The Hydrogen Motorsport Challenge

MSc Advanced Motorsport Engineering Group Design Project

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Introduction

The aim of the investigation was to explore the potential for an accessible race series using a hydrogen powered internal combustion engine. A low cost two seater competition car has been designed and is able to demonstrate that performance and safety can be achieved.

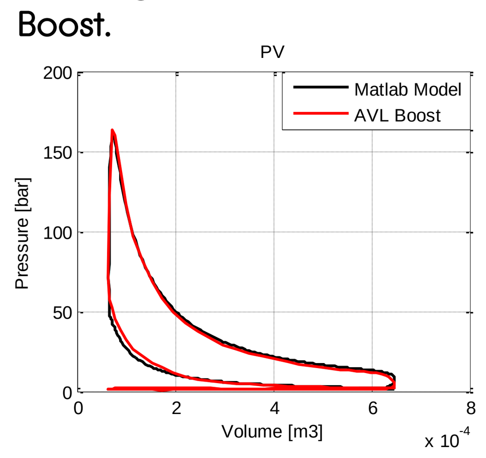
Objectives

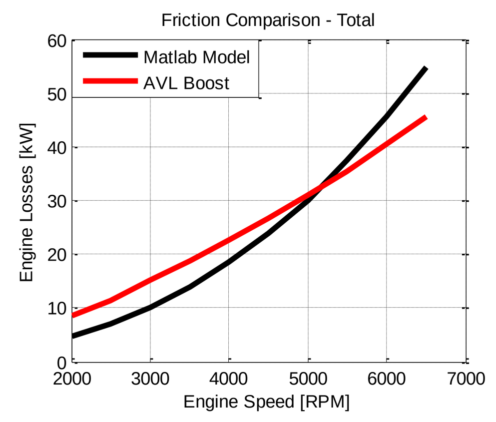
- To design a chassis to include a hydrogen storage system and protect it in a side impact.
- Design of a storage system that safely contains and delivers the fuel to the engine.
- The optimisation of a spark ignition engine to run on hydrogen and quantify its performance.

Powertrain

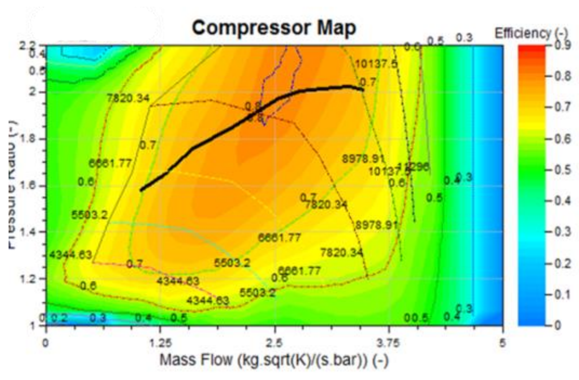
V6 3.5L Ford EcoBoost Engine hydrogen combustion modelling

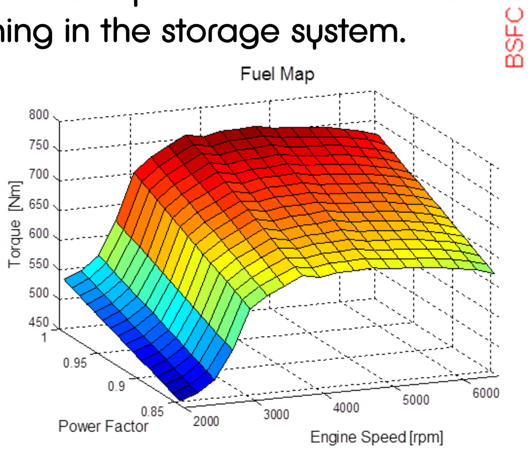
A 1D theoretical model of a cylinder's 4 stroke cycle and associated friction losses was formulated in Matlab. This provided an initial understanding of the mathematics behind engine simulations and expected performance indicators, allowing for validation and realistic results determined using AVL Boost.

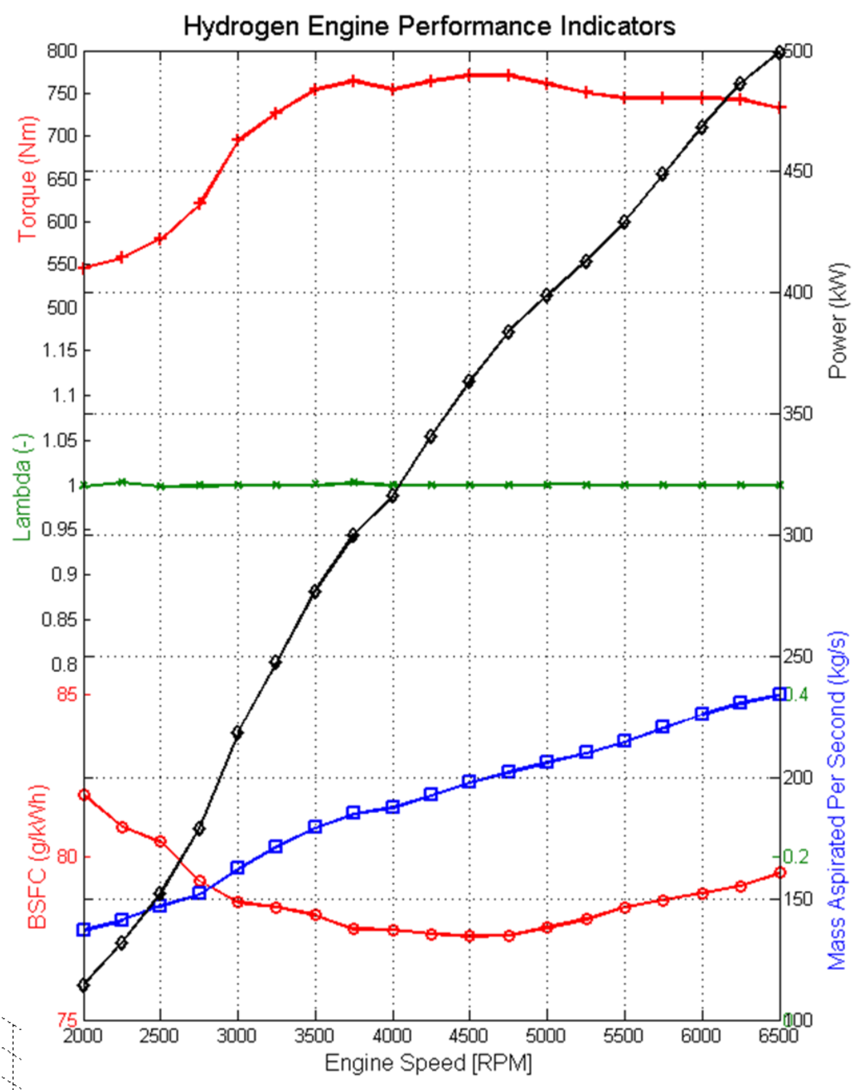




To maximise the performance of the hydrogen ICE, new turbochargers were selected with the addition of external wastegates to regulate the compressors' operating region. A Fuel Map was created with an algorithm that optimises the fuel flow rate dependant on the mass remaining in the storage system.



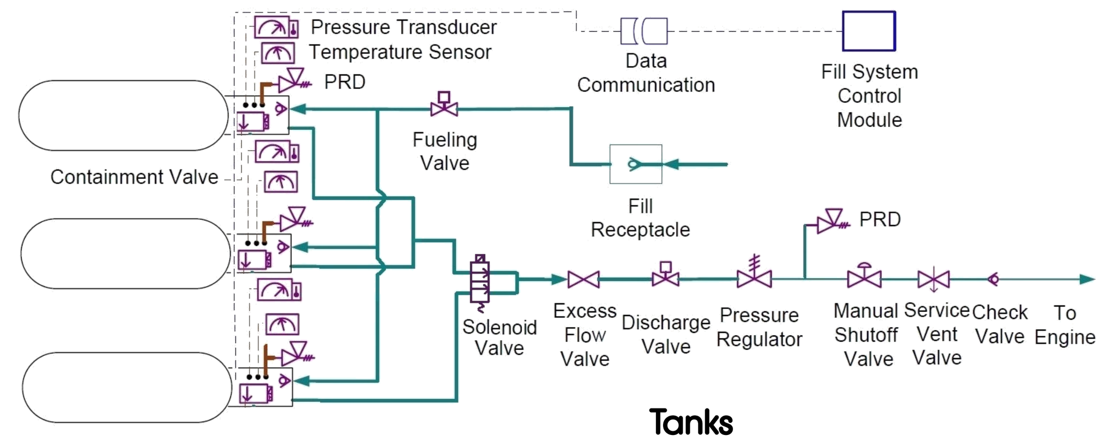


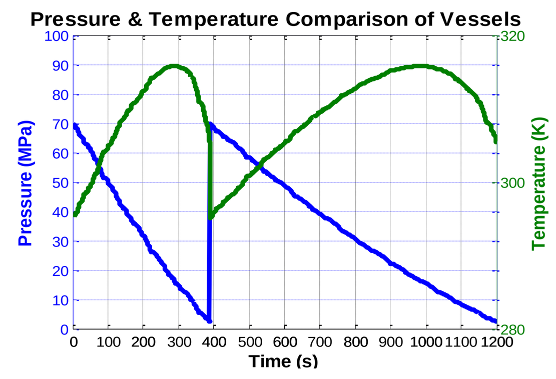


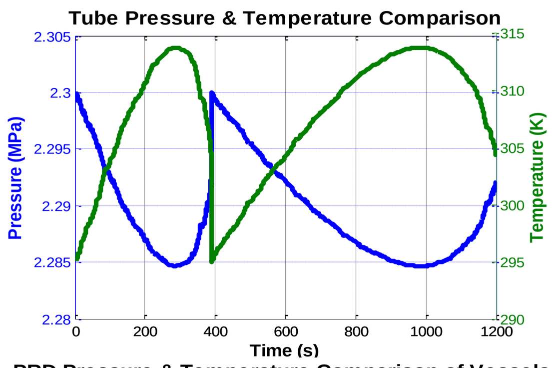
Hydrogen Storage

Layout

- Based on requirements defined in the draft European regulations.
- In-Tank regulator implemented to avoid high pressures in tubes with pressure in tubes with pressure difference control.
- Solenoid valve implemented to empty the two highest vessels first in order to lower COG during the race.
- Joule-Thomson effect increases temperature upon expansion.





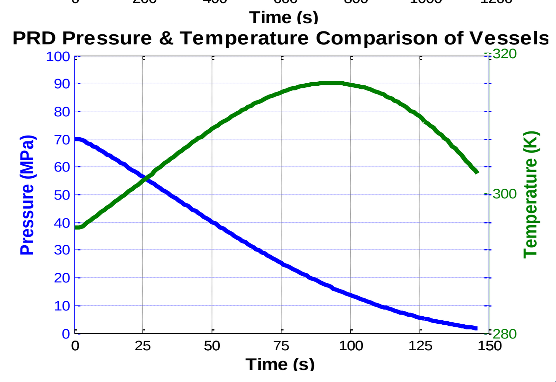


Safety System

- Pressure relief device employed
- Emergency evacuation: 150 seconds
- Leakage safety mechanism through comparing in-tank pressures and flow rates to the engine.

Tanks

- Nominal Pressure: 70 MPa
- Filling Pressure: 85.6 MPa
- Burst Pressure: >160 MPa
- Vessel Volume: 1x112.5L and 2x28.75L
- Hydrogen Mass: 6.69 kg, 6.40 kg (usable)



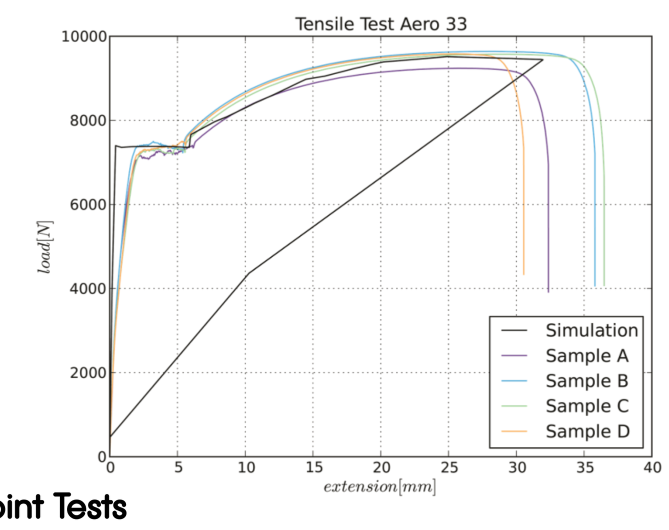
Concept

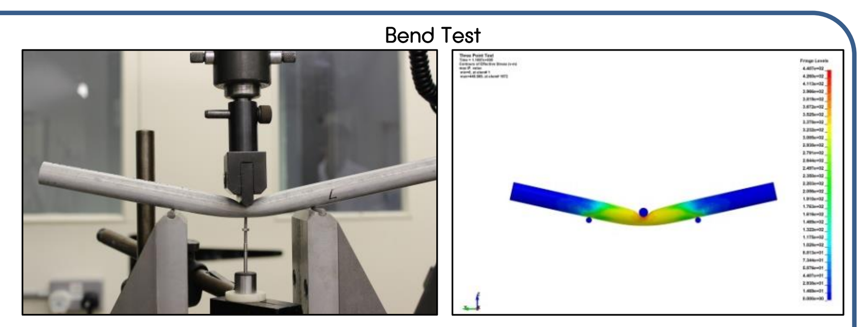
Finite Element Analysis

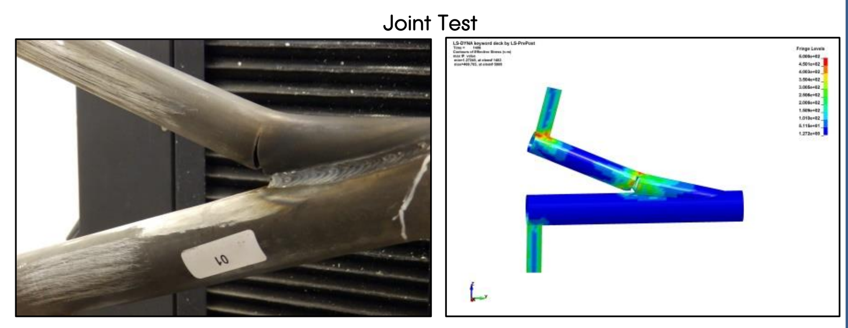
FEA Process Validation

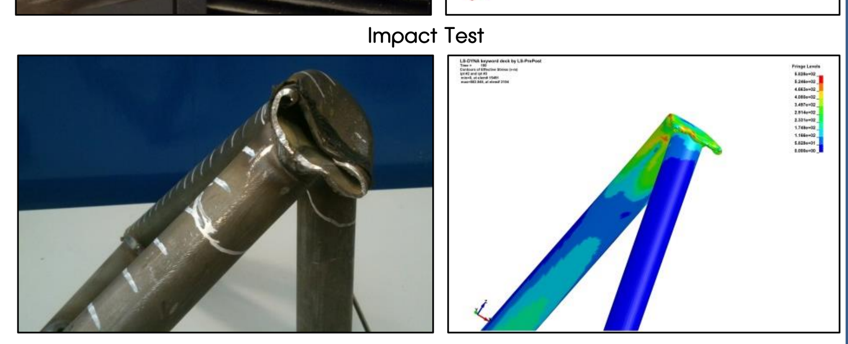
Material Tests

- Tensile and three point bend tests to derive true stress-strain curves.
- FEA simulations developed to validate the material data input, using an iterative process with LS-DYNA and the material card 24 Piecewise Linear Plasticity.







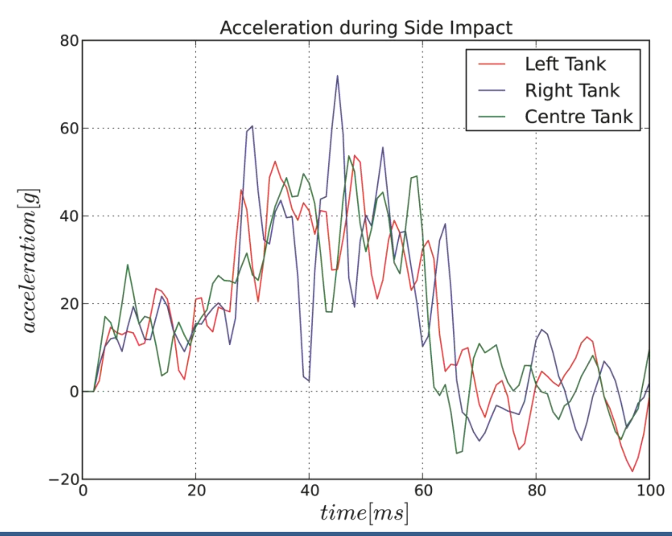


Joint Tests

- Tensile and peel tests of welded joints from Radical RXC chassis.
- The joints did not fail in the welds, but did in the heat affected zones around them.
- The failure behaviour was replicated in LS-DYNA by modelling the heat affected zones and using a contact definition without failure.

Substructure Impact Tests

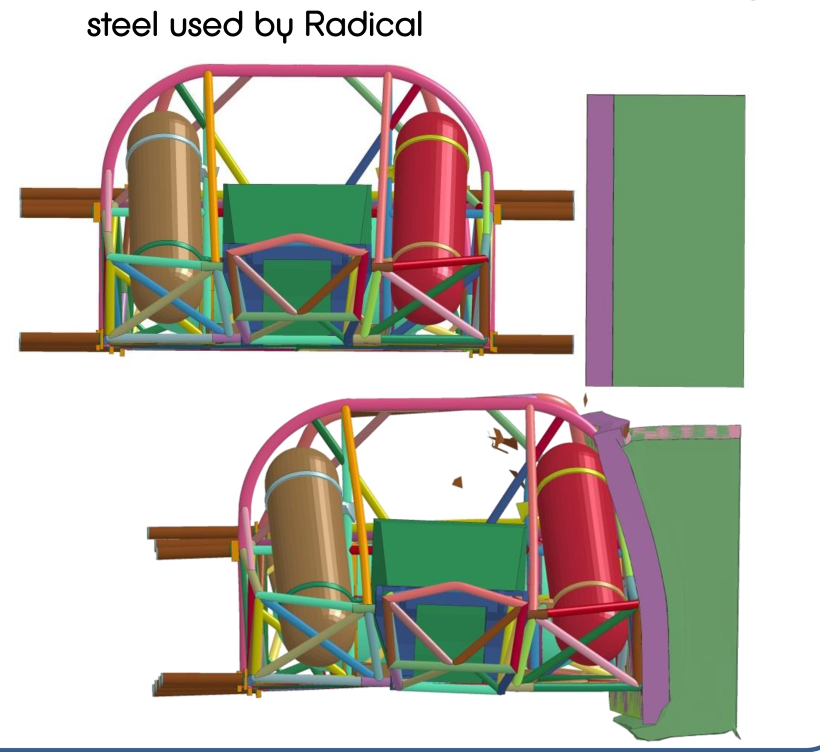
- Drop tower test with substructures cut from the Radical RXC.
- FEA simulations showed a better correlation with the real material behaviour by not using the material failure option in LS-DYNA.



Crash Simulation

(Side Impact / 55kph / deformable barrier)

- Stiff structure around the tanks
- Iterative optimisation process:
  - Optimisation of the FEA modelling approach
  - Chassis structural changes
  - Addition of a basic impact structure
  - Different materials: Aerocom 33 and original steel used by Radical



Conclusions

- Engine modifications resulted in a peak deliverable torque of 768.3 Nm at 4750 rpm and peak power of 498.6 kW at 6500 rpm. The quantification of the performance of a hydrogen internal combustion engine has been achieved.
- The storage system contains 6.69 kg of compressed hydrogen gas. The devices employed provide sufficient safety and delivery to the engine.
- Material and joint tests were conducted and the representative FEA simulations replicated the results which provided validation for the FEA process.
- A chassis including the hydrogen storage system was designed and successfully shows that the safety requirements have been met.
- The study demonstrates that the performance and safety of a low cost 2 seater race car powered by a hydrogen internal combustion engine can be achieved.

Supported by: Radical, CRANFIELD MOTORSPORT SIMULATION, CRANFIELD IMPACT CENTRE, AEROCOM METALS LIMITED, Altair, BOOST, GRM Optimised Engineering Design

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