experimental characterization and numerical modelling of composites at low cryogenic temperatures for the development of LH2 tanks

J. Renart

Girona, 15th July 2022

The objective:

Development of tools and methods for the experimental characterization and numerical modelling of composites at low cryogenic temperatures for the development of LH2 tanks for the aircraft industry

The team:

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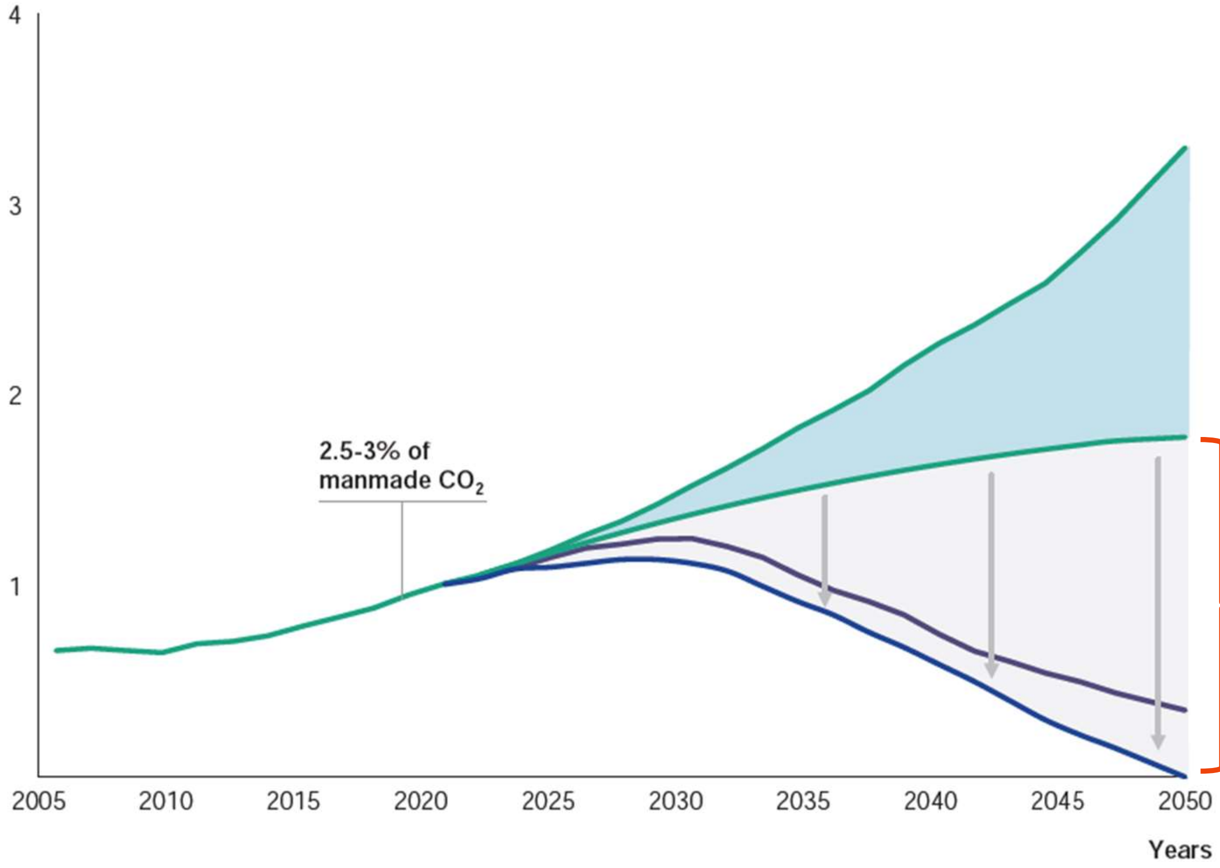
Background

Why?

The problem

Gt (10^9 t) CO_2 emissions from aviation (Source: McKinsey & Company 2020)



Demand growth of 4% p.a. (ATAG: Air Transport Action Group)
24% of manmade CO_2 (Roland Berger 2020)

Efficiency improvements of 2% p.a. (ICAO: International Civil Aviation Organization)

SAF (Sustainable Alternative Fuels) and radical technologies

ATAG target: -50% vs. 2005

Net-zero target

SAF and radical changes: use of H_2 as fuel

Comparison of climate impact from H2 propulsion and synfuel (Source: McKinsey & Company 2020)

	Change of in-flight emissions and emission related effects[1]				Climate impact reduction potential[4]
	Direct CO_2	NO_x	Water vapor[2]	Contrails, cirrus	
Synfuel	-0% / -100% (Net)[3]	-0%	-0%	-10-40%	-30-60%[3]
Hydrogen turbine	-100%	-50-80%	+150%	-30-50%	-50-75%
Hydrogen fuel cell	-100%	-100%	+150%	-60-80%	-75-90%

3. Net CO_2 neutral if produced with CO2 captured from the air
4. Measured in CO2 equivalent compared to full climate impact of kerosene-powered aviation

UdG

Kerosene vs GH_2 vs LH_2

Kerosene	GH_2	LH_2
43 MJ/Kg	123 MJ/Kg	123 MJ/Kg
800 Kg/m^3	($8 \cdot 10^{-5}$ to 40 Kg/m^3)	71 Kg/m^3

For the same quantity of energy...

1L = > 3000 L H2 gas at 1 bar (293 K) = 4 L LH_2 (20K)

6 L H2 gas at 700 bar (293 K)

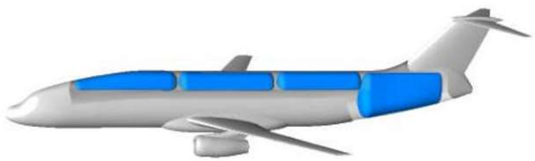
LH_2 tanks: Dimensions

- Use of wing tanks would be too heavy (Brewer 1991, Airbus 2003, Suresh 1998)

LH_2 tanks: Dimensions

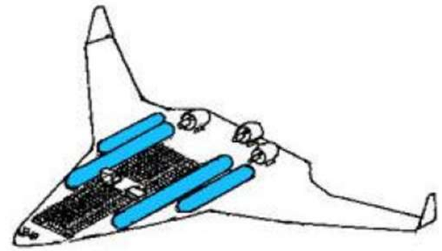
- Use of wing tanks would be too heavy (Brewer 1991, Airbus 2003, Suresh 1998)
- Best options: tanks in the fuselage or new aircraft designs (Source: Airbus 2003)

Short regional flights



Medium range

Long range aircrafts

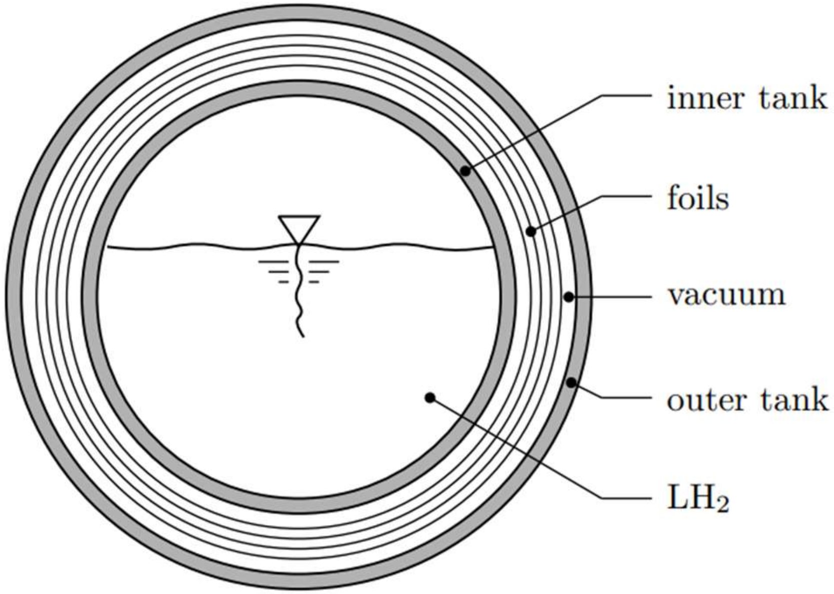


Blended wing aircraft

Tanks made of composite are an attractive option

LH_2 tanks: Materials

Schematics of a tank (Schultheiß, 2007)



Metallic or polymeric thin layers (liners) can be applied to external inner/outer tank surfaces to protect the tank against permeation

Material configurations (Airbus 2021)

- I: all metal (aluminum or steel)
- II: inner tank metal, outer tank CFRP
- III: CFRP inner tank + metallic liner + insulation
- IV: CFRP inner tank + polymeric line + insulation
- V: CFRP linerless + insulation

Thin plies / hybrid laminates

Weight reduction

LH_2 tanks: Materials

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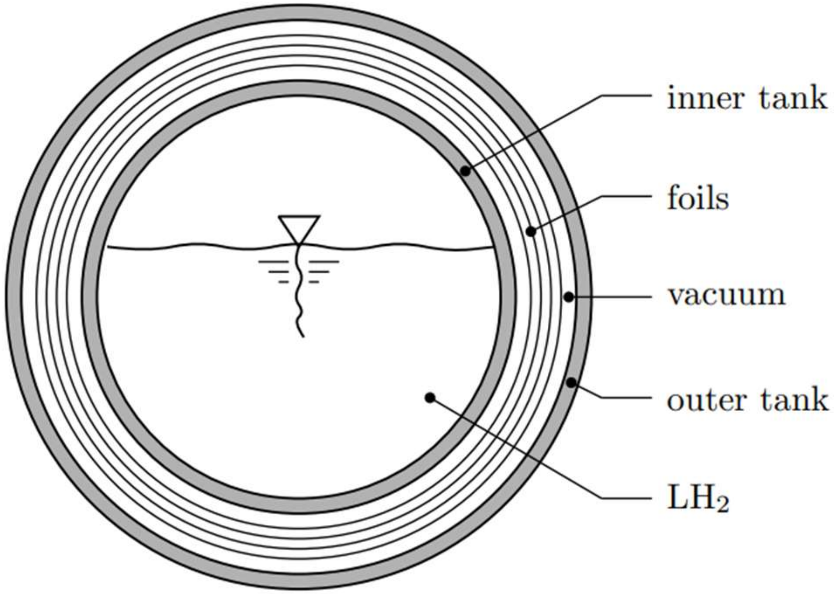

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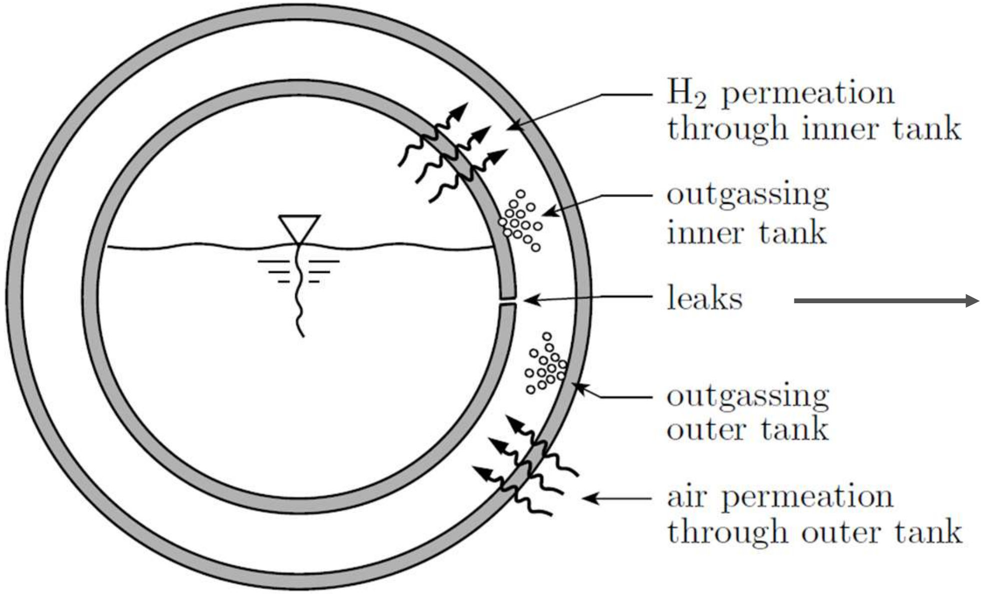
Full composite tank (Mc Carville 2018)

- Collaboration between Boeing / NASA
- Hybrid materials: thin plies to avoid permeation and thick plies (manufacturability)

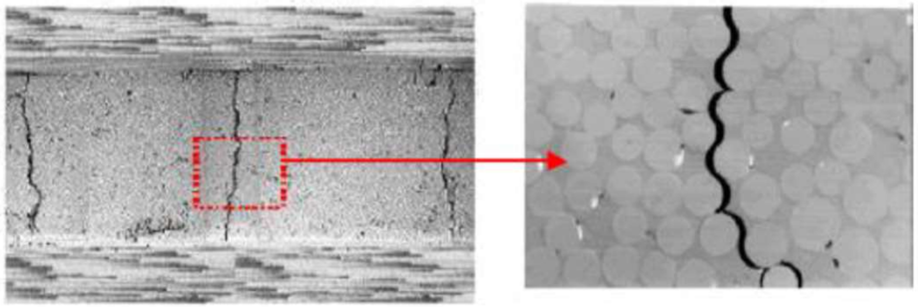
UdG

LH_2 tanks: Service life (I)

Main factors that can deteriorate a LH2 tank (Schultheiß, 2007)



Matrix cracking



Permeation of H2 and air

Leaks

Outgassing

Reduce insulation by vacuum

Evaporation of H2

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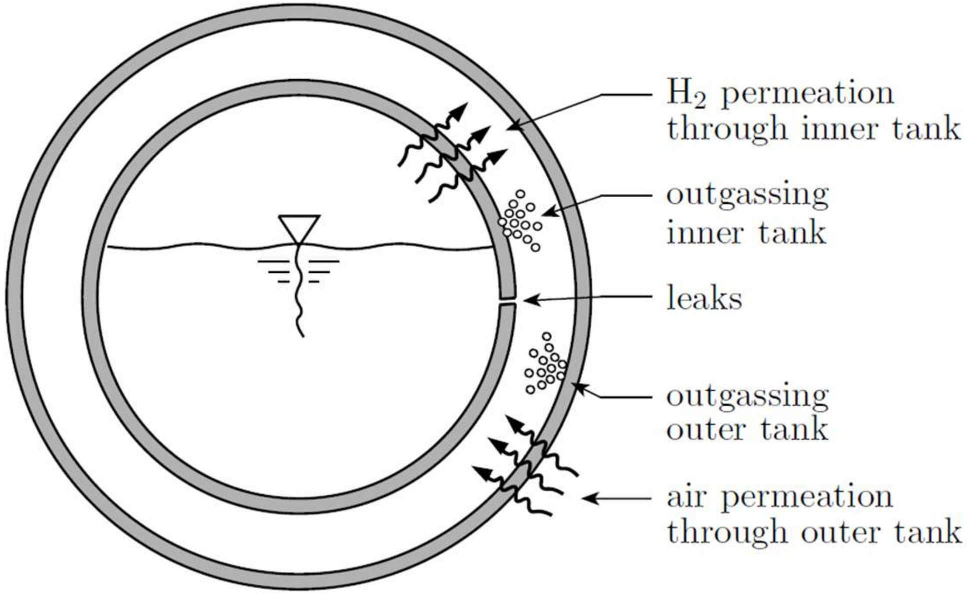
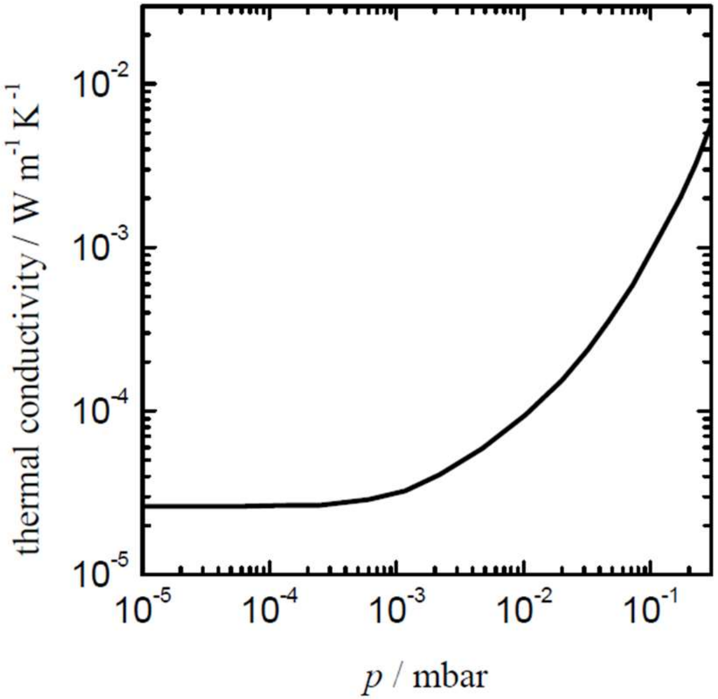


Thermal conductivity of the insulation against vacuum pressure (Schultheiß, 2007)



Permeation of H2 and air

Leaks

Outgassing

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Evaporation of H2

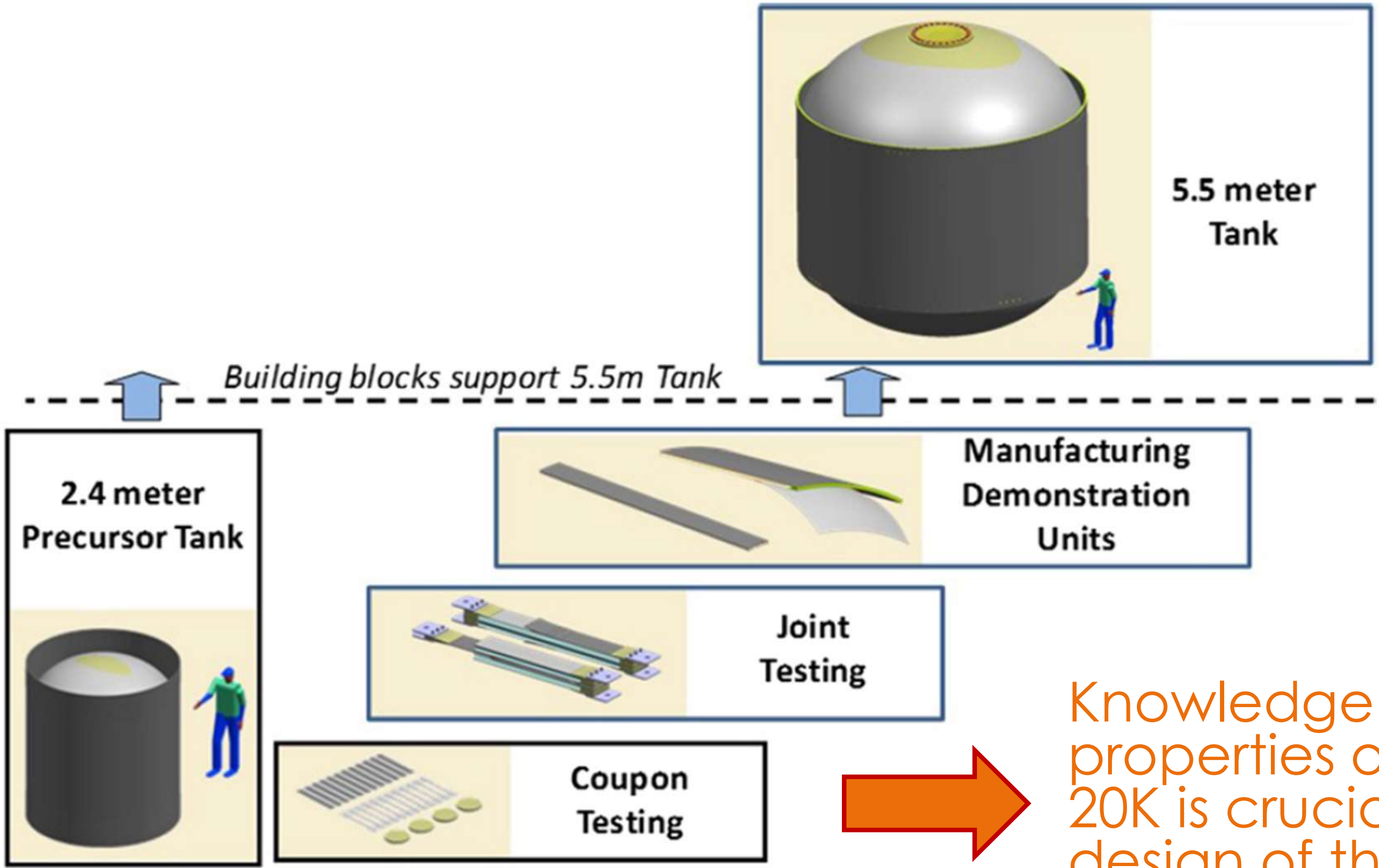
LH_2 tanks: Service life (II)

Other important aspects:

- Inner temperature: ~20 K (H_2 boiling point), low internal pressure in comparison to GH_2 tanks (700 bar)
- Life: LH2 tanks for aircrafts or GH2 tanks for cars (~15 years) in comparison to duration of aerospace LH2 tanks (8 ½ minutes to reach orbit)
- Inactivity times of 12h in aircraft industry, higher permeability requirements.
- Refuelling and maintenance, thermal fatigue

LH_2 tanks: Design

LH2 tank Building Build Approach (McCarville 2018)



Knowledge about the properties of the material at 20K is crucial for a proper design of the tank

What?

Objectives

Objectives

- **Enhance test facilities for testing at 20K with GHe instead of LH2 (more safe)**
- **Experimental characterization of CFRP laminates at 20K**
  - Development of measurement and calibration procedures
  - Development of test setup and procedures for the characterization under static and thermal fatigue loads
  - Understand the mechanical performance under extreme LCT
- **Numerical simulation of CFRP at 20K**
  - Formulate thermomechanical constitutive models for interlaminar and translaminar static and thermal cyclic loading

How?

Projects

OVERLEAF: nOVel low-prEssure cRyogenic Liquid hydrogEn storAge For aviation

- European H2020 project
- IP: Albert Turon
- Duration: 36 months (July 2022 – July 2025)
- Participants: 10, coordinator: ACITURRI
- Budget 6M€ (AMADE: 570 k€)
- Summary: Development of a game changer low-pressure LH2 tank made of CFRP for the aircraft industry. Definition of materials, characterization of materials, design, manufacturing, integration and demonstration.
- AMADE participation: design of the tank and mechanical testing

CRYFTO: TowaRds the design of saFe liquid hYdrogen tanks for effiCient and green Transport applicatiOns

- National project “Generación de conocimiento” (CICYT)
- IP: Albert Turon / Jordi Renart
- Duration: 36 months (September 2022 – September 2025)
- Participants: 2 (AMADE, INTA), coordinator: AMADE
- Budget 157 k€
- Summary: understanding the material behaviour and providing reliable tools for the design of liquid hydrogen fuel tanks. Enhance test facilities, development of test methods, material characterization, structural health monitoring (SHM) techniques, simulation of the thermomechanical performance and SHM

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