



HEAVEN project: overview of the first piloted Flight of LH₂ Powered Electric Aircraft

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Project cofinanced by :



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H₂ aboard : 10 years of R&D in Air Liquide



2013-2019

350bar gaseous H₂ tank
non-propulsive energy

Low gravimetric index
(<5%)

Projects co-financed by

:



World premiere

2020-2023

Liquid H₂ tank
for propulsive energy
permit to fly

High gravimetric index
(>15%)

LH₂ VS Kerosene

Cryogenic tank competitive in mass

1 kg LH₂ ~ 4 kg Kerosene

12 kg of CO₂ saved

BUT 3 X bigger

Powering aircraft with liquid Hydrogen :

When the dream goes to



© Jean-Marie Urlacher / H2Fly



A LH₂ tank with a Fuel Cell

- **Objectives**

- Demonstration of a manned flight powered by a FC fed supplied by a LH₂ Tank.

- **Challenges**

- Put the tank onboard an existing aircraft called “HY4”
- Interface the tank with the aircraft and the existing powertrain system (fuel cell fed with HP GH₂)
- Sufficient performances to be able to fly
- Safety (design , procedures, airport, Permit To Fly)



Vent line outlet

Not just a tank : a comprehensive cryogenic system

Many operational functions to perform

- Cool-down/warm-up, refueling/defueling, pressurization, FC feeding by LH₂ vaporization, standby, etc...

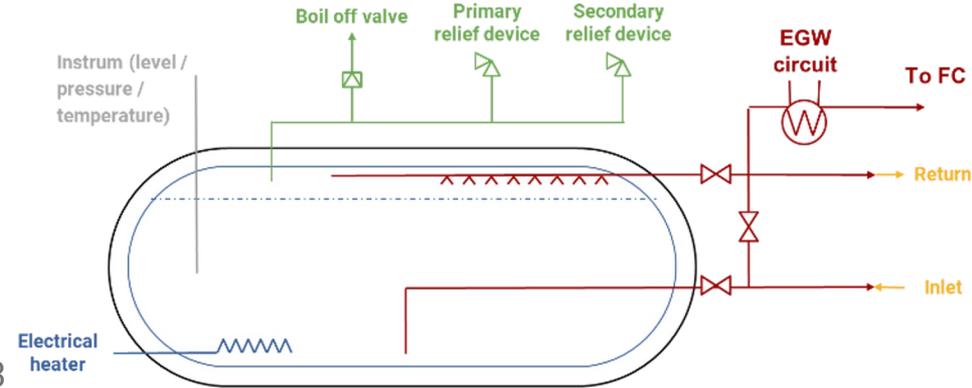
Performances of the LH₂ Tank

- Aluminium vessels, vacuum insulated, operates at 6.3 barA
- 15 kg of usable LH₂ - gravimetric index 11%
- Can feed up to 100 kW Fuel Cell

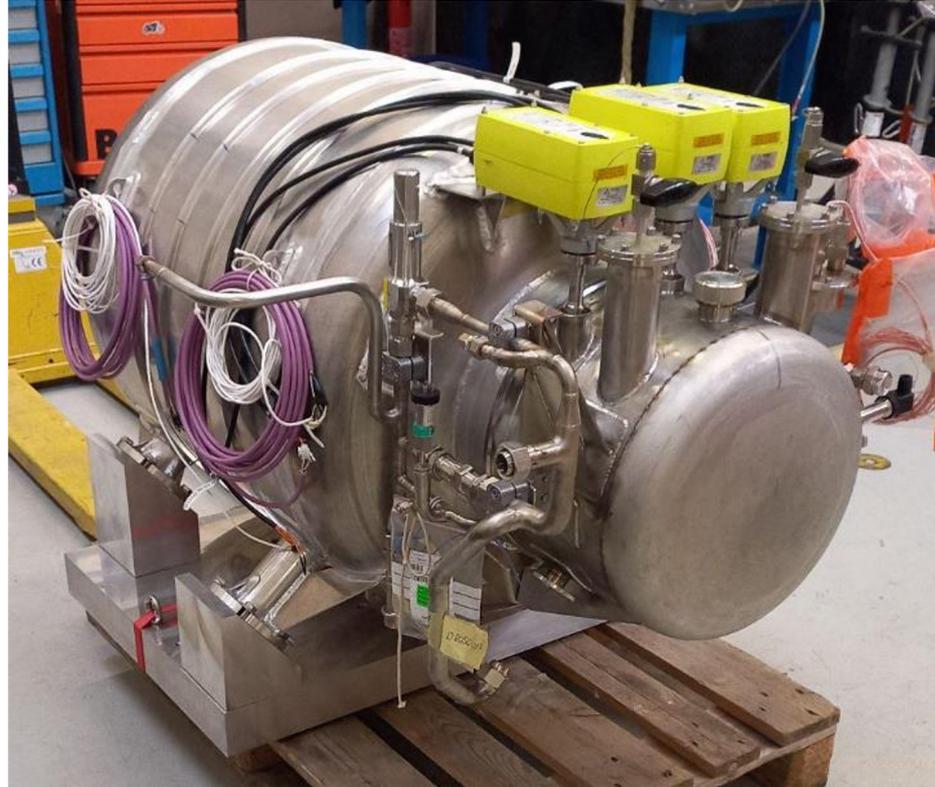
All safety analyses performed according to ARP4761 (SAE) guidelines in all operations

Ground refueler

- Interface between LH₂ trailer and aircraft



Design and manufacturing



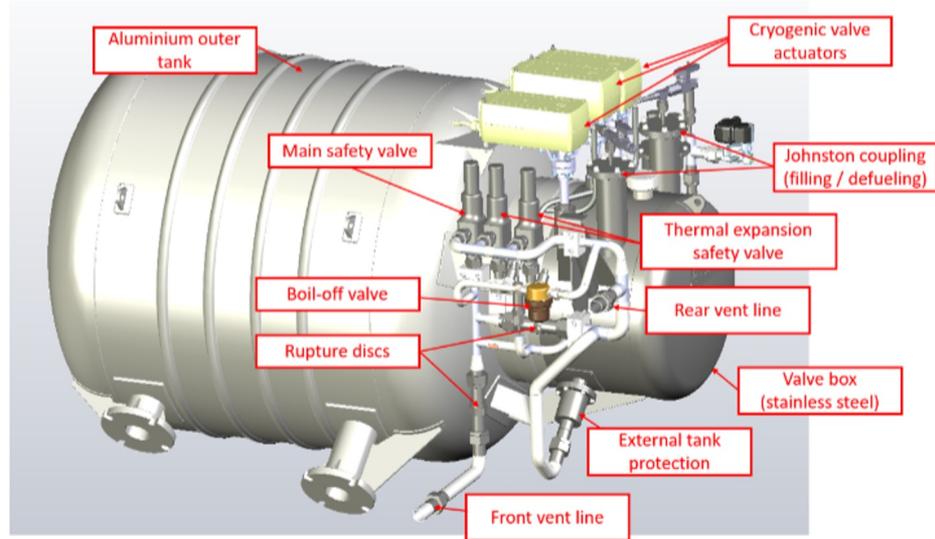
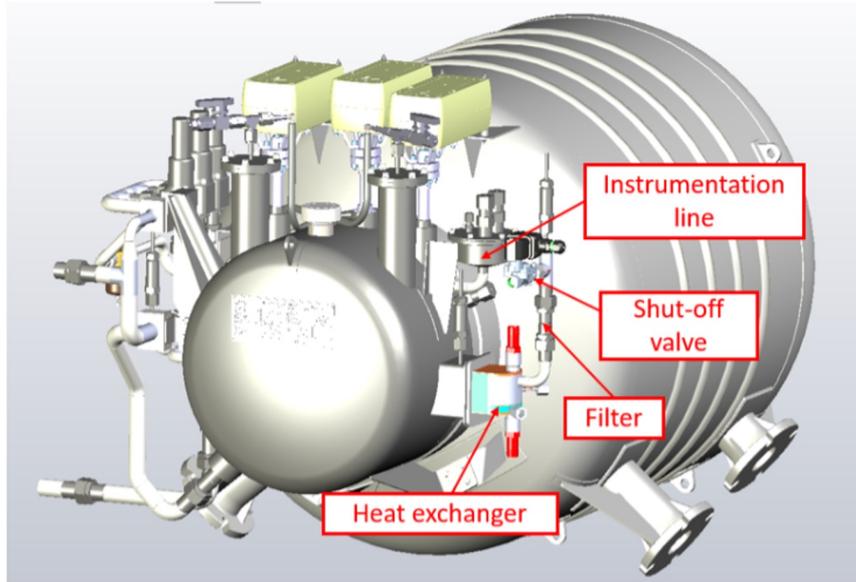
Key design features of Heaven LH₂ tank

Aluminium inner and outer tank -> mass reduction

Titanium neck -> mechanical and thermal optimization

Welded stainless steel plate HX for vaporization -> reliable and compact

Electrical heater for tank pressurization -> light and reliable



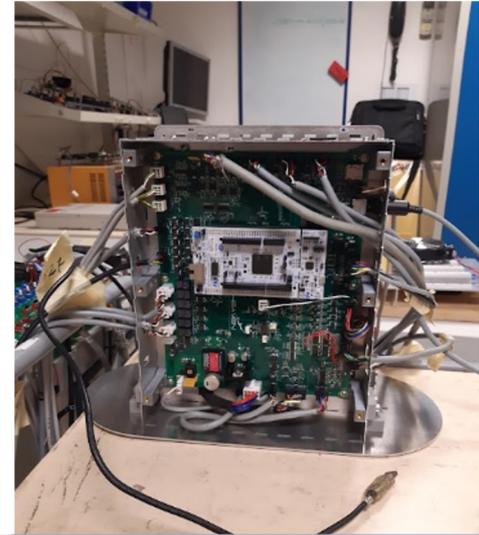
A dedicated control/command system

Developed internally at ALAT

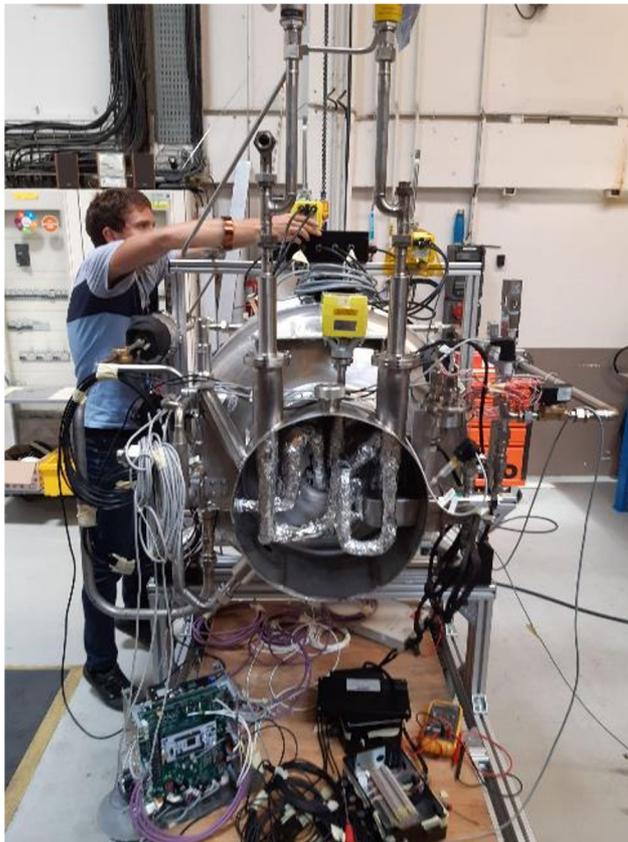
Fully automatic system : it maintains a constant pressure in flight whatever the flow rate required by the fuel cell

Key informations only are sent to the pilot that can switch off the tank at anytime

All operational and safety functions are analogic



A complex integration process



Entirely designed,
manufactured and tested
in ALAT's premises



Tests before flight



Tests before flight

Before flight, a lot of tests have been performed to demonstrate that the tank :

- Can supply the FC at required flow rate (2.4 g/s) at a constant pressure, in transient
- Has a sufficient time to boil-off (10 to 20 h after filling before boil-off valve opening)
- Can withstand aeronautical environment without leak / mechanical integrity deterioration
- Generates no glitch by its control/command

Tests before flight : 1 - ALAT test center

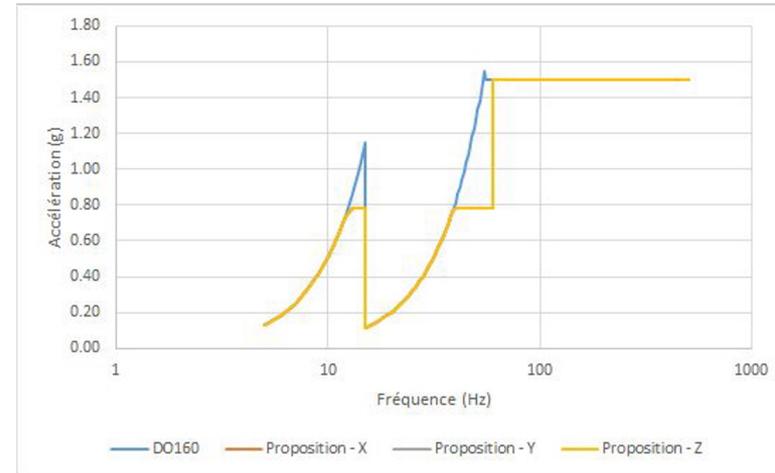
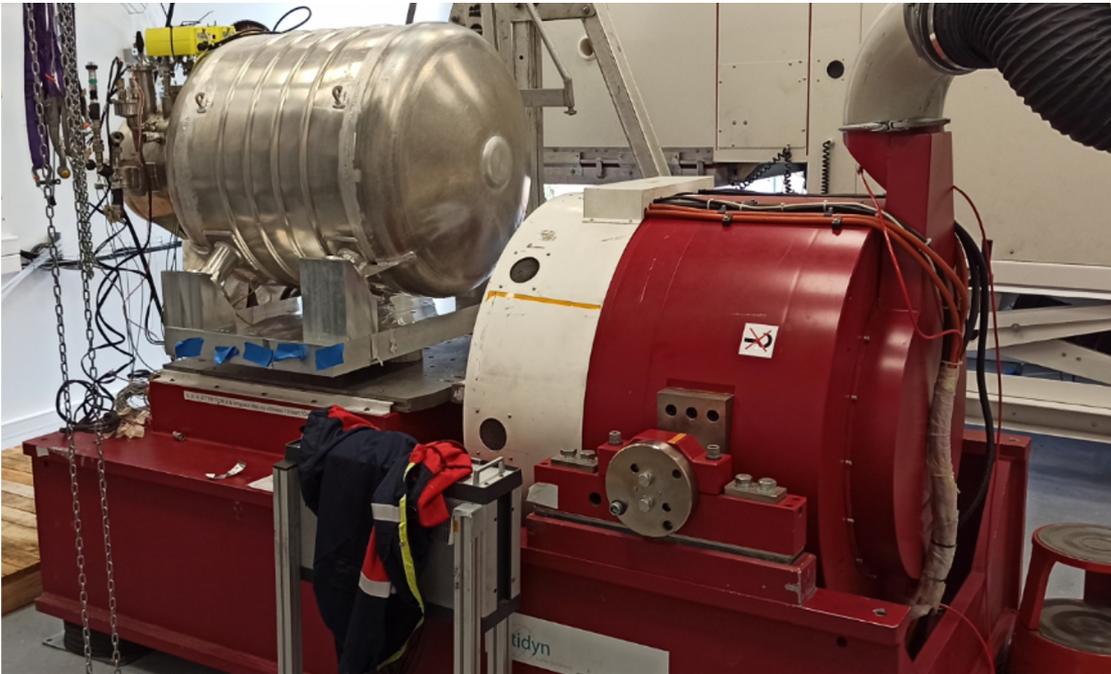
LN₂ and LH₂ tests on ALAT test center with flight controller - key conclusions :

- Time to boil-off ~10 h between 1 and 7 barA
- Up to 3 g/s of LH₂ can be withdrawn while keeping pressure constant
- Absence of LH₂ leak validated / all safety functions tested



Tests before flight : 2 - Vibration tests

Tests successfully performed according to DO160 with 15kg of LN₂ at ALAT vibration test bench



Tests before flight : 3 - coupling tests on ALAT test center

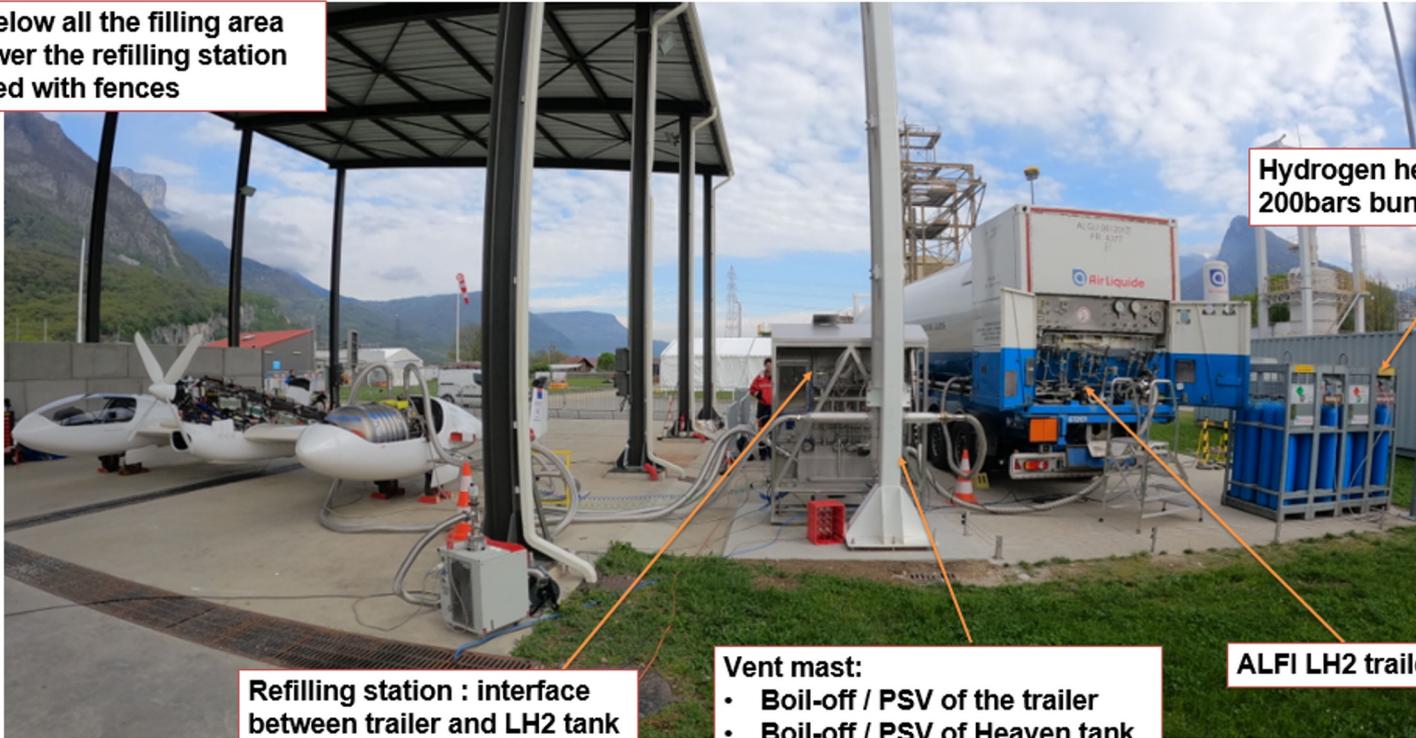
Target : Test the whole system on ALAT test center before flight tests

- Refilling of Heaven LH₂ tank from an AL trailer through dedicatedrefilling station
- Supply the fuel cell with LH₂ to start the electrical motor
- Validate the safety switch between LH₂ tank / HP GH₂ tank



Tests before flight : 3 - coupling tests on ALAT test center

- Concrete below all the filling area
- 230V to power the refilling station
- Area secured with fences



Hydrogen helium nitrogen
200bars bundles

Refilling station : interface
between trailer and LH2 tank

Vent mast:

- Boil-off / PSV of the trailer
- Boil-off / PSV of Heaven tank
- Return gas during refilling

ALFI LH2 trailer

Flight tests

Maribor airport (Slovenia) early September 2023



Flight test - refilling area

- Tests performed at Maribor airport - Slovenia
- Air Liquide LH₂ container on site for 2 months (pre-tests + flight tests)
- LH₂ safety training on airport fire brigade
- Permit to test fly granted by Slovenian civil aviation authorities



CONCLUSION : A world premiere : a manned e-A/C powered by LH₂

- A 4 year project that led to the world first LH₂ flight with a fuel cell and pilots on board
- Perfect coordination with H2FLY (head of project) and Pipistrel (aircraft maker)
- Apart from minor glitches, the tank behaved as expected
- Authorizations and operations at the airport went smoothly
- All functions for future a/c implemented and tested

This HEAVEN tank can be replicated
or adapted to other aircraft

It paves the way to liquid H₂-powered a/c

