Future technology opportunities in fluid power

Rob Miller

James Taylor, Tony Dickens, Anna Young, Tashiv Ramsander, Will Playford, Nick Atkins, Anna Young, Carl Sequeira, Judith Farman, Ivor Day, Martin Goodhand Graham Pullan, Chris Freeman, ,

UNIVERSITY OF CAMBRIDGE

Fluid power

NACA0012 aerofoil

Re=10^6

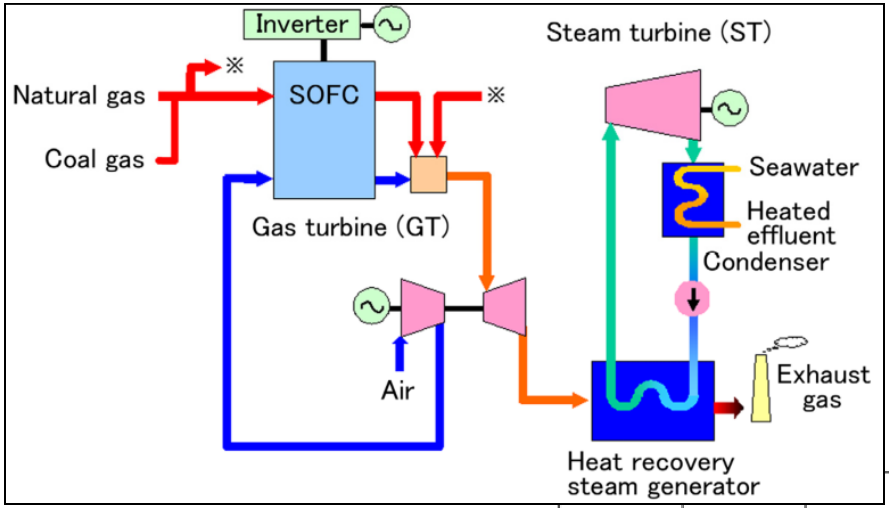
$\frac{L}{D} = 75$

$$\frac{\text{Rate KE destructionBlade}}{\text{Power to flow}_{\text{Blade}}} = \frac{2 \times V \times D}{\left(\frac{V}{\sqrt{2}}\right) \times \left(\frac{L}{\sqrt{2}}\right)} = \frac{4}{\left(\frac{L}{D}\right)} \approx 0.05$$

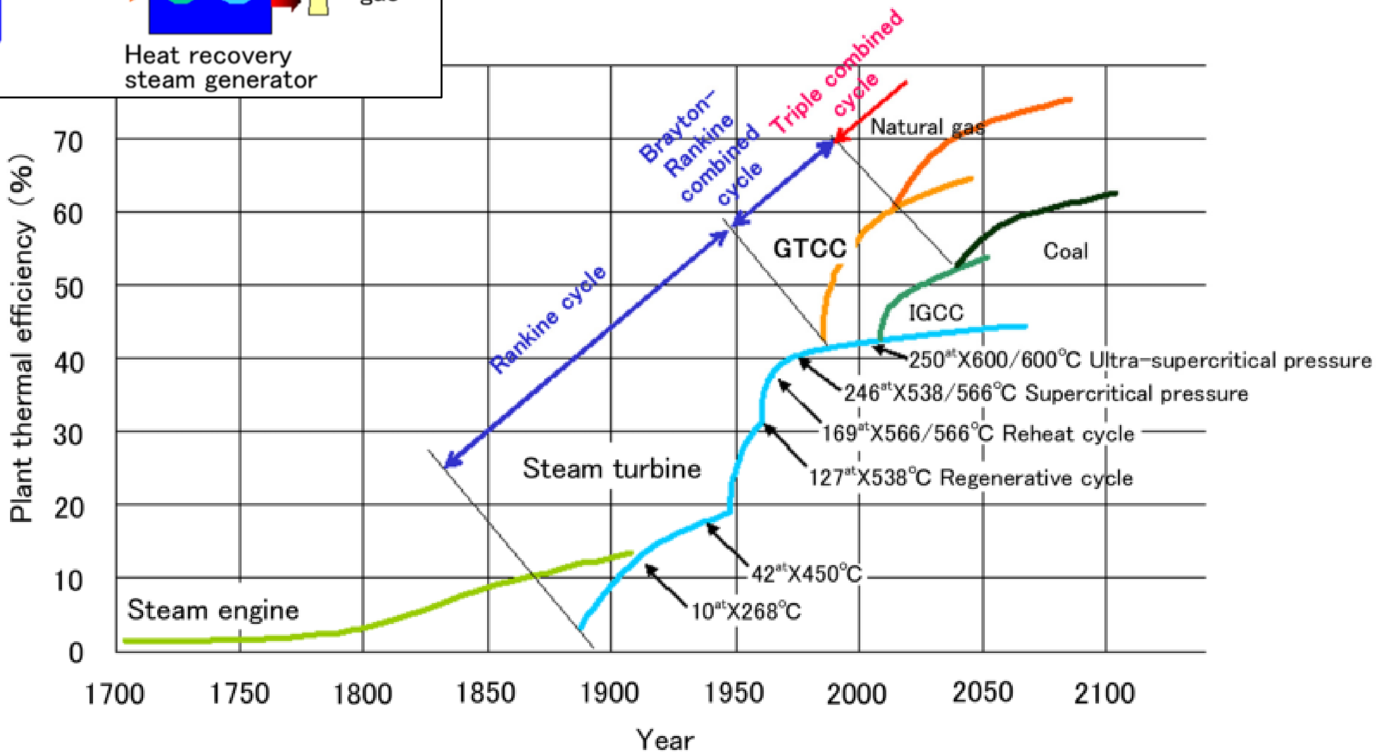
Efficiency = 95%

Efficiency of modern compressor ~92%

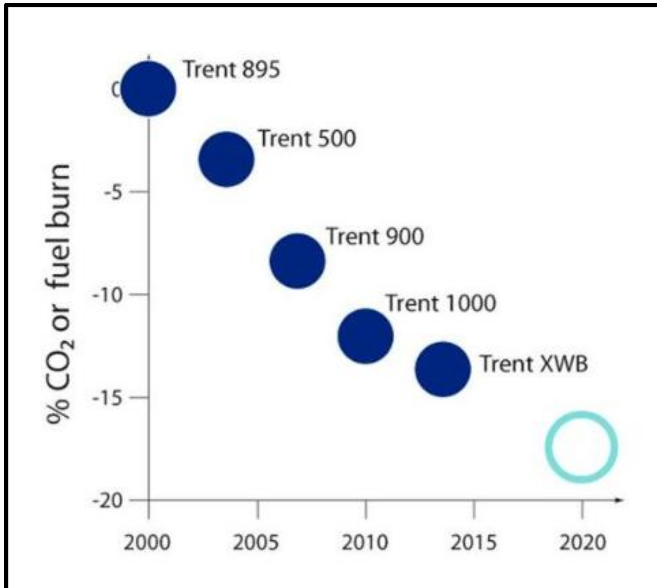
Land based power opportunities



Triple combined cycle
MHI



Aviation power opportunities



Rolls-Royce

ADVANCE

UltraFan

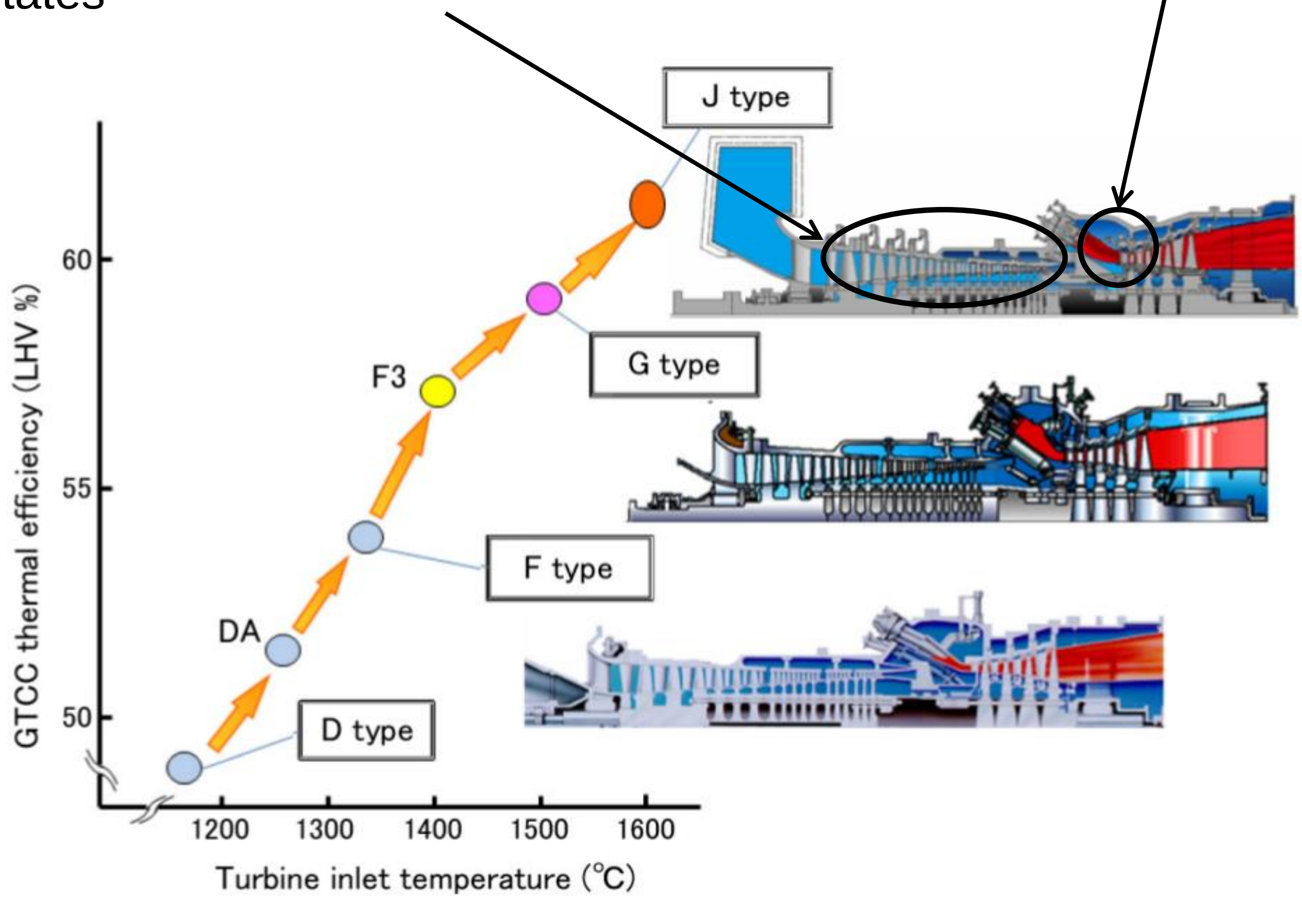
Technology EIS Readiness	2020+	2025+
Bypass Ratio	11+	15+
Overall Pressure Ratio	60+	70+
Efficiency relative to Trent 700	20%+	25%+

1. Engine measurements
2. Tidal power
3. Improving performance through life

Engine measurements

2. Little understanding of boundary layer states

1. No measurements in the hot section



MHI development of land based gas turbines

Measuring temperature in hot section

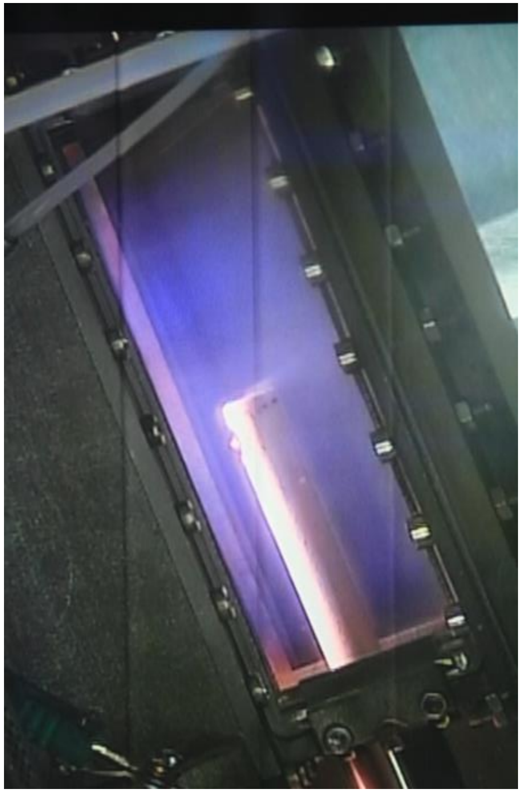
Tashiv Ramsander, Rob Miller

Limitation of current technique

- Thermocouples (Flame radiation error, drift over 1200K, recovery factor)

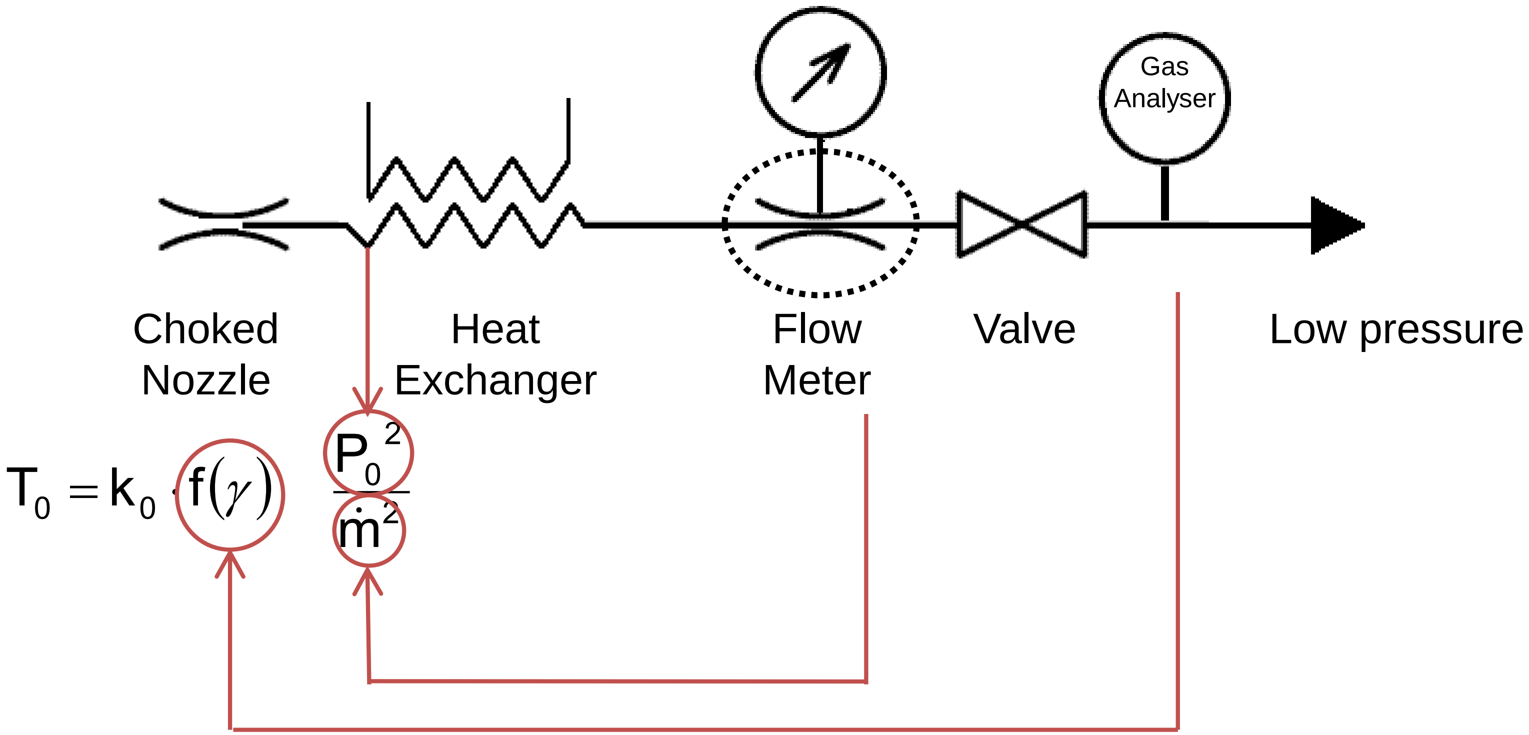
New technique

- Measuring temperature using a sonic orifice.
- 2nd order radiation and recovery factor error



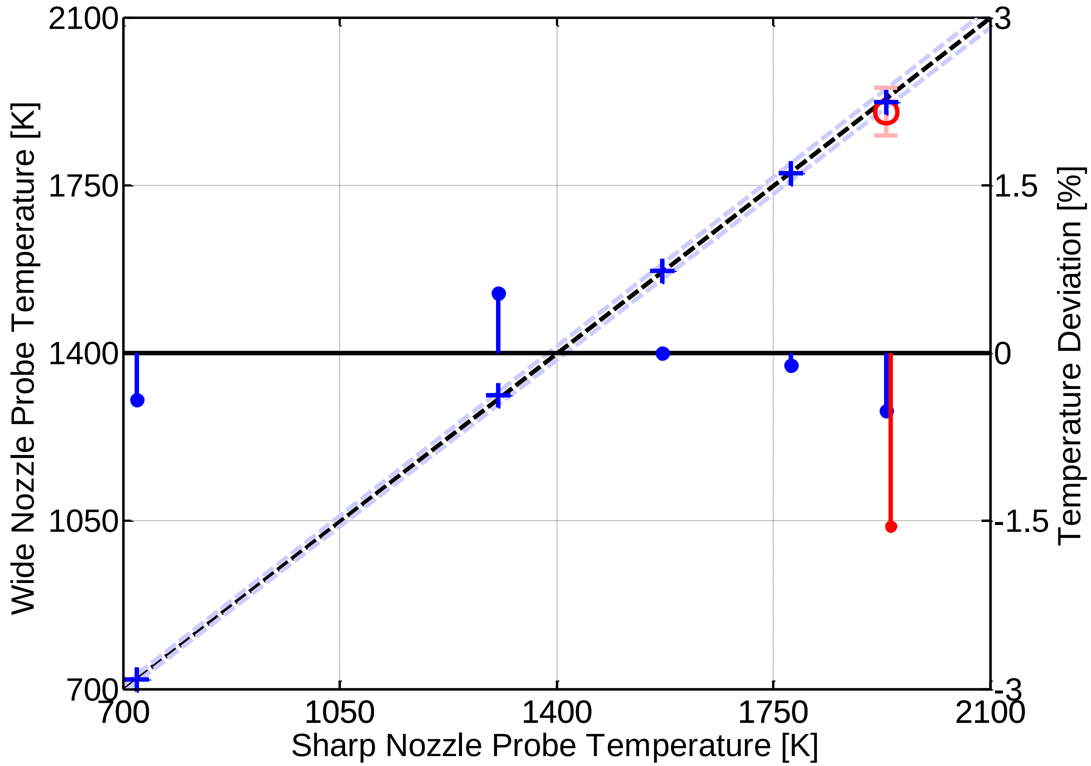
DLR Cologne testing
T= 1950K

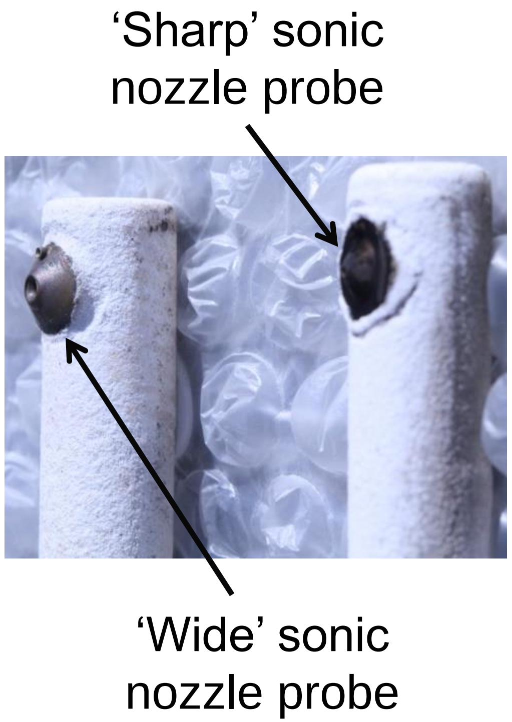
Measurement technique



- Accuracy of ±0.5% (10K)
- Operation up to 25 bar 2350K+

DLR Cologne: Comparison of techniques





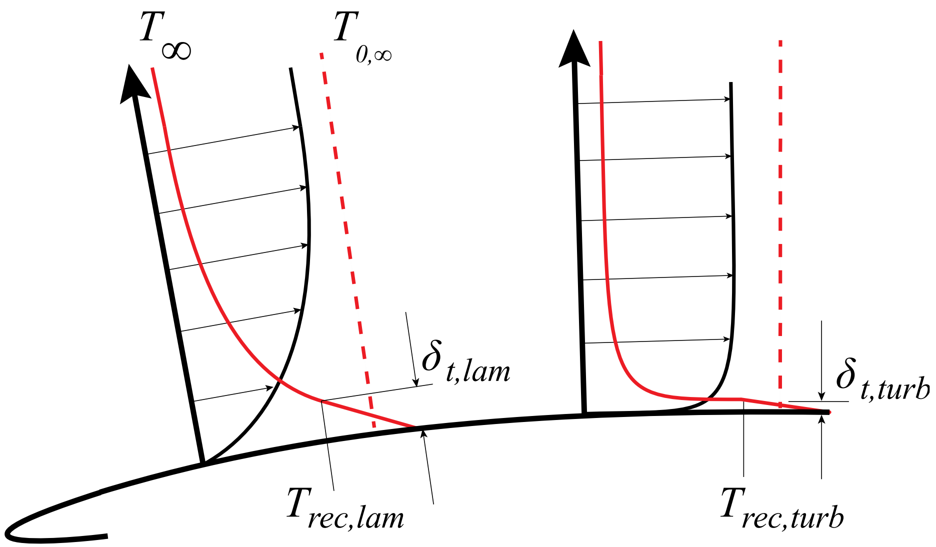
1) Two designs of sonic aspirating probe agree to <0.5%.
2) Sonic aspirating probe and OH-PLIF (uncertainty 2.7%) agree to 1.6%.

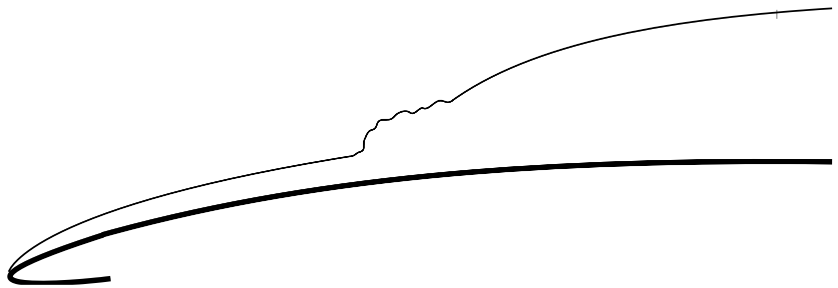
Measuring boundary layer state

Will Playford, Nick Atkins

Turbulent boundary layers dissipate kinetic energy at a rate 2-5 times higher than laminar boundary layers

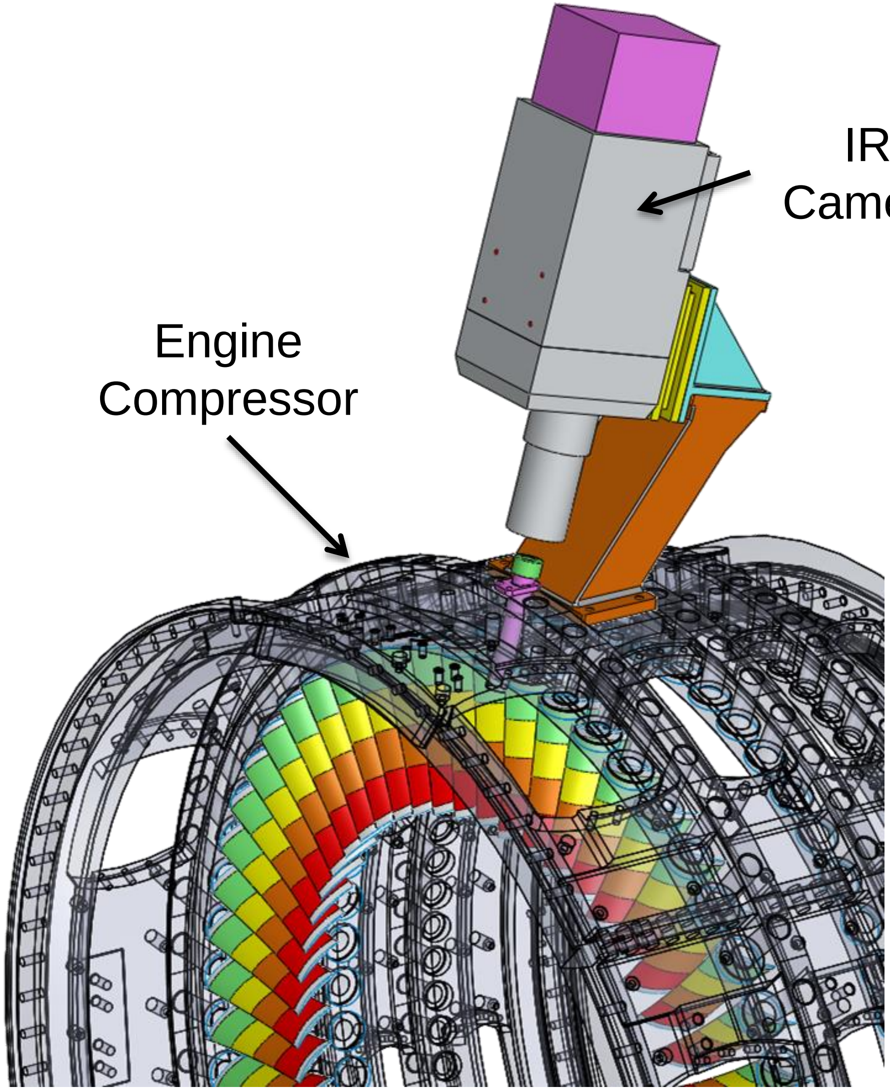
- Turbulent boundary layer has much lower thermal resistance
- Addition of a thin layer of insulation we can '**see'** the boundary layer state



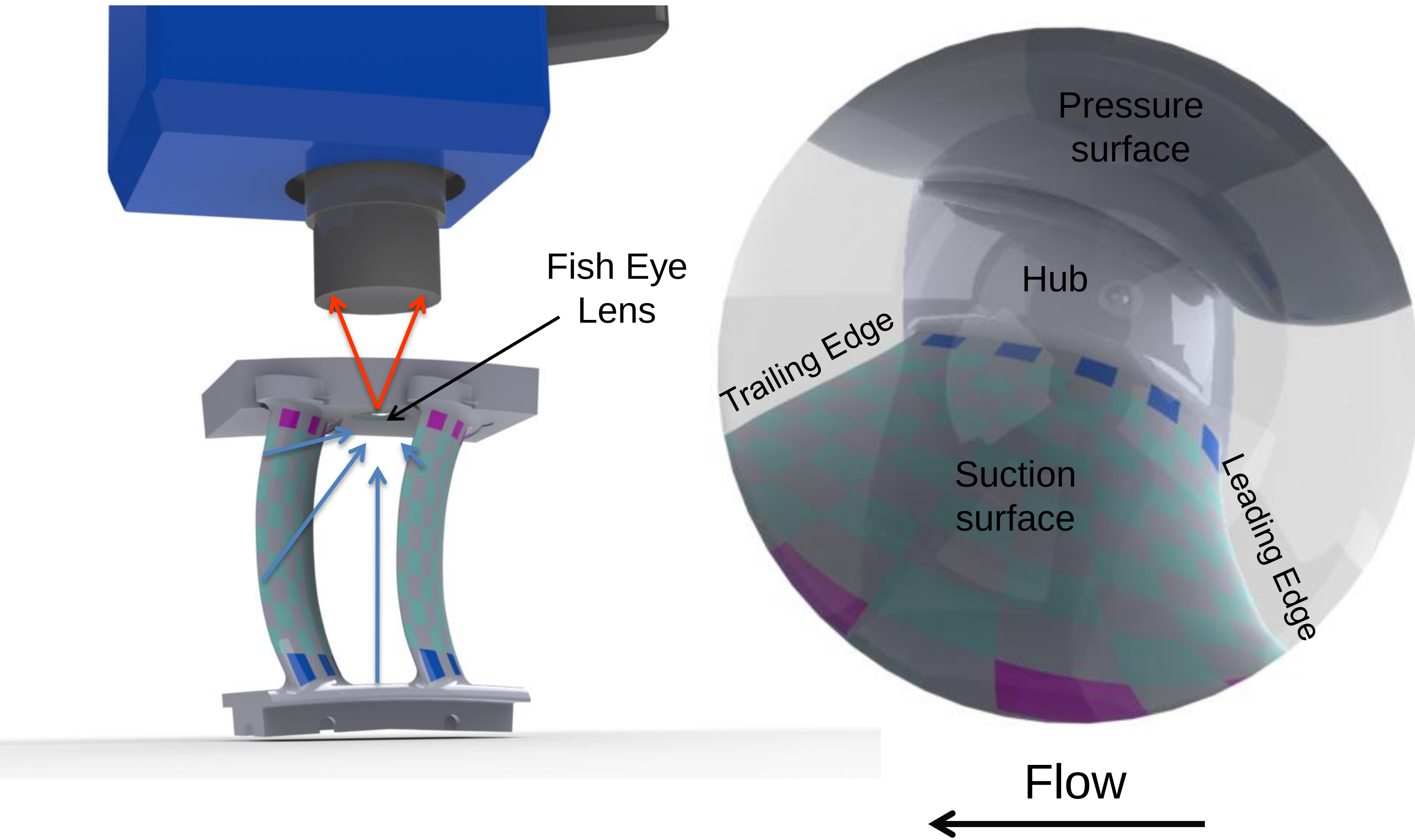


Engine instillation

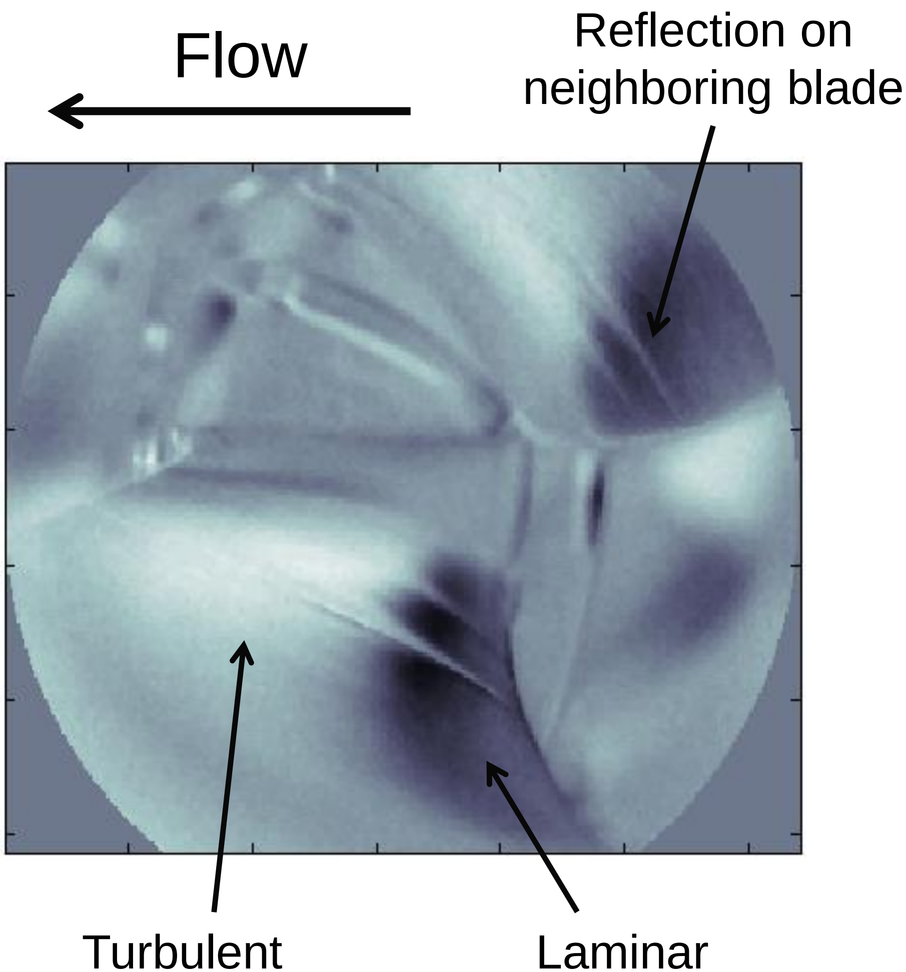
Yttria-Stabilised Zirconia coating

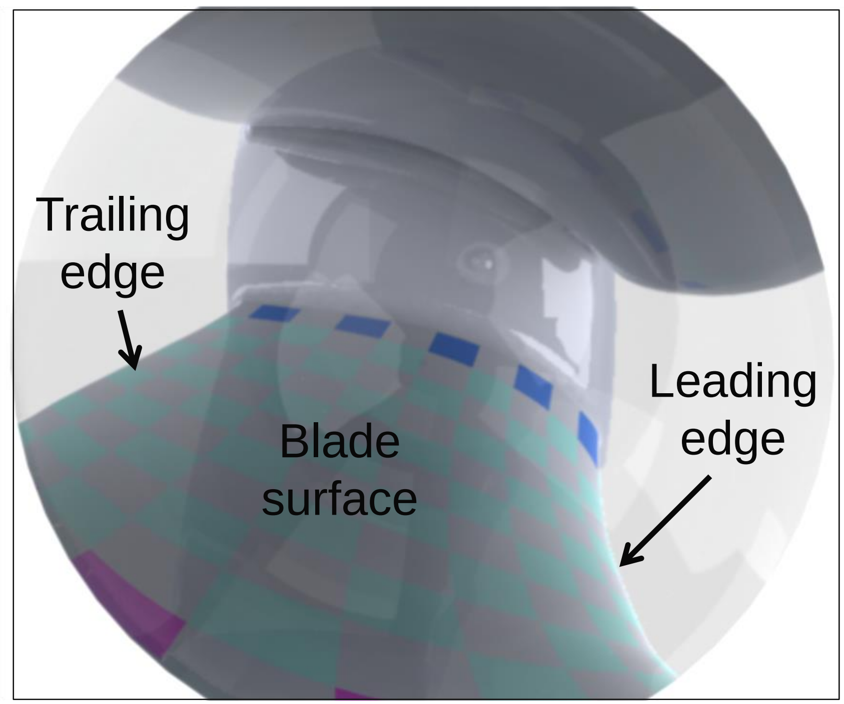


Engine instillation



Measurements of boundary layer states





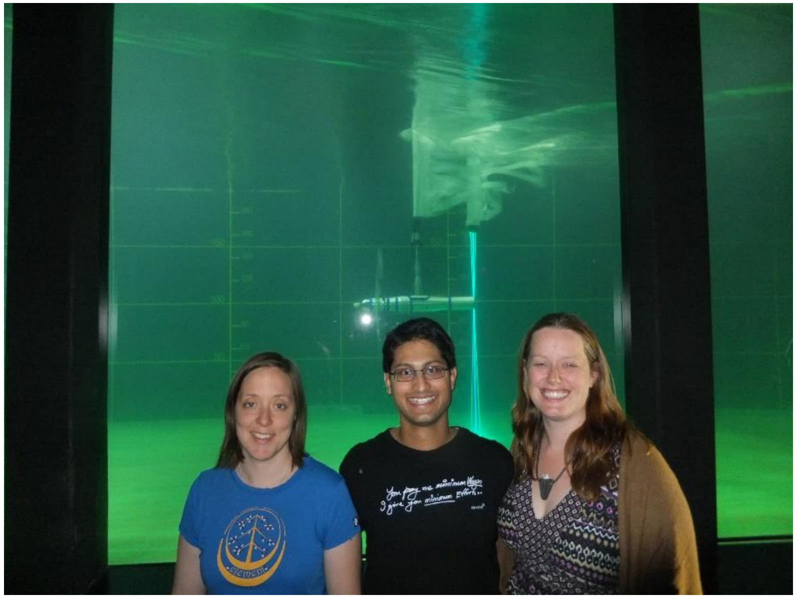
Opportunities to help

1. Mounting gauges directly on blade surface
2. Thin insulative blade coatings
3. High temperature sensor

1. Engine measurements
2. Tidal power
3. Improving performance through life

Tidal power

Anna Young, Carl Sequeira, Judith Farman, Rob Miller, Ivor Day, Chris Freeman



Testing IFREMER France

Cambridge Tidal Group

2010 Rolls-Royce University Technical Centre in Tidal Turbine Hydrodynamics

2014 Alstom University Technical Centre in Tidal Turbine Hydrodynamics

UK resource estimated to be capable of producing 20-30% of UK electricity production

UK Tidal Current Resource & Economics
Carbon Trust & Black and Veatch 2011

Challenge

Verdant Power

Blade off and bent
1 day of operation

OpenHydro

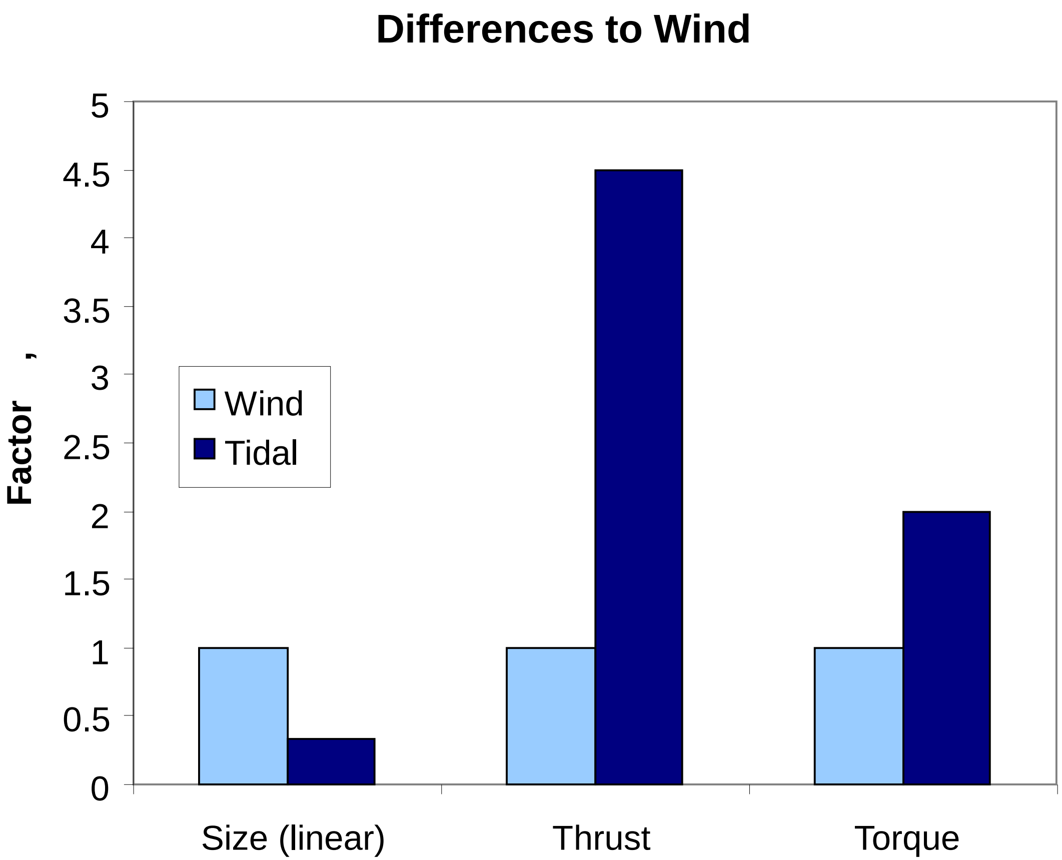
Blade off
Unknown operating time

Atlantis

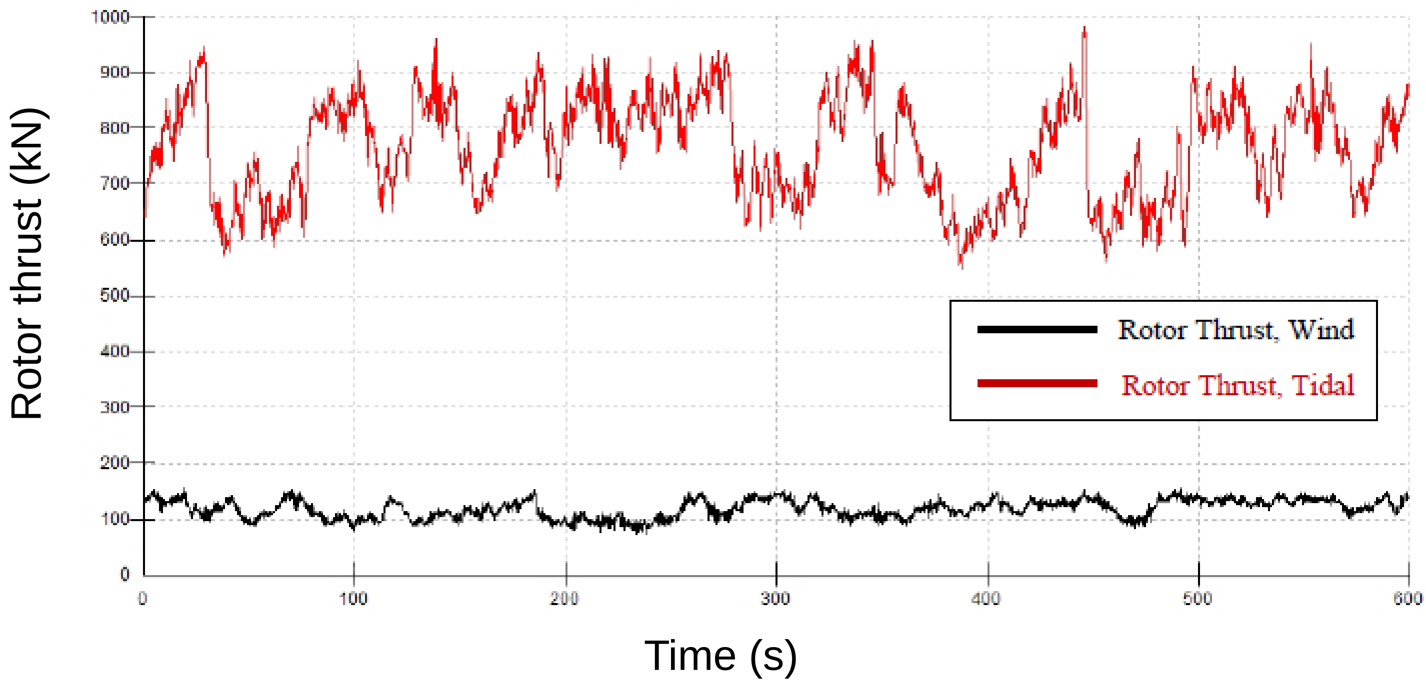
Cracks in blade
Without even operating

Unsteady blade loading

Comparison with wind turbine - 1Mw

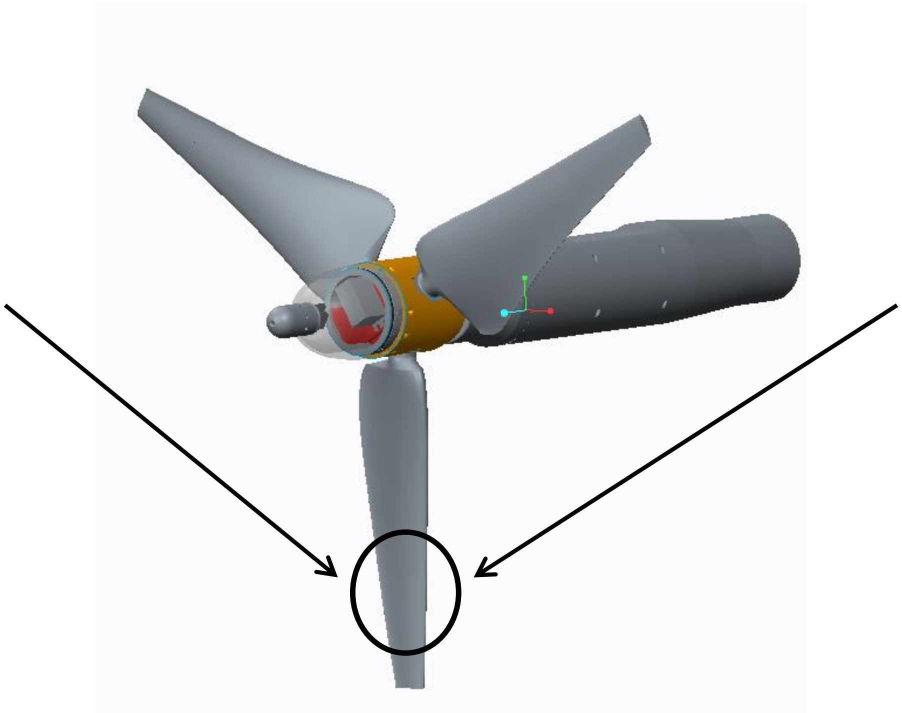


Comparison with wind turbine - 1Mw



Take-off thrust of Trent XWB is 430kN

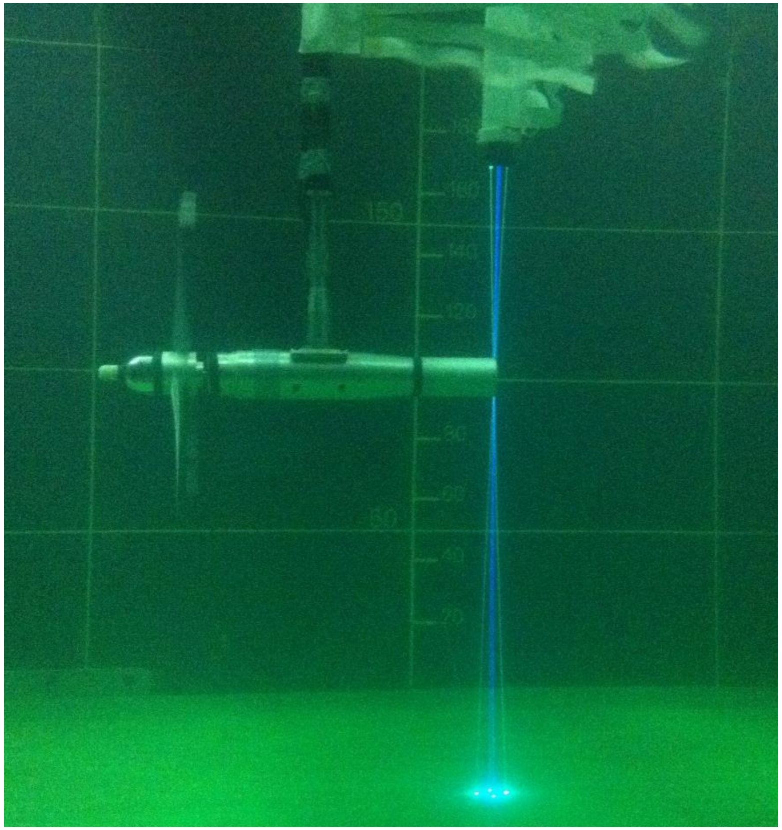
Unsteady load alleviation



Low frequency unsteadiness – Low inertia drive train/Generator

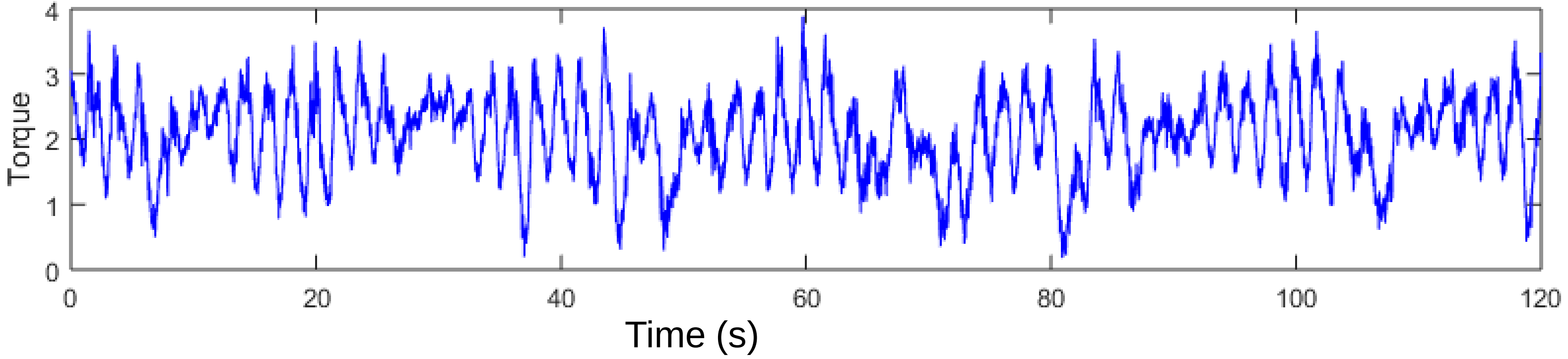
High frequency unsteadiness – Load shedding

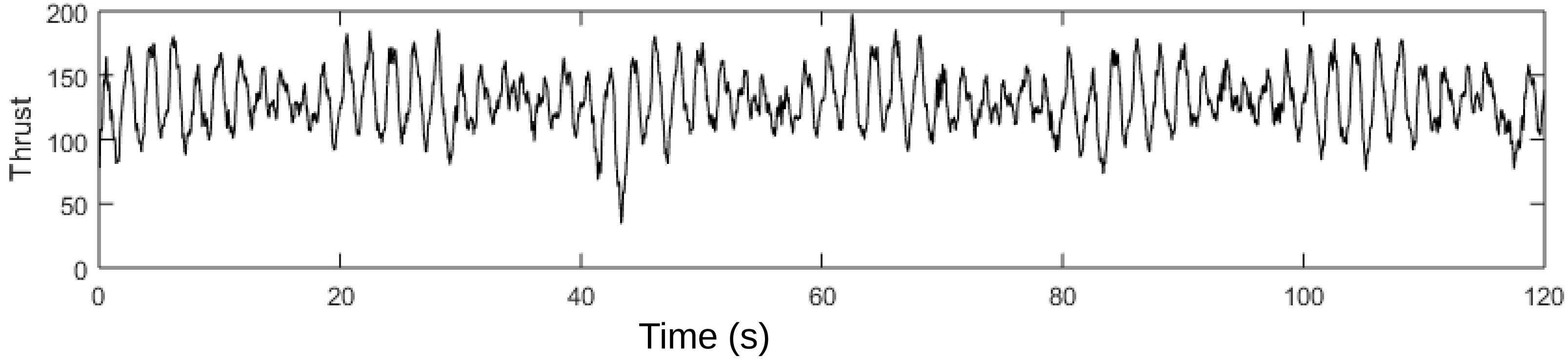
Unsteady load alleviation: Lift shedding



Testing IFREMER France

Lift shedding





Device operated at 0.55Hz

Opportunities to help

1. How can turbulence be measured in the sea?
2. How can unsteady loading be accurately predicted in preliminary design?
3. How can unsteady load be alleviated?
4. Trip or flap mechanisms which will operate in sea environments?

1. Engine measurements
2. Tidal power
3. Improving performance through life

Improving performance through life

Martin Goodhand, Rob Miller

Rolls-Royce predicts aftercare services will be worth US$700 billion over the next 20 years.

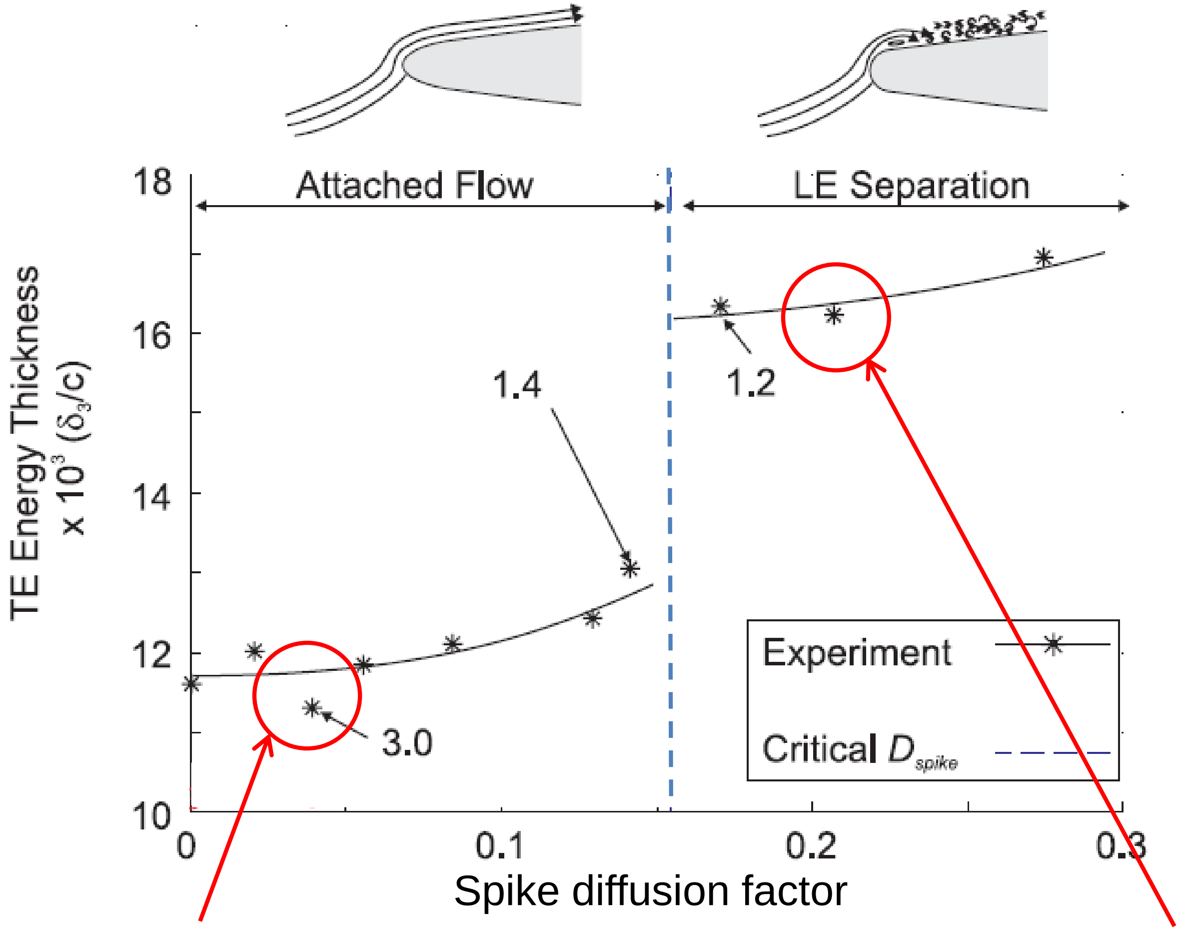
Aviation Week 2015 '*A 2009 Trent 700 Enhanced Performance (EP) kit is proving popular with airlines, improving efficiency by 1%'*

What's it worth? Whole fleet saving, $180 million per year

- 1500 Trent 700's in-service
- 1% fuel burn worth $240k per aircraft per year

Aviation Week 2015 '*EP kit includes elliptical leading edges on compressor blades and super-polish of high and intermediate-pressure turbine blades*'

Impact of leading edge highly non-linear



EP kit Trent 700 leading edge

⟵ Ellipse ratio increase

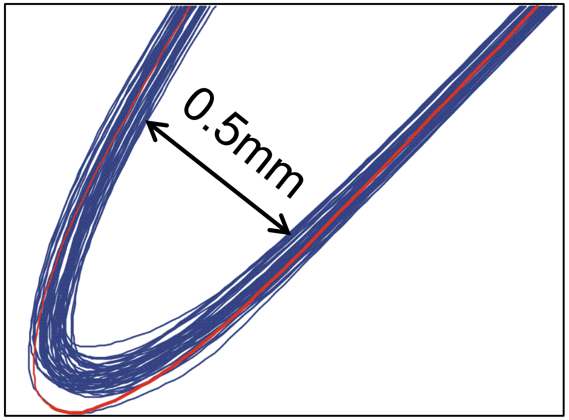
Original Trent 700 leading edge

25% reduction in blade loss

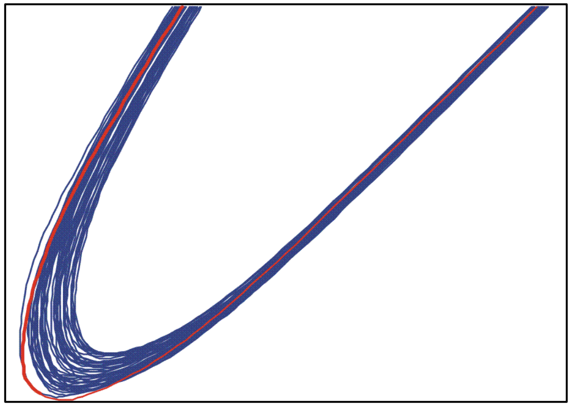
How to tolerance geometry ‘detail’?

Historically ~10 measurement points a section

Optimal scanners on production line



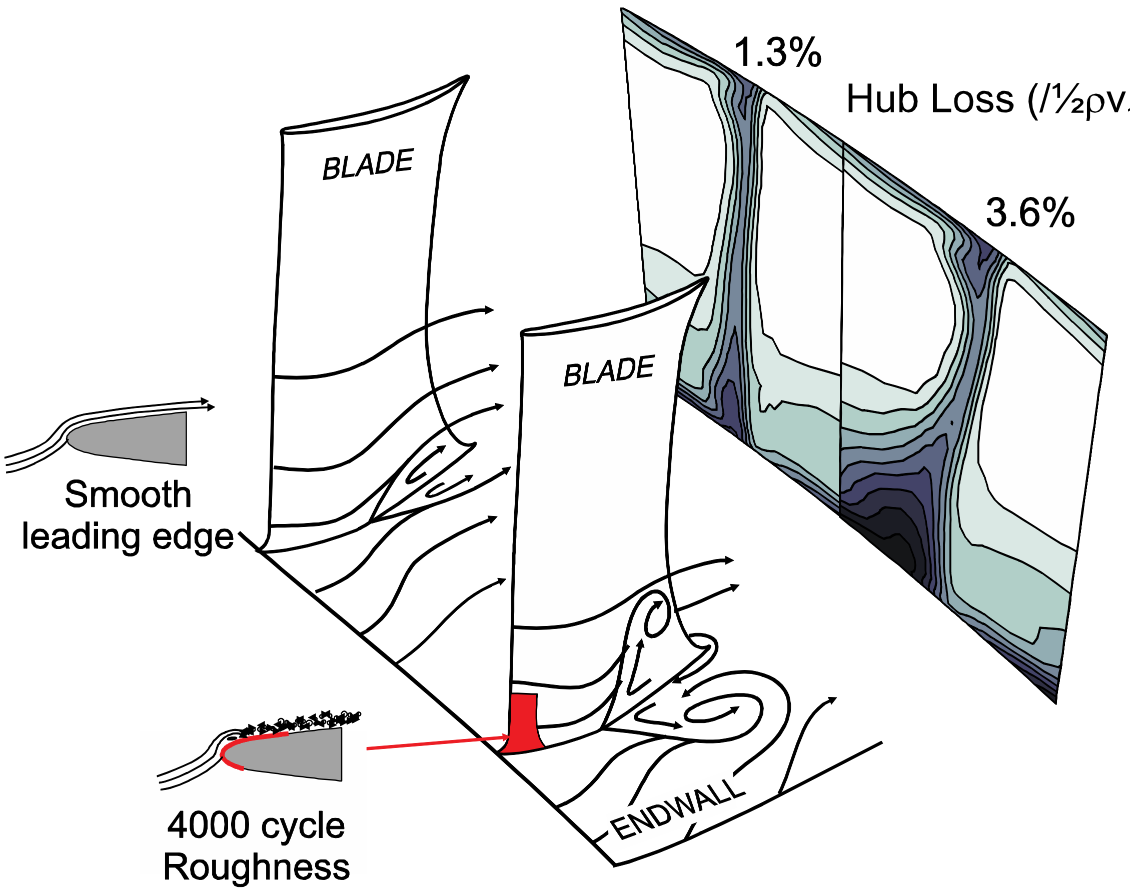
Drop forged



ECM

Impact of roughness highly non-linear

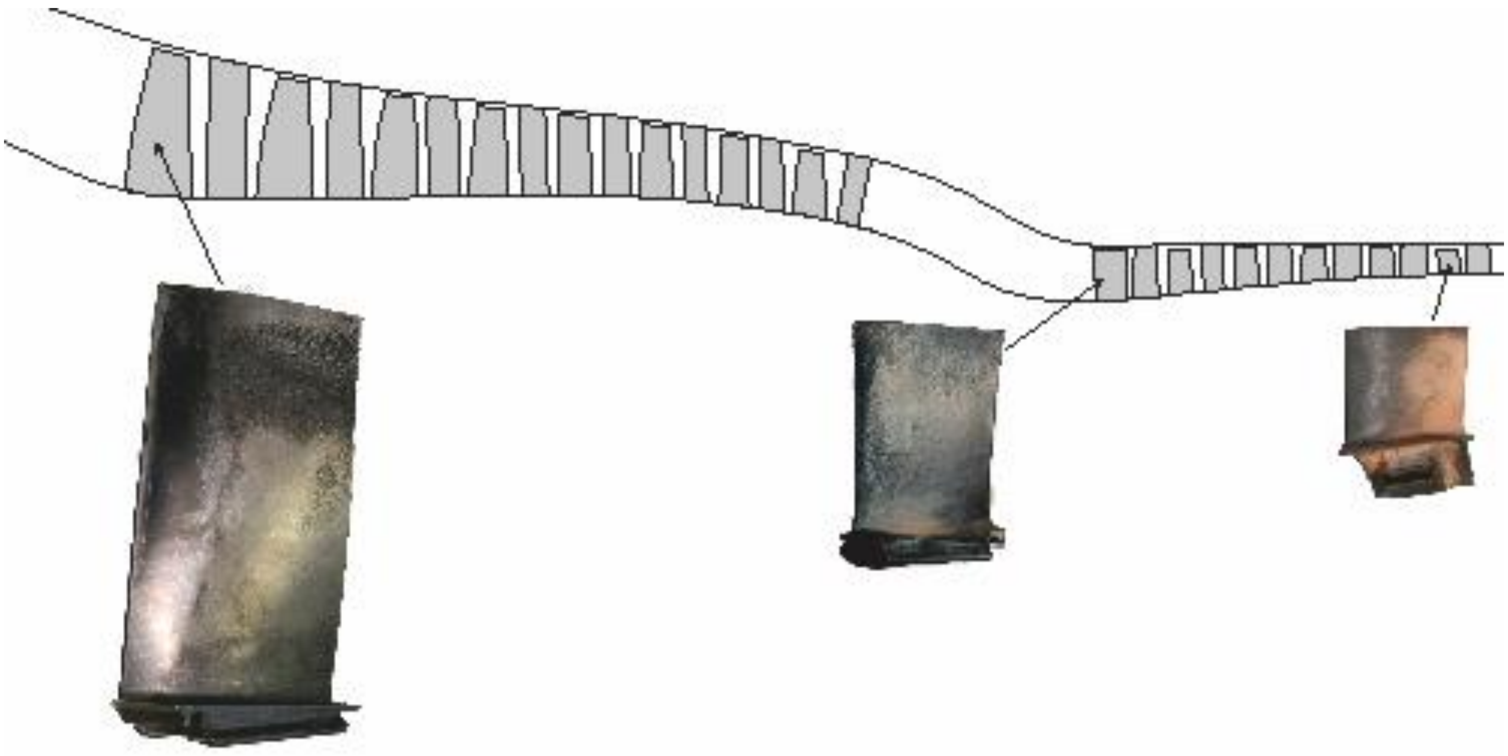
Experimental loss measurements in Whittle Lab compressor



Roughness close to endwall causes 180% in endwall loss

How to tolerance in-service roughness

In-service roughness varies through engine



Which areas of roughness change cause a non-linear change in performance?

Opportunities to help

1. How should we tolerance blade geometry?
2. New types of coating (hardness, deposition resistance)?
3. Can new material allow thinner blades (current limit ~0.5mm)?
4. Can new manufacture techniques allow more precise geometry for the same unit cost?

1. Engine measurement
2. Tidal power
3. Improving performance through life

Rapid concept testing

James Taylor, Tony Dickens, Rob Miller

Rapid prototyping has cut testing time from 4-6 months to 2-4 days.

Single stage compressor