MATURATION OF PROMISING CFRP-LATTICE AND SANDWICH TECHNOLOGIES FOR REPRESENTATIVE FUTURE LAUNCHER INTERSTAGE AND INTERTANK STRUCTURES

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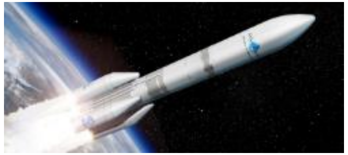
MT AEROSPACE – WHO WE ARE

MT AEROSPACE
An OHB Company

OHB

OHB Systems



Aerospace & Industrial Products

- **OHB SE** one of the largest European space companies
  - Revenue 1 BN€
  - ~ 3000 employees
- **MT Aerospace AG** is the launcher division of OHB
  - Established in 1969
  - ~ 500 employees
  - Revenue 122 M€ (2021)

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Space

- Launcher
- Spacecraft
- Satellite Components
- Structures & Tanks
- Development & Manufacturing

Aeronautics & Defence

- Water Tanks & Structures
- Development & Manufacturing

Infrastructure & Ground Services

- Ground Infrastructure
- Launch Site Operations

MT AEROSPACE – WHAT WE DO

MT AEROSPACE
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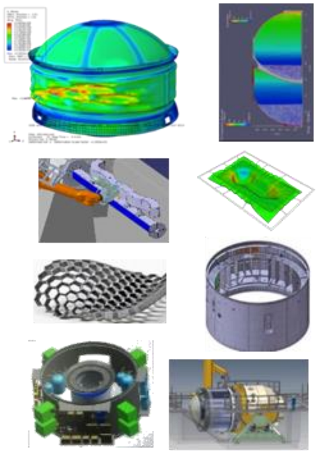
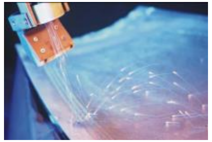
Matured over decades to a Tier 1 Aerospace Supplier

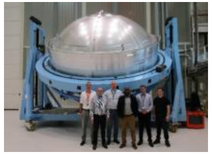


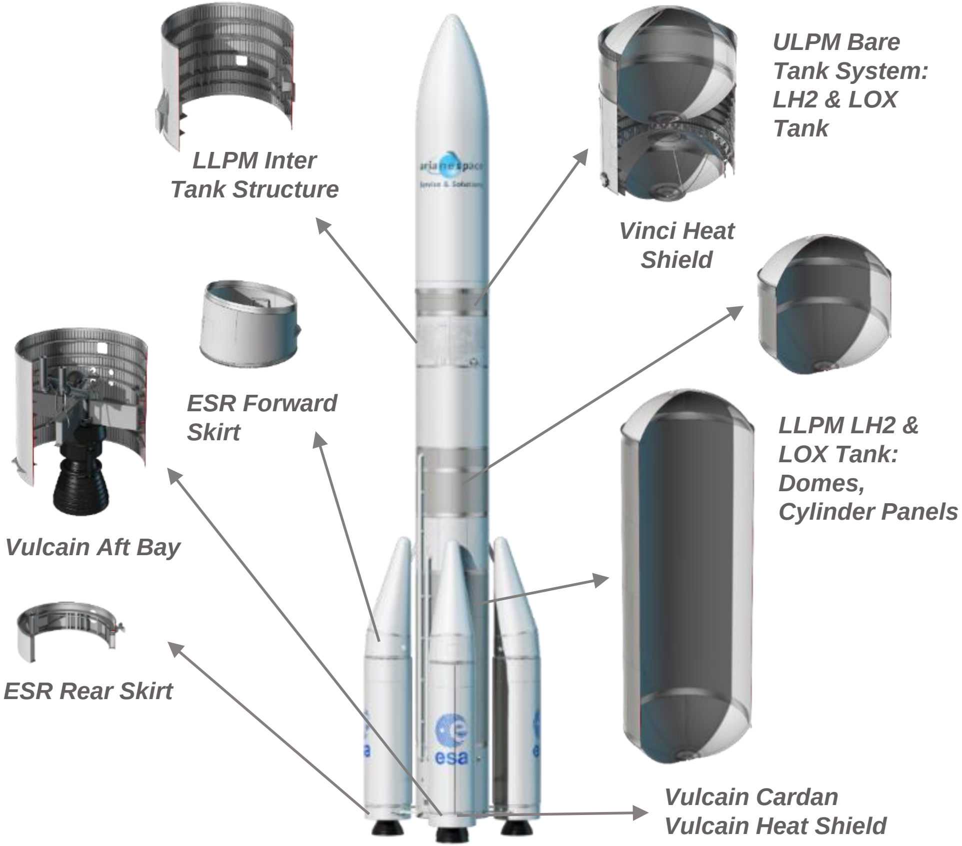
Large Machining
Advanced Forming
Welding (FSW / EB / TIG)
Assembly
Additive Manufacturing
Automated Fiber Placement
Winding
Sandwich
Light-RTM
Hybrid
Out of Autoclave
Advanced NDI
Testing
System Engineering
Aynalysis & Simulation
Design

ARIANE 6

- MT Aerospace holds about 10% workshare in Ariane 6
- Design definition authority for metallic aero structures
- Design and development responsibility for core manufacturing processes/facilities

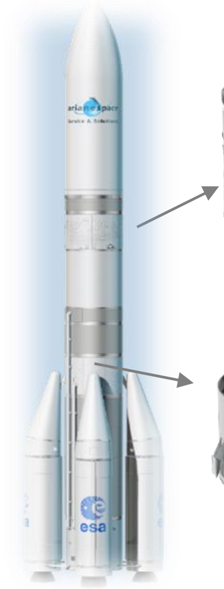




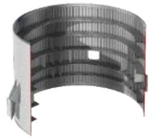


A6 INTERTANK STRUCTURE

- Two metallic A6 intertank structures (ITS) are manufactured at MT Aerospace (main and upper stage)
- The upper stage dry mass is one important parameter for the payload performance
  - 1 kg upper stage mass decrease means 1 kg payload increase
  - 1 kg main stage mass decrease means only about 0.3 kg payload increase
- ➔ Upper stage dry mass decrease is main focus at A6 optimization
- ➔ Development of complete CFRP upper stage currently done by MT Aerospace and Ariane Group Bremen in ESA FLPP program
- ➔ Main focus in this presentation: development of CRFP intertank structure



ULPM Bare Tank System: LH2 and LOX Tank, Inter Tank Structure

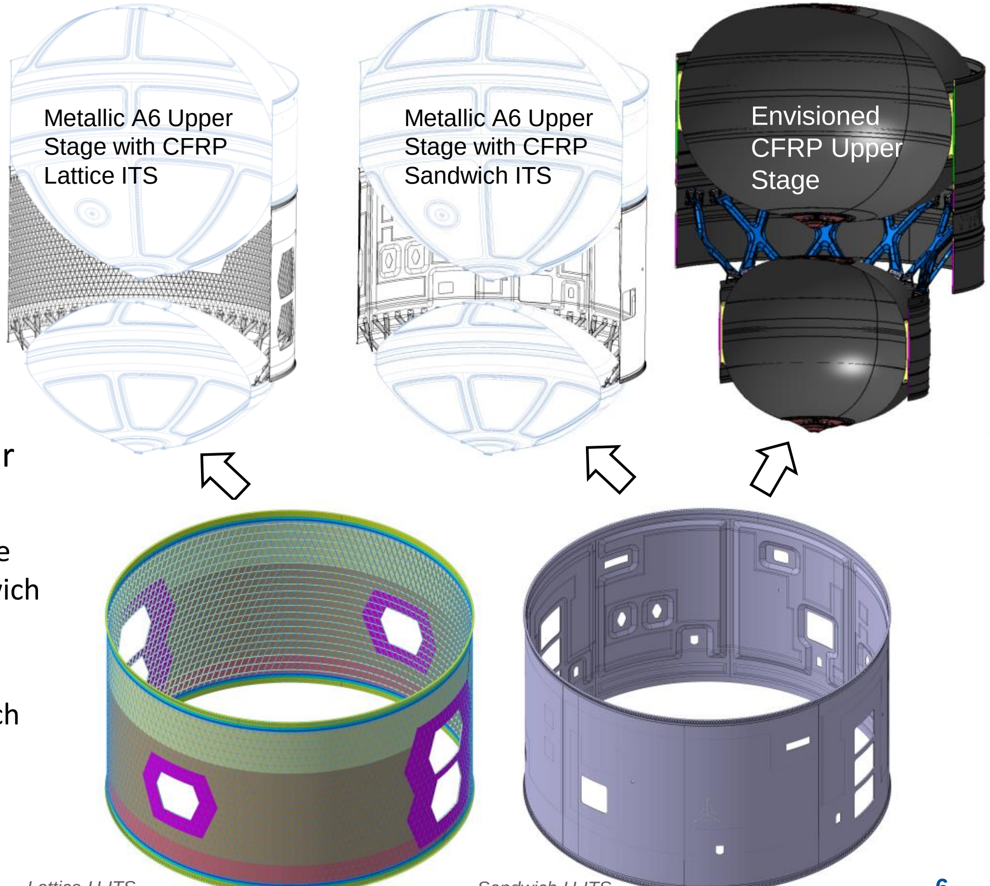


LLPM Inter Tank Structure

Top: Metallic A6
Right: envisioned CFRP Upper Stage

A6 UPPER STAGE INTERTANK STRUCTURE (U-ITS)

- Aim of introducing CFRP material into the upper stage is to reduce the upper stage mass considerably and to reduce the costs by highly automated manufacturing
- For unpressurized structures two technologies present themselves
  - Lattice technology
  - Sandwich technology
- Depending on the boundary conditions each technology has advantages and disadvantages for launcher application
  - For an A6 intertank structure, where interfaces to the metallic parts are necessary both a lattice and sandwich structure is a possibility
  - For a complete CRFP upper stage, where sandwich technology is already present for the tanks a sandwich ITS makes more sense (no additional IF)



Lattice U-ITS

Sandwich U-ITS

TARGET APPLICATION – U-ITS REQUIREMENTS

- To compare both technologies fair, the same target application (A6 upper stage - U-ITS - h ≈ 3.0 m, d ≈ 5.4 m) is chosen
- Based on the same requirements the target application design is defined and verified by analysis for both technologies
- To improve the technology and manufacturing readiness level (TRL and MRL) coupon samples, test elements and breadboards are designed, manufactured and tested
  - The design of the test elements and breadboards are based on the target application design
  - Boundary conditions and loading should be similar to the target application

Target Application: Metallic A6 Upper Stage

Development and Verification Approach

TARGET APPLICATION – U-ITS REQUIREMENTS

- Following main requirements must be met:
  - Transfer of high general flux loads (tension/compression)
  - Connections to metallic LH2 and LOX tank and composite interface structure (IFS)
  - Withstanding of high local loads due to LOX tank suspension
  - Cut outs for local interfaces with high/medium and low loads for equipment and access
  - Withstand high thermal gradients
  - Provide connection points for equipment e.g. avionic
  - Withstand low inner pressure for cavity flushing between tanks
  - Overflux within given boundaries
  - A highly automated manufacturing process with AFP
  - Considerable mass decrease and reduced costs compared to metallic version

Target Application:
Metallic A6 Upper Stage

DEVELOPMENT AND VERIFICATION APPROACH

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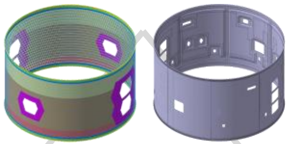
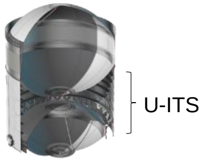
Design Reference
- Loading and boundary conditions
- Performance
- Mass
- Costs





Target Application A6 U-ITS (theoretical)

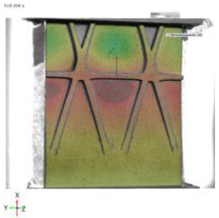
Lattice Breadbord test in 2020
Sandwich Panel test in winter 2023
Tested under representative compressive loading
- Mechanical justification
- Verification of manufacturing quality
- Improve of numerical methods
- Real field data concerning costs
- Lattice TRL 4, Sandwich TRL 4-5

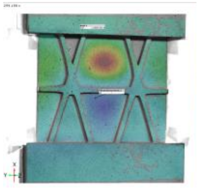
Ø ≈ 0.9 m

One panel of full scale cylinder

Sub-scale Breadboard Tests at RT

Understanding of singular effect
- Tested under representative loading
- Calibration of FE models
- TRL 3





Test Elements at RT

Characterization of CFRP and core materials
- Same manufacturing process as for structural parts used
- Temperature impact investigated

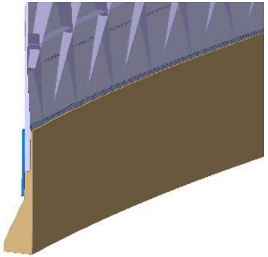
Coupon Samples at 77K/RT/80°C

TARGET APPLICATION DESIGN – MAIN INTERFACES

- The intertank structure connects the two propellant tanks LH2 and LOX and provides a connection to the interface structure (IFS, main stage)
- All interface partners are metallic components
  - due to present extreme temperatures (20K [upper IF to LH2 tank] – 353K [lower IF to IFS]) the thermal mismatch is a topic to be solved
- High compression/tension flux loads must be transferred over the main IF
- At the interface to the LOX tank an additional radial deformation is present, which occurs due to the deformation of the tank under pressure

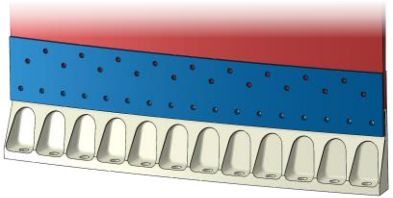
Lattice Technology

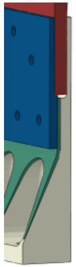
- Transition from lattice with skin to pure monolithic zone



Sandwich Technology

- Reinforced monolithic zones defined for all main interfaces





TARGET APPLICATION DESIGN - CUT OUTS

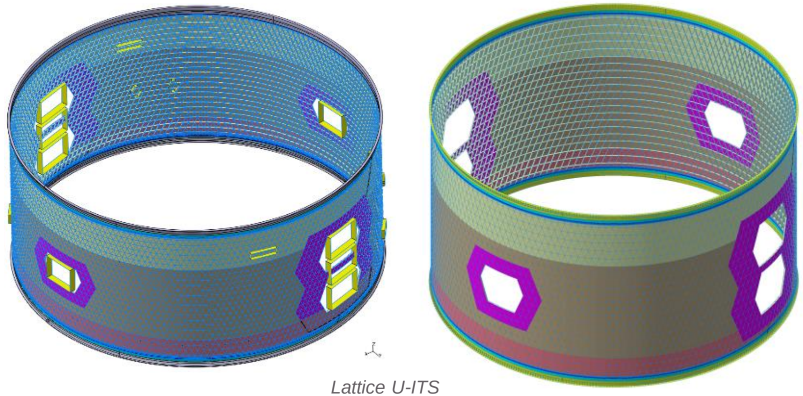
- Cut outs and local interfaces are necessary for equipment mounting and access to the tanks/equipment
- Depending on the size of the cut outs and magnitude of the local loads different design solutions are present

Sandwich Technology

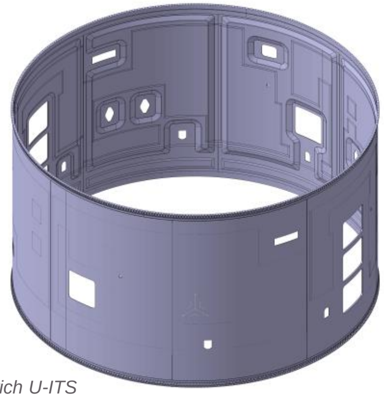
- Cut outs have identical geometry as for metallic design
- Monolithic regions around cut outs to simplify mounting

Lattice Technology

- Cut outs must be adapted to typical lattice geometry (yellow metallic cut out geometry, purple lattice cut out geometry)



Lattice U-ITS



Sandwich U-ITS

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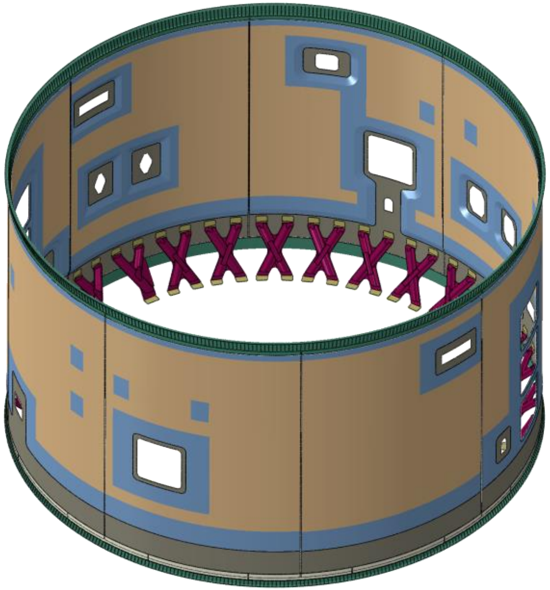
- General flux loads lead to homogenous load over the cylinder
- Due to cut outs, local loads and the LOX tank connection the loading varies over the circumference and in axial direction
- To save mass a near (high loaded area) and far field (lower loaded area) approach is chosen

Lattice Technology

- Near field compared to far field
  - Increased rib height
  - Steeper helical rib angle
  - Skin locally reinforced

Sandwich Technology

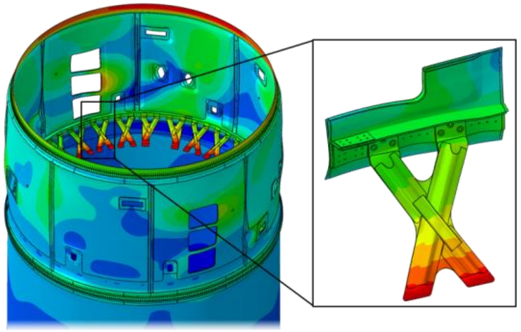
- Near field compared to far field
  - Honeycomb core with smaller cell width and higher density chosen
  - Honeycomb stabilized with core filler
  - Facesheets locally reinforced



Sandwich U-ITS
blue: near field
brown: far field

TARGET APPLICATION – STRUCTURAL JUSTIFICATION

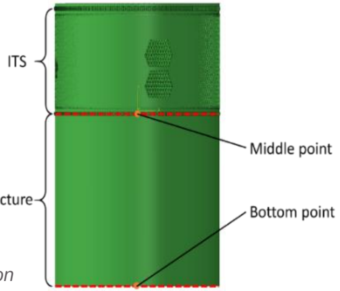
- For the strength and stability justification of the U-ITS a geometrical and material nonlinear, implicit analysis with ABAQUS as solver is chosen
- Global and local models (GFEM/DFEM) are used

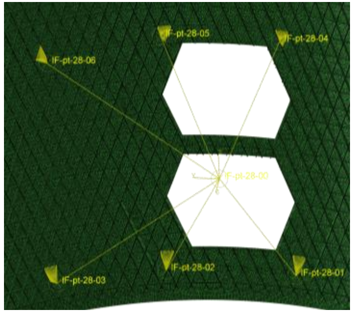


Left: GFEM: SW U-ITS
Right: DFEM: LOX IF

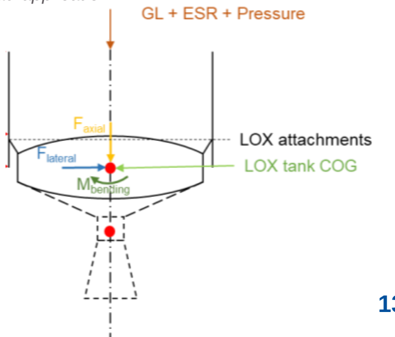
- Applied loads and boundary conditions
  - Global flux (compression/tension and mounting)
  - Temperature field (hot and cold load case)
  - Adjacent structures (LOX & LH2 and IFS)
    - Radial deformation
  - LOX- and VINCI/VITF-loads
    - Axial force
    - Lateral force
    - Bending moment

    → Can rotate freely around axis of flight direction
  - Local I/F loads (AVSS, TFB, Cable Duct etc.)





Right: BC
Left: Local load introduction
Middle: Load application



TARGET APPLICATION – MANUFACTURING PROCESS

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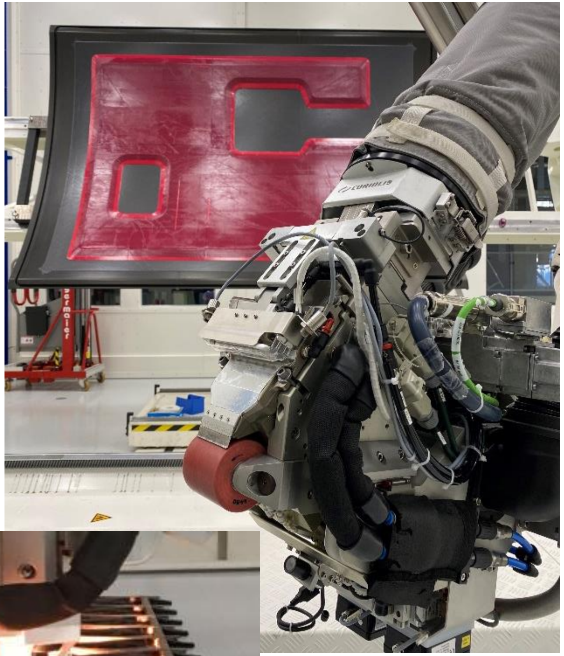
- General
  - Fully automated deposition
  - Digital integration from design and analysis to manufacturing
- Sandwich technology
  - Co-cured – the sandwich structure is realized in a single curing step
- Lattice technology
  - Original manufacturing method for the lattice structure is based on a technology developed by ATG Europe B. V. (manual process)
  - Process is adapted for automated fiber placement process



Top: AFP manufacturing Sandwich
Bottom: AFP manufacturing Lattice Grid

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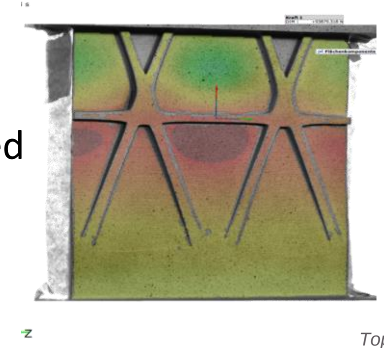
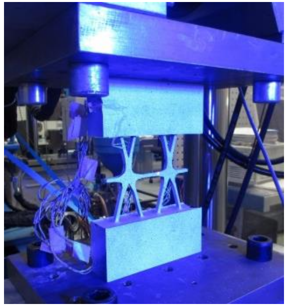
- Compression test on flat knot samples
  - Samples with skin
  - Samples without skin
  - Main interface zone
- Based on breadboard design
- Influence on manufacturing method investigated
  - Manual
  - AFP process
- Comparison between FE analysis and test results performed
  - ➔ To validate FE approach used for the sub and full scale analysis



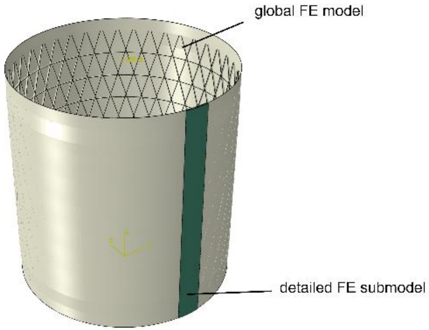


➔ Samples manufactured by AFP process showed a significant higher strength

Top: AFP manufacturing
Bottom left: Main IF sample
Bottom right: Knot w/o skin sample

- Design
  - target application geometry adapted to the dimensions of the breadboard (Ø ≈ 0.9m)
  - maintaining the structural characteristics representative in comparison to the full scale design
- Manufacturing
  - A manual manufacturing has been used for the test breadboard (TBB)
  - For a later serial production a AFP process, proven by the knot samples, is foreseen
- Test Prediction
  - Based on as build geometry and knot sample results
  - Nonlinear analysis using ABAQUS
  - To understand the global and local behavior a solid element based submodel was embedded in a global shell model

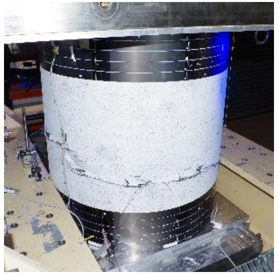
Subscale lattice structure (TBB)



Schematic of the analysis approach using the submodel technique

LATTICE - TEST BREADBOARD

- **Test**
  - In January 2020 a compression test was successfully performed in Augsburg
  - Failure occurred at a maximum load of ~2800 kN
  - To understand the failure mechanics different measurement systems were used:
    - Optical measurement (ARAMIS) from four sides
    - Radial and axial displacement transducers
    - Strain gauges



Lattice structure TBB after the test showing a circulating fracture

- **Test Evaluation**
  - A fracture directly under the knots occurred mid cylinder
  - The seen failure mode was in line with the prediction
  - Failure procedure:
    - failure occurred locally at a single knot probably following a local skin buckling
    - after the fracture of a single knot, the local failure spread out to the other knots following a load transfer

Fracture pattern of the lattice structure TBB after the test

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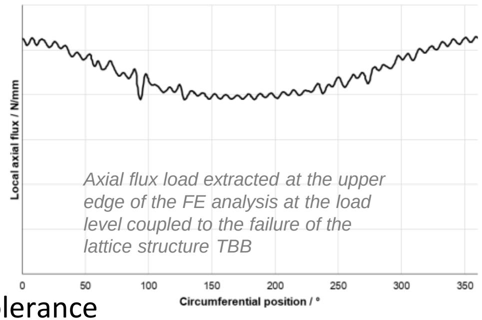
- Test Correlation
  - Based on the measurements, implementation of the inhomogeneous load introduction in the FE analysis
    - Increased deformation near the circumferential position of 0°
    - Inhomogeneous flux loading (highest flux loads near 0°)
  - Embedding detailed solid submodel into 360° shell model at 0° position
    - Failure occurs at the load level observed during the test
    - Strength failure directly under a knot mid cylinder ➔ correlates very well with the test
    - Deviation of the global failure load and the one observed in the test within the given tolerance

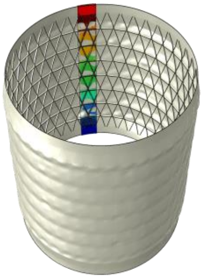


Axial flux load extracted at the upper edge of the FE analysis at the load level coupled to the failure of the lattice structure TBB

➔ Successful subscale test

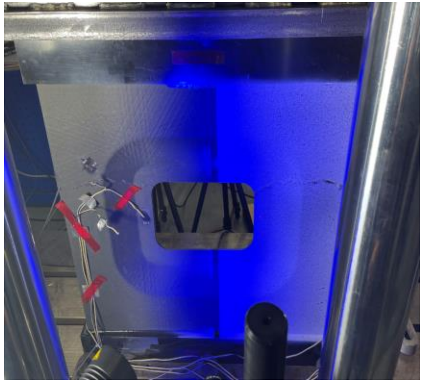
➔ Prove of analysis methods

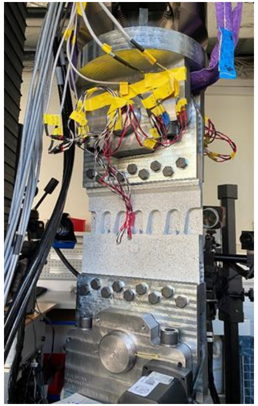
➔ With this knowledge a significant mass decrease compared to A6 upper stage ITS is possible


Deformation of the FE implementation at the load level coupled to the failure in the test; detailed submodel showing contour plot

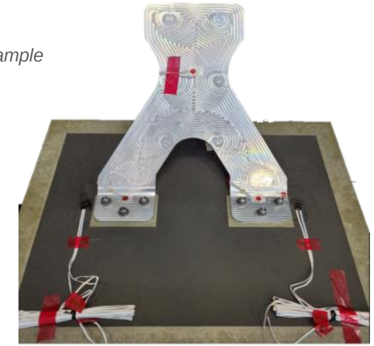
SANDWICH - TEST ELEMENTS

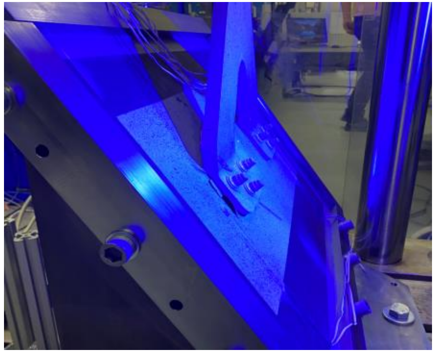
- Compression/tensile test on flat samples
  - Cut out
  - LOX tank attachment
  - Main interface
- Based on target application design
- Manufacturing quality investigated
- Comparison between FE analysis and test results performed
  - → To validate FE approach used for breadboard and full scale analysis





Top: Cut Out Sample
Right: LOX introduction IF sample
Left: Mail IF sample





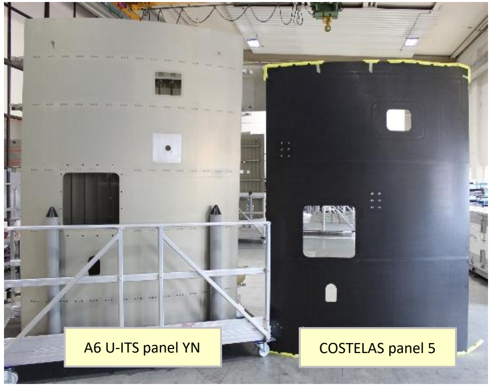
SANDWICH - TEST BREADBOARD

- **Design**
  - One full scale panel of target application (Ø ≈ 5.4 m, h ≈ 3 m, b ≈ 2 m)
  - All important features included
    - Main interfaces
    - Cut outs and local interfaces
    - Far field and near field including stiffening elements

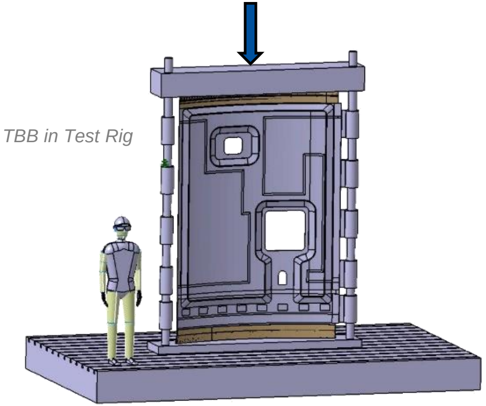
- **Manufacturing**
  - Same automated fiber placement process as planned for serial production
  - Co-cured – the sandwich structure is realized in a single curing step

- **Test Predition and Test**
  - Including general compression fluxes
  - Nonlinear analysis using ABAQUS based on as built geometry
  - Test planned in Q3/4 2023

Metallic A6-UITS Cylinder Panel next to Sandwich Manufacturing Breadboard (MBB)



TBB in Test Rig



- Mass:
  - CFRP solution is developed in order to aim for 25% mass reduction compared to corresponding metallic baseline
  - No significant mass difference between the two CFRP technologies can be seen
  - Limitations: Lattice mass only achievable if a significant rib height can be realized (needed for Ø ≈ 5.4 m)
  - Significant mass impact due to local interfaces for both concepts
- Costs:
  - Cost performance of CFRP solution can be better than corresponding metallic baseline
  - Using same production set-up Lattice technology is significant more expansive than Sandwich technology
  - By investing in more machining (parallel production – higher NRCs) the Lattice RC can be reduced to a comparable range
  - Significant cost and mass impact due to segmentation for both technologies
  - Material handling for only one material (Lattice technology) saves costs
- Technology readiness level (TRL) at MT Aerospace:
  - Lattice: TRL 4 (subscale barrel test breadboard)
  - Sandwich: TRL 4-5 (full scale panel test breadboard)

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- Included design features:

	Design		Test Breadboard	
	Lattice	Sandwich	Lattice	Sandwich
Main IF				
Cylindrical IF (LH2 tank and IFS)	x	x	x	x
Conical IF (LOX tank)	x	x	-	x
Cut outs and local interfaces	x	x	-	x
Segmentation	-	x	-	x
Far and near field	x	x	-	x

- Open Point:
  - Segmentation for Lattice technology or integral solution for Sandwich technology
  - Connection between grid and skin for Lattice technology in combination with AFP

→ Both technologies have advantages and disadvantages depending on the application and requirements. Therefore, it is beneficial to have both technologies in the portfolio. Depending on the requirements, the most appropriate technology must be chosen. To apply the technologies on the U-ITS a certain development is still necessary.

- MT Aerospace would like to thank our customers. The development of a CFRP U-ITS for maturing technologies, which are key for a future mass optimized Ariane 6 upper stage, is only possible due to the German funding of the DLR Agency via ESA's Future Launchers Preparatory Programme (FLPP).
- Furthermore, we thank all our partners, especially Ariane Group in Bremen as well as ATG Europe for the good collaboration.

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