2020 Cranfield Motorsport Group Design Project
Green Gulf

Mission Statement

H2 Ace Racing aims to create a Westfield 250 based concept design of a sustainable race car for a future middle-east entry level series called Green Gulf. It features a hybrid powertrain, where the rear wheels are driven by an internal combustion engine fuelled by hydrogen and the fronts by an electric powertrain. Using hydrogen eliminates CO, CO2, HC and PM emissions creating a modern, environmentally friendly race car that maintains the old spirit of motorsport.

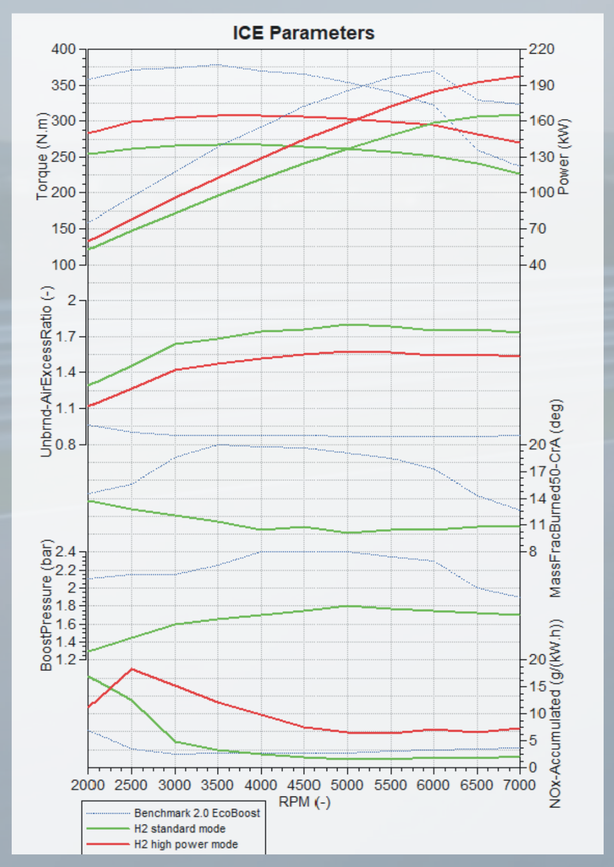
Overview

Region	Saudi Arabia
Track	Ad Diriyah
Ambient Temp.	16-37°C
R&D Cost	£ 500k
Unit Price	£ 102k

Green Gulf

Hydrogen Conversion

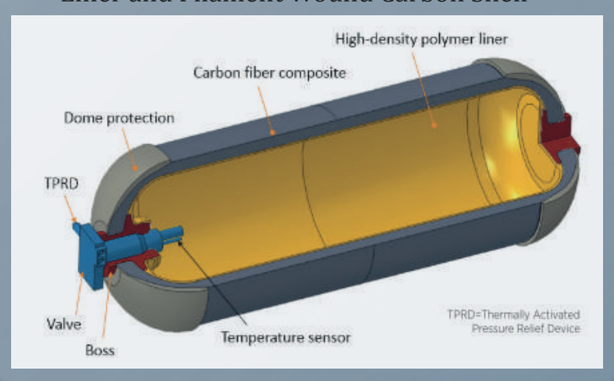
Ford 2.0 EcoBoost engine converted to run on direct injected gaseous hydrogen



- Higher autoignition temperature, flame velocity diffusivity
- Lower quenching layer thickness, minimum energy to ignite
- MBT with no detonation limit
- Lean mixture for optimised efficiency
- Eliminate HC, CO, CO_2 and PM emissions
- NOx emissions as conventional gasoline engines
- High end replacement parts to withstand challanging racing conditions
- Qualifying mode with 30Nm extra torque

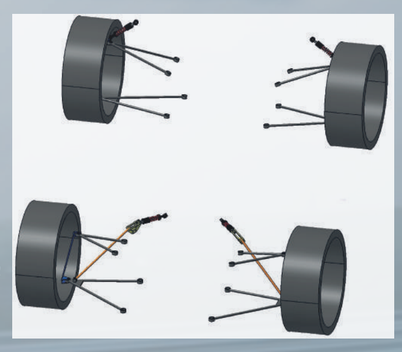
Hydrogen Storage

- 1000 bar Operating Pressure giving High Density of 77.56kg/m3
- Low Tank weight of only 47kg
- Fuel capacity of 5kg
- Type IV type Pressure Vessel with a HDPE Liner and Filament Wound Carbon Shell



Vehicle Dynamics

- Tyres used: Avon ZZS semi slick
- Front and rear suspensions were modified to allocate the electric powertrain/impact attenuator and the hydrogen tank, keeping the overall changes to a minimum to prevent high costs
- Directly actuated coilovers on the front suspension were replaced by pushrod system
- Rear suspension mounting points were moved further back
- Suspension response was analysed with 7 degree-of-freedom model that allowed a full optimisation of the setup by reducing the maximum and mean response in both heave and pitch



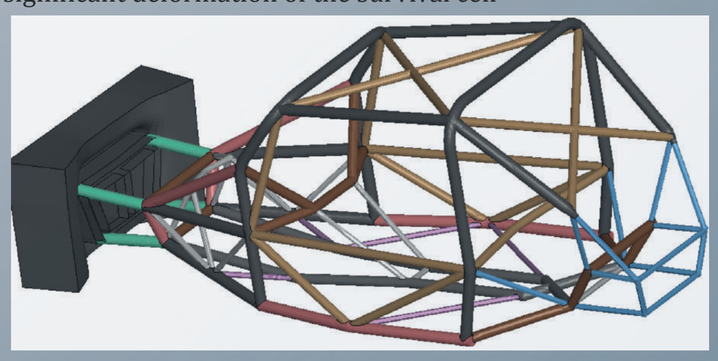
Structural Design

All new chassis design

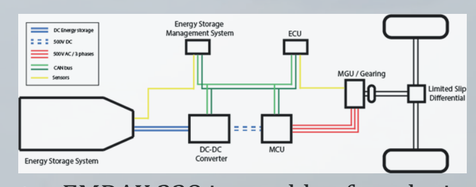
- Roll Over Protection System incorporated as structural component
- 270% increase in torsional stiffness
- 215% increase in specific stiffness
- Detachable impact absorption structure

Impact simulation results:

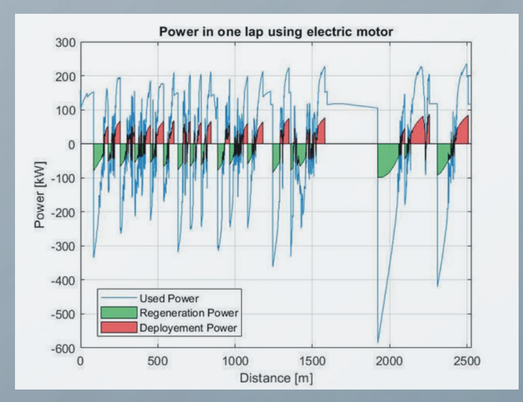
- 18.6g average acceleration
- 28.7g peak acceleration
- No significant deformation of the survival cell



Electric Powertrain

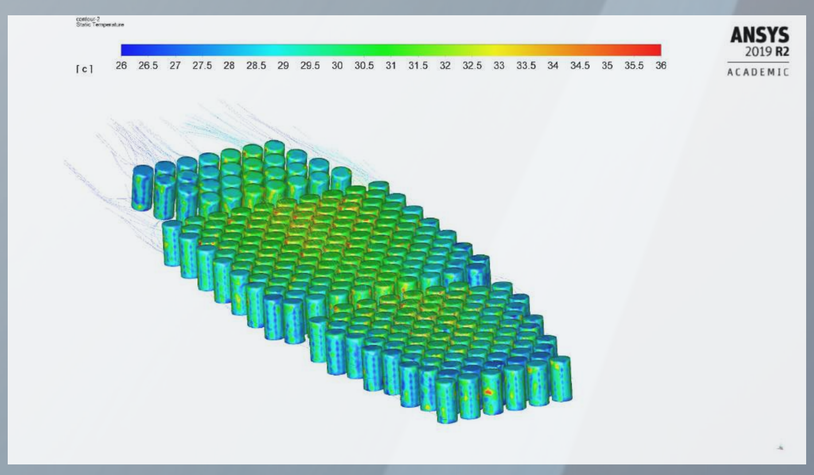


- The electric motor EMRAX 228 is capable of producing and recover as much as 109kW
- Supercapacitors are used for the energy storage system which allow a maximum operating temperature of 85 deg C and have the following stats:
  - Volume 31 dm^3
  - Energy storage of over 142 Wh
  - Weight of 22.2kg
- Designed and optimised circuit of DC-DC converter for best voltage matching of the advanced supercapacitors technology
- Faster charge/recharge time compared to battery and energy generated entirely by braking
- High endurance and high cycle life in most extreme conditions



Thermal Simulations

- Thermal simulations using Ansys Fluent CFD simulating multiple laps of supercapacitor deployment allowing for highly detailed models highlighting regions of peak temperature
- Ansys Workbench Transient Thermal model utilised in combination validating CFD results with a high degree of agreement (≈3degC variance). This model has a reduce computational expense allowing for detailed strategic simulations, such as multiple laps of continuous use, cooldown after a one-lap of use, only charging the supercapacitors over a lap, discharging the supercapacitors over a lap
- Both methods used for design verification of the packaging and as a check on the usage profiles for the supercapacitor deployment



Aerodynamics

Three evolutions made with differing levels of aerodynamics from a conventional to a downforce optimised version

	FA (m^2)	C_D	C_L	Lap Time
camel	1.26	0.69	0.24	87.71
onyx	1.1	0.58	0.08	87.48
falcon	**1.20**	**0.58**	**-0.11**	**87.34**

Strategy

- 2 Engine Power Modes with 0.4 second laptime difference
- Hybrid Motor Usage allows for 0.6 second Lap Delta
- Up to 13 laps continuous hybrid usage without thermal derating (3°C/lap increment)
- Up to 20 laps total usage under thermal derate

Lap Time Delta (s)		
	No KERS	KERS
Race mode	0	-0.653
Qualifying mode	-0.348	-0.908

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Alok Apte	Hydrogen tank design, thermal and lap time simulations
Dean Driver	Powertrain, thermal simulations
Pablo Delrivo	Structural design, crash tests, suspension design
Matteo Gala	Electric powertrain
Thara Guggiilla	Structural design, research & study,
Nimrod Ludescher	Powertrain, project management, ROPS simulations
Yoshiki Ohmura	Aerodynamics, packaging
Caique Sanches	Electric powertrain
Ariel Sapollnik	Vehicle dynamics
Ziwen Li	Electric safety

Racecar engineering · STAR-CCM+ · Westfield · AVL · ChassisSim The Winner's Edge · CATIA · LS Dyna · MathWorks · ANSYS

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GDP 2020 - Team 4

Green Gulf

HyPerformance Chassis Technology

Introduction

Green Gulf is a new single make, starter racing series set in the Middle East with the Ad-Diriyah E-Prix circuit providing the location, and a Westfield Sport 250 derived hybrid race car delivering the action.
The aim was to develop an accessible, innovative and safe race car.

Objectives

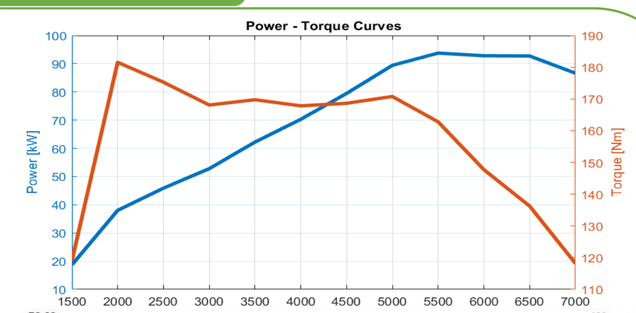
- Develop a Westfield derived hydrogen fuelled hybrid race car
- Produce a lap time estimate for Ad-Diriyah E-Prix circuit
- Prove chassis safety with a standardised impact test

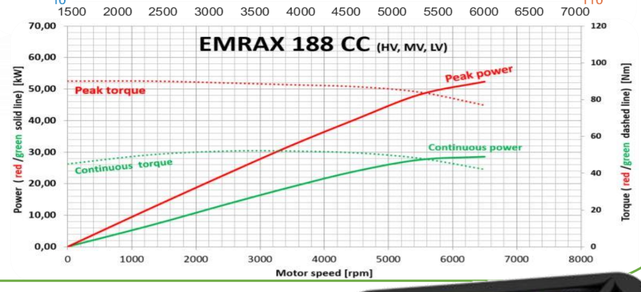
Powertrain

H_2 ICE modelled in AVL Boost
- 104kW at 6500rpm
- 188Nm at 2000rpm

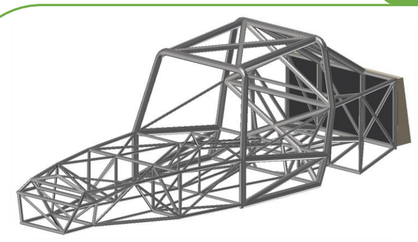
Model targets informed by circuit power sensitivity study

Emrax 188 Motor
- Peak Power: 52kW
- Peak Current (10s): 660A
- Op. Voltage: 60-116 VDC

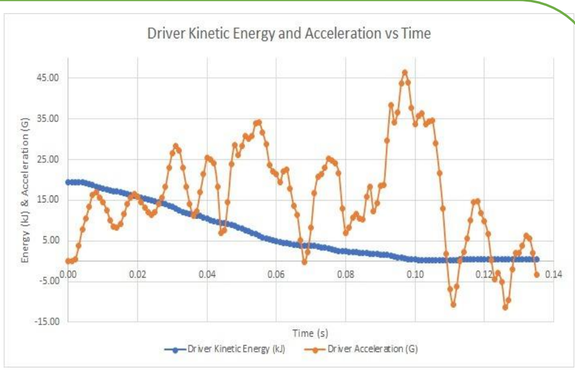




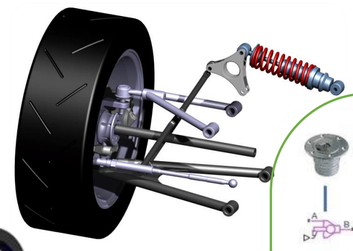
Chassis

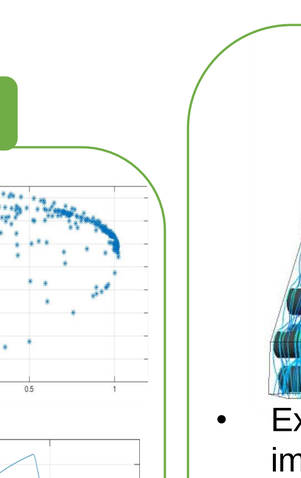


Westfield derived T45 welded steel spaceframe with rear impact attenuator, total mass of 90.01kg

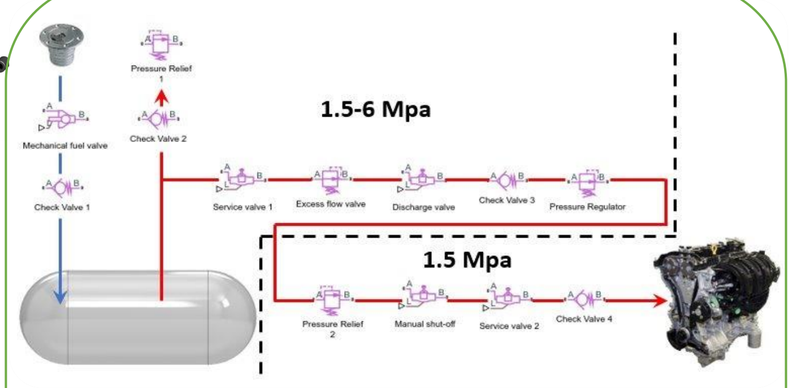


- Torsional stiffness of 23.1kNm/deg
- Peak deceleration of 37.29G in frontal impact



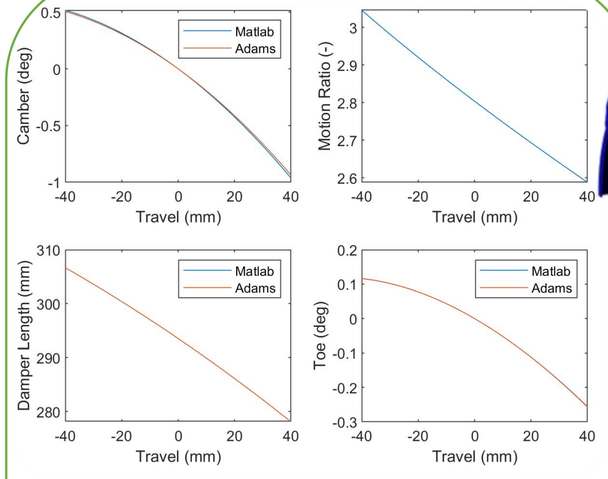


Hydrogen System



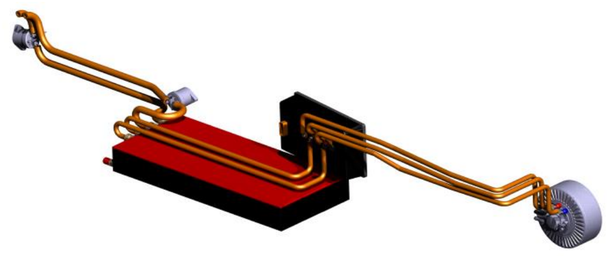
AL-6061T6 double walled tank
- 19kg empty, 23.25kg full
- 63.5L storage volume
- Liquid H_2 pressurised to 6 MPa

Vehicle Dynamics



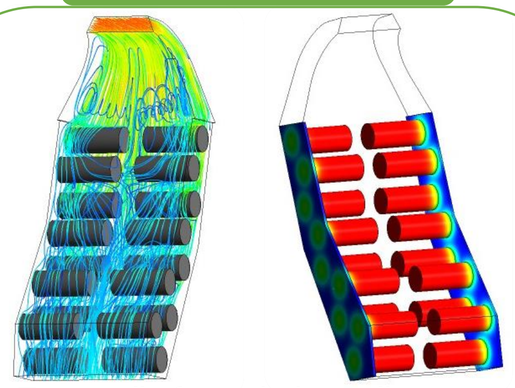
Matlab kinematic & Simulink pitch models validated using Adams Car & IPG Carmaker
Custom tuneable tyre model interface

Hybrid System



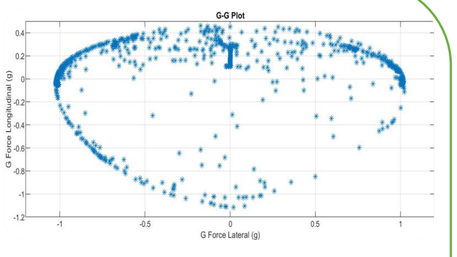
- Sevcon Gen 4 Side 6 Controller
- Brusa BDC546 DC/DC converter
- System mass: 40.46kg

Energy Storage

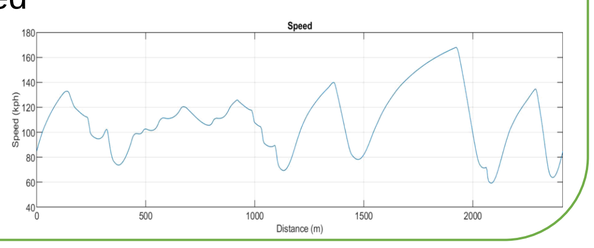


- Externally forced air cooling to improve performance
- 36 Maxwell Supercapacitors stored in two banks (52.5 kg total)
- 0.57MJ of deployable energy

Lap Time Simulation



Models created in Simulink & Matlab using GPOPS
- Lap time: 1:24.157



Conclusions

- The Westfield chassis provides a good platform to incorporate the hydrogen and hybrid systems
- Powertrain performance and energy strategy developed around Ad-Diriyah circuit, others would require further work

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Group Design Project 2020 - Team 3

Green Gulf

Objective: Design a low-cost hybrid hydrogen/electric race car based on the Westfield sport 250 to start a new series in the Middle East

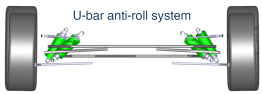
Vehicle Dynamics

CG position (at 145 mm ride height) = **397** mm
Weight distribution F:R = **43:57**

High roll centers to minimise ARB contribution to single-wheel bump

Direct acting damper

U-bar anti-roll system



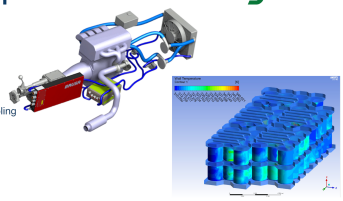
Cooling

Water Cooling System

Primary Cooling System
- Engine cooling
- Two pumps in parallel
- Pressurised up to 100kPA

Secondary Cooling System
- DC/DC converter, inverter, and MGU cooling
- One water pump and one boster pump

"**Double-Deck**" Radiator
- E-NTU validation method
- First deck for primary circuit
- Second deck for secondary circuit



SC pack cooling

- **NACA** ducts strategically placed on the bodywork allow for an effective airflow into the supercapacitor bank

- Air cooling system consisting of **6** fans across the length of the bank

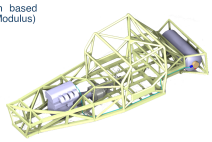
- Small ducts directing flow into areas furthest from inlet

Hydrogen Tank

Gaseous Hydrogen

3.29 kg of H2 stored, for a volume of **80.679** L

- Hydrogen stored under **70 MPa**
- **Type IV** vessel in a cylindrical design with a torispheric head
- 5.38 mm thick wall made of TORAY T1100G carbon based composite (3,460 MPa Tensile Strength / 185 GPa Tensile Modulus)
- Approximative total weight: **50-60 kg**
- Dimensions: Length = **916.5** mm / Radius = **343.5** mm
- Pressure relief valves and pressure regulators for safety

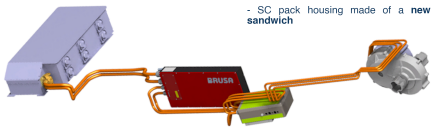


Electric Powertrain

60 kW MGU
from Integral Powertrain

110 supercapacitor cells in series to store up to **167** kJ

- **Axle parallel hybrid configuration**
- Energy deployement strategy: recovered during braking and deployed during the next acceleration
- **HV system**: 700V after the DC/DC converter, between 260 and 313.5V before
- **Shutdown circuit** compliant with FSAE regulations to ensure safe working conditions
- **Pre-charge and discharge circuits** to protect components and people around the car
- SC pack made of **5 independent modules** of 22 cells each
- SC pack housing made of a **new aluminium hybrid foam sandwich**

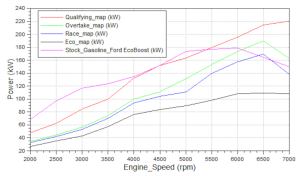


SKM-HH01

Internal Combustion Engine

4 Engine maps

OVERTAKE | QUALIFICATION
Race | Economy



- Qualification mode: allows a maximum of **220** kW to be extracted for that ultimate performance
- Race mode: outputs a mighty **170** kW, ensuring that the driver will be on the edge of his seat for the whole 45-minute race
- Overtake mode: delivers **186** kW and is designed to allow easier overtakes and thus make the racing series more interesting
- Eco mode: outputs a modest **110** kW, mainly aimed to save fuel during the race

Due to the number of maps available, drivers can also race strategically to gain an advantage over their competitors.

Chassis

Custom made chassis structure preserving the original sports car design

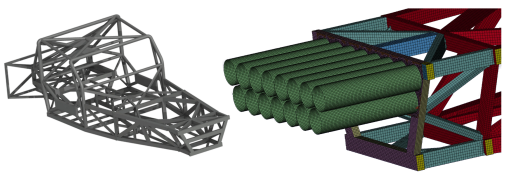
Chassis weight = **173** kg

Made of 4130 Cold Drawn Seamless tubes

Full roll over protection system compliant with the FIA Schedule J Global Standards

Rear end designed to ensure fuelling system protection

Front impact attenuator (**100 kJ**)



Summary

- Mass (with driver) = 922 kg

- Maximum power = 280 kW

- Top Speed = 189.2 km/h

- Lap time (Ad Diriyad circuit) = 1min31s400

Simulation and performances

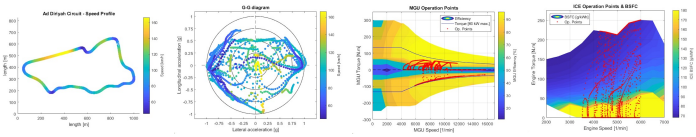
Test track: Ad-Diriyad E-Prix circuit

Laptime: **1min31s400** (in qualifying mode)

Fuel consumption: **72 L** (in race mode)

Number of laps completed: **29** (during the 45-minute race) plus 1 formation lap and 1 in lap

Designs validated using IPG CarMaker and a purpose built QSS MatLab script



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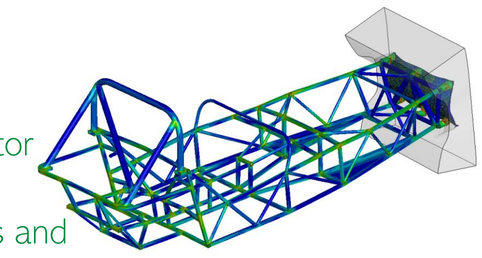
H2Dust Racing
Proposal for Green Gulf Series

Aim:

Designing a low cost, powerful and environment-friendly racing car for the Green Gulf Series. The competition will take place at Ad Diriyah circuit in the extreme weather of South Arabia.

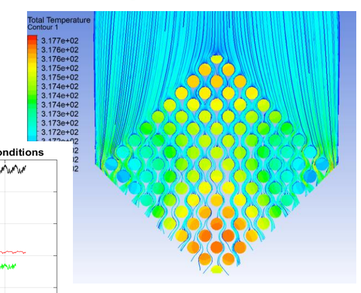
Chassis:

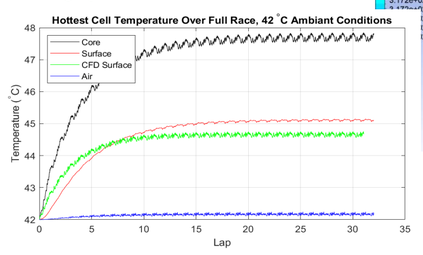
AISI 4130 space frame
AA6061-T6 impact attenuator
Weight: <100 kg
Optimised torsional stiffness and impact crashing at minimum cost
Survives frontal impact at 75 km/h without exceeding 30G's



CFD and Cooling Systems:

Improved cooling in CFD simulations
45°C final racing temperature for batteries
Steady-state and transient using RANS eq.
At 110kph:
Cd = 0.69; Cl = 0.3
A_{front} = 0.76 m^2





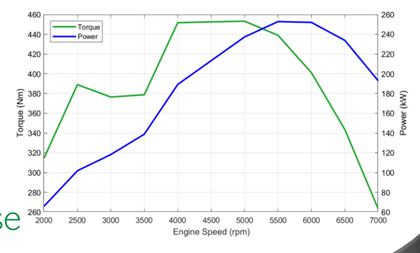
Powertrain System:

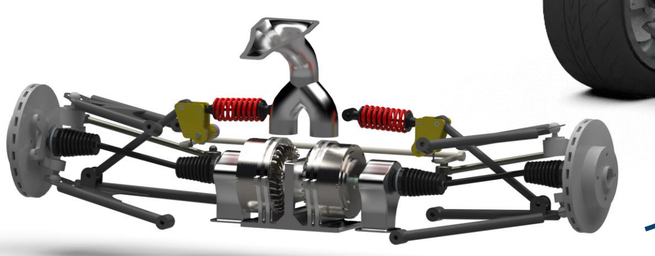
ICE:

2.0l Ford Ecoboost
253 kW @ 5500 rpm
453 Nm @ 4000 rpm
High-Pressure Direct-Injection

Supercharger:

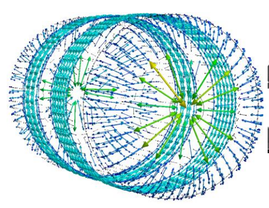
48V AeS802C
Centrifugal
0.107 kg/s max. flow
<0.33 s transient response





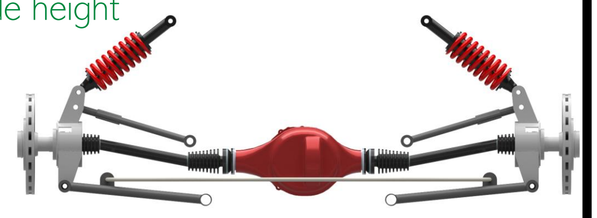
Fuel Storage System:

Cryo-Compressed technology
Max storing pressure: 300 bar
Capacity: 0.74 m^3 (> 6 kg of H_2)
System weight: 81.9 kg
System cost: < 1,600 £



Rear Suspension System:

Low cost modifications
Low ride height



Front Pack System:

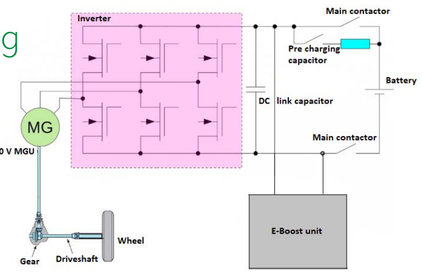
Advanced cooling duct tested in CFD

Front suspension:

Compact design
Minimised camber gain
Anti-Ackermann steering
Zero bump steer

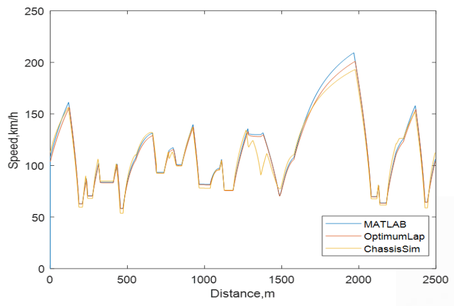
Front Motors (Regen):

Voltage: 60 V
Peak power: 6 kW
Peak Torque: 25 Nm
Weight: 8 kg



Performance:

Lap time: 1:27:58
Top speed: 206 km/h
Max lateral acceleration: 1.2 g
Fuel consumption: 0.174 kg/lap



Battery System:

98 cells, 15.8 kW Peak power
Total energy capacity 930 kWh
Nominal voltage 50 V
Cells weight: 7 kg
Sinks weight: 9 kg
Electrical layout: 14 Series x 7 Parallel

Lightweight
800 kg

Powerful
453 Nm
253 kW

Low Budget
£23k Upgrade

Low Emissions
Zero Carbon

Improved
Design

Team Members:

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