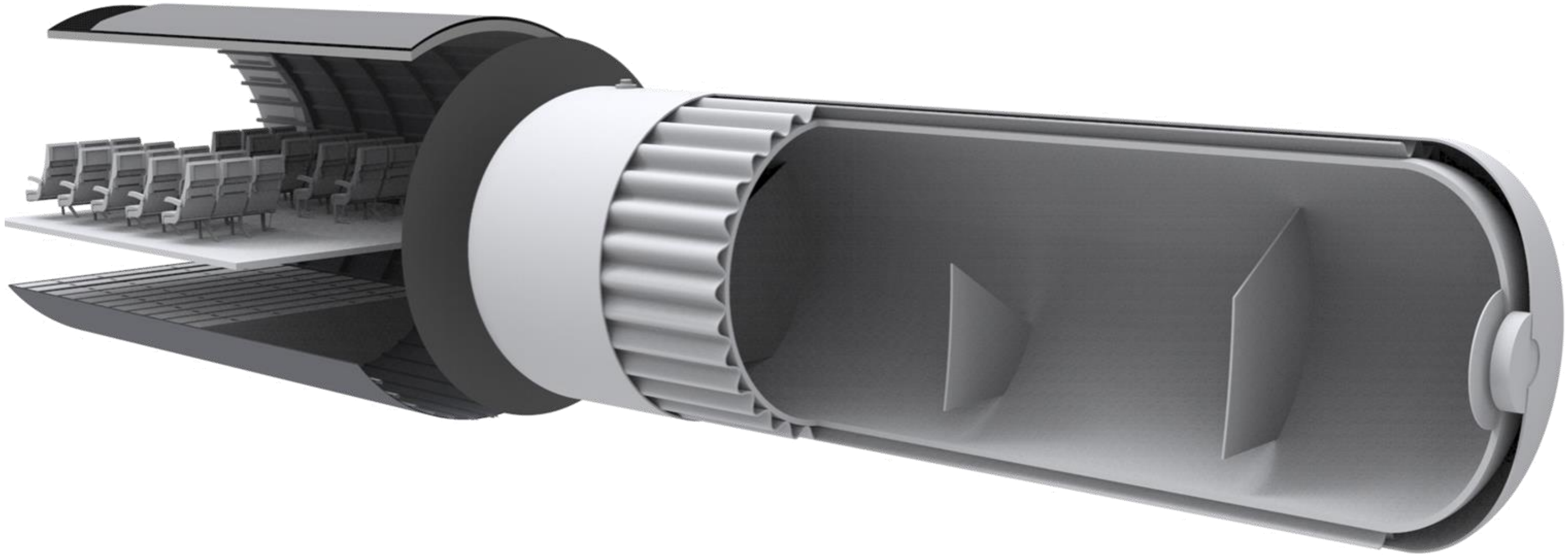
Mobile Lightweight Hydrogen Storage for large Quantities

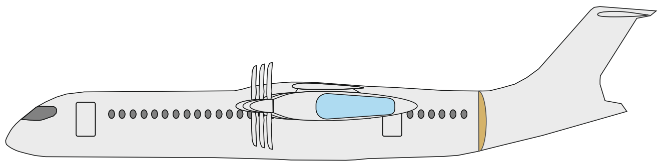
Philipp Hilmer, Markus Kleineberg, Dirk Wilckens
DLR Institute of Composite Structures and Adaptive Systems
LightCon, Hannover, June 2nd 2022

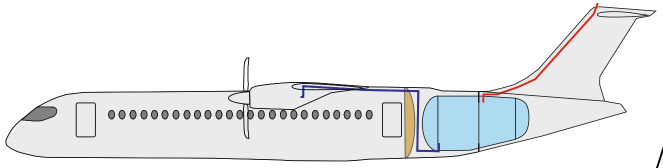
DLR Strategy for Composite Cryo LH_2 Tank Enabling Zero Emission Flight

- **LH2 tank integration options**
- **LH2 tank design**
- **Material development**
- **Manufacturing capabilities**
- **Test facilities**

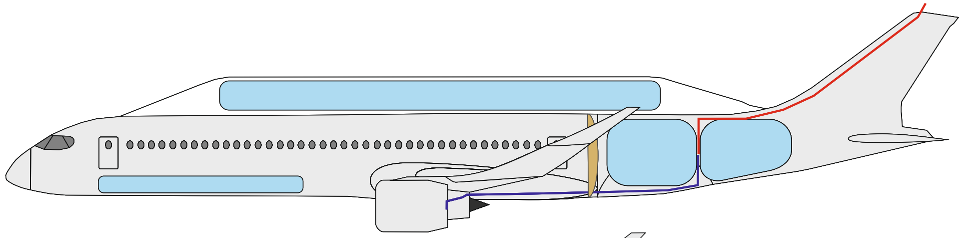


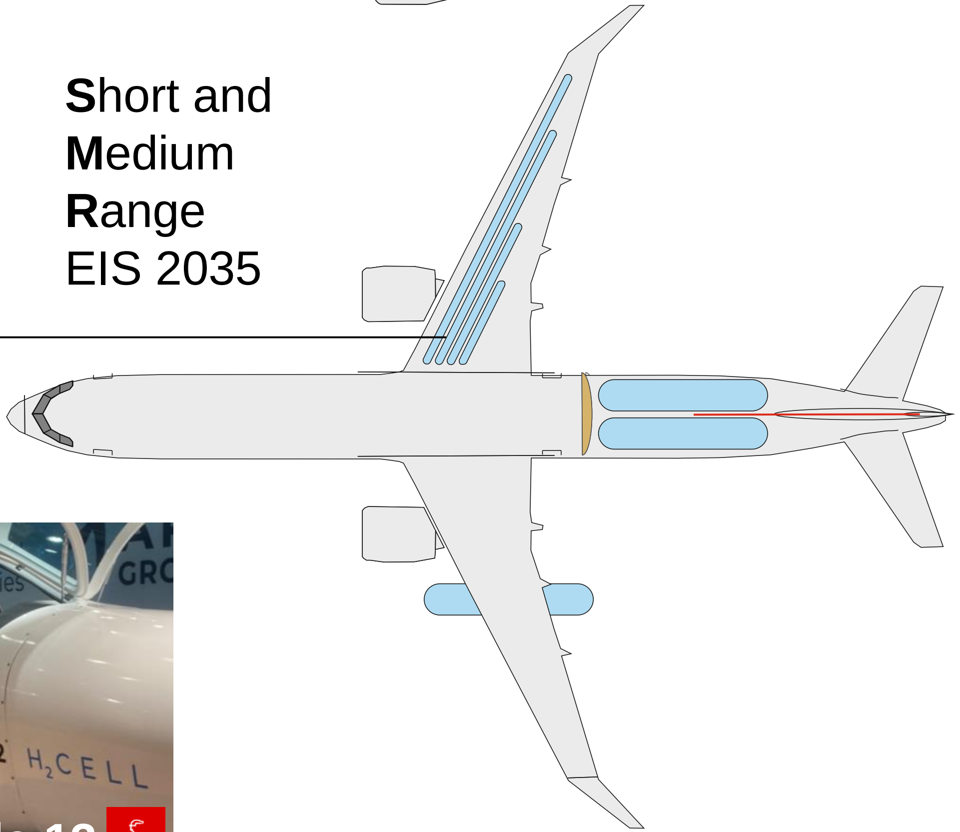
Integration of LH_2 Tanks: Scope and options



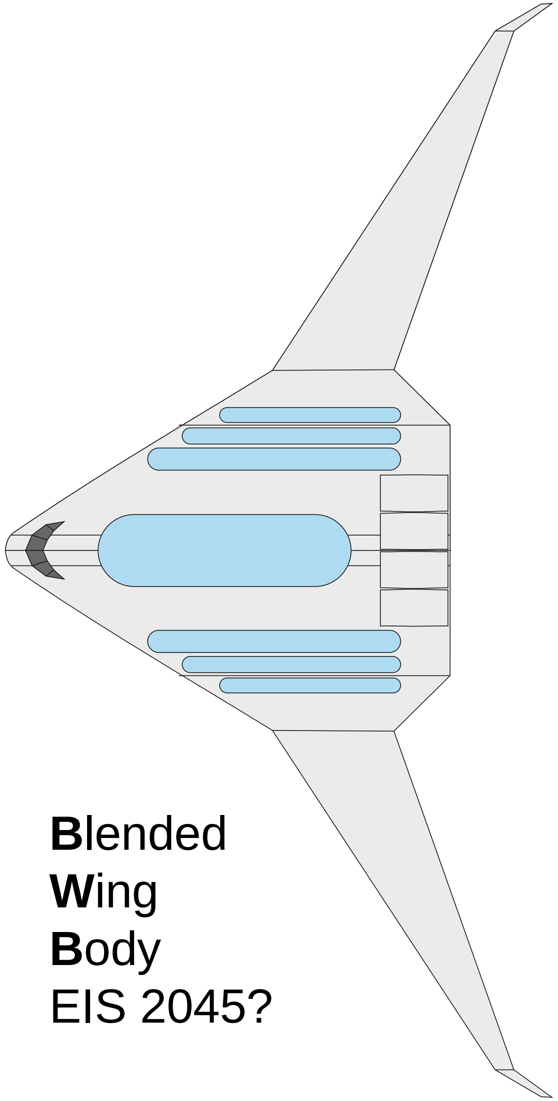


Regional
Airliner
EIS 2030?



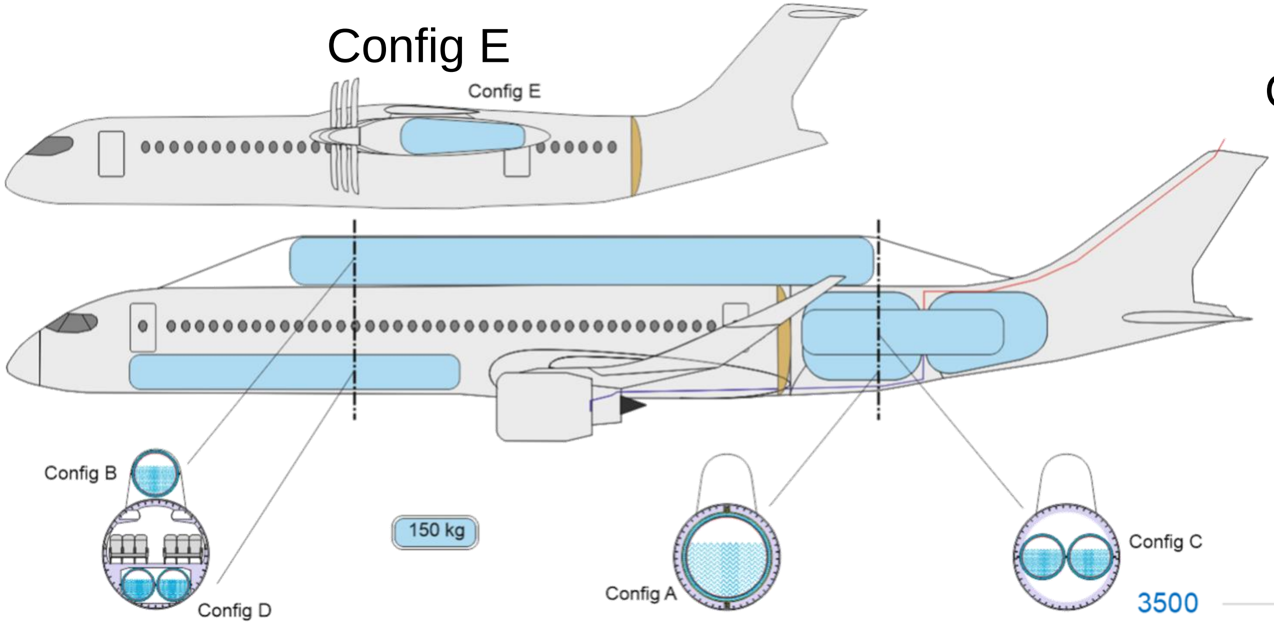


Short and
Medium
Range
EIS 2035

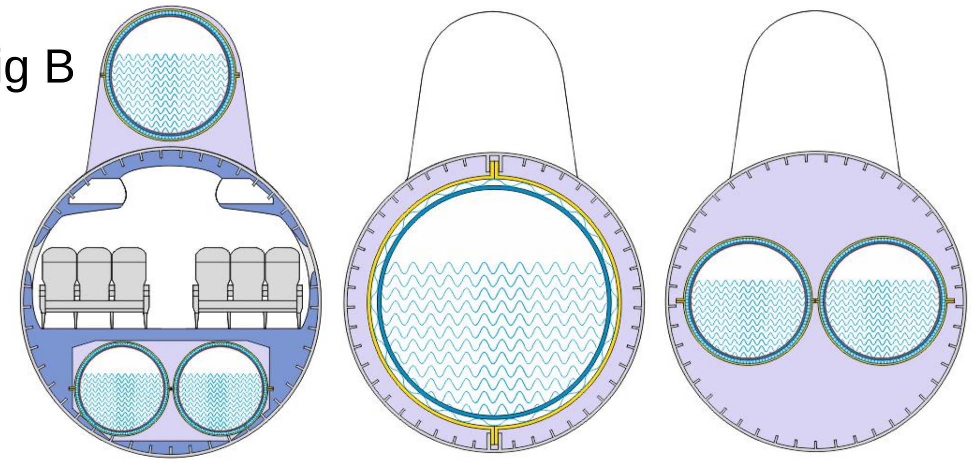


Blended
Wing
Body
EIS 2045?

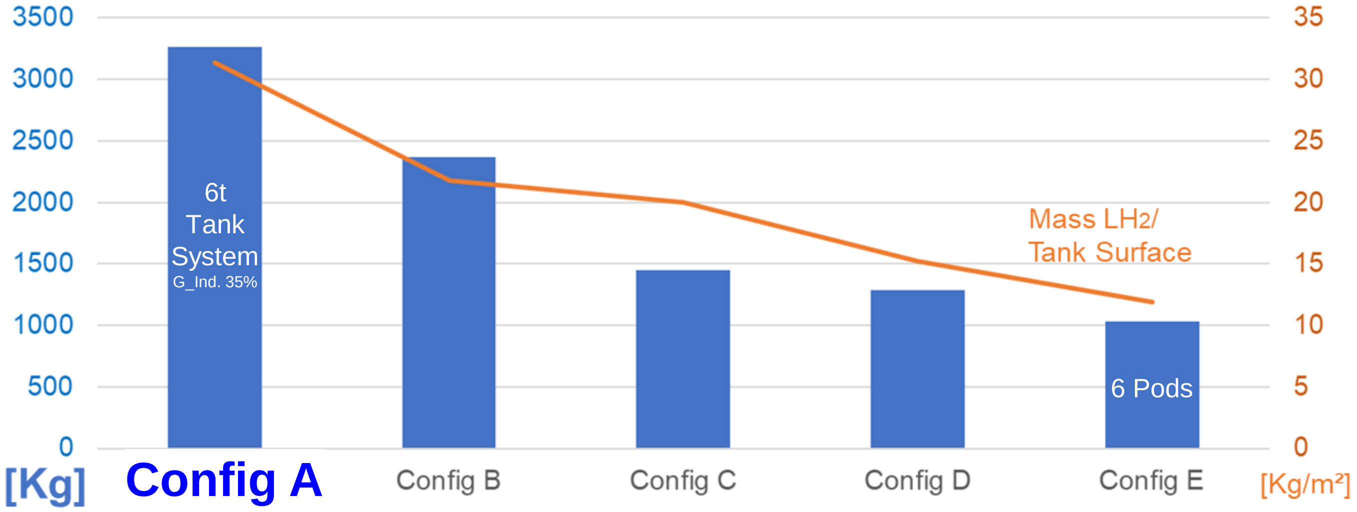
Integration of LH_2 Tanks: Scope and options



Config B



Config D Config A Config C

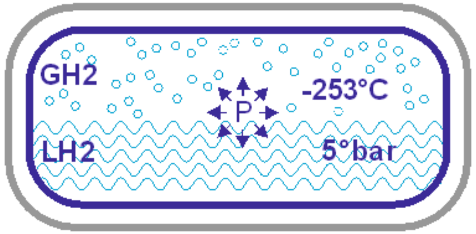


Airbus A320 NEO kerosene energy equals 8000 kg LH_2

https://en.wikipedia.org/wiki/Airbus_A320neo_family

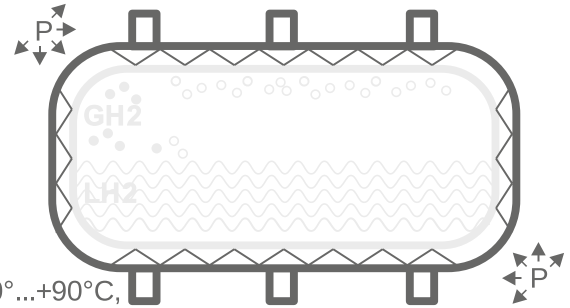
A320 Fuel Capacity	30.000 l
Kerosene Density	0.8 kg/dm3
Kerosene Energy Density	40 MJ/kg
LH2 Energy Density	120 MJ/kg

Trinity of Challenges of an Aircraft LH_2 Tank



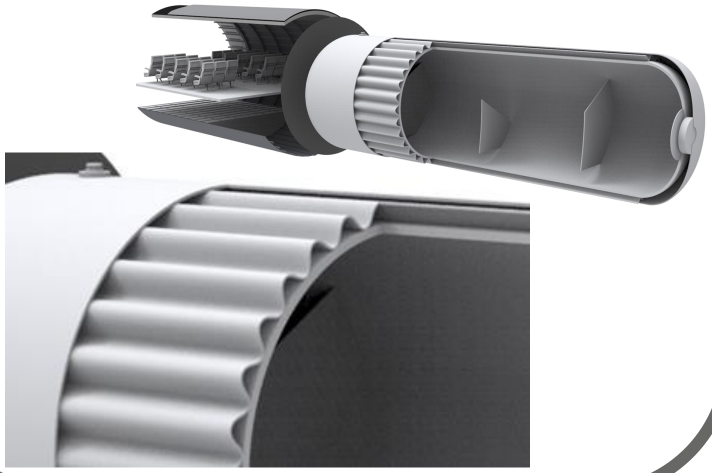
“LH_2-Cryo-Tank“

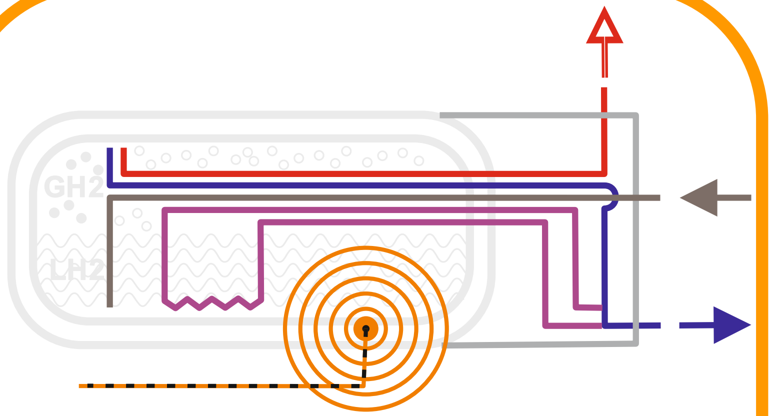
“CHATT”
150kg Tank



-60°...+90°C,
0,2 ...1,1 bar

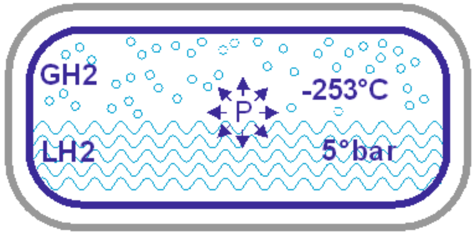
“Tank Integration/Insulation“





„Hydrogen System“

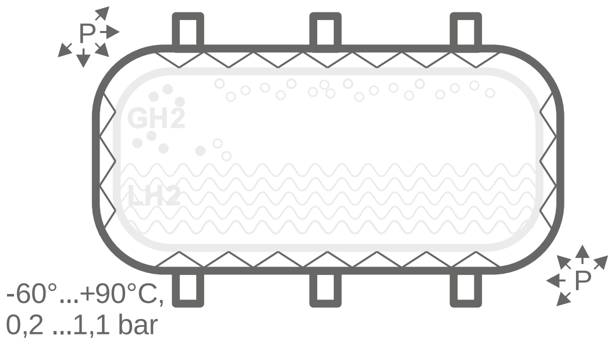
Trinity of Challenges of an Aircraft LH_2 Tank



"LH_2-Cryo-Tank"

Completely New Challenge!!!

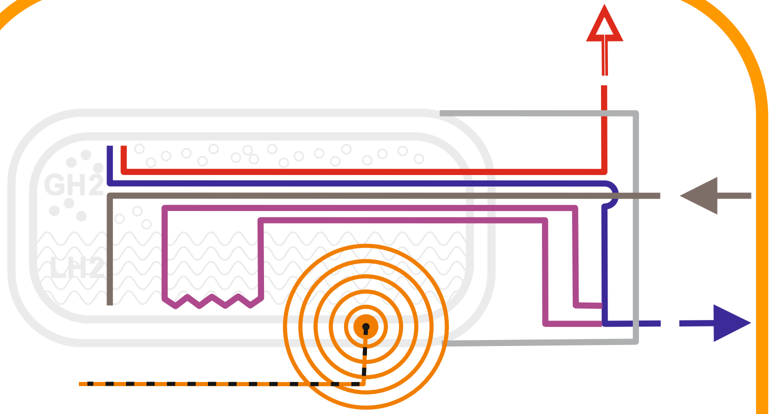
- Inner Pressure Driven Structure
- Cryogenic Environment
- Multiple Thermal effects
- Sealings / H_2 Permeability
- Weight / Cost / Production Rate



"Tank Integration/Insulation"

CS 25 Based Approach

- Stability Driven Structure
- Structural Interaction / Interfaces
- Classic Impact Scenario
- Extended Temperature Range
- Weight / Cost / Production Rate



„Hydrogen System"

Multi ATA Approach

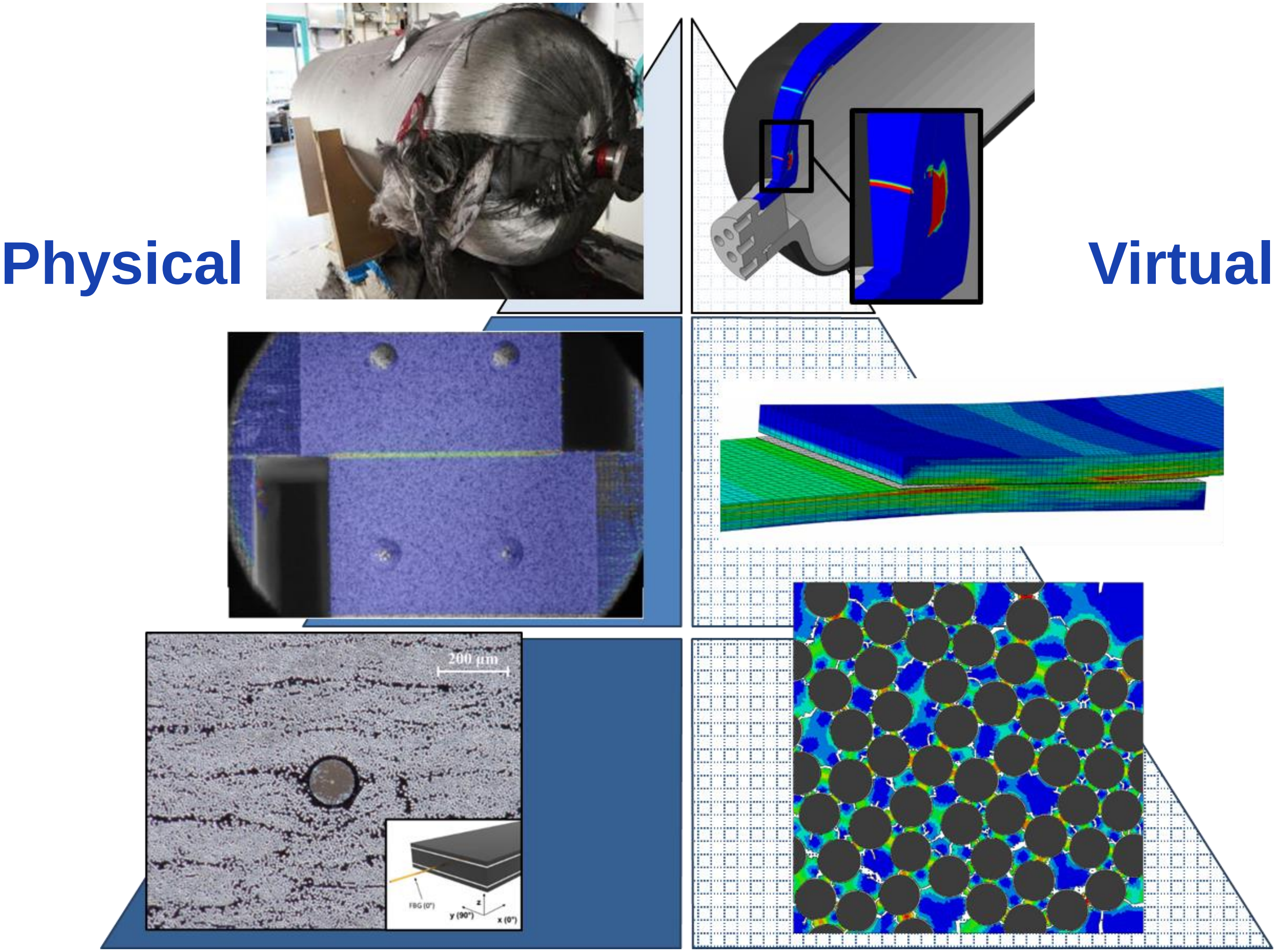
- System Installation / Sealing
- Sloshing / Refilling
- Pressure / Boil-Off Management
- Operational Safety Monitoring
- Weight / Cost / Production Rate

Hybrid “Physical-Virtual” Product → Path towards Certification

- **Design and analysis**
  - Tank integration and joining concepts
  - Probabilistic analysis
  - Process simulation and optimization

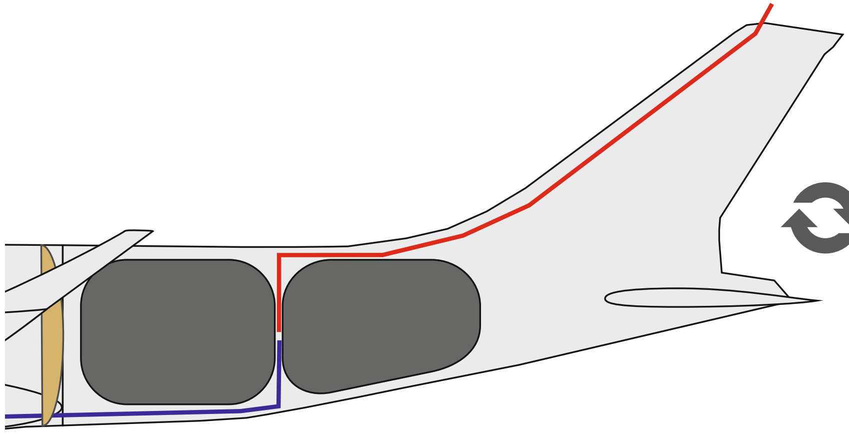
- **Thermal Analyses**
  - Thermal fatigue under cryogenic conditions
  - Thermal insulation
  - Impact on boil-off

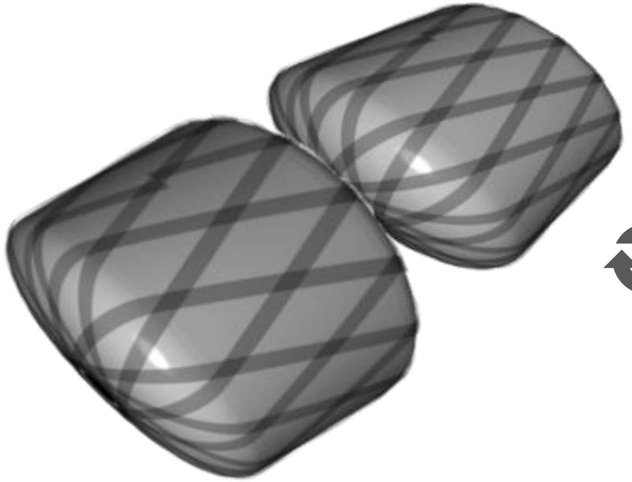
- **Virtual testing towards certification**
  - Burst pressure and fatigue life analysis
  - Holistic life time assessment incl. SHM
  - Digital twin & as-built assessment



CFRP Tank Design Optimization

Aircraft Design → Winding Simulation & Layer Optimization → Manufacturing Interface



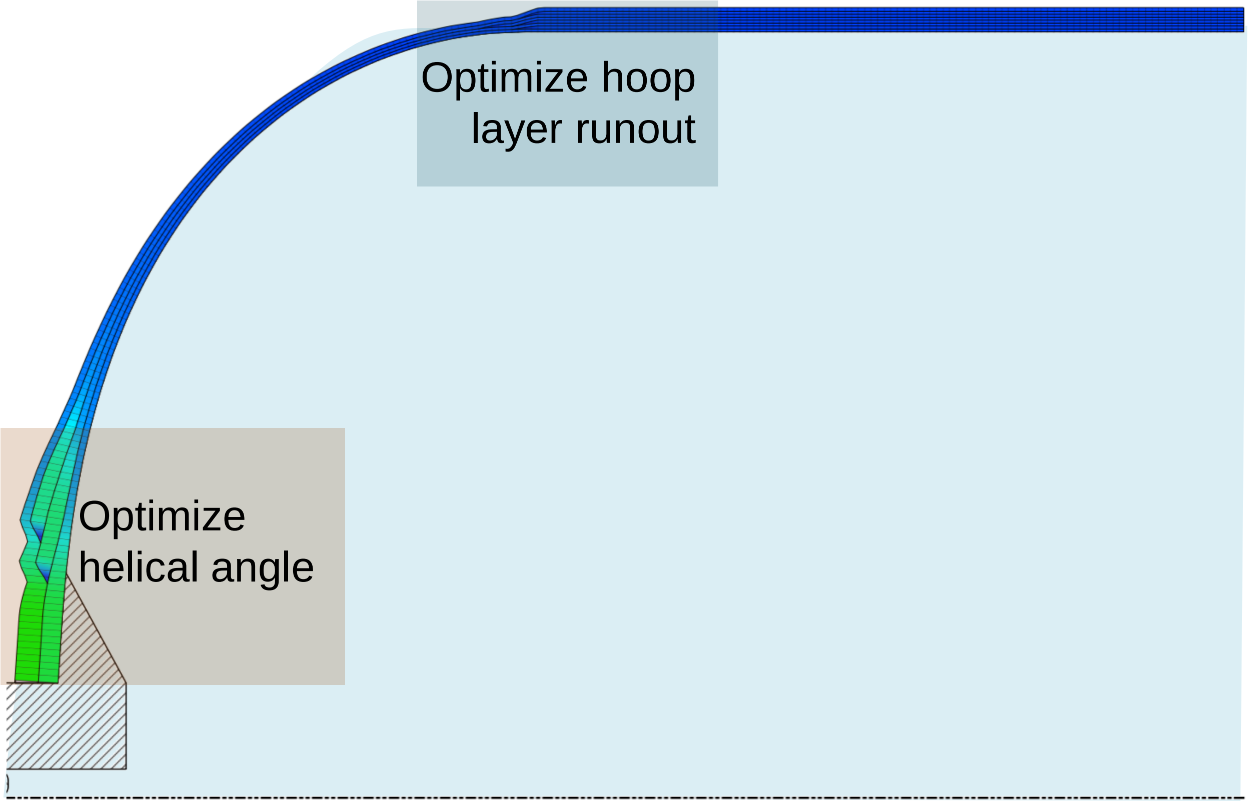


tankoh2

Winding (µWind – commercial)
- CFRP winding simulation

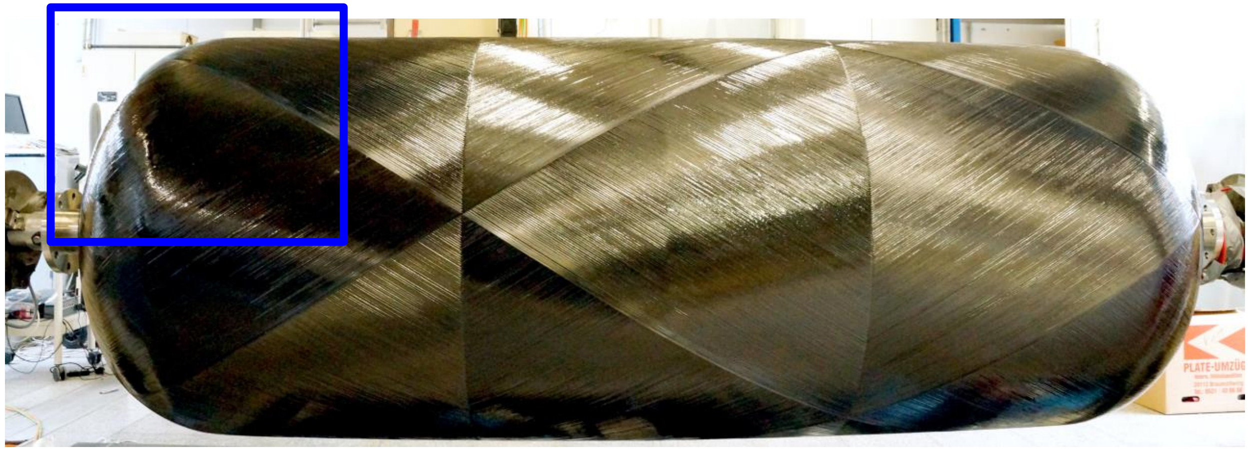
Optimization (tankoh2 – DLR)
- Optimize layer angles automatically

CFRP Tank Design Optimization



Automated Optimization

- Goal: minimize mass
- Parameters: layer angles, hoop layer runout
- Boundary Cond: volume, radius,
  manufacturing constraints

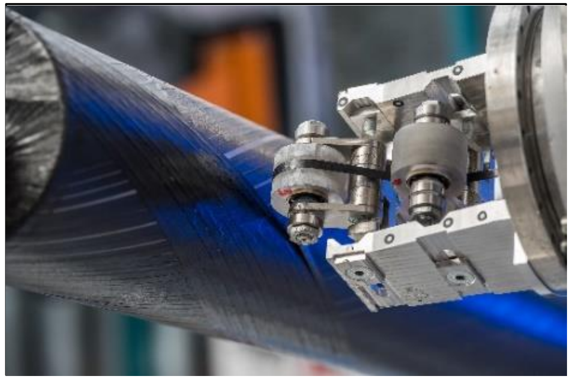


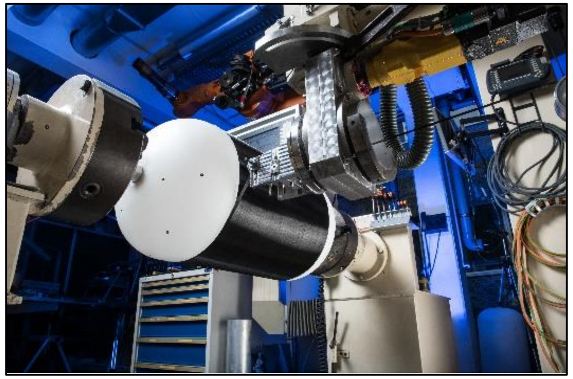
Manufacturing

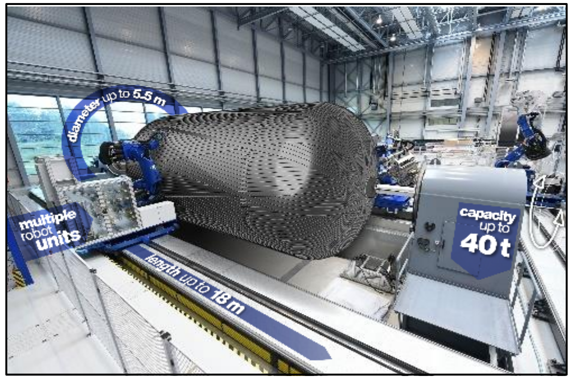
- Supply optimal layup
- Band path including thickness accumulation
- Generate machine code

Stepwise Approach: From tubular specimen towards full scale LH_2 structure

150mm diameter tubes → 400mm diameter tank (L=800mm) → 1000mm diameter tank (L=3m) → 3m diameter tank (L=6-8m)







High Rate Screening:
- Permeability tests
- Material characterization
- Basic manufacturing technology assessment

Higher TRL Validation Options:
- Manufacturing technology assessment
- Tooling concept assessment
- Cryo-shock / sloshing testing
- Simplified burst & fill-and-drain test
- SHM integration

Representative Validation:
- manufacturing demonstration
- Full size tooling effects
- Cryosystem testing
- Burst & fill-and-drain test on certification level

log of process parameters for the digital twin and virtual manufacturing towards LCA and LCCA

"GroFi" Full Size Tank Manufacturing in Stade

Manufacturing Infrastructure

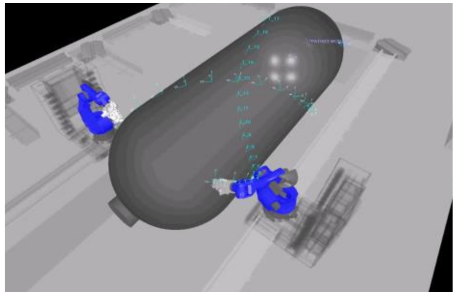
- Multi robot, multi technology (TS/TP) layup
- Filament winding / AFP / ATL hybridisation
- Innovative "Flash Lamp" heating system

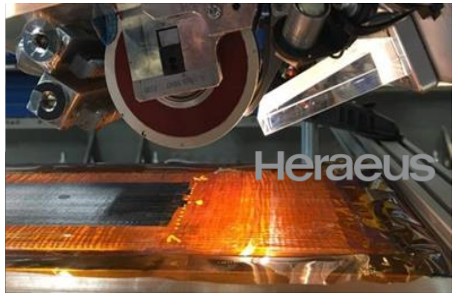
Real Time Quality Assurance

- Laser based layup monitoring
- Real time correction of layup deviations
- Mould integrated US sensor process control

Digitalisation

- API based digital machine/shop floor network
- Specialised process support simulations (API)
- Integrated **E**co **E**fficiency **A**nalyses (API)

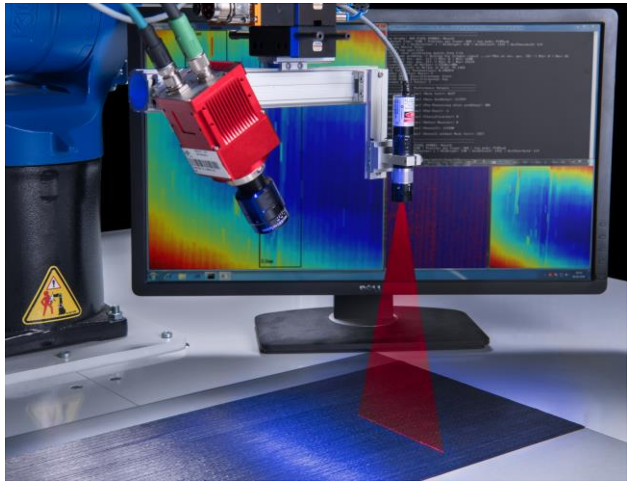


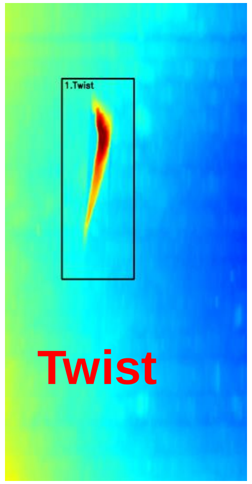


TS: Thermoset, TP: Thermoplast, AFP: Automatic Fibre Placement, ATL: Automatic Tape Laying, US: Ultrasonic, API: Application Programming Interface

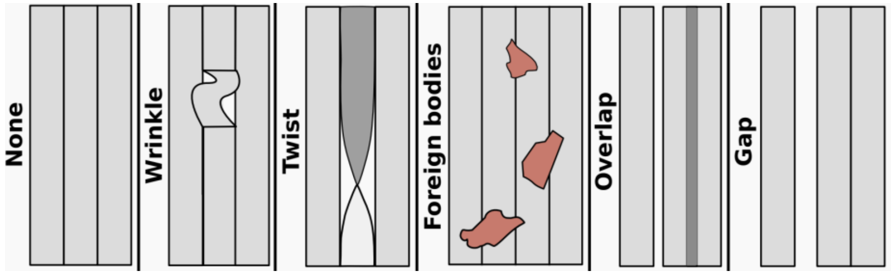
AI based Inline Quality Inspection

Robust and explainable AI analysis…

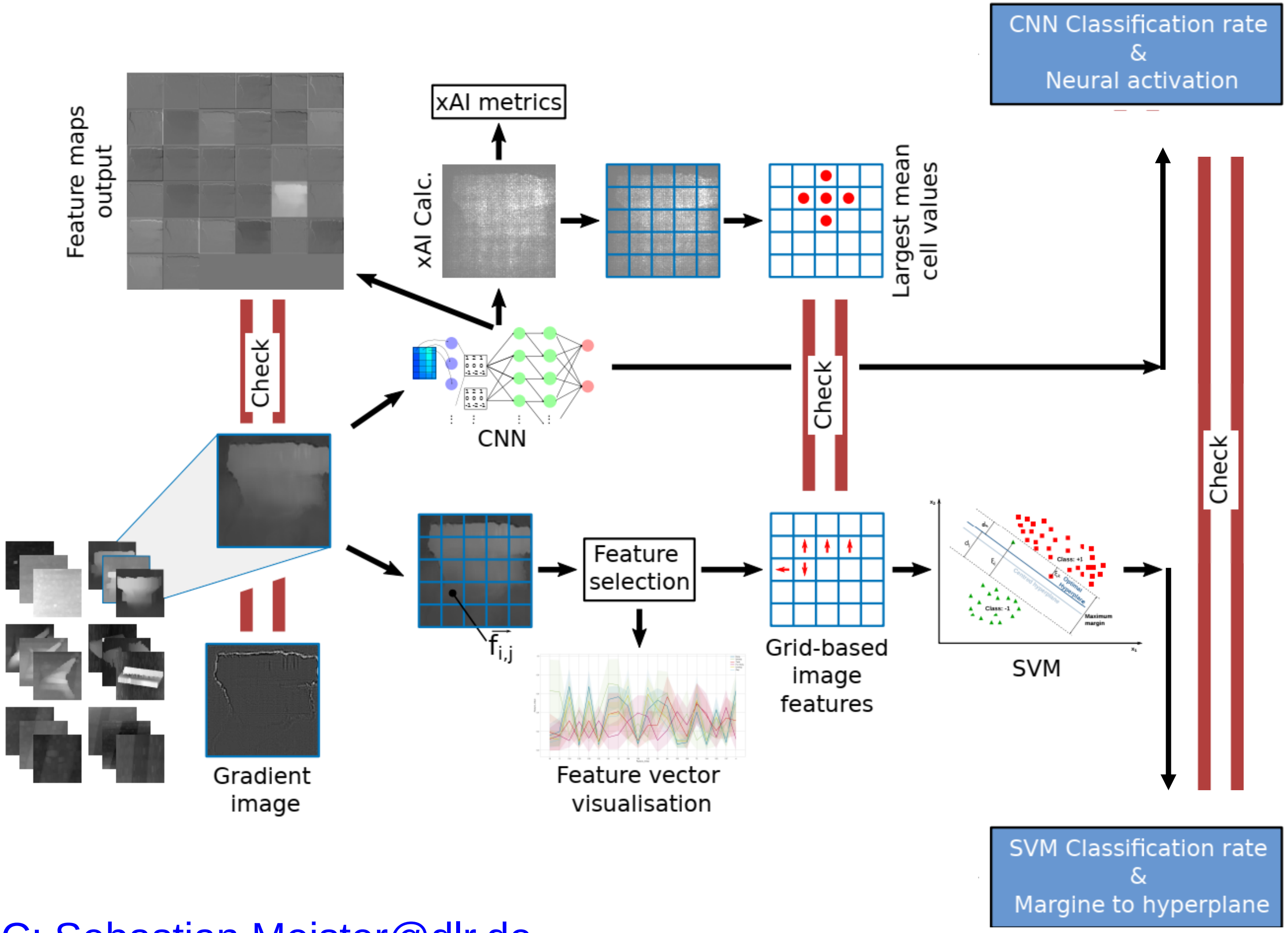




…of fibre layup defects…



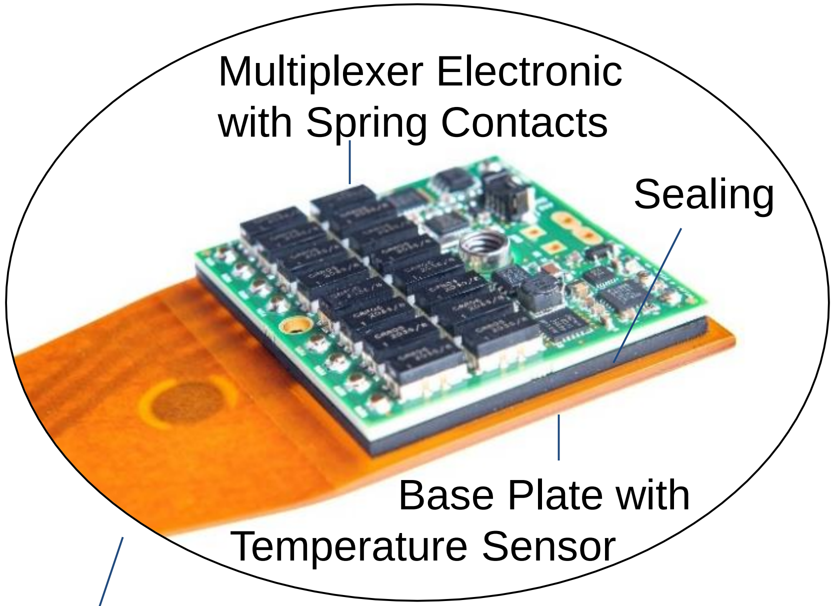
…using original and fully synthesised data for better traceability

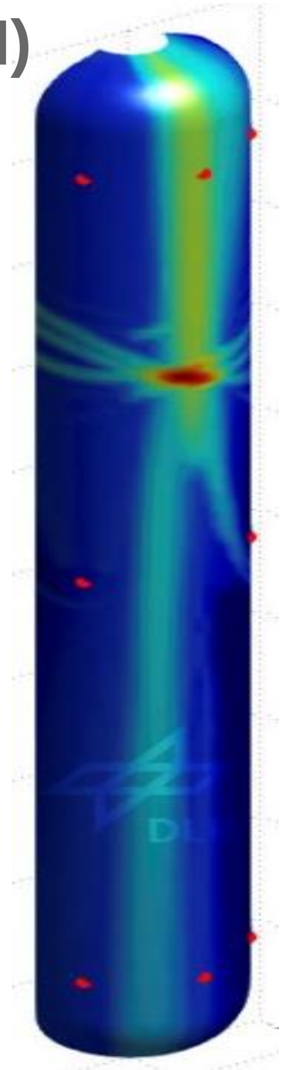


POC: Sebastian.Meister@dlr.de

Operational Aspects: Approach for Structural Health Monitoring (SHM) of Hydrogen Tanks

- Combination of acousto-ultrasonic (Lamb Wave) and acoustic emission for robust damage detection
- Robust piezoceramic network
- Pattern recognition algorithms for robust damage detection and localization under varying operation conditions
- Automated software for data assessment, damage detection and self-test of piezoceramics
- Experience from test of SHM systems in different applications (aeronautic, automotive, wind energy etc.)

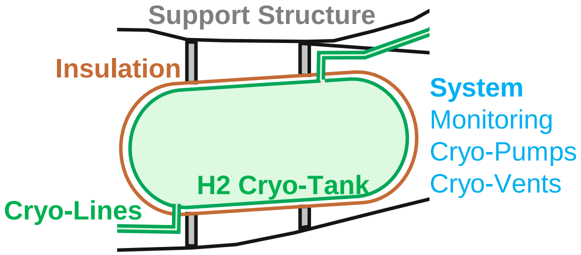


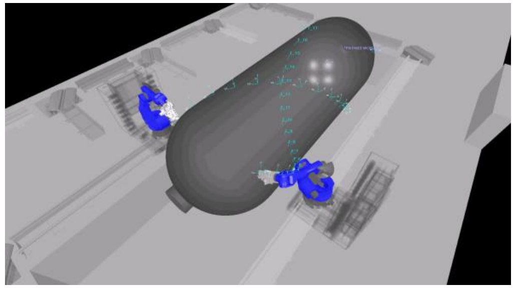


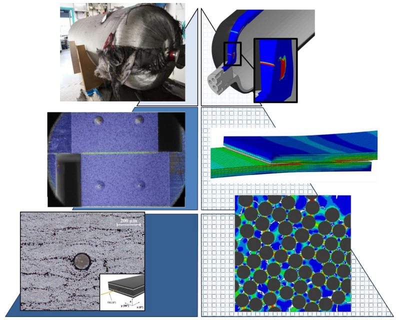
Reconstruction of acoustic emission event on hydrogen tank

Certification Aspects: DLR Project HYTAZER & Virtual Product House

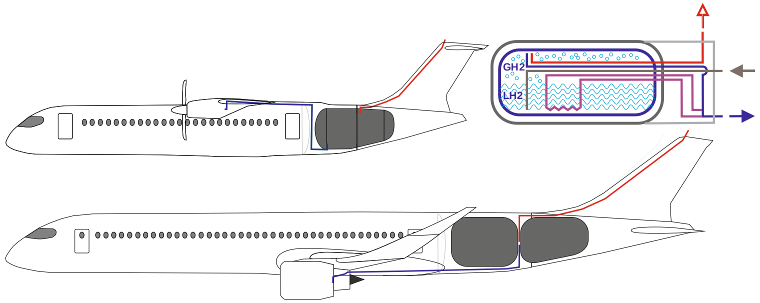
Digital Design to Certification → H2 Tank Components

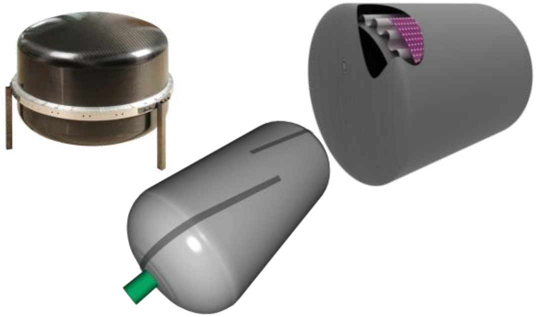


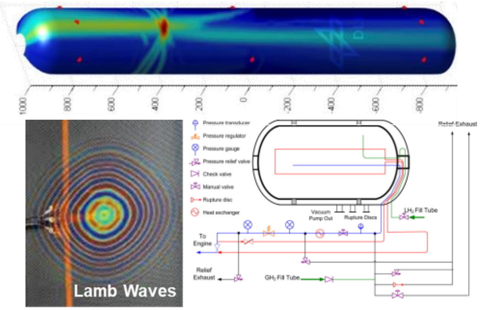




Req's & Spec's → *Architectural concepts* → *Structural Integration* → *Virtual Detailed Design* → *Virtual Production* → *System Integration, SHM* → *Virtual Testing* → *Virtual Certification*





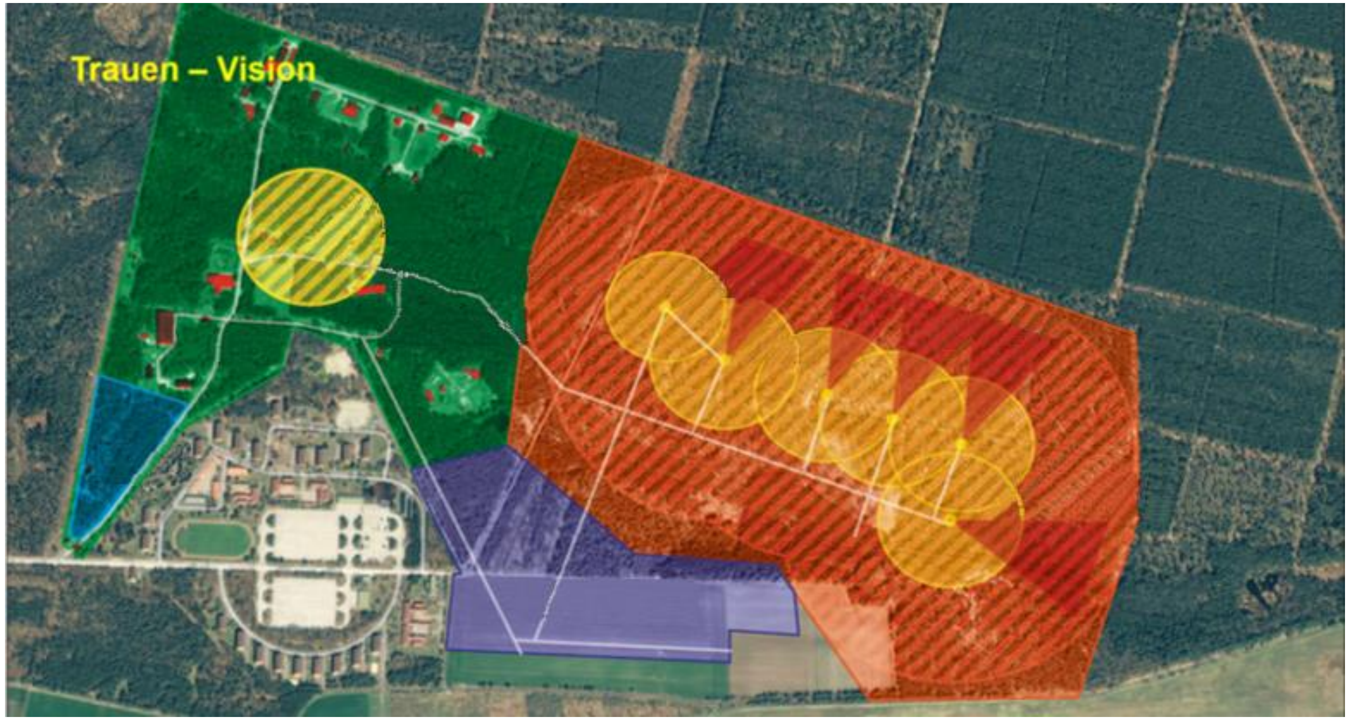


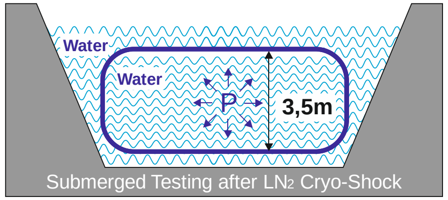
EASA European Aviation Safety Agency

⇨ Close collaboration with Airbus ZEDC, ECOMAT H2Lab, Ariane Group

“Trauen“ Cryogenic Tank Test Facility: Towards Certification Capabilities

- **2022**
  - Tubular Coupons LH_2 Tests (8 dm³)
  - Type IV Pressure Tank Test (90 dm³)
  - Test Instrumentation
- **2024**
  - DLR-HYTAZER Certification Strategy
  - Submerged (2400 dm³) Test (LN_2 Cryo Shock)
  - Full Size LH_2 Tank Test Concept
- **2028**
  - Submerged Full Size Test (LN_2 Cryo Shock)
  - Full Size LN_2 Tank Test (BC tbd.)
  - Full Size LH_2 Tank Test (BC tbd.)





LH_2: Liquid Hydrogen (-253°C), LN_2: Liquid Nitrogen (-196°C), BC: Boundary Conditions

Thank you!

Contact:
Philipp.Hilmer@dlr.de
Markus.Kleineberg@dlr.de
Dirk.Wilckens@dlr.de