Electrical Propulsion
Onwards and Upwards

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Agenda

A. Developments in aircraft electrification

B. Environmental pressures

C. Implications for the aerospace industry
A. Developments in aircraft electrification

### More Electric Aircraft (MEA)

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing 737</td>
<td>1967</td>
</tr>
<tr>
<td>Airbus A380</td>
<td>2007</td>
</tr>
<tr>
<td>Boeing 787</td>
<td>2011</td>
</tr>
<tr>
<td>Next gen</td>
<td>2025+</td>
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</tbody>
</table>

#### Electrified components
- Pneumatic
  - Fuel pump
  - Landing gear actuation
  - Engine start & controls
  - Thrust reverser
- Hydraulic
  - Wing anti-icing
  - Flight controls
  - Environmental Control System (ECS)
- Mechanical
  - Engine start & controls
  - Brakes actuation
  - Thrust reverser
- Electrical
  - Cabin equipment
  - IFE
  - Lighting
  - Avionics

### Electrical Propulsion (EP)

#### Hybrid-electric
- **Parallel hybrid**
  - Battery
  - Motor
  - Turbofan
  - Fan
- **Series hybrid**
  - Turboshaft
  - Generator
  - Motor
  - Fan

#### Turbo-electric
- **Turboshaft**
  - Generator
  - Motor
  - Fan

#### All-electric
- **Battery**
  - Motor
  - Fan
The pace of introduction of new, electrical propulsion developments has risen very sharply in the past few years.

Known electrically-propelled aircraft developments by announcement date, 2009-Oct 2018\(^1\) [cumulative #]

\(^1\) Only including developments with first flights after 2010, excluding UAVs and purely recreational developments

Source: Secondary research, Roland Berger
The Urban Air Taxi and General Aviation segments comprise c. 90% of aircraft development programmes, with two thirds all electric.

Distribution of ~130 publicly known electrically propelled aircraft programmes, Oct-18

- Hybrid propulsion: 30%
- All electric propulsion: 70%

- Urban air taxi (UAT)/eVTOL: 45%
- General aviation (GA): 43%
- Regional aviation: 10%
- Large commercial aircraft: 2%

1) Only including developments with first flights after 2010; 2) Mainly turbo-electric
The traditional aerospace centres of Europe and North America are home to the majority of electrically propelled aircraft developments.

Distribution of ~130 publicly known electrically propelled aircraft programmes, Oct-18

### Zunum Aero
**Seattle, WA, US**
- **Type:** Regional
- **Propulsion:** Hybrid
- **Passengers:** 120-180
- **First flight:** 2019

### Wright Electric
**Los Angeles, CA, US**
- **Type:** Commercial
- **Propulsion:** Hybrid
- **Passengers:** 120-180
- **First flight:** 2019

### Ehang 184
**Guangzhou, China**
- **Type:** Urban air taxi
- **Propulsion:** Battery
- **Passengers:** 1
- **Thrust:** 8 propellers
- **First flight:** 2016

### Eviation Alice
**Kadima, Israel**
- **Type:** Regional
- **Propulsion:** Battery
- **Passengers:** 11
- **Thrust:** 3 propellers
- **First flight:** 2019

### Embraer X eVTOL/Uber Elevate
**São José dos Campos, Brazil**
- **Type:** Urban air taxi
- **Propulsion:** Battery
- **Thrust:** 1 ducted fan and 8 propellers
- **First flight:** 2020

### Aston Martin Volante
**Cranfield, UK**
- **Type:** Urban Air Taxi
- **Propulsion:** Hybrid
- **Passengers:** 3
- **Thrust:** 3 propellers
- **First flight:** 2020

### Airbus/Siemens/Rolls-Royce E-Fan X
**Munich, Germany**
- **Type:** Regional
- **Propulsion:** Hybrid
- **Passengers:** 50-100
- **Thrust:** 3 turbofans + 1 hybrid
- **First flight:** 2020

### Vickers WAVE eVTOL
**Hamilton, New Zealand**
- **Type:** Urban air taxi
- **Propulsion:** Hybrid
- **Passengers:** 4
- **Thrust:** 8 propellers

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1) Only including developments with first flights after 2010
A&D professionals broadly agree that a hybrid-electric aircraft could enter commercial service by the early 2030s, while all-electric is less clear.

Results from Roland Berger survey of Aerospace & Defense professionals, 2017-75 [#]¹)

### Hybrid-electric aircraft

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2032</td>
<td>2038</td>
<td>2018</td>
<td>2050</td>
<td>7.3</td>
</tr>
</tbody>
</table>

### All-electric aircraft

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2043</td>
<td>2045</td>
<td>2025</td>
<td>2075</td>
<td>12.9</td>
</tr>
</tbody>
</table>

¹) Results based on a 2017-2018 survey of ~40 Aerospace & Defense professionals
B. Environmental pressures
A transition to electrical propulsion is required if aviation is to remain close to today's contribution to global CO₂ emissions

Estimate for aviation's share of global anthropogenic CO₂ emissions¹) in 2050 [%]

- **Baseline: continued industry evolution at current pace**
  - Fleet growth of 4.0% p.a. to 2050, aircraft retirement age of 25 years
  - Fuel burn reduction of 1% p.a. on new aircraft through technology improvement with cap at 15% relative to today as technology matures
  - No production of electric or hybrid regional or large commercial aircraft

- **Accelerated evolution of today's technology**
  - Fuel burn reduction of 2.5% p.a. on new aircraft through technology improvement with cap at 42% relative to today²)
  - All other assumptions as Scenario A

- **Adoption of electric propulsion due to "normal market forces"**
  - Production of hybrid-electric aircraft starts in 2035
  - Production of all electric aircraft starts in 2040
  - All other assumptions as Scenario B

- **Regulatory-driven transition to electrical propulsion**
  - Forced retirement of all existing aircraft at 10 years with replacement by electric from 2030 onwards
  - All other assumptions as Scenario C

1) For each scenario, the range is obtained by considering different global emissions Representative Concentration Pathways. Namely, RCP 2.6 for the maximum value and RCP 8.5 for the minimum value. RCP 4.5 is used to obtain the average; 2) Based on Clean Sky assumptions for airframe, system and network improvements

Source: Roland Berger emissions model, IPCC, AG analysis, EU Clean Sky
Scenario D would require a rapid transition to hybrid and electrically propelled aircraft, adding up to c. 70% of the global fleet by 2050.

Global aircraft fleet\(^1\) breakdown by propulsion type – Scenario D, 2016-50 ['000 aircraft units]

1) Includes LCA, RCA and freighters

Source: Flight Global, Boeing, Airbus, External research, Roland Berger
C. Implications for the aerospace industry
Significant progress has been made against the barriers to electrical propulsion…but a number of questions are yet to be answered

Landscape of barriers for aircraft electrification

**Technology**
- Effective batteries
  - Battery performance
  - Battery safety/hazard containment
- Efficient electric machines
  - Light, high power density generators and motors
  - Power electronics
  - Safe and light high voltage distribution
- Autonomous flight technology
  - Essential for UAT business case

**Policy**
- Regulation driving change
  - Emissions controls
  - Noise targets
- Regulation adapting to change
  - Certification of novel technology
  - Air traffic management of Urban Air Taxis
  - Management of data & network security
- Infrastructure requirements
  - Implementation of charging points in airports
  - Additional solutions for electricity generation

**Market demand**
- Passenger demand
  - Consumer preference to fly "green"/low noise a/c
  - Consumer acceptance of autonomous flight
  - Willingness to pay for Urban Air Mobility
- Airline demand
  - Airline willingness to take new technology risk
  - Airline ability to maintain/increase profits with electric propulsion
  - Demonstrating similar/reduced cost per seat mile

What product architecture(s) will emerge to overcome these barriers?
Will electrical propulsion power Airbus and Boeing's next aircraft which are to expected to enter service in the early 2030s?

Overview of all-new historical and future civil aircraft development programmes
Which type of player will emerge to control electrical propulsion systems' development & certification?

Source: Airbus, Rolls-Royce, Siemens, Roland Berger
What clean energy generation solutions will be required to power future airports?

Energy demanded by UK airports and potential solutions for London Heathrow (2050)

UK power demand for electric aircraft (MW)\(^1\)

<table>
<thead>
<tr>
<th>Airport</th>
<th>Demand (MW)</th>
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<tbody>
<tr>
<td>LHR</td>
<td>1,300</td>
</tr>
<tr>
<td>LGW</td>
<td>400</td>
</tr>
<tr>
<td>MAN</td>
<td>300</td>
</tr>
<tr>
<td>BHX</td>
<td>200</td>
</tr>
<tr>
<td>Rest of UK</td>
<td>1,300</td>
</tr>
<tr>
<td><strong>Σ</strong></td>
<td><strong>3,500</strong></td>
</tr>
</tbody>
</table>

Potential solutions for London Heathrow

- **Solar**
  - c. 30x current LHR area\(^2\)
- **Onshore wind**
  - c. 2,000 90-m tall wind turbines
  - c. 55x current LHR area\(^3\)
- **Grid**
  - c. 0.5% of UK 2050 generation capacity\(^4\)
- **Nuclear**
  - c. 1/3rd of nuclear power station Hinkley Point C\(^5\)

1) Employing electrification scenario D, and assuming 24 hour constant charging for replacement batteries; 2) Land use 0.03km\(^2\)/MW for concentrated solar power and 10% load factor; 3) Land use 0.15km\(^2\)/MW and average turbine power 2.5MW, based on Whitelee Wind Farm, largest onshore wind farm in the UK, and 28% load factor; 4) Based on National Grid forecast without electric aircraft; 5) Station with 2 EPR reactors totalling 3,200 MW
Aerospace incumbents must begin considering how to survive – and thrive – in an electrically propelled future

Key questions for aerospace players in electrical propulsion

<table>
<thead>
<tr>
<th>Airframers</th>
<th>Engine companies</th>
<th>Systems suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; What electrical propulsion segments should you play in?</td>
<td>&gt; Focus on hybrid-electric or battery-electric technology?</td>
<td>&gt; Where to focus R&amp;D efforts?</td>
</tr>
<tr>
<td>&gt; How to get involved? (venture capital model, direct R&amp;D, development partnerships?)</td>
<td>&gt; How to capitalise on existing capability?</td>
<td>&gt; Who to partner with and how (e.g. start-ups)?</td>
</tr>
<tr>
<td></td>
<td>&gt; What electrical propulsion segments should you play in?</td>
<td>&gt; How to capitalise on existing capability?</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-tier suppliers</th>
<th>Operators</th>
<th>Policy makers</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; How to develop product portfolio to be ready for an electrically propelled future?</td>
<td>&gt; Who will emerge to operate the new aviation segments (sub-regional, Urban Air Taxis)?</td>
<td>&gt; How can airworthiness authorities enable the trend but maintain safety standards?</td>
</tr>
<tr>
<td></td>
<td>&gt; Will safety levels for these be the same as traditional aerospace?</td>
<td>&gt; How will airspaces change?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; How will public infrastructure evolve to enable the shift?</td>
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