Introduction of ECLAIR and Research on eVTOLs in JAXA

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Flight test of an unmanned Schweizer 300C helicopter

Prototype Kawada RoboCopter Development and test

HK-MAV (SAT-UAV) Development

Humanoid Development (Motor drivers and attitude estimation)

Prototypes for University of Tokyo

Demonstration of HRP together with AIST (産総研)
Current productions of Kawada Robotics, Inc

https://www.kawadarobot.co.jp/
Personal Experience: 2006 – , JAXA, Rotorcraft R&D

Numerical Analysis Flow

- Blade structural properties (Rotating speed, Root constraint conditions)
- Flow conditions (Rotor blade controls, Trim conditions)
- Observer conditions
- rMode
- rFlow3D / JANUS
- rNoise
- Natural frequencies
- Natural mode shapes (represented with polynomials)
- Surface pressure on rotating blades
- Sound pressure history at observation points

HART-II Fan-Plot, PL=1080 [Nm/rad]

ロータ騒音計測の風洞試験と騒音予測（rNoise）

回転翼機空力・弾性・騒音統合解析ツールrFlow3Dの解析例

高速回転翼機（JAXA提案）

可変ピッチ制御マルチコプタに関する研究（ImPACT、科研費）
Personal Experience: 2006 – , JAXA, Rotorcraft R&D

Numerical Analysis Flow

- Blade structural properties
  - Rotating speed
  - Root constraint conditions
- Flow conditions
  - Rotor blade controls
  - Trim conditions
- Observer conditions

rMode

rFlow3D / JANUS

rNoise

- Natural frequencies
  - Natural mode shapes (represented with polynomials)
- Surface pressure on rotating blades
- Sound pressure time history at observation points

Construction of a Multidisciplinary Analysis Toolchain for Rotary Wings
Personal Experience: 2006 – , JAXA, Rotorcraft R&D

Methodologies and samples of results of rFlow3D/JANUS
Personal Experience: 2006 –, JAXA, Rotorcraft R&D

Result samples of rMode and rNoise

BVI noise reduction test using active flaps
Personal Experience: 2006 – , JAXA, Rotorcraft R&D

R & D of a concept of high-speed compound helicopter

R & D of variable pitch-controlled multirotor drones [funded by ImPACT and KAKENHI (Grant-in-Aid for Scientific Research)]
Ground Effect for a Quadrotor Drone

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**Graphs and Data**

- **C_q** vs. **h/D**
  - Single Rotor
  - Quad-Rotor [average]
  - Single Rotor [OGE]
  - Quad-Rotor [OGE]

- **Images**
  - h/D = 0.25
  - h/D = 1.0
  - h/D = 3.0
  - h/D = 0.50
Noise prediction for a virtual eVTOL

SkyDrive SD-3
(The noise prediction on this page is NOT based on this aircraft)

Aerodynamic intensity on the ground

A-weighted sound pressure level [dB]
Recent activities on aircraft electrification by JAXA/ECLAIR

Akira Nishizawa (Presented by Yasutada Tanabe)
Aeronautical Technology Directorate
JAXA

ECLAIR web site: http://www.aero.jaxa.jp/about/hub/eclair/index.html
Overview of ECLAIR

Established July 1, 2018

Electrification Challenge for AIRcraft (ECLAIR) Consortium

Electrification of passenger aircraft
Ultra-low fuel consumption, reduction in CO₂ emission
⇒ Realization of emission-free aircraft

Electrification of small aircraft
Electrification of components

Steering Committee [Members]
- IHI Corporation
- Japan Aerospace Exploration Agency (JAXA)
- Kawasaki Heavy Industries, Ltd.
- Ministry of Economy, Trade and Industry
- Subaru Corporation
- Japan Aircraft Development Corporation
- Hitachi, Ltd.
- Mitsubishi Heavy Industries, Ltd.
- Mitsubishi Heavy Industries Aero Engines, Ltd.
- Mitsubishi Electric Corporation

[Observers]
- AIATS, SJAC, MLIT Civil Aviation Bureau, NEDO,
- The University of Tokyo, ATLA, MEXT

Aeronautical industry
- Aircraft design, development
  - JAXA
  - Electrified propulsion system
  - Aerodynamics - Mechanics - Control
  - Ground/Flight tests

Electrical industry, raw material/parts industry
- Electrification elements (Battery, power electronics, motor, ...)
- Peripheral technology

Cooperation Assemble different fields

Industry × Academia × Government

Next Generation Aeronautical Innovation Hub Center
(JAXA Aeronautical Technology Directorate)

Application to fields outside aviation

Utilize Japan's strength by cooperating with various sectors.

Though it is difficult for JAXA alone to tackle the issue of "electrification", there are a number of domestic companies with high potential with electrification technology.

In July 2018, the "Electrification Challenge for Aircraft Consortium" was established. With this consortium, we aim for technological development and fortification of globally competitive technology power that are necessary for development of the "emission-free aircraft" enabling the realization of drastic reduction of CO₂ emission by combining Japan's world class electrification technology and aviation technology.

http://fanfun.jaxa.jp/jaxatv/detail/12230.html
Electrification Challenge for AIRcraft (ECLAIR) Consortium

Vision for The Future ver.1 [Summary]  Dec. 17, 2018

Purpose of Consortium: Through cooperation and partnership both with aeronautical engineering and other fields, create innovative technologies for electric aircraft in order to drastically reduce the impact on environment such as CO$_2$ emission, and contribute to sustainable development of aeronautical industry.

Significance of formulating Vision for The Future: By sharing the directionality and making communication and cooperation smooth among the consortium participants, promote research and development toward realization of electrifying aircraft and help expand the range of the participants. (The Vision for the Future shall be refined, and it will be updated according to the changes in the trend.)

Summary of the Vision for The Future  Practical implementation and contribution to global aeronautical industry

Societal background: Demand for air transportation will increase to 2.4 times in the next 20 years.

CO$_2$ emission reduction target for aircraft: To achieve "half of 2005 by 2050", in addition to introduction of bio-fuel, the innovative technology for electrifying propulsion is essential.

International technology trend: Reached the level of practical electrified propulsion system for small aircraft.

2020’s: Start implementation of electrification technology for low power use (small electrified aircraft and MEA).

2030’s: Expand application of electrification technology to commercial aircraft (Smaller than narrow body).

2040’s: Greatly reduce the fuel consumption of aircraft with electrification as the core technology.

2050’s: Reach the ideal goal of electrification. Clear contribution to CO$_2$ reduction.

Year 2020 2030 2040 2050

ECLAIR web site:  http://www.aero.jaxa.jp/about/hub/eclair/index.html  E-mail to (Consortium office): eclair_sec@chofu.jaxa.jp
3.2 System Types (2/4 Early Stage of Hybrid Mode)

Early stage electric hybrid system which is easily applicable to commercial aircraft.

- Parallel hybrid
- Twin engines
  
  ✓ Possible to continue conventional Tube&Wing design mostly as is.
  ✓ Possible to suppress the electrification power level to small values.

- Series-parallel-partial hybrid
- Twin engines + Elec. fan aft fuselage

Relatively high risk system.

- Series hybrid
- Multi-distributed fan design
  
  ✓ Departure from conventional Tube&Wing design
  ✓ Electrification power level is maximum

● As an early stage electric hybrid system for commercial aircraft, systems such as parallel hybrid and series-parallel-partial hybrid are the strong candidates as these can continue the conventional Tube&Wing design and suppress the electrification power level to small values.
Map of Technological Challenges (1/2 Reduction in Fuel Consumption※)

- **Reduction in fuel consumption**
  - Improvement in thermal efficiency
  - Weight reduction
  - Improvement in propulsion efficiency
  - Improvement in lift/drag ratio

- **Applicable technology field**
  - High efficiency motor
  - High efficiency generator
  - High efficiency inverter
  - High efficiency converter
  - High capacity storage cell
  - Low loss power transmission
  - Low loss breaker/distributor
  - High efficiency fuel cell
  - High efficiency cooling system
  - High power density motor
  - High power density generator
  - High power density inverter
  - High power density converter
  - High energy density storage cell
  - High power density auxiliary equipment
  - Light weight liquid hydrogen tank
  - High power density fuel cell
  - Advanced technology material

- **Electrification technology**
  - Next generation high performance motor
  - Next generation high performance generator
  - Advanced heat resistant material
  - Advanced insulation material
  - Advanced magnetic material
  - Advanced conducting material
  - Digital twin
  - Advanced technology sensor
  - All superconducting motor
  - Superconducting power transmission
  - Extreme low temperature composite material tank
  - Post Li-ion battery
  - Advanced technology material

- **Notes**
  - ※1: BLI (Boundary Layer Ingestion)
  - ※2: BWB (Blended Wing Body)
  - ※Note: Here, technologies only for small aircraft and those common to both passenger and small aircraft are described without distinction.
## Extraction of Important Technological Issues

<table>
<thead>
<tr>
<th>Classification</th>
<th>No.</th>
<th>Important Technological Items (Summary)</th>
<th>Elements/System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A) Important technological issues common to all altitudes</strong></td>
<td>①</td>
<td><strong>High power density</strong>&lt;br&gt;(Feasibility for weight secured; heat-resistance, cooling, and heat dissipation for securing running time with maximum power output.)</td>
<td>Electrical elements (electric motor, generator, power electronics, batteries, circuit breaker, distributor, electrical wires, etc.)</td>
</tr>
<tr>
<td></td>
<td>②</td>
<td><strong>Compatibility of safety in batteries and high energy density</strong>&lt;br&gt;(Compatibility of containment of runaway over-heating risk and high energy density of the cell system as a whole.)</td>
<td>Batteries (Power storage)</td>
</tr>
<tr>
<td></td>
<td>③</td>
<td><strong>High efficiency</strong>&lt;br&gt;(Improvement of propulsion efficiency by BLI and distributed propulsion system, improvement of heat efficiency of propulsion system.)</td>
<td>Integration of propulsion and airframe system, hybrid system, electrified elements.</td>
</tr>
<tr>
<td></td>
<td>④</td>
<td><strong>Assurance of safety and reliability</strong>&lt;br&gt;(Assurance of safety and reliability of the system with increased failure rate due to addition of electrification components.)</td>
<td>Electrified propulsion system, hybrid system, electrified elements.</td>
</tr>
<tr>
<td><strong>B) Important technological issues only in high altitude environment</strong></td>
<td>⑤</td>
<td><strong>Withstanding electrical discharge and radiation</strong>&lt;br&gt;(Managing high voltage element, system discharge, and radiation effect in high altitude environment)</td>
<td>Power electronics, electric motor, generator, electrified elements.</td>
</tr>
<tr>
<td></td>
<td>⑥</td>
<td><strong>Heat and power management and control</strong>&lt;br&gt;(Heat and power management under low air density and high temperature environment in and out of the gas turbine engine.)</td>
<td>Electrified elements, electrified propulsion system, hybrid system.</td>
</tr>
<tr>
<td><strong>C) Important technological issues only under low altitude operation</strong></td>
<td>⑦</td>
<td><strong>Fault resistance</strong>&lt;br&gt;(Fault resistance and fault tolerance design against emergency landing or continued flight with propulsion system failure)</td>
<td>Electrified propulsion system.</td>
</tr>
<tr>
<td></td>
<td>⑧</td>
<td><strong>Low noise</strong>&lt;br&gt;(Reduction of aerodynamic noise from fans and propellers)</td>
<td>Fans, propellers.</td>
</tr>
</tbody>
</table>
Electrification ChaLlenge for AIRcraft (ECLAIR) Consortium

**Technology Road Map**

**Vision for Future**

- **Small**
- **MEA**
- **Narrow**
- **Wide**
- **Ideal**

**Progress of Development**

- Development of aircraft
- Demonstration environment
- System development/integration
- Research and development
- Choice of method
- Feasibility study
- Formulate strategy

**Year**

- **2020**
- **2030**
- **2040**
- **2050**

**2020**
- High power density
- Adapting to high altitude environment
- High efficiency electric system
- High energy density cell, safety

**2030**
- MEA system
- Electric hybrid system
- High energy density cell, safety

**2040**
- Combined cycle, use of liquid hydrogen
- BWB design
- Multiple and distributed series propulsion fan
- Super conductivity

**2050**
- Reach the ideal goal of electrification
- Clear contribution to CO₂ reduction

- Conduct ground test and flight demonstration with an appropriate timing for practical implementation.
- The common technology such as the high power density of the electrical element can be expanded not only to the commercial aircraft but also to MEA and small electrified aircraft at an early stage.
## Technology Development Group

<table>
<thead>
<tr>
<th>Area</th>
<th>No</th>
<th>Name of sub group</th>
<th>Objectives</th>
<th>Main organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>① Cooperative</td>
<td>①-1</td>
<td>Aircraft electrification common basis</td>
<td>• Sharing the aircraft concept (Technology Reference Aircraft) to be developed&lt;br&gt;• Sharing tools and methods for performance evaluation at aircraft levels</td>
<td>JAXA + 15 organizations</td>
</tr>
<tr>
<td></td>
<td>①-2</td>
<td>Business model of small electric aircraft and consideration of ground infrastructure</td>
<td>• Study of use cases and business model for eVTOL in Japan&lt;br&gt;• Consideration of ground infrastructure such as charge point and verti port</td>
<td>Keio univ. + 13 organizations</td>
</tr>
<tr>
<td>② Competitive</td>
<td>②-1</td>
<td>Development of high power density electric motor adapting advanced magnetic circuit technology</td>
<td>• High power density motor&lt;br&gt;• Demonstration with prop</td>
<td>DENSO</td>
</tr>
<tr>
<td></td>
<td>②-2</td>
<td>High altitude environment adaptive power conversion and distribution system</td>
<td>• High power and light weight power conversion / distribution&lt;br&gt;• Partial discharge suppression / radiation resistance</td>
<td>MELCO</td>
</tr>
<tr>
<td></td>
<td>②-3</td>
<td>Low-noise propeller for eVTOL application</td>
<td>• CFD &amp; experimental study of loop-shaped low noise propeller for eVTOL applications</td>
<td>JAXA</td>
</tr>
</tbody>
</table>
Summary

- The electrification technology for aircraft is the key to achieve dramatic reduction of CO2 emission from passenger aircraft and innovative changes to everyday transportation services for small aircraft.
- Through open innovation by strengthening cooperation with different sectors, aim for expansion of the aviation industry by applying the electrification technology, which Japan has the technological advantage, to the aviation field.
- JAXA, under the cooperation of Electrification Challenge for Aircraft Consortium, promotes the research and development of the technology that is essential to the common system components of small and passenger aircrafts and that greatly contributes to fuel consumption reduction.
- We shall continue extending the results from above for electrification of the components of small aircraft in the short to mid term plan, and for electrification of the passenger aircraft in the long term plan.
Thank you!

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