- Impact Tests in the Dome Area –



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- DTA Requirements for the Composite -
- Impact Tests in Cylinder and Skirt Area –

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DTA Requirements for the Composite -

- Impact Tests –

The following table summarizes performed impacts at different locations with different energies and the measured dent depth in mm in the dome area.

Location	Distance	5 J	10 J	15 J	17.5 J	20 J	25 J
1	300 mm	0.1	0.1 – 0.15	0.1	0.1	0.15 – 0.2	0.2
2	400 mm	0 – 0.1			0.15	0.1	0.1
3	500 mm				0.1	0.1	0.1
4	600 mm				0.15	0.1	0.1

Tests in the other areas of vessels gave similar results.)

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DTA Requirements for the Composite -
- Impact Tests –

IDI has been performed to determine damage of the impact surrounding.

5 J

y hand held US)

ages are:
in the composite
=> none
etween composite
=> yes
=> none

The obtained US-results clearly indicate that the damaged area is not in the composite overwrap, but in the bonding between composite and liner.

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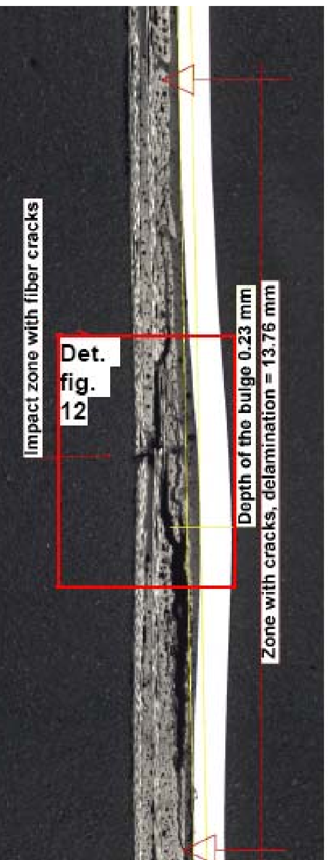
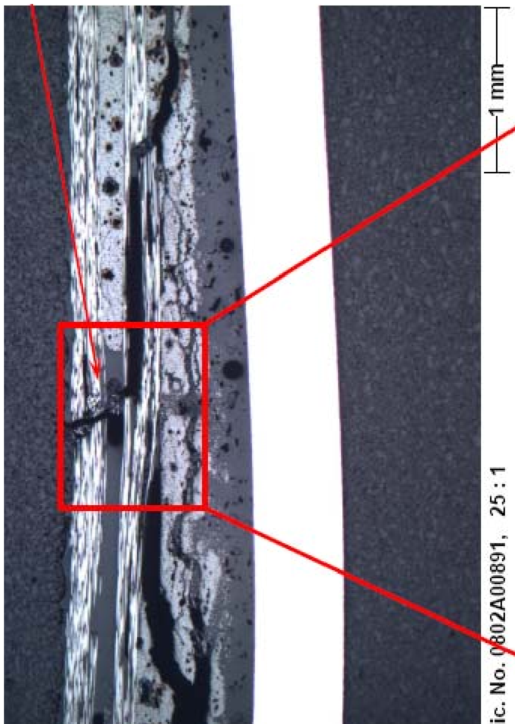
DTA Requirements for the Composite -
- Impact Tests –

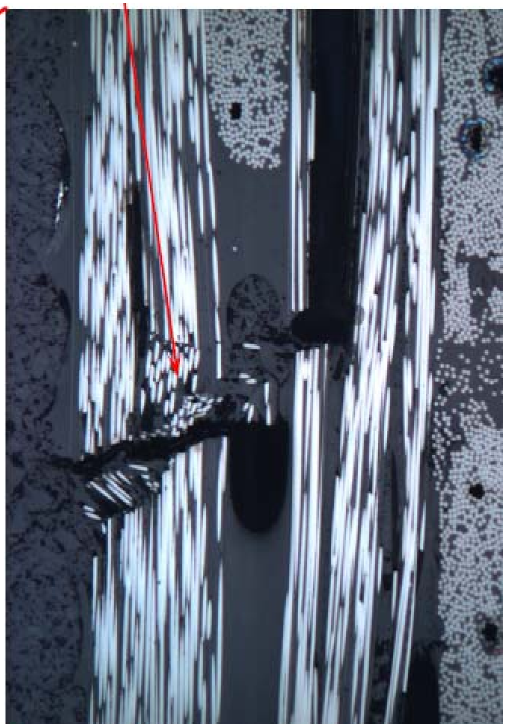
ue to the fact that other tests with the Alphabus vessel unit were foreseen, it was not possible to establish micrographs of damaged areas as done on other vessels.



Figures are giving micrographs of a *COPV with steel liner*.



Fibre Failure



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DTA Requirements for the Composite -
- Impact Tests –

leanwhile with this Alphabus vessel vibration tests according to the requirements have been performed with all of the applied impacts.

lo change, shifting of eigenfrequencies has been observed.

fter these tests the US-inspection has been repeated. No increase of before determined debonded areas has been recorded.

: is foreseen to cut the vessel and to establish micrographs for this vessel as shown before, too.

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DTA Requirements for the Composite -

- Impact Tests Summary –

- The obtained US-results are clearly indicating that the damaged area is not in the composite overwrap, but in the bonding between composite and liner.
- Fiber failure has not been observed in all applied impacts.
- Delaminations have been determined even at impact energy levels, which did not create visible damages on the surface (=> BVID).
- It is also evident that at higher energy levels the delaminated areas are such that there is an interaction between neighboring impacts.

rom the obtained results it was not possible to determine a BVID-limit.

- Based on this result and the damage threat analysis a tough protection concept has been established for the vessel.
- A currently running R&D-program will allow numerical evaluation of impact damage influences in the future. The obtained US-results are clearly indicating that the damaged area is not in the composite overwrap, but in the bonding between composite and liner.

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Summary

- *Important mass reduction by carbon fibre overwrapping of large titanium tanks for storable propellants*
- *Mill products liner fabrication approach*
- *Very thin liner under damage tolerance control*
  - *Safe life analysis*
  - *LBB analysis*
  - *Sustained load check*
- *Composite shielding of the liner & independent sealing and load bearing respectively not taken into account for the time being*
- *Adhesive bond between liner and overwrap*
- *Integrally fabricated skirt*
- *Carbon fibre wrap and skirt under damage tolerance control*
  - *Potential defects screening*
  - *Damage threat analysis*
  - *Protection plan*
  - *Safe life demonstration*