Measurement of dynamic rotor blade deformation (BLADESENSE)

Airbus Helicopters UK, Cranfield University, BHR Group, Helitune

Project details:

Improving the efficiency of future transport systems is a significant aspect of the UK’s strategy towards sustained economic growth. This not only requires innovation in the areas of aircraft design and manufacture, but also a focus on means of improving the efficiency of processes for aircraft maintenance and operations.

The overall project objective is to develop a high performance, robust instrumentation system capable of operating in the challenging and harsh environment of a helicopter rotor hub. This will provide the capability to monitor the health of the rotor blades through direct blade shape deformation measurements. Such technology brings benefits to operator and maintainer through continuous in-flight monitoring which results in flight safety, operations and maintenance and contributes towards reductions in point to point travel time.

Existing methods using strain gauges have numerous disadvantages. These range from operational limitations, such as high sensitivity to temperature and precipitation to fundamental limitations, such as the collection of strain data from which shape deformation can only be indirectly inferred. The search for new measurement techniques has been the subject of numerous studies, yet, none of these methods are mature enough to be efficiently used in flight test.

The activities within the project will be focusing on (a) the development of a fibre-optic instrumentation for direct shape deformation measurement, (b) transfer of data between the rotating rotor hub and the airframe and, (c) incorporation within a health monitoring solution. The key requirements are high reliability, robustness to weather conditions, sufficient sensory bandwidth and simple integration in or outside of the airframe. Moreover, an investigation of all potential avenues of exploiting such a technology within the rotorcraft industry will be performed to maximise the impact of the project.

Figure 1: Project Overview
Table 1: Summary of the project grant details

<table>
<thead>
<tr>
<th>Project</th>
<th>Funding</th>
<th>Lead Partner</th>
<th>No. of Partners</th>
<th>Partner Composition</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>102381</td>
<td>Total: £2.0m</td>
<td>Airbus Helicopters</td>
<td>4</td>
<td>1 Large companies, 2 SMEs</td>
<td>Nov 2015-Nov 2018</td>
</tr>
<tr>
<td>BLADESENSE</td>
<td>Grant: £1.0m</td>
<td></td>
<td></td>
<td>1 Academic</td>
<td></td>
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Table 2: Summary of the project focus areas

<table>
<thead>
<tr>
<th>ATI Value Streams</th>
<th>ATI Enablers</th>
<th>ATI Attributes</th>
<th>Strategic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Aircraft</td>
<td>Aerodynamics</td>
<td>x Safety</td>
<td>x Secure</td>
</tr>
<tr>
<td>Structures</td>
<td>x Manufacturing</td>
<td>Cost</td>
<td>x Exploit</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Materials</td>
<td>Environment</td>
<td>x Position</td>
</tr>
<tr>
<td>Systems</td>
<td>Infrastructure</td>
<td>Fuel Burn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Process and Tools</td>
<td>x Operational Needs</td>
<td>x Passenger Experience</td>
</tr>
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Technology Achievements:

Sensor technology scope:

- Measure the dynamic strain and shape of helicopter blades using robust sensors.
- Exploit fibre-optic sensors integrated along the blade length.
- Locate instrumentation in the hub support cap.
- Data transmission using WiFi to stream strain and blade shape data during operation for health monitoring.

Roles of the collaborative partners:

Airbus Helicopters UK, being the lead partner in this collaborative project, is not only responsible for coordinating the technical challenges of this project, but also for the experimental testing phase. This includes static and dynamic testing, preparation of the flight test with the RT-Tip Trak in conjunction with Helitune, and also providing the rotor blades for the installation of the fibre-optic instrumentation system. Airbus Helicopters UK’s engineering, manufacturing and flight test teams will design, manufacture and install the Bladesense system to a helicopter, along with the necessary modification approval, in order to conduct dynamic testing of the system and technology on an H135 helicopter.
Cranfield University is responsible for the design and development of the fibre-optic instrumentation. In order to measure strain on a surface often commercial available fibre Bragg gratings (FBG) are used. If a FBG is under strain, a wavelength shift ($\lambda$) occurs from which the fibre strain can be calculated. Up to 4 fibres with 64 FBGs can be placed along a helicopter blade to measure strain during powered operation and stream live data for analysis.

A novel approach of the instrumentation technology allows direct dynamic shape sensing within a low-profile multi-core fibre/fibre bundle. The advantage of direct fibre optic shape sensing is the use of interferometric interrogation of fibre segments. This allows much higher curvature sensitivities when compared to other optical fibre based indirect curvature measurement approaches, for example, FBG based approaches, using similar numbers of sensors. Other shape sensing approaches require either a model of the underlying structure (indirect shape sensing) or require a solid guiding structure to which the fibre is attached to and which needs to be attached to the object to be measured. For this project, the use of indirect shape sensing is undesirable. It requires knowledge of, and perfect strain transfer from the underlying structure and the measurements can be compromised by temperature fluctuations.

Besides developing the instrumentation system, Cranfield University will develop a mathematical framework for optimal fibre optic sensor positioning. This mapping task is defined as an optimization problem based on results from finite element analysis. It will be ensured that the fibre optic mapping is in accordance with the instrumentation’s design parameters. With the use of CFD/FEA (FSI) simulations, BHR Group will develop a computationally efficient, validated mathematical model to predict the mechanical loading and the deformation of the blades for various flow conditions. The simulation results will provide input data for the development of a computationally efficient mathematical model using stochastic methods. Experimental data from flight trials using Helitune’s RT-TripTrak camera to measure blade tip deflection is used to validate FSI simulations and the stochastic models.
Helitune are responsible for providing the “black box”, the HT-VHM, to capture and record data generated from the fibre optic sensor systems (developed by Cranfield University). Helitune is focusing primarily on the integration of the HT-VHM, specifically its Mini-HUMS offering, on the H135 to capture data not only from the fibre optic sensors, but also from other sensors and on-board avionics.

In conjunction with the information provided by the fibre optic sensors Helitune can, by installing and capturing data from the RT-TipTrak, feed additional information into the stochastic model being generated by BHR Group and Cranfield University.

Table 3: Summary of the technology achievements

<table>
<thead>
<tr>
<th>Project</th>
<th>Performance Improvements</th>
<th>TRL Progression</th>
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<tbody>
<tr>
<td>102381</td>
<td>Development of novel fibre optic instrumentation system</td>
<td>TRL 4 – Nov 2017</td>
</tr>
<tr>
<td>BLADESENSE</td>
<td>Reduction of rotor blade maintenance costs by up to 40%</td>
<td>TRL5 – Sep 2018</td>
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Economic Impact:

The output of this project will be unique and its applicability universal. Its development will lead to implementation opportunities on board both fixed wing and rotary wing aircraft and even on wind turbines. The return for the investment in this research will come in the form of:

- reduced maintenance
- increased product life
- improved fleet availability.

During the entire life of a rotor blade, the customer spends around £75,000 for the periodic 1000hrs inspection. This excludes repair issues which have to be addressed every 5000 hours.

With this new technology being able to inform the decision as to when to carry out inspections and repairs, it is envisaged that the maintenance costs can be reduced by up to 40%.

The figure below gives an overview of the forecasted impact on maintenance of a rotor blade during its entire lifecycle. A comparison is shown between current periodic maintenance cycles of the rotor blade and the reduced maintenance cycles to be achieved in the future.
Industrial impact of BLADESENSE

The proposed technology will impact Airbus Helicopters market share (one of the largest share of the rotorcraft market) and additionally this customer tailored maintenance will impact directly the UK economy via efficiency gains in sectors where helicopters see significant usage. These will in turn allow the UK rotorcraft sector to respond to growing customer needs and increase its competitiveness.

Assuming the recovery of investment within three to four years and upgrades on 450 rotorcraft, Helitune alone can increase their profit by £1M (at 10% profit margin) and significantly increase their annual turnover from such instrumentation (sales of RT-TipTrak camera and Mini-HUMS system HT-VHM).

This new measurement technology provides AH UK with the perfect opportunity to develop in-house expertise, methods and tools, as well as a research portfolio covering the key areas of:

- instrumentation systems experimental flight testing
- aerodynamics and aerostructures (via collaboration with BHR group)
- vehicle health monitoring (via collaboration with Helitune)

Exploitation plans:

- Exploitation in rotary applications through development of key technologies, such as direct shape sensing sensors to use for track and balance systems for helicopters.
- Investigation of how the sensed blade deformations can be exploited in the overall aircraft design, such as flight control, blade design and other systems.
- Spill-over into fixed-wing or wind turbine technologies due to robust measurement technology.
- Supporting the UK MRO sector in order to increase product life of the rotor blades, reduce maintenance time and improve fleet availability.

“BLADESENSE is developing unique technologies for accurate, real time measurement of rotorcraft blade deformation during flight. Although blade deformation in flight is standard and blades are designed to flex in flight, this project will provide an opportunity to further reduce costs and improve predictive maintenance and monitoring. Key benefits are to both pilots and crew as a result of higher reliability and enhanced safety. This research project expands Britain’s capability and skills through Airbus Helicopters UK’s development and application of world-leading advanced modelling, sensing and flight testing technologies.” Richard Atack Vice-President Design and Customisation at Airbus Helicopters UK Ltd