The Future of Propulsion

Highlights from ISABE 2017

Professor Ric Parker
President ISABE

with Ibrahim Eryilmaz
Cranfield University

International Society for Air Breathing Engines
Agenda

• ISABE 2017, Manchester
• The Future of Propulsion
  • Commitments
  • Enabling Technologies
• ISABE 2017 Highlights
  • Words from Keynotes
  • Words from Presenters
• Electric propulsion (Rolls-Royce)
• Next Conference - ISABE 2019, Canberra
ISABE 2017, Manchester - Economy, Efficiency & Environment

Hosted by Rolls-Royce and UK Organising Committee

Co-hosted by Cranfield University

Supported by

Manchester City Council

Sponsored by

Rolls-Royce

Manchester City Council

Honeywell

Canada

ITP

UNSW

GKN Aerospace

NASA

GE

SAFRAN

Manchester Central Convention Complex

The city where The Honourable Charles Rolls met Sir Henry Royce

ICAS 2018 – Belo Horizonte
Highlights from ISABE 2017 - Manchester
ISABE 2017, Manchester - Economy, Efficiency & Environment

- 370 registered participants
- 18 keynotes
Interactivity and Interactive parallel sessions

- 248 papers

Panel discussions + Q&A
The Future of Propulsion - Commitments

- CO₂ emissions 75% ↓*
- NOₓ emissions 90% ↓*
- Noise emissions 65% ↓*
- 0 emissions taxi
- Integrated systems engineering
- Certification cost 50% ↓

Innovation

- Air traffic management 25M flights/year
- EU travel within 4 hours
- Arrivals within 1 minute

Market

- EU Flightpath - 2050

Environment

- NOₓ emissions 90% ↓*
- CO₂ emissions 75% ↓*

Research

- Technology Network
- Universities & Industry
- Public & Private

Safety

- Accidents 80% ↓
- Manned/unmanned vehicles together

*reductions w.r.t 2000

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Highlights from ISABE 2017 - Manchester
The Future of Propulsion – Enabling Technologies

- UHBR engine sizing - Integrity and installation challenges
- Cycle innovations – variable cycles
- Manufacturing - Additive manufacturing & fast prototyping
- Virtual engine design systems
- Integrated aircraft and propulsion system design
  - Boundary layer ingestion
- Electrification (Separate presentation)
  - More electric aircraft
  - Electric augmented
  - Hybrid electric
  - Electric propulsion
From Keynotes – Safran Aircraft Engines

2018 LEAP-1C entering into service
• Certified by EASA & FAA

By additive manufacturing
• 20% reduction in engine parts by 2025

Powering COMAC 919
• Narrow body, 2 engine aircraft

Green taxiing®
• 2-4 % fuel burn reduction
From Keynotes – Rolls-Royce

Global Partnership
• 31 University Technology Centres
• 14 Research Centres and other Partnerships

UltraFan® gearbox
• The world’s most powerful gearbox has run to max. power

DaVinci
Design and Validate in the Computer Investment
• Less testing, better quality, lower cost
From Keynotes – Airbus

Existing product improvements – on track
  • Design for Additive Layer Manufacturing
    • 5% waste material
    • up to 50% potential weight saving

New configurations
  • Hybrid electric propulsion

Better integration and architecture – BLADE: Breakthrough Laminar Aircraft Demonstrator in Europe
  • 2017 – Flight tests on Airbus A340

Towards Urban Air Mobility
  • Pioneering role in opening the market
From Keynotes – Cranfield AIRC & DARTeC

• AIRC
  • A £35m investment by Cranfield, HEFCE, Rolls Royce and Airbus
  • Surrogate airframer for Rolls-Royce & surrogate component supplier for Airbus

• DARTeC
  • A £65m investment by Cranfield, HEFCE, Thales, SAAB, Boeing UK, Raytheon, Monarch Ltd
From Keynotes – Aerospace Technology Institute

UK Aerospace programme roles

ATI Portfolio by Value Stream

Impact of New Technologies – Case

Advanced Wing Assembly
- Right first tie assembly
- Cost & lead time reduction

Harsh Environment Electronics
- 250 °C capable environment

AMRC Titanium Casting
- World’s largest Ti casting facility
- £15M investment
From Keynotes – Clean Sky Joint Undertaking

A public-private partnership- A focal point in European Aviation

- 14 Industrial leaders & EU Commission
- €1.8Bn EU funding, 4B € total cost, >800 participants

Contra-Rotating Open Rotor, SAFRAN
- Ground test demonstrator
- Compliant with the new noise standards
- Offering 30% ↓ in fuel burn compared to 2000

Geared turbofan demonstrator, MTU
- New systems for a more electric engine
- All electric VGV actuator
From Presenters – Boundary Layer Ingestion

View of the RAPRO2 BLI experimental system in the L1 wind tunnel - ONERA

- Distorted fan flow
- Less drag on fuselage and nacelle
- BLI reduces global power needed
- Less fuel to drive the fan

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Power coefficient as a function of the global axial force CT-CD

Power_{Exp} No BLI

Power_{Exp} With BLI

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Fan Exit Po

Po No BLI

Po With BLI

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Highlights from ISABE 2017 - Manchester
Installation challenge, system sizing and synthesis

- Optimized pylon & nacelle geometry and wing shape
  - Straight (low) wing, gull wing, truss braced wing

Impact on landing systems length and weight

- FAA minimum ground clearance $\geq 9$in
- Minimum allowable roll angle $\geq 8$ degrees
From Presenters – UHBR Engine Sizing

- VPF- No thrust reverser
- Less landing gear ↑ with a slimmer nacelle to accommodate UHBR
- opt. FPR ~1.3-1.35 - VPGF < FPGF

- High wing
- No ground clearance constraint
- High span - gate compatibility issues
- Further fuel burn ↓ - opt. FPR<1.2
From Presenters – Manufacturing

EOS GmbH & Universität der Bundeswehr
• Compressor vane with pressure probes - Additive Manufacturing, DMLS

Rolls-Royce Advance3
• Critical long lead time parts - Fast Make SCUs
• Intercase cast in sub-sections and bolted
• Blisk stages machined from solid and Electron Beam welded

CastBond™ HP-NGVs
• Cooling capability
From Presenters – Virtual Engine Design Systems

3-D transient dynamic sub-systems modelling, LS-DYNA

AECC Ltd.
• Fan shaft is connected
• Stress under FBO loads

Cranfield Rolls-Royce UTC
• Shaft failure – no connection
• Turbine overspeed

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18
From Presenters – Cycle Innovations

Candidate technologies for year 2050 engines – qualitative assessment

- Intercooling
- Recuperation
- Variable geometry
  - VIGVs for IP and HP compressors
  - Variable pitch fan
- Secondary combustion

- Topping cycles - pressure rise combustion
  - Pulse-detonation combustors
  - Piston engines
- Bottoming cycles
  - Use the core exhaust as heat input
  - S-CO₂

Reverse flow core turbofan engine architecture with several features
From Presenters – Cycle Innovations

The variable cycle engine – quantitative assessment

- 3 spool mixed flow turbofan
- Variable fan IGV
- Variable compressors
- Variable turbines
- Variable mixer
- Variable nozzle

- MTU cycle code
  - Thermodynamics
- Meanline code
  - Flowpath design
- Preliminary mechanical design tool
  - Weight prediction

![Graph showing SFC improvement with various cases: Reference (Basis), VCE (No adjustment losses), VCE (With adjustment losses).](image)

- Reference (Basis)
- VCE (No adjustment losses) with a 7.9% improvement
- VCE (With adjustment losses) with a 1.3% improvement

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20
From Presenters – Noise Reduction

The NASA Aircraft Noise Reduction Sub-project
• Acoustic liner technology
• Propulsion airframe aeroacoustics

Over-The-Rotor Liner (Acoustic Casing Treatment)
• Casing grooves over the fan tip
• Groves have porosity to allow communication between unsteady flow and absorbers

Challenges
• Fan losses, already solved: to be published soon
• Fabrication
From Presenters – Turbo-Electric Propulsion

Techno-economic and environmental risk assessment (TERA) of NASA's N+3-X aircraft
- TERA methodology by Cranfield
- Boundary layer ingestion
- Turbomachinery
- Aircraft performance
- Economic modelling

Improvements w.r.t improved baseline aircraft (IBA) derived from Boeing 777-200LR

60% fuel reduction target
List of References

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- ISABE 2017 keynote, Paul Stein, Rolls-Royce plc
- ISABE 2017 keynote, Simon Weeks, Aerospace Technology Institute UK
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- ISABE-2017-22536, G. Billonnet, O. Atinault and R. Grenon, Assessment of the Fan Simulation for quantifying the Boundary Layer Ingestion benefits on an Experimental Propulsion System
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- ISABE-2017-22705, A. Geer, The Rolls-Royce Advance3 Project – Proving our Future Core
- ISABE-2017-22675, S. Hu, X. Chai, Application of Sub-Modelling Technique for Whole Engine Transient Dynamic Analysis
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Electric propulsion

Professor Ric Parker – Special Advisor

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Electrification

- Micro-grids
- Hybrid Trains
- Hybrid Ships
- E-Fan X
## New directions for aviation through electrical power

<table>
<thead>
<tr>
<th>Products</th>
<th>Military</th>
<th>Personal Mobility</th>
<th>Hybrid Turboprop</th>
<th>Helicopter Replacement</th>
<th>Hybrid Turbofan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>Capability</td>
<td>Capability (time)</td>
<td>Local Environmental Impact</td>
<td>Capability &amp; Safety</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Timing</td>
<td>Now</td>
<td>~2020s</td>
<td>&gt;2025</td>
<td>&gt;2025</td>
<td>&gt;2030</td>
</tr>
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Personal Air Taxi image © Airbus, Helicopter Replacement Image courtesy of Aurora Flight Sciences - a Boeing Company
Electric Propulsion Benefits

Hybrid Electric Propulsion Transforms Aircraft Design Space

- **Efficiency**
  - High levels of efficiency
  - Allows energy-use optimisation

- **Capability**
  - High level of control
  - Easily configurable
  - Propulsion airframe integration
  - Novel architectures

- **Emissions**
  - Zero local emissions
  - Potentially lower levels of noise

- **Maintenance**
  - Single engine, increased redundancy
  - Power Management control to reduce wear
Growing electrical capability

Data for “aerospace grade” technology
How might it impact aviation?

**Incremental**
(Electrification)

**Disruptive**
(Electric propulsion)

**Incremental**
More electric Aircraft
Electrical content increasing
Electrical technology advancing
Electrical enhancement - BLI

**Disruptive**
New airframe and/or transport concepts could appear
Scope of supply may change
New entrants may appear in market
### Disruption in short/medium travel.

#### Short Range

<table>
<thead>
<tr>
<th>1-4 pax</th>
<th>Personal Transport</th>
<th>Time Saver</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Congestion Beater</td>
<td>Convenience Option</td>
</tr>
</tbody>
</table>

#### Medium Range

<table>
<thead>
<tr>
<th>4-20 pax</th>
<th>Regional VTOL</th>
<th>VTOL unlocks new Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Local Commuter</td>
<td>Potential to take share of small business jet market</td>
</tr>
</tbody>
</table>

#### Long Range

<table>
<thead>
<tr>
<th>20-100 pax</th>
<th>Regional Hybrid</th>
<th>Alternative to rail and current aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Economic advantage over new Rail Infrastructure</td>
<td>Ability to operate closer to destination than conventional aircraft</td>
</tr>
</tbody>
</table>
Disruption in short/medium travel.

A shift in transport mode
Enabling innovative civil aerospace and defence operations

- Reduced operating cost
- Reduced emissions
- Reduced aircraft noise
- Flexibility in vehicle propulsion integration
- Flexibility to energy source
It’s not just about the airplane...

New policies on transportation subsidies
Digital ticketing
New physical and cyber security systems
Minimalist city airport design
Security pre-clearance
Ground Infrastructure
Dynamic air traffic management
Single pilot operation
Mobility as a service
New aircraft types (STOL, low noise)

Revolution in regional transport
Technology Development

Rolls-Royce Electrical – Hybrid Technologies
- Parallel Hybrid
- Series Hybrid
- Turbo-electric distributed propulsion

Focus on Technology Advancement and Demonstrators for Early Product Opportunities

More Electric Engine
- Starter-Generator
- Electric Accessories
- Secondary Aircraft Systems Electrification

Full system Electrification (Turbo-Electric, no energy storage)
- Starter-Generator
- Electric Accessories
- Secondary Aircraft Systems Electrification
- Propulsion Electrification

Partial system hybridization (Parallel) – combined engine + energy storage
- Starter-Generator
- Electric Accessories
- Secondary Aircraft Systems Electrification

Full system hybridization (series, larger energy storage)
- Starter-Generator
- Electric Accessories
- Secondary Aircraft Systems Electrification
- Propulsion Electrification (Pure Electric Thrust)
Electrically enhanced larger aircraft – aft body BLI*

*Boundary Layer Ingestion
Hybrid short-range regional aircraft
Hybrid regional demonstrator
Airbus, Roll-Royce Siemens
Hybrid MoM
Airbus, Rolls-Royce

E-Thrust
Key challenges

Electric and Hybrid Electric propulsion are poised to reshape the aerospace industry

Systems Integration

The ability to integrate mechanical, electrical and thermal systems

- Safety & certification
- Electro mechanical integration
- Cooling
- Control
- Corona discharge

Component Technology

The ability to design high performance, high integrity components

- Lightweight, high power density machines
- High temperature electrical materials
- Fault tolerant power electronics
Next Conference – ISABE 2019, Canberra