Technologies to enable sustainable growth

ISABE

Manchester, 3-8 September 2017

Paul Stein
Chief Technology Officer

Trusted to deliver excellence

Rolls-Royce

The Company

Civil Aerospace	Defence Aerospace	Marine	Power Systems	Nuclear
				
Our engines keep up to 400,000 people in the air at any one time	160 armed forces around the world depend on our engines	30,000 commercial and naval vessels use our marine equipment	Reciprocating engines for propulsion and distributed energy systems	Submarine and civil nuclear power plants

Rolls-Royce Product Divisions

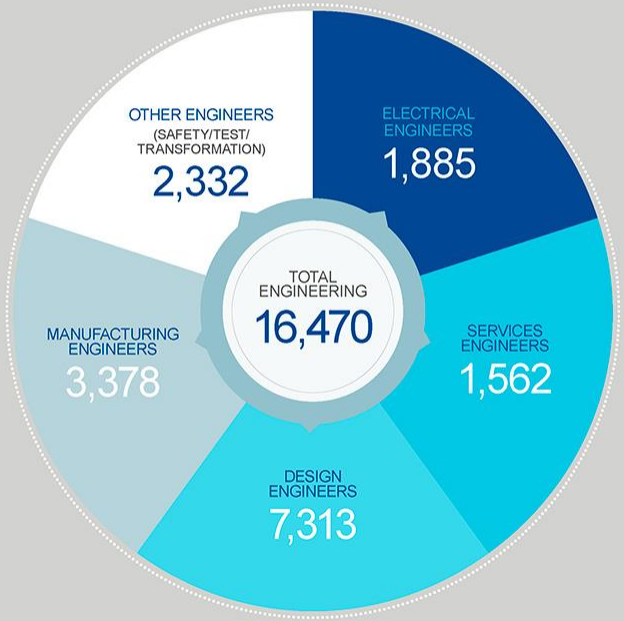
Rolls-Royce

Investing in our future development

£1.3bn
invested in Research and Development in 2016

672
patent applications in 2016

We anticipate technology then create products and services that our customers need ahead of market requirements.



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Global Partnership

31

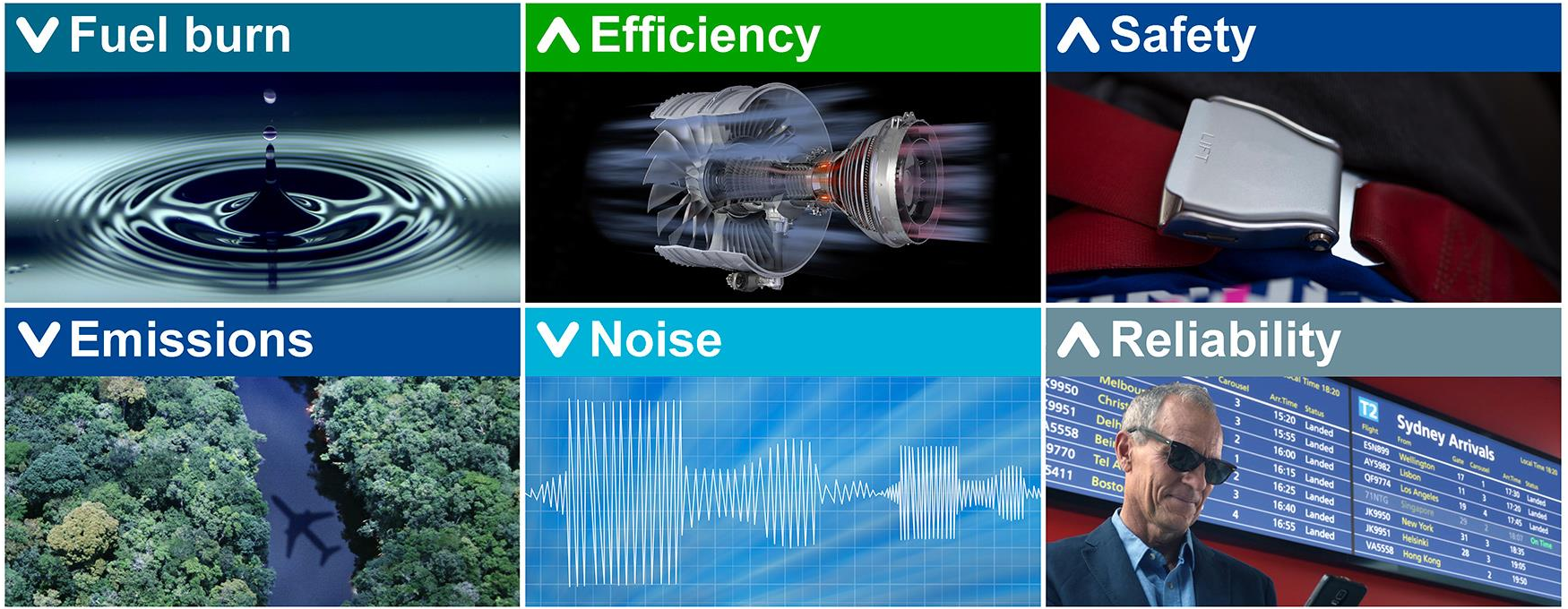
University Technology Centres

14

Research centres and other Partnerships

Rolls-Royce

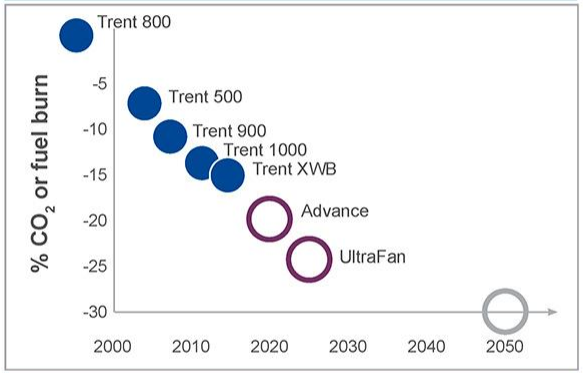
Flying is more efficient, cleaner and quieter than ever



Rolls-Royce

Flying is more efficient, cleaner and quieter than ever

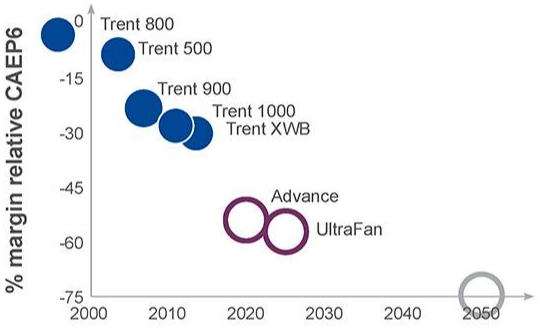
CO_2 (Engine)



ACARE goal -75%
CO_2 overall reduction:

- -30% Rolls-Royce contribution

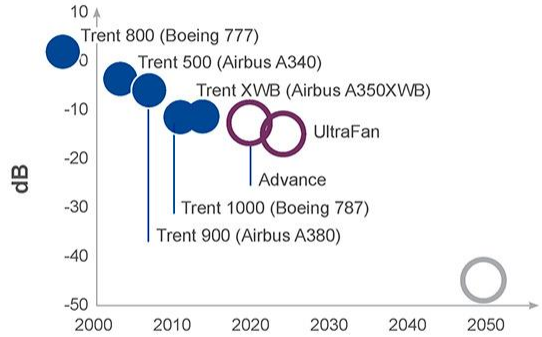
NOx (Engine)



ACARE goal -90%
NOx overall reduction:

- -75% Rolls-Royce contribution
- -15% from operational efficiency improvements

Noise (Aircraft)



ACARE goal -65%
aircraft noise reduction:

- -45dB cumulative
- Operational improvements and aircraft design will give significant further reductions

Trent family

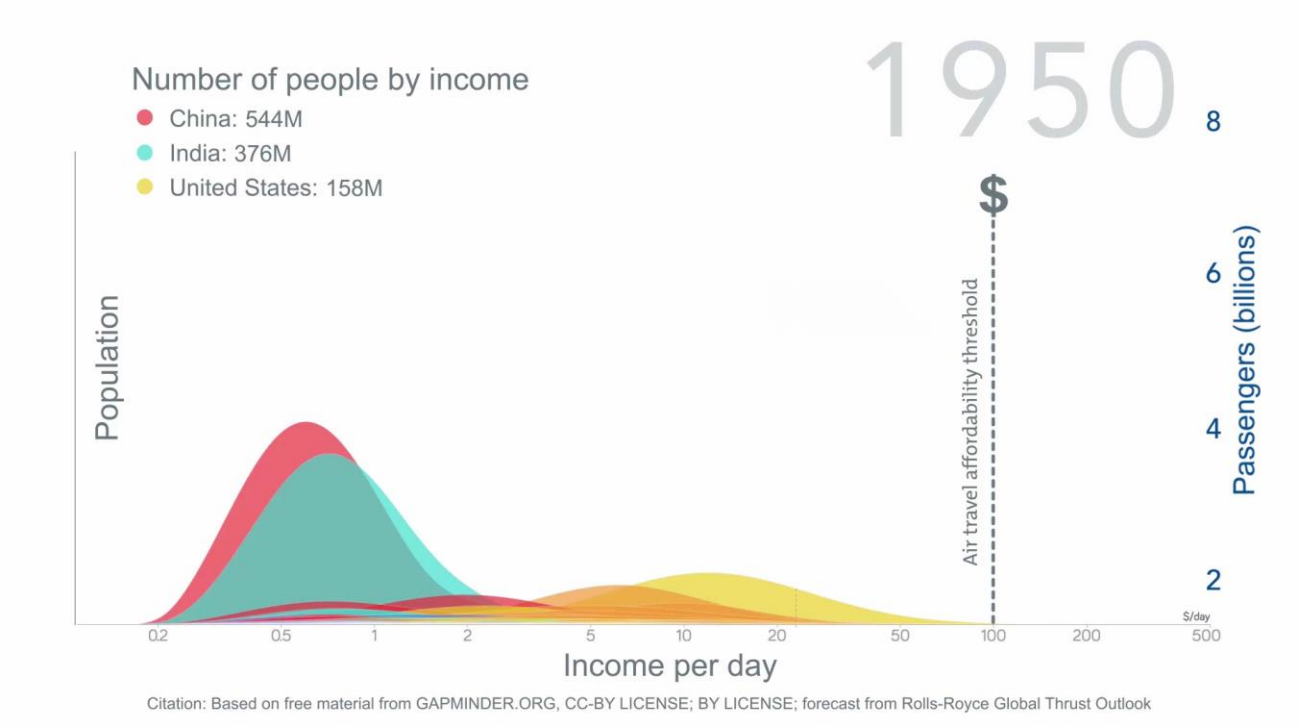
Technology demonstrator engine targets

ACARE (Advisory Council for Aviation Research and Innovation in Europe) Flightpath 2050 target

UltraFan® is a registered trademark

Rolls-Royce

Our changing world



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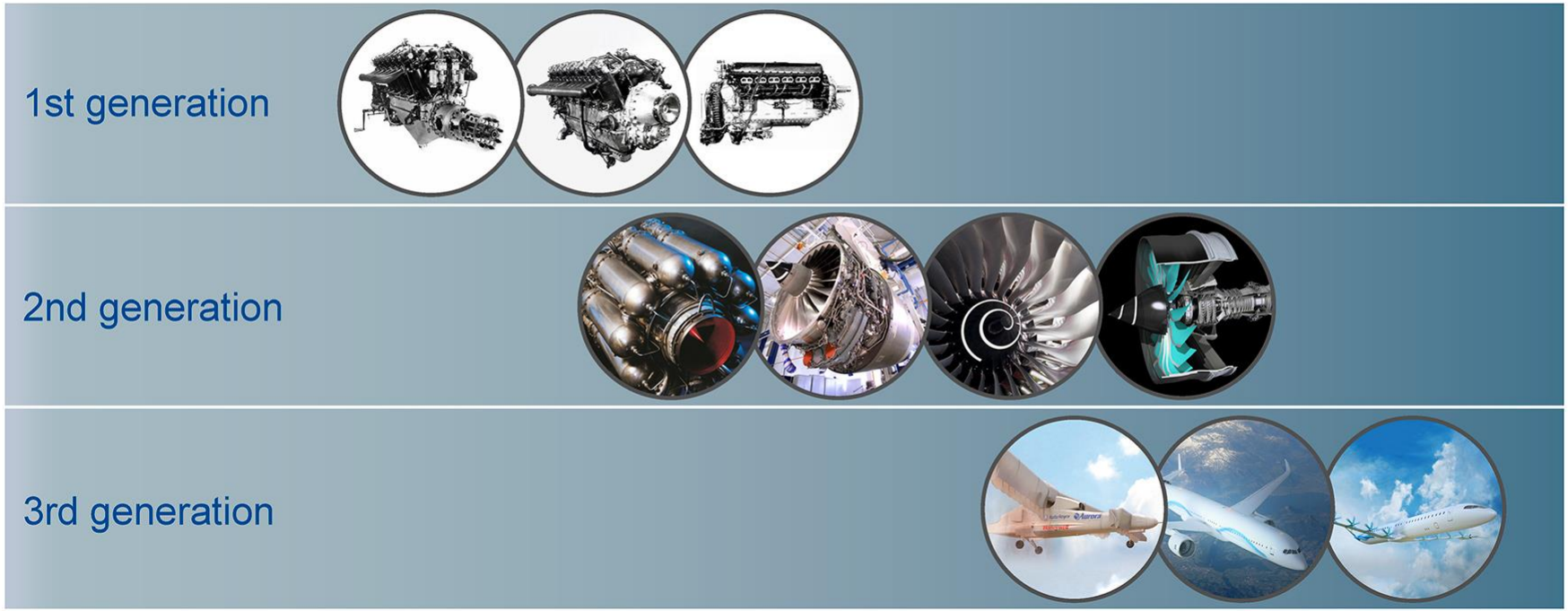
The evolution of engines



CS34

Image courtesy of © Darpa

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Bringing our Vision to life

Darpa X-Plane courtesy of © Darpa

Rolls-Royce

Trent XWB

Delivering the best customer value

Entry into service 2014

The world's most efficient large aero engine

All the thrust you need

Airbus A350-900
Airbus A350-1000

The best technology, at the lowest risk

Thrust 84,000lb - 97,000lb

Rolls-Royce

Robust capability acquisition

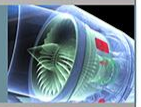
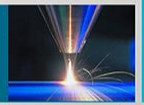
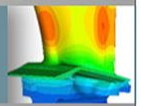
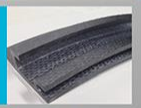
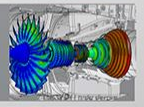
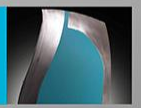
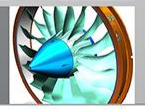
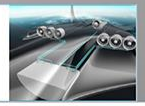
Technology readiness (TRL)

Research Partners and UTCs

Manufacturing readiness (MCRL)

Rolls-Royce

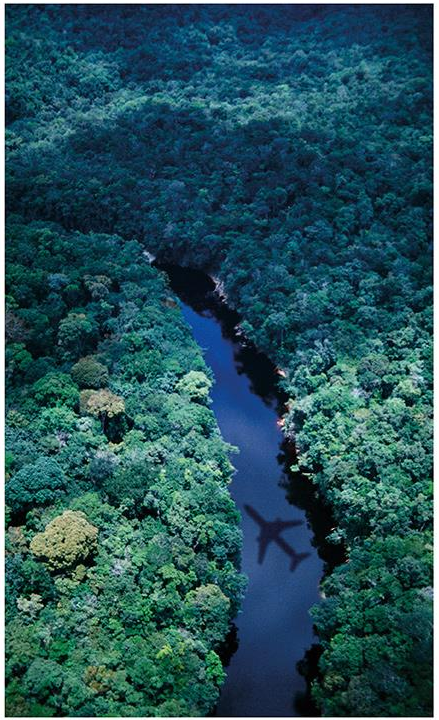
Our full-scale Technology programmes

Architecture and design	Manufacture	Advanced materials	Intelligent systems
Advance Core architectures 	Advanced manufacturing research centres 	Advanced alloys: TiAl 	Future systems 
Lean burn / Low emissions combustion 	Additive Layer Manufacturing 	Advanced alloys: Ni Alloys 	Aerothermal excellence 
UltraFan (VHBR) 	Specialist turbine manufacture 	Ceramic Matrix Composites (CMCs) 	
Virtual engine 		Lightweight C(Ti) fan system 	
Small engine core technologies 			
Small engine fan 	Advanced concepts 		

Underpinning our Vision strategy for Civil Aerospace

Rolls-Royce

Committed programmes towards ACARE goals



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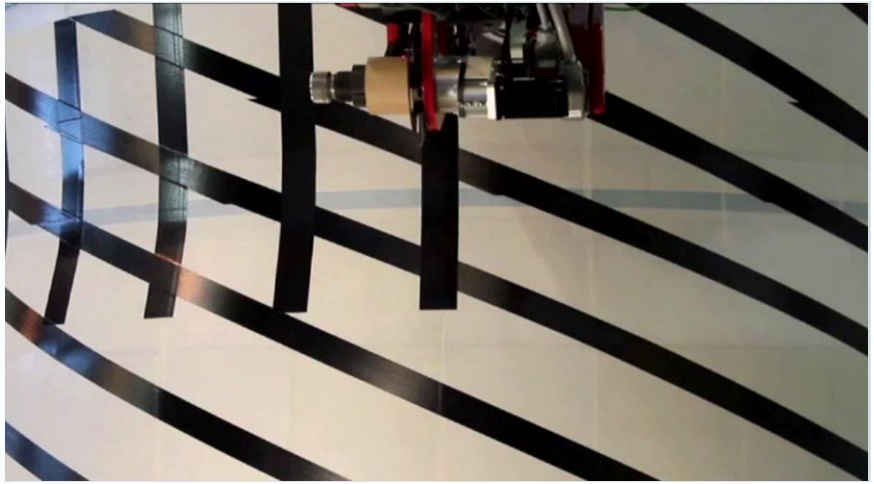
Benefiting from manufacturing technology

State-of-the-art production facilities

- Manufactured using state-of-the-art composite construction methods and materials
- Manufacturing fan blade, case and annulus fillers
- Composite Centre of Excellence being established in Bristol (UK)
- Pre-prod facility established at CTAL and commences relocation to Bristol in 2017

Pre-prod facility at CTAL

National Composites Centre



- Fully-automated construction with 3D reinforcement
- Specially developed composite matrix material
- Optimized integration of advanced fibres, adhesives and coatings

Rolls-Royce

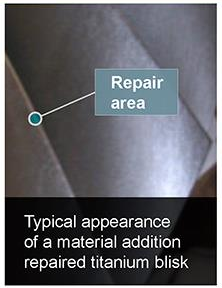
World leader ALM/3D printing

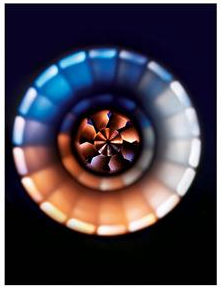
Flying the largest ALM aero-engine structure

- Significant load bearing structure - 1.5m diameter and 0.5m long
- Pioneered use of the world's largest EBM titanium 3D machines
- 30% 'like for like' reduction in manufacturing lead time

Deploying ALM for repair and development

- Enhanced performance and extended working life of high integrity components
- Fast and cost-effective design iterations for new prototypes in development





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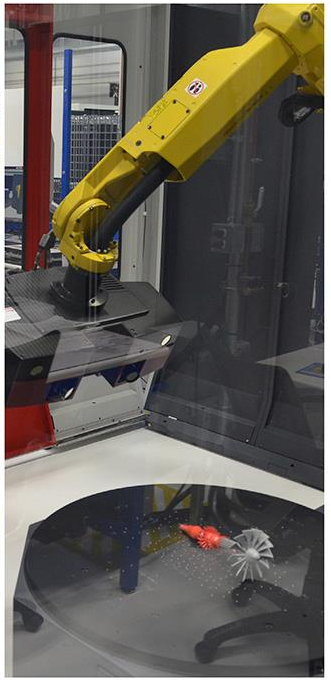
Ceramic Matrix Composites

- 62,000 square foot R&D facility formally opened in 2016
- For CMC processes and materials for a range of turbine components
- Production ready processes, manufacturing components for engine test programs to support certification



Delivered components for the Advance3 demonstrator

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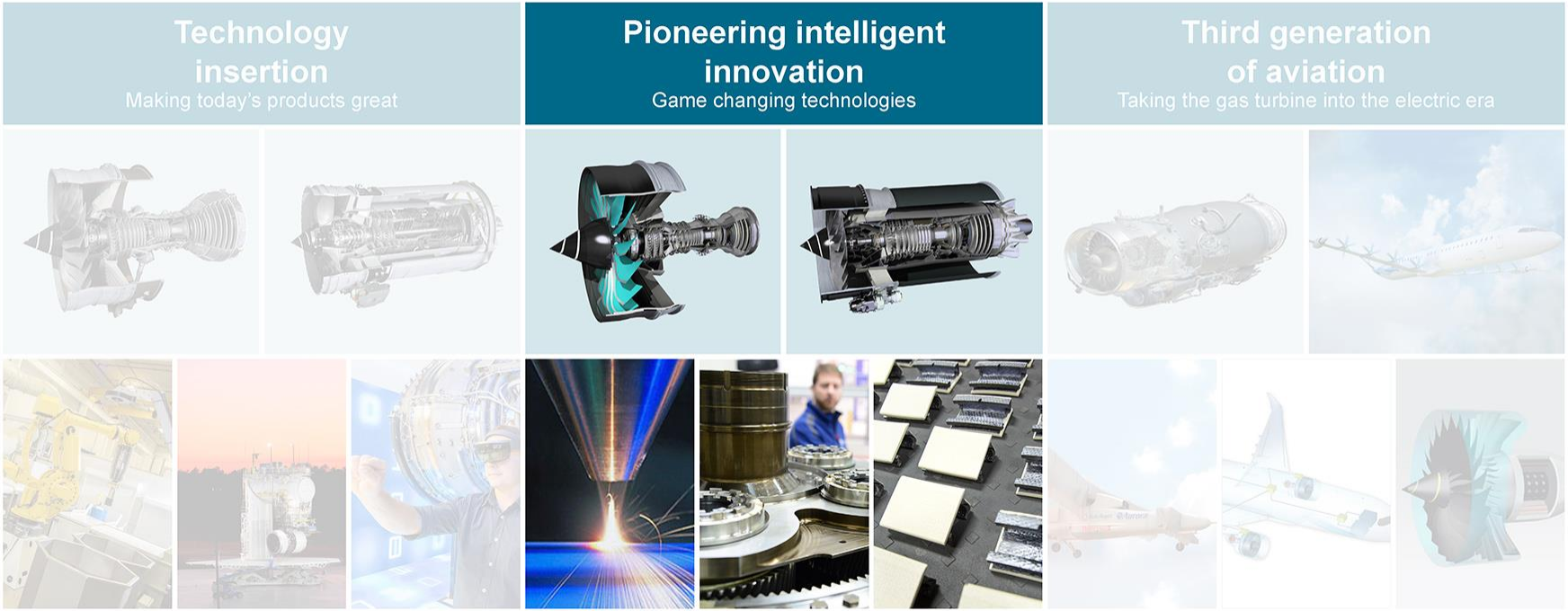
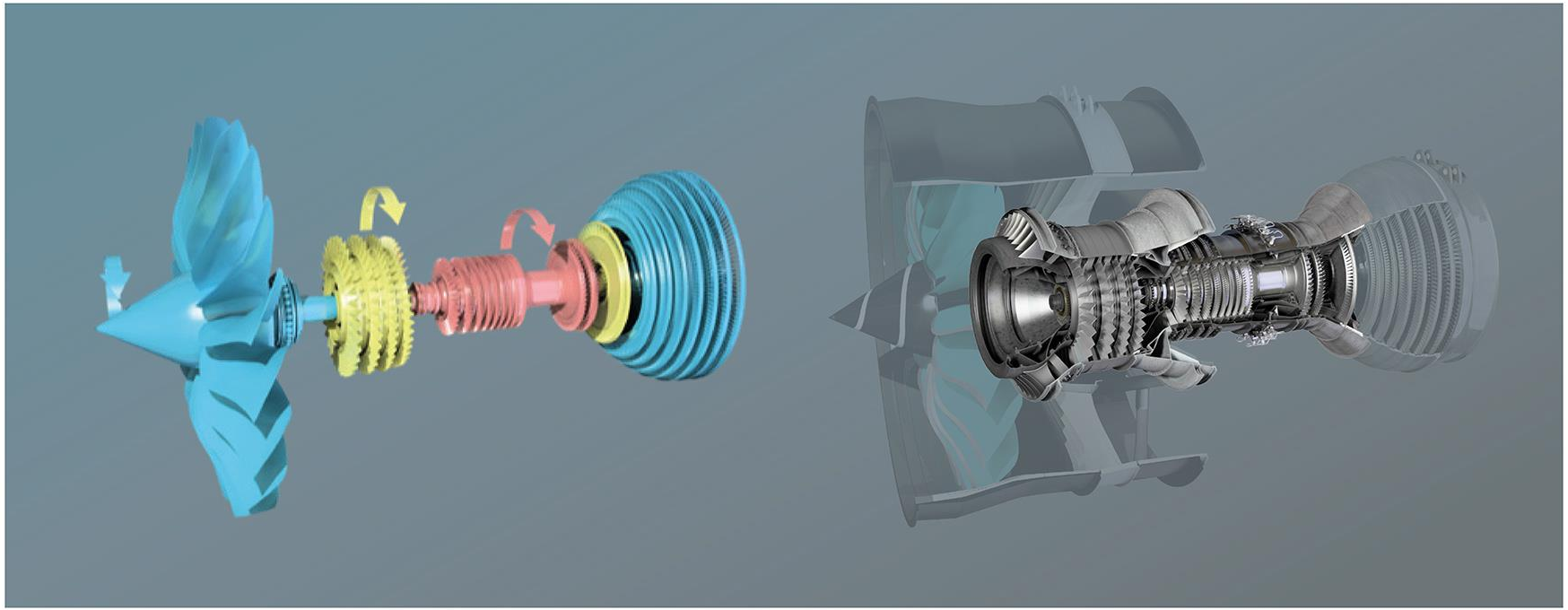
Bringing our Vision to life



Darpa X-Plane courtesy of © Darpa

Rolls-Royce

Advance3 demonstrates our new core design



Laying the foundation for UltraFan

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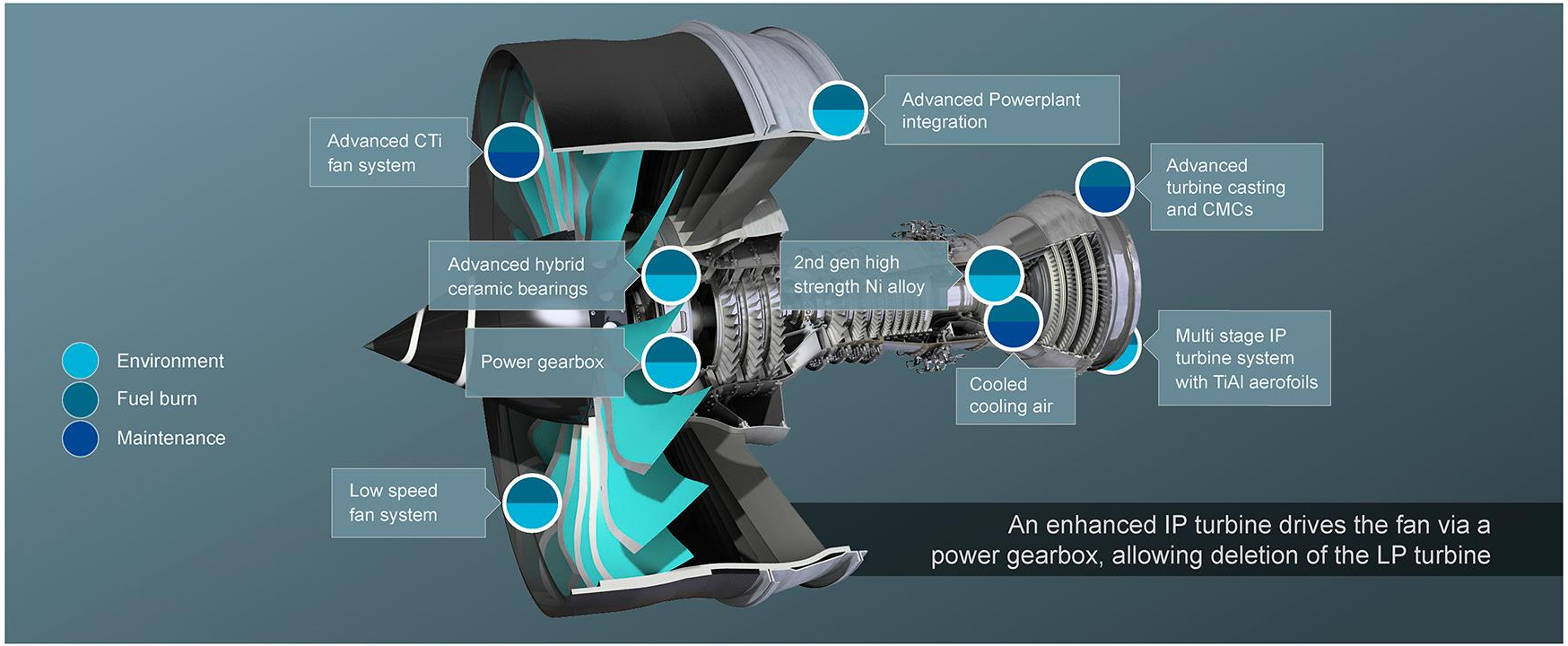
UltraFan walkaround



Delivering a 25% efficiency improvement

Rolls-Royce

The world's most powerful aerospace gearbox

Demonstrator gearbox has now run to max power!

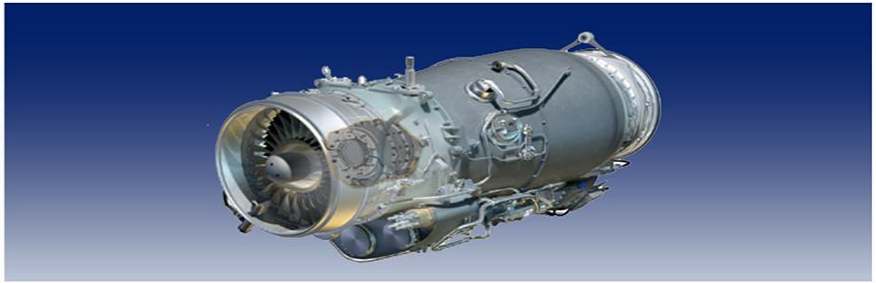
Bringing our Vision to life

Darpa X-Plane courtesy of © Darpa

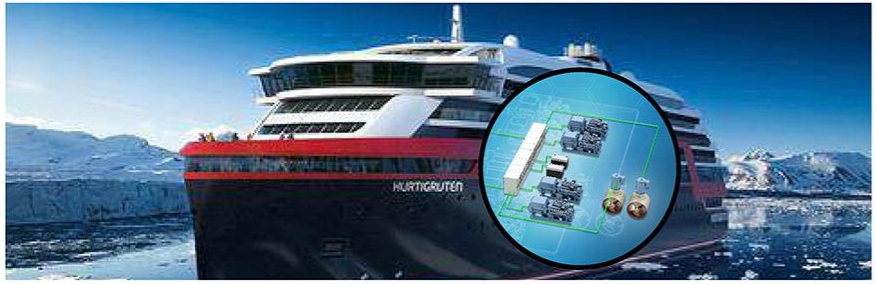
Rolls-Royce

Electrification is relentless

Hybrid trains



Embedded electrical starter generator (E2SG)



Hybrid ships

Darpa X-Plane

Rolls-Royce

Electrified Aircraft, Future Opportunities

	Military	Hybrid turbofan	Hybrid turboprop	Helicopter replacement	Personal mobility
Products					
Driver	Capability (on-board power)	Efficiency	Local environmental impact	Capability and safety	Capability (time)
Timing	Now	>2030	>2025	>2025	~2020s
Market	Significant	Large (as today)	Unknown	Unknown	Unknown

Helicopter replacement image © Darpa, Personal mobility image © Airbus,

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Growing Electrical Capability

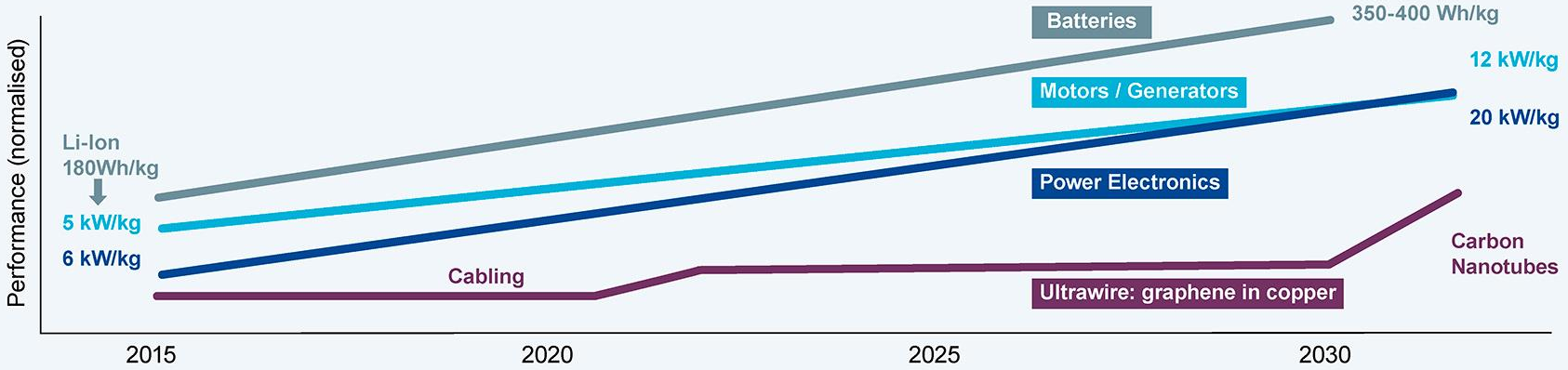

Hybrid train


More electric aircraft


Personal Air Taxi


Regional aviation

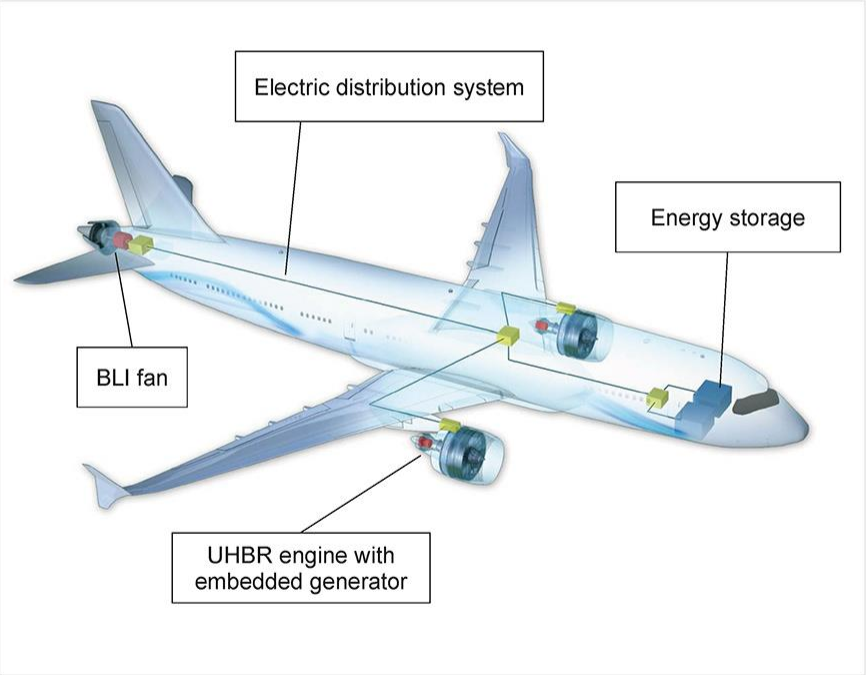

High Power Aerospace

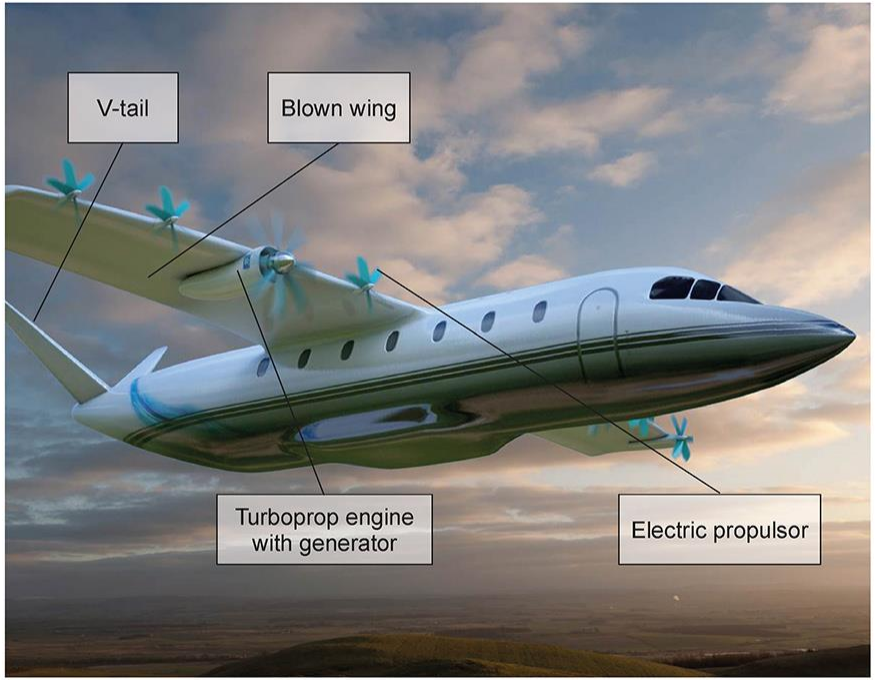


Personal Air Taxi image © Airbus

Rolls-Royce

Hybrid-electric propulsion evolution





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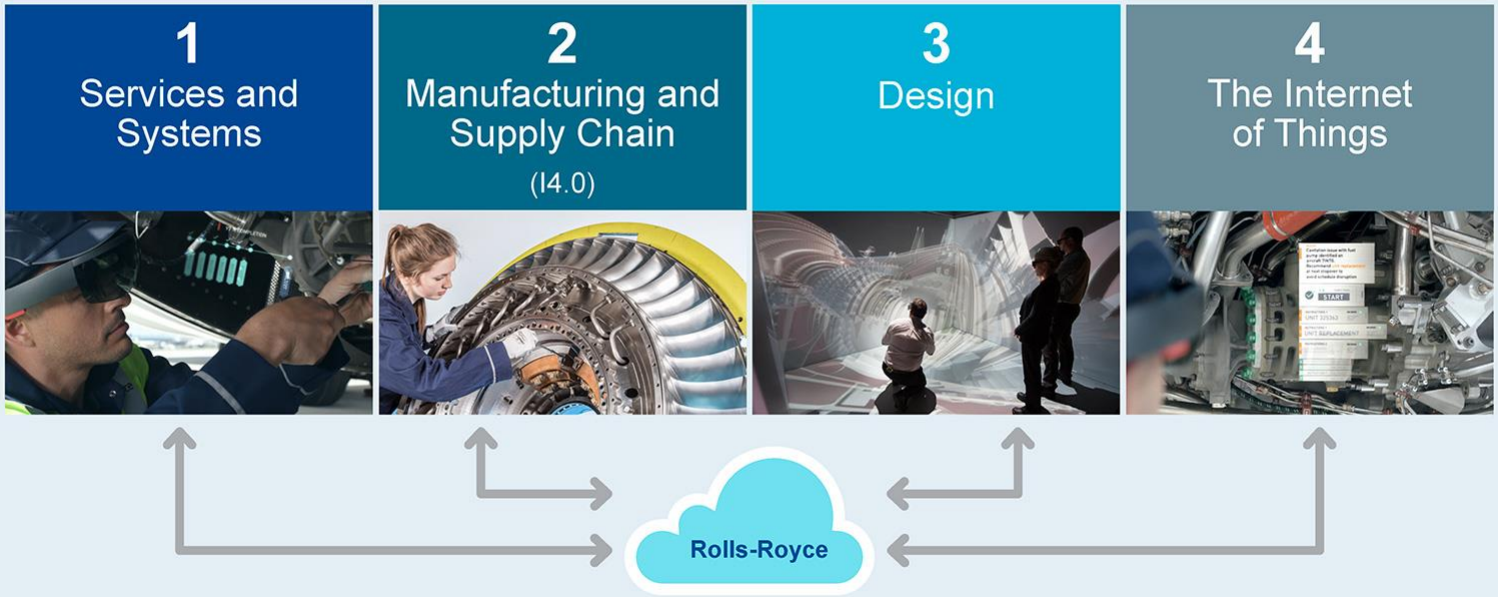
Harnessing the Digital technologies that matter



Our approach to Digital

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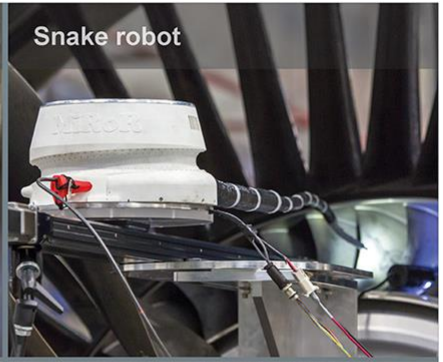
Deploying technologies in service – current and future state

- **Inspection**
  - Capsule cameras
  - Snake robots / continuum robots
  - Engine CCTV – embedded visual inspections
  - ‘Swarm’ inspection by collaborative robots
- **Restoration**
  - Boreblending
    - Mechanical
    - Laser ablation
  - Boreblending by remote control
  - Cleaning of turbine aerofoil cooling holes
  - Laser material deposition
  - Thermal barrier coating repair



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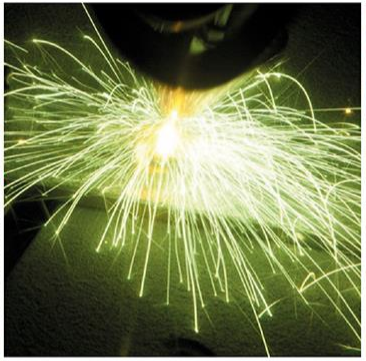
Manufacturing and Supply Chain (I4.0)



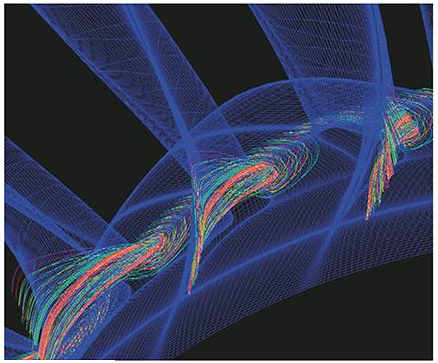
The fourth industry revolution

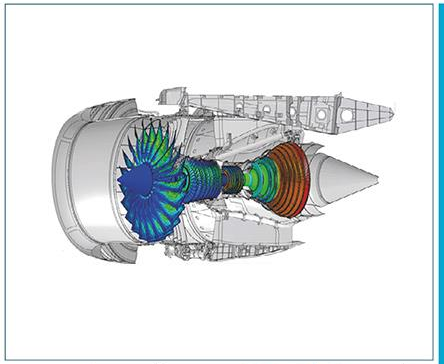
Digital version of factories, continuously being updated with live manufacturing data

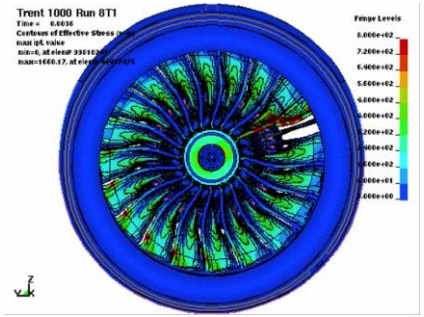
Embedded sensors can self-diagnose machinery

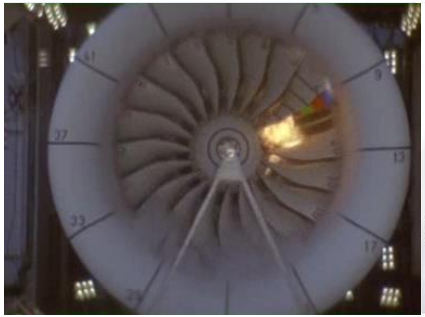
Rolls-Royce

Design - Virtual Engine









Design and Validate in the Computer Investment (DaVinci) programme

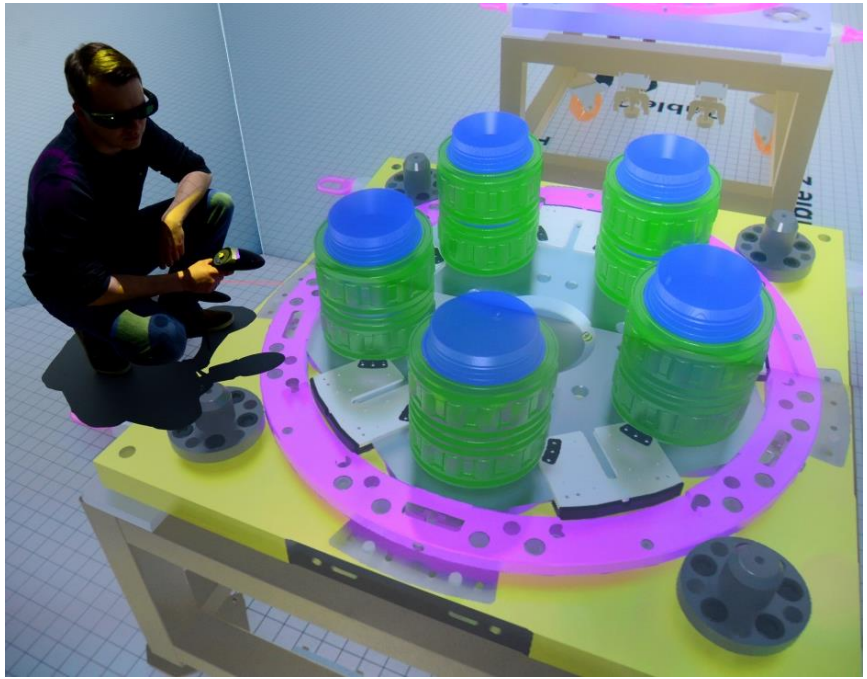
Engineers can experiment with concepts digitally and accurately

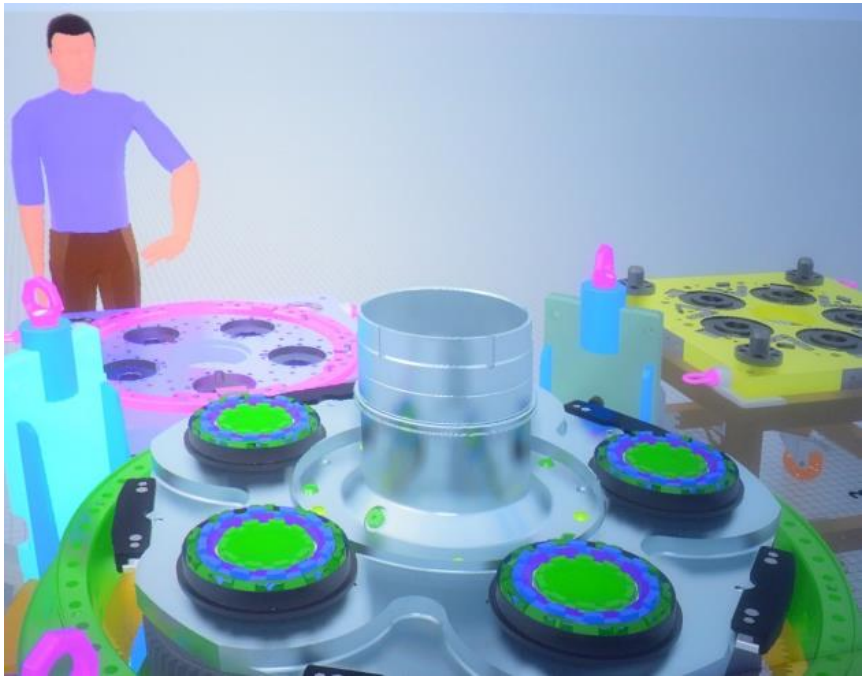
Less testing, better quality and lower cost

Introduce products up to a year faster

Rolls-Royce

PGB designed and built using VR





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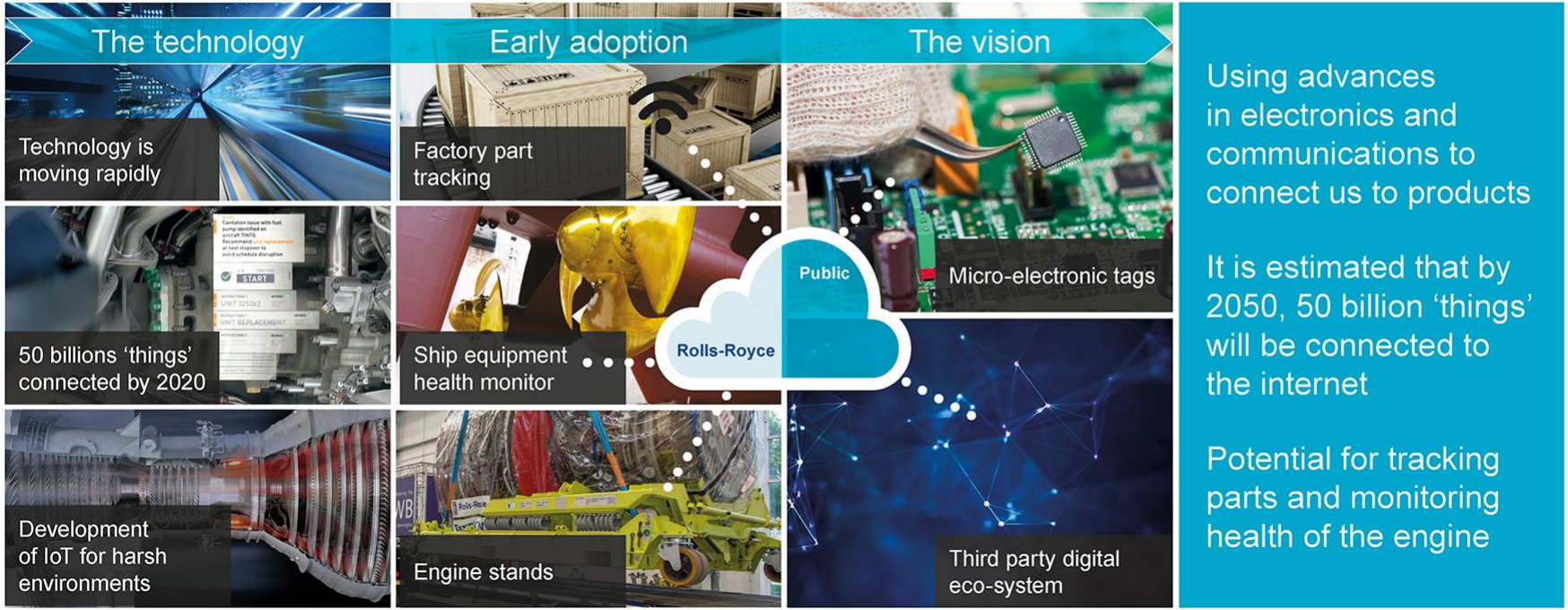
Internet of Things



Using advances in electronics and communications to connect us to products

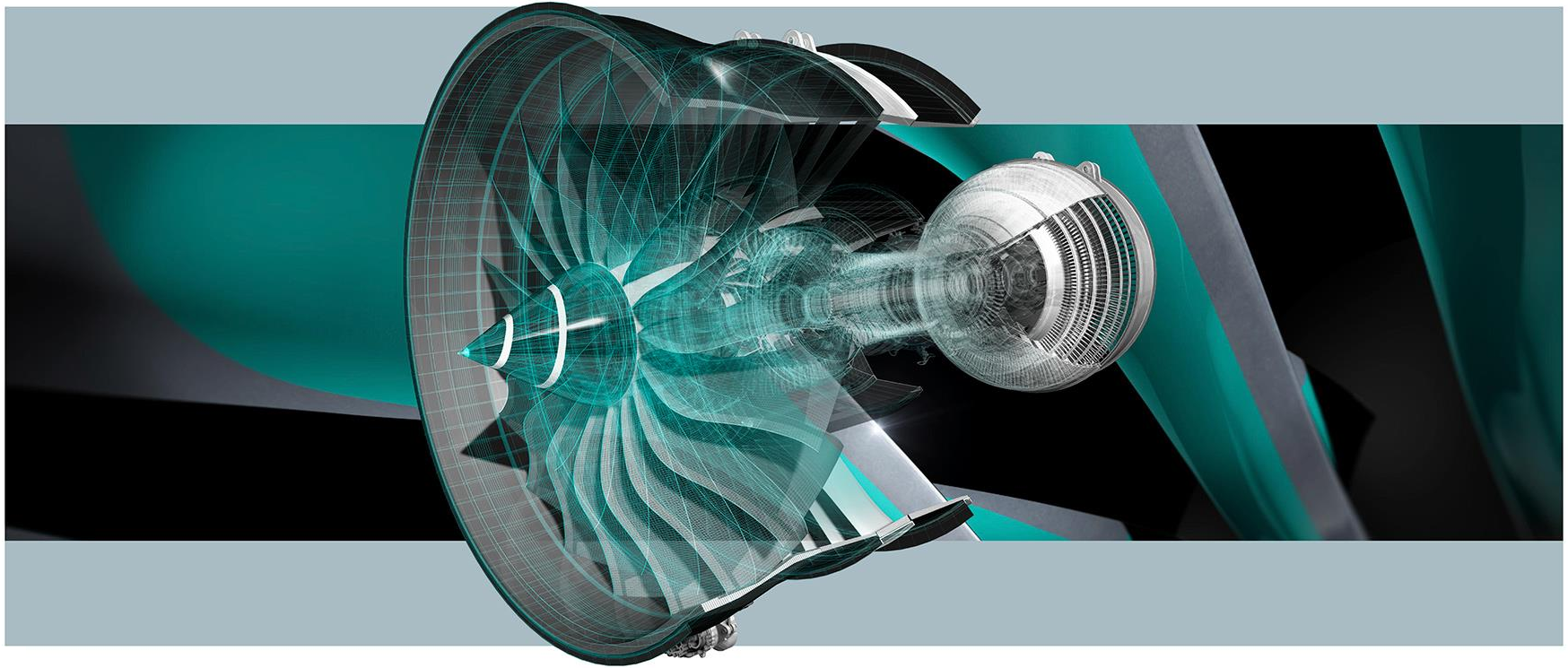
It is estimated that by 2050, 50 billion ‘things’ will be connected to the internet

Potential for tracking parts and monitoring health of the engine

Rolls-Royce


LOWER CASING
TRENT 5000X
42% PRINTING
ENGINE CORE
TRENT 5000X
72% PRINTING
LP FAN CASE
TRENT 5000X
85% PRINTED
Rolls-Royce

Intelligent innovation in everything we do



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trusted to deliver excellence