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Numerical and analytical thermo-mechanical modelling of electrical machines and power electronics for propulsion and power generation systems

Dr Antonino La Rocca

Fluids and Thermal Engineering Research Group – FLUTE

Power Electronics, Machines and Control Research Group – PEMC

University of Nottingham

Researcher Links UK-Russia Workshop: Newcastle, November 19th – 22nd

Presentation Outline

- Personal background
- The University of Nottingham
- FLUTE and PEMC Research Groups
- Recent & Ongoing work I am currently involved in
- Testing Facilities

Personal background

Dr Antonino La Rocca – Research Fellow

FLUTE/PEMC Research Groups, University of Nottingham

- **PhD** in Mechanical Engineering : University of Nottingham, UK (2012 – 2016).
- **CEng:** Chartered Engineer, Italy (2012)
- **MEng**: Mechanical Engineering -Thermofluidynamics: University of Palermo, Italy (2010 - 2011).
- **BEng**: Mechanical Engineering: University of Palermo , Italy (2006 - 2010).
- **Expertise**

Conjugate Fluid Flow and Heat transfer modelling for novel cooling designs for electrical machines for wide range of applications from aerospace to marine and automotive. Extensive experience in use of Lumped Parameters Thermal networks (LPTN) and Computational Fluid Dynamics (CFD) for the design of novel cooling concepts for advanced generation and propulsion systems. Mechanical modelling and design of rotating shafts. Design of experimental facilities for liquid cooled equipment

University of Nottingham

- 4 campuses around Nottingham
- Campuses in China and Malaysia
- 50,000 students

University of Nottingham – Faculty of Engineering

- Around 700 staff FTE in the UK, including ~230 academics and ~250 research staff
- Turnover of ~ £ 135M, total research portfolio of ~ £ 200 million
- £13 million investment in technical capabilities, world-leading researchers and demonstrator platforms (Beacon of Excellence)
- Top 10 in REF (Research Excellence Framework) 2014; most Departments ranked in the top 10 in the UK in recent league tables
- Strong history and reputation of working with industry

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PEMC - FLUTE – Industrial Partners

PEMC - FLUTE – International links

PEMC – FLUTE research areas

Research themes

- Power electronics
- Integration and packaging
- Electrical machines
- Electrical drives and control
- Internal Combustion Engines
- Powertrain

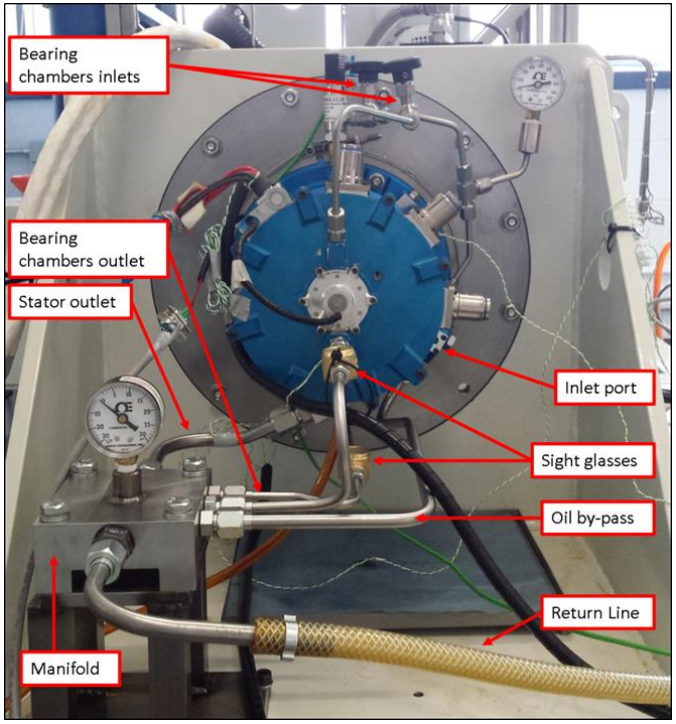
Application areas

- More Electric Transport
  - Automotive
  - Aerospace
  - Marine
- Energy conversion and recovery
  - Industrial drives
  - Renewable energy

PEMC Group Expertise

Machine Types:

- Synchronous Generators
- Permanent Magnet Machine, interior/surface-mounted
- Various machine speeds, 10's to 10,000's rpm
- Various machine sizes, rotor diameters mm's to m's
- High power density machines
- Designs for harsh environments
- Air cooled, Directly/Indirectly liquid cooled



Majority of the novel concepts are fully designed, manufactured and tested in-house up to TRL 5 (Technology Readiness Level)

Overview of my research field – within Thermo-Mechanical team

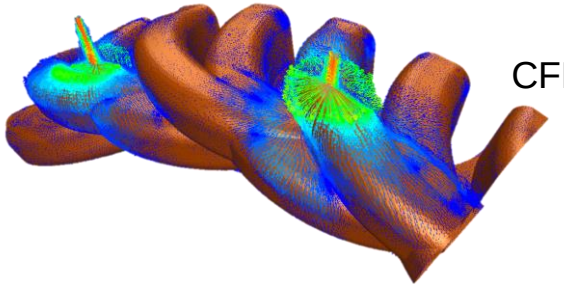
Electrical Machines

Thermal analyses

- Analytical (LPTN) Modelling
- Conjugate Heat Transfer Computational Fluid Dynamics (CFD)
- Experimental thermal and fluid investigations

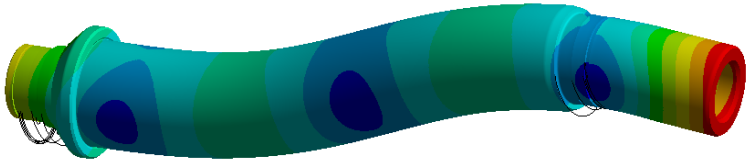
Mechanical Design

- Structural design
- Bearing selection
- Materials selection
- Manufacturing techniques
- Rotor dynamics



CFD

Mechanical FEA



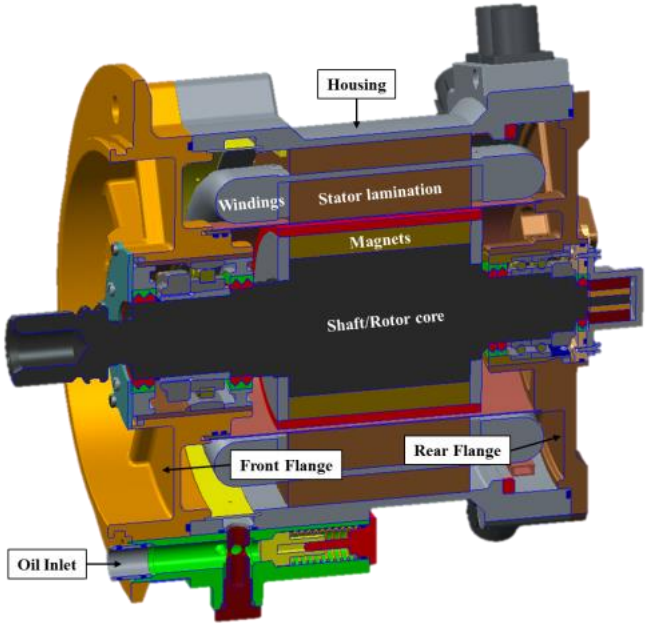
Power Electronics

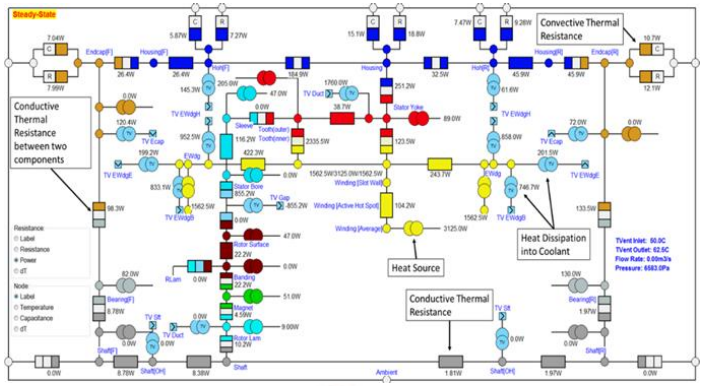
- Converter mechanical design
- Converter thermal design, including heat-sink, cold-plate design

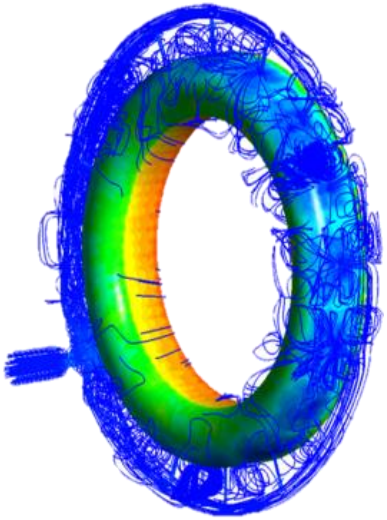
Recent & Ongoing work

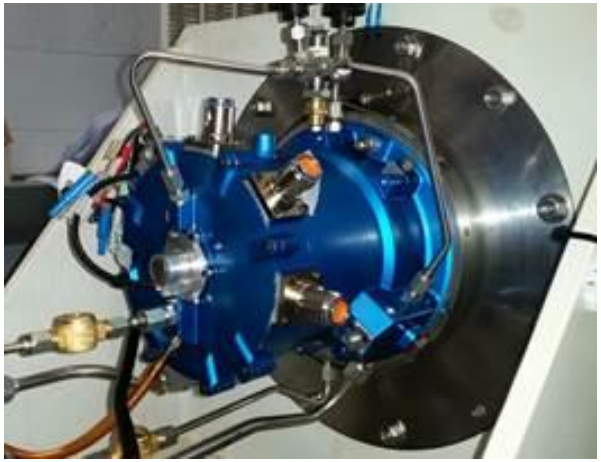
AEGART (CleanSky/DassaultAviation) – Awarded as best CleanSky Project in 2016

- Thermal Design of high speed, power density starter/generation system
- A semi-flooded cooling arrangement was used (numerical and analytical design followed by experimental validation performed entirely at UoN)





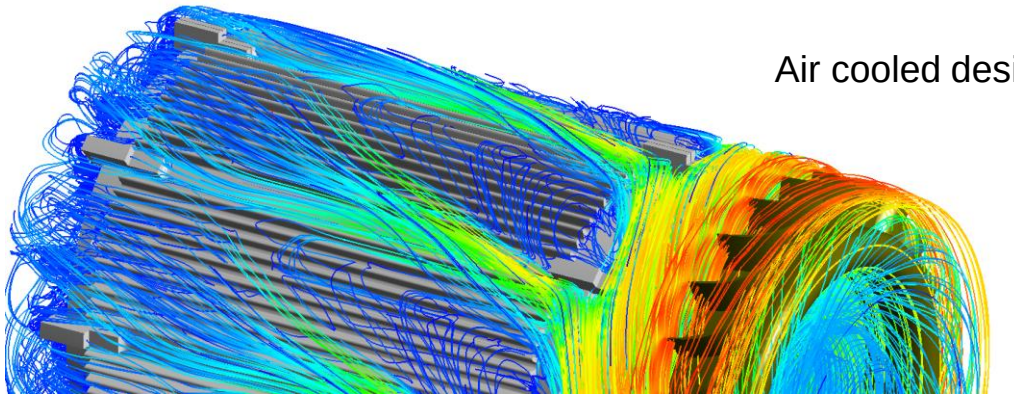




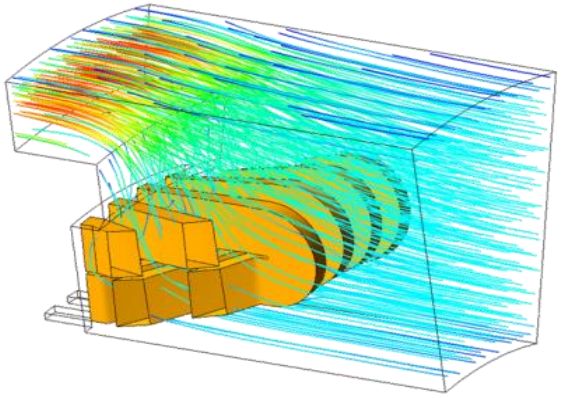
Recent & Ongoing work

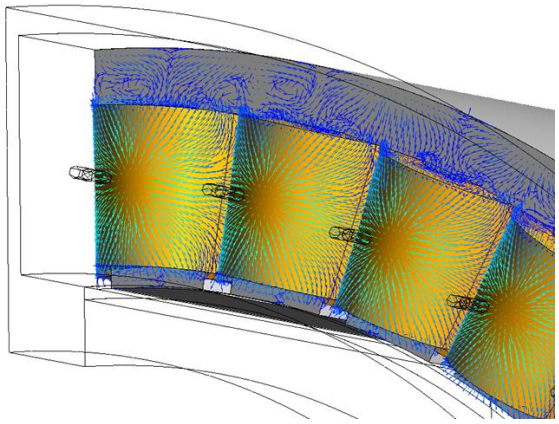
Consultancy work for Industry

- Conjugate heat transfer analysis of water/air cooled low speed motor for marine application
- Fans design and manufacturing carried out at UoN; performance were experimentally validated
- Development of testing enclosure for the testing of several liquid cooling configurations for different stator designs/arrangements

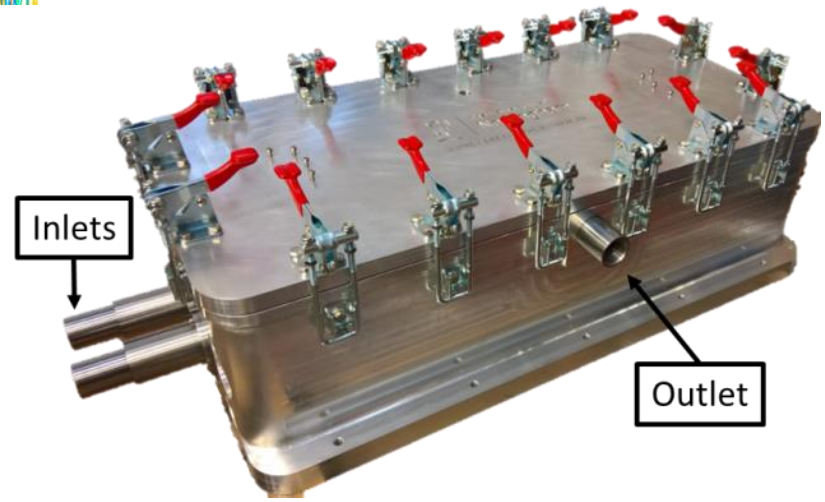


Air cooled designs





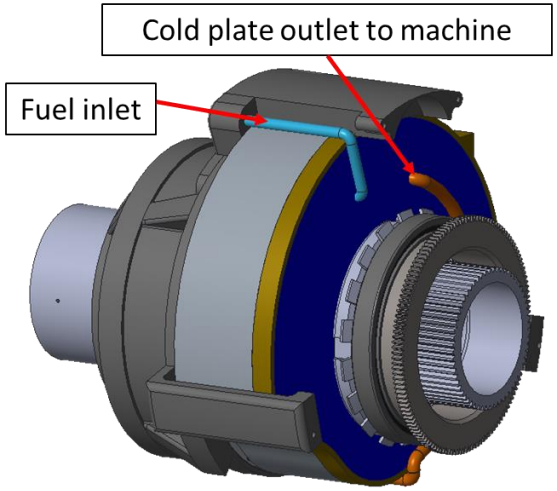
Directly liquid cooled designs



Recent & Ongoing work

ACHIEVE Project (CleanSky/Safran) - Ongoing

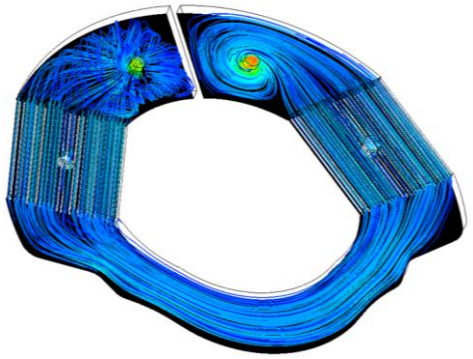
- Thermo-Mechanical design of an integrated generator/control system for aerospace application located
- Numerical and Analytical thermal design of both machine cooling system and heat sink for electronics carried out at UoN

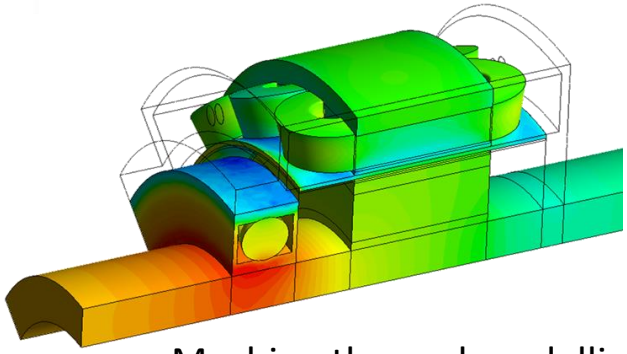


Fully assembled system

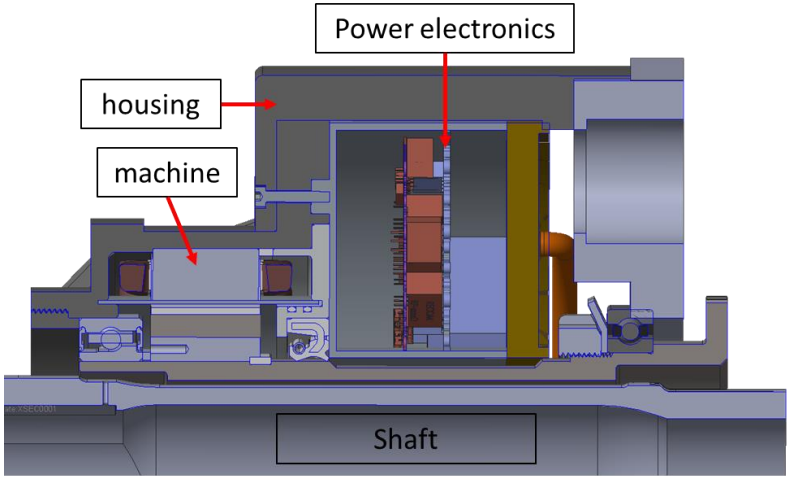
Power rating over 30 kW
Total axial length – **150 mm**

custom cold plate design





Machine thermal modelling

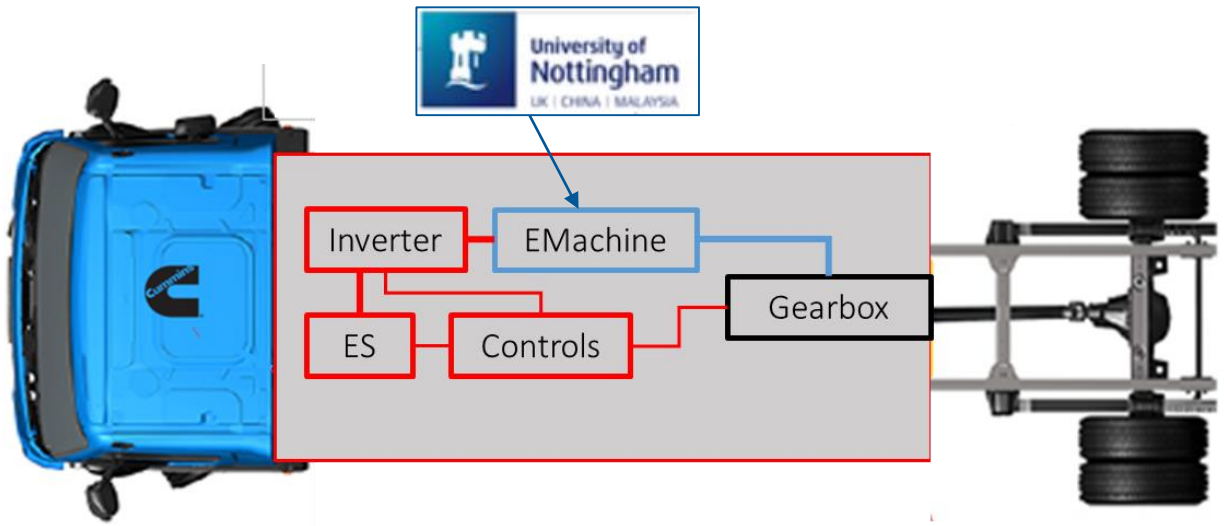


System section view

Recent & Ongoing work

ELITS Project (Cummins Generator/Innovate UK)

- Thermo-Mechanical design of a high speed, high power machine for an integrated traction solution
- Mechanical design of machine shaft



The University of Nottingham ELITS - Efficient Lightweight Integrated Traction Solution Innovate UK

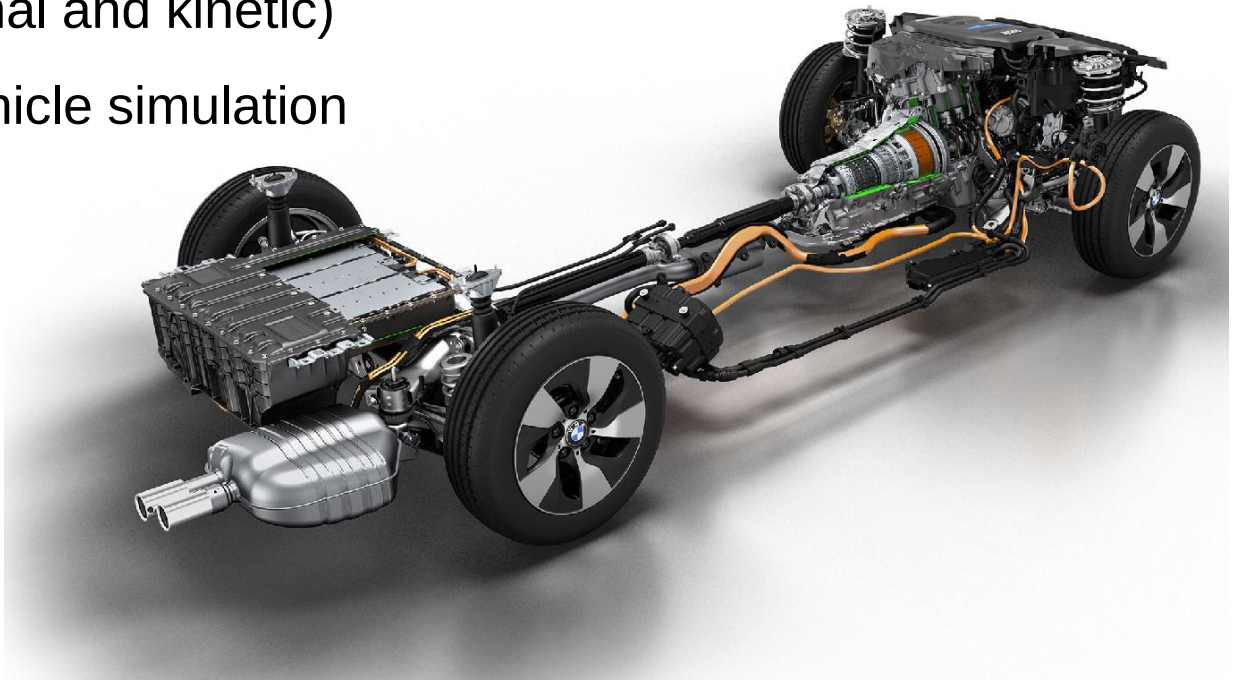
Reference requirements

EMS 18 SERIE
Battery: 120-240 kWh
Range: 100-250 km
Motor power: 250 kW
Torque: 3.400 Nm
Charging time: 3-6 hours
GVW: 18.000 kg

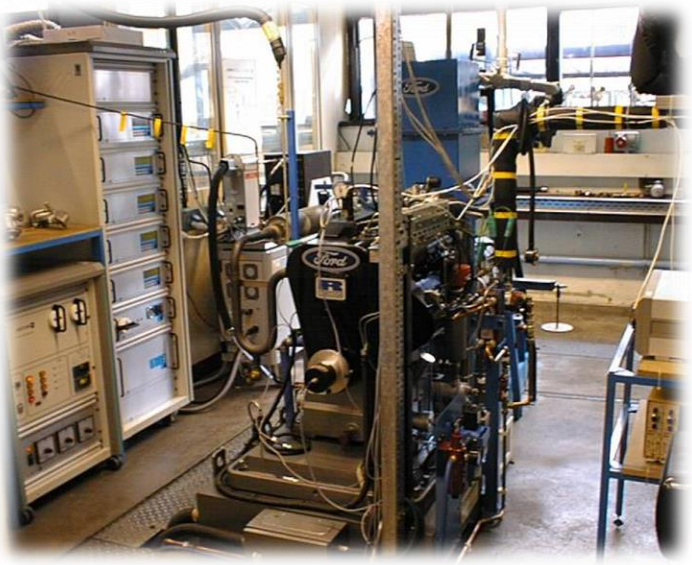
FLUTE (Engines) Group Expertise

We work on many aspects of automotive propulsion:

- ICE combustion, performance, fuel economy & emissions
- Powertrain thermal management (ICE, hybrid & BEV)
- Parasitic loss reduction
- Energy recovery (thermal and kinetic)
- Advanced engine & vehicle simulation

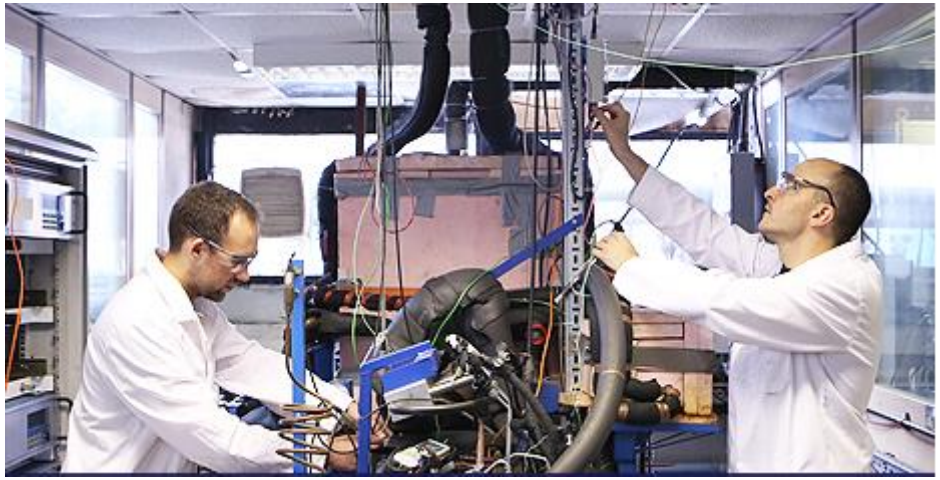


Powertrain Lab Facilities



- 9 Engine test beds (light duty)
- Friction rigs (floating liners, bearing rig)
- 460kW transient dynamometer (8 litre Volvo D8)
- Modelling powertrain performance, thermal and batteries

Planned & Ongoing Upgrades



- Planned hybrid test cell facility to allow collaborative full demonstrator projects in powertrain (mechanical and electrical engineering)

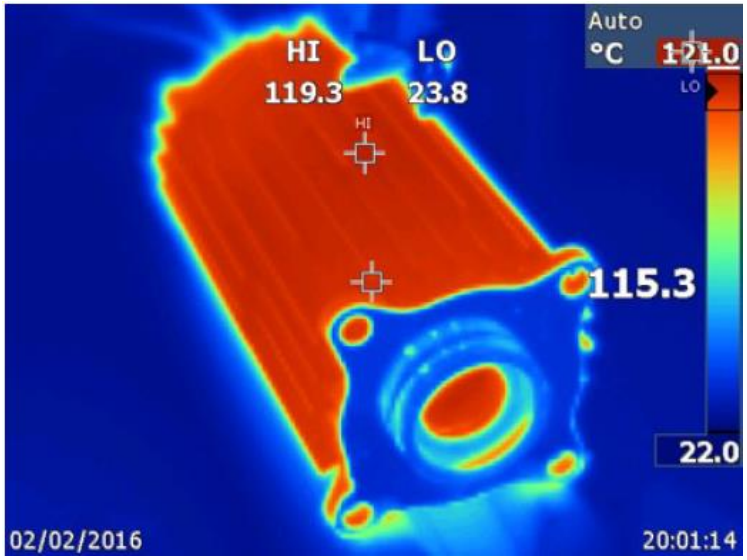
- Thermal management rig based around a Nissan Leaf battery

Lab Facilities - Thermal

- Temperature regulated oil system (>500 litres/min, 150kW)
- Refrigerated Water chillers (>250 litres/min, 150kW)
- Environmental chamber (temp: -70^{0}C to +200 ^{0}C, pressure: sea-level to 100,000 ft)

Experimental measurement types:

- Temperature (thermocouple, RTD, thermal imaging)
- Surface heat transfer coefficients (heat-flux sensors)
- Mass flow rate
- Pressure
- Thermal conductivity



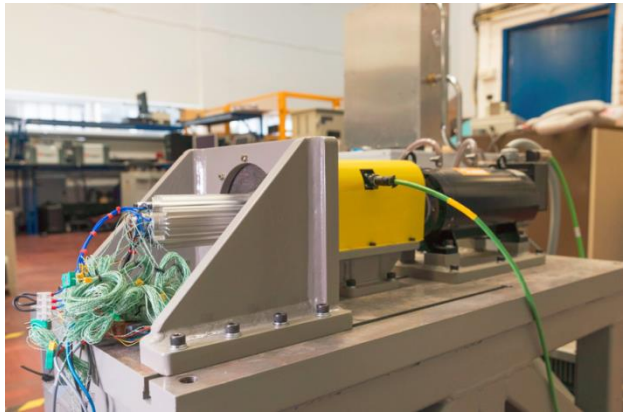
Thermal imaging

High Speed Rigs

- 150kW AC Dynamometer
- 3 - 20kW AC Dynamometer
  - Liquid Cooled
  - Conventional
  - Precision
- 35kW AC Dynamometer

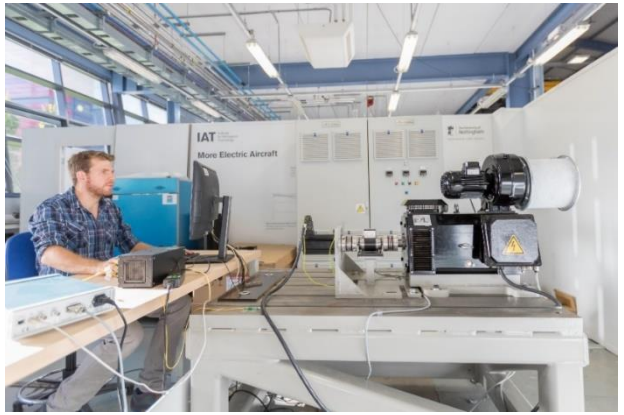
Precision 120kRPM – 35kW

Aerospace Grade (Copper Bird) 35kRPM – 150kW



20kRPM – 20kW – Liquid Cooled

20kRPM – 20kW

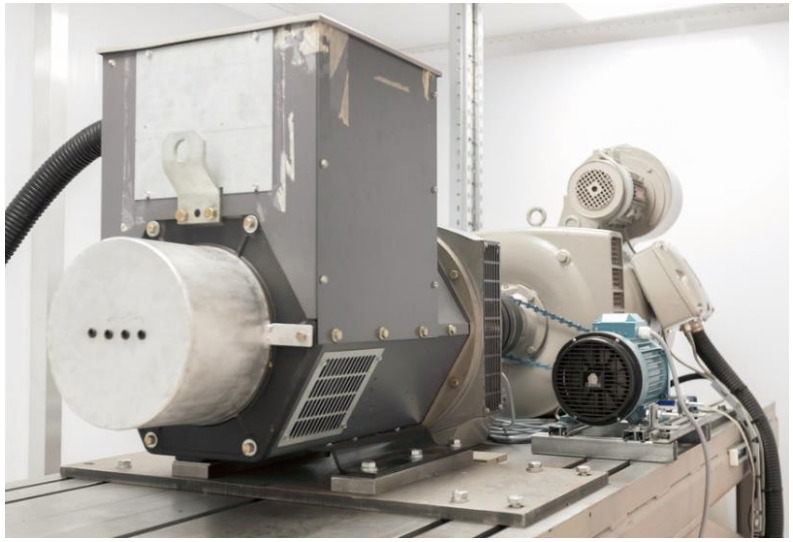


Precision 20kRPM – 20kW

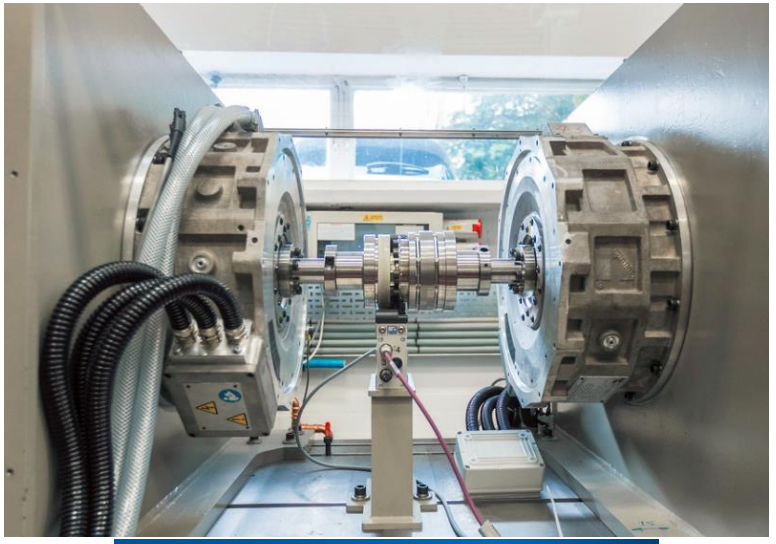
High Power Test Rigs

- 800kW AC Dynamometer
- 150kW DC Dynamometer with Thermal Enclosure
- 160kW DC Dynamometer
- 150kW Back to Back Test Setup
- 100kW AC Dynamometer

800kW AC Dynamometer



150kW DC Dynamometer



150kW Back 2 Back Setup

Links to Russia so far

Currently establishing a collaboration with the Electro-Mechanical Department of the ***Ufa State Aviation Technical University***

(Ref – Prof. F.R. Ismagilov, Dr. V.E. Vavilov)

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Thank you - Спасибо