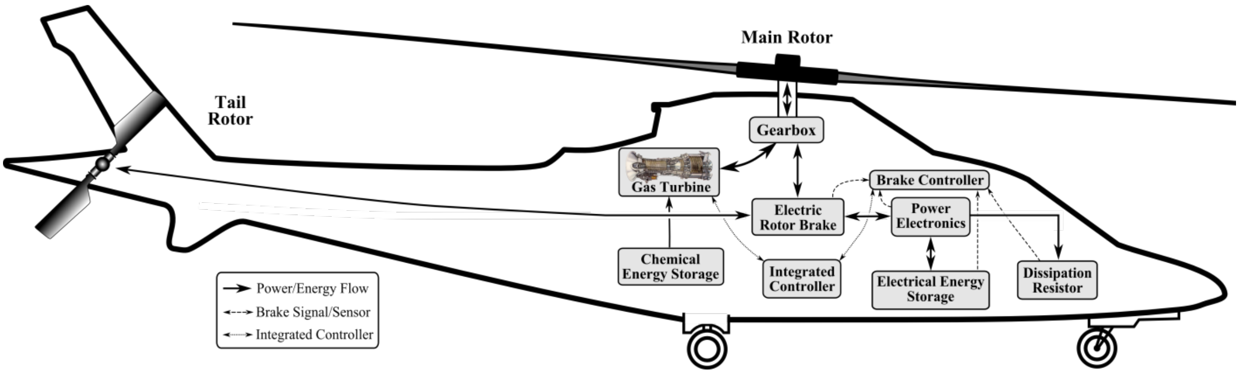
HERRB – Helicopter Electric Regenerative Rotor Brake



Publishable Summary

State of the art – Background

The trend towards increased use of "more-electric systems" in fixed-wing aircraft is motivated by improved overall system efficiency, reduced fuel burn and lower maintenance costs.

Compared to large civil aircraft the "more-electrification" of rotorcraft is less advanced. If approached holistically, replacement of conventional power systems with electric equivalents has equal potential for fuel savings and reduction in whole life costs. However, for these benefits to be realised significant architectural changes are needed

To reduce development risk, the JTI Clean Skies Rotorcraft is employing a range of technology, that, together, would demonstrate the significant fuel saving and performance benefits required for adoption in future rotorcraft.

One potential route to improve the overall system efficiency of an rotorcraft's electrical system is to recover energy from the aircraft that would normally be lost. In a rotorcraft, a significant amount of energy is stored in the rotating blades of the main rotor system. In all current helicopters, this energy is dissipated through a conventional mechanical brake as heat and hence wasted.

An electric machine can be used to provide a controlled regenerative deceleration of the main rotor. Given that the braking function would only be required after the aircraft has landed, further benefits include:

- the unit could be used as an electric generator during normal flight, allowing the de-rating of the existing electrical generators.
- provision of an electrically assisted start procedure
- provision of an electrically assisted and controlled autorotation in the event of main engine failure

Objectives

The main project aim is the delivery of model based design framework and construction of a full-scale, all-electric braking system prototype for the main and tail rotors of a helicopter including a static brake.

The final solution should be as weight competitive with the systems that it intends to replaces as possible. Hence, a critical element of the project presented here will be to minimise the weight of the system well below existing commercially available machines, exploiting the very low duty cycle required from the application whilst maintaining the levels of safety and reliability needed from this type of aircraft system. For this to be viable, a thorough understanding of the electrical and thermal behavioural of the electric braking system must be formulated, resulting in the lowest mass system possible.

The objectives of the project are:

1. To determine and demonstrate the suitability of the finally selected electrical braking architecture as the ideal candidate for the dynamic braking application being studied
2. To deliver the capability of accurately modelling the electro-mechanical behaviour of a full regenerative rotor braking system for the selected topology under a range of rotor braking scenarios.

3. To evaluate the thermal and dynamic performance of the supplied prototype regenerative rotor braking system.
4. To demonstrate the capability and suitability of the final solution to be integrated to an existing rotorcraft's transmission with minimal design modifications.

Description of work

The work in the HERRB project can be broadly categorised into four main areas being covered by seven technology focused work packages:

WP0.	Design Specification
WP1.	Rotor Deceleration System
WP2.	Electrical Power Conditioning
WP3.	Rotor Stop and Hold Mechanism and Control
WP4.	Aircraft Installation Configuration
WP5.	Safety and Certification
WP6.	Prototyping and Test

and a management work package:

WP7.	Management

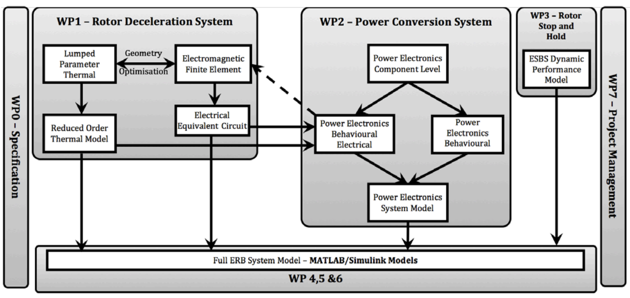


Figure 1: Integration of Work Packages

The inter-dependence of the technology focused work packages can be seen in Figure 1.

Specification (WP0)

The call for proposal outlined the aim of the project and gave an outline of aircraft level requirements specific for a braking application. In order to allow for a meaningful comparison and to agree target requirements that meet the Technology Readiness Level (TRL) of the Call for Proposal (CfP) a detailed specification was carried out based upon research of the state of the art in the area, current standards, focus groups with project stakeholders and the relevant Green Rotorcraft team (GRC3) lead. The Preliminary Design Specification (PDS) that resulted drove the design of each of the various systems in each of the project packages (WPs).

The preliminary design specification encapsulated requirements for both the mechanical and electrical systems of a potential solution to the problem of electrically actuated main rotor braking.

Rotor Deceleration System (WP1) and Electrical Power Conditioning (WP2)

WP1 & 2 focused on the design and optimisation of the dynamic (or regenerative) aspect of the rotor brake. Detailed and coupled modelling of the thermal and electromagnetic and electric machine, power electronics based converter and drove the final design towards a minimum installed mass of the entire system rather than on a component wise basis.

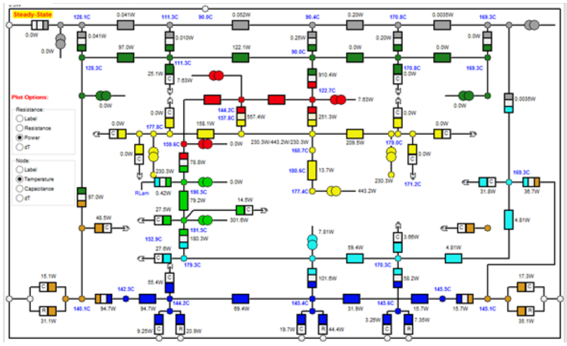


Figure 2: Electric Machine Thermal Model

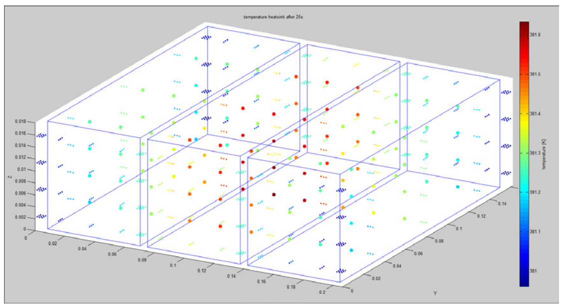


Figure 3: Transient Heatsink Model Showing Transient Temperature Variation in Heatsink

Results Generated

During the course of the project the following scientific/technological results were generated:

- Integrated machine design for used in a medium sized rotorcraft without supplementary cooling
- Development and calibration of a full thermal model for the finally selected topology of electric machine
- Validated optimisation process for balancing of DC and AC copper losses in the design process of a fixed speed electric machine.
- Process for early stage (pre-prototype) calibration of complex stator assemblies in thermal models
- Design and test of a magnetically active mechanical wedge for secure, vibration resistant coil retention in concentrated wound open slot machines.
- Temperature dependent system level models for fast simulation of converter/heatsink thermal behaviour including machine and controller behaviours.
- Validated switching period based calculation of losses with potential for real-time estimation of losses

Rotor Stop and Hold Mechanism and Control (WP3)

WP3 considered the design of the electric static (or holding) brake from the concept stage right through to embodiment and final prototype. Unlike the dynamic brake, topological constraints existed on this aspect of the design resulting in a large solution space that needed be methodically and objectively searched resulting in an integrated and optimum final outcome.

A morphological approach was used to devise concepts that could potentially satisfy the requirements based its individual sub-functions. These were then rated and ranked objectively yielded the final design. A new modelling framework and generation of new data was created/measured to support the design optimisation to ensure a low-mass final design.

A final optimisation phase was conducted that demonstrated that without functionally altering the method of operation and hence final performance, an aircraft system could be realised at a mass much lower than that of the initial prototype.

Results Generated

During the course of the project the following scientific/technological results were generated:

- Morphological approach to a system design for a static electric helicopter brake
- Validated generalised design framework for the finally selected static, electrical braking system
- Static and quasi-static co-efficient of friction data for key materials used in friction-based braking systems
- Validate and optimised solution to the static braking requirement for a medium size helicopter

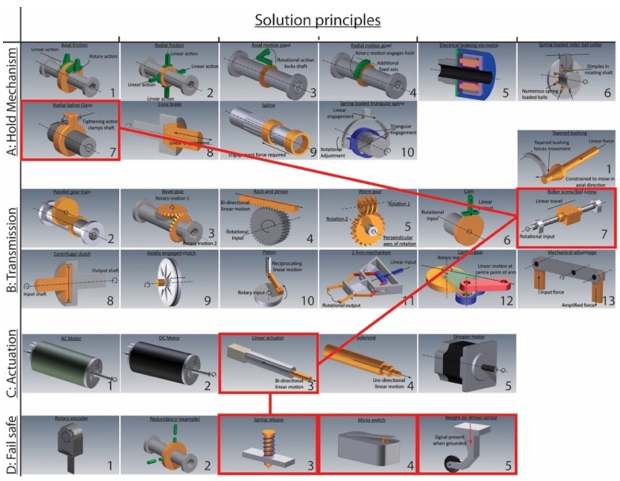


Figure 4: Morphological Chart

Aircraft Installation Configuration (WP4), Safety and Certification (WP5)

WP4 considered the designs proposed in WP 1, 2 & 3 and based jupon analysis or optimisation of the designs, ensured that they met as closely as possible at the prototype stage requirements for a modern rotorcraft in terms of packaging, integration, reliability and safety.

A full analysis of the machine integrity (static and dynamic) was undertaken and demonstrated that the assembly was both functional and designed to safety factors appropriate to the function of the brake and the TRL being pursued. The principle exciting frequencies were identified and the implications of tight integration of the rotor brake highlighted.

A system-level model was constructed that took low- (or component-) level data as its input and abstracted it to the detail required to allow simulations of long time durations to be undertaken allowing loss analysis under various scenarios to be reviewed.

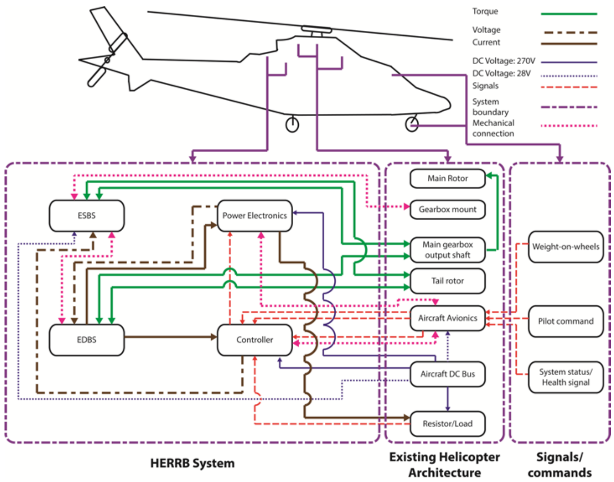


Figure 5: Full HERRB systems and interactions

Various case studies were compared in terms of time to achieve a complete braking cycle, energy recovered on land, total predicted conversion efficiency. The toolchain also permitted the ability to conduct an initial study into the potential for the electric machine and converter (electric dynamic brake) to act as a rotor acceleration device prior to the rotorcraft engines being engaged for a simultaneous engine and main rotor start.

As well an an integration study, a reliability and full failure modes and effects analysis was undertaken for the prototype solutions proposed within the HERRB project based upon their state of development at the critical design review (CDR).

The study demonstrated several cases for all severity ratings in which the reliability of the developed systems fell outside of the target ranges for that severity rating highlighting those system that would require further attention prior to being considered to be sufficiently fault tolerant to enter service.

Results Generated

During the course of the project the following scientific/technological results were generated:

- Design modelling framework for assessing the compatibility of the rotor brake prototype with an existing airframe
- Full system non-linear level coupled model of the chosen electric drivetrain derived directly from component level analysis
- Application of system model for optimisation of prototype subsystems based upon system-wide constraints.
- Generation of reliability data and associated fault assessments for full permanent magnet electric drive systems of significant power.
- Fault tree analysis of a braking system for a helicopter considering all possible interactions between various subsystems and harsh environment experienced during rotorcraft flight.

Prototyping and Test (WP6)

A test rig was constructed that could operate over the operating ranges of the prototyped equipment.

Each of the three systems were prototyped based upon the status of the designs at the Critical Design Review.

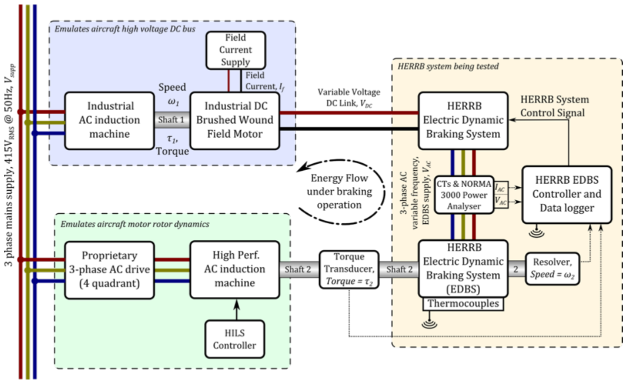


Figure 6: EDBS Dynamometer Design

Each of the systems was tested in order to both characterise that system and provide validation data for the modelling tools developed. Test results demonstrated that the final machine prototype had an electromechanical performance very close to that predicted.

Generator ratings were measured based upon needing enough thermal headroom to accommodate the extra measured transient temperature rise required for a single optimised braking cycle. The results agreed well with the predictions made in the thermal model at the Critical Design Review.

Predicted generator continuous ratings were measured at lower values than predicted at the Critical Design Review. Calibration of the thermal modelling highlighted the primary factors responsible for the differences between predicted and measured behaviour.

The power converter measurements demonstrated results commensurate with expectations for a such converter, as predicted by the modelling activity. This confirmed the converter to be an appropriate match for the electric machine.

Results Generated

During the course of the project the following scientific/technological results were generated:

- Manufacture and characterisation of a full-scale integrated electric machine prototype for use on the main gearbox of a medium-sized aircraft
- Validation of the structure of the thermal model and the results output from the finally calibrated thermal model for the electric machine
- Validation of a real-time capable loss predicting mechanism for a IGBT-based power electronic converter which has the potential not only to inform design but allow continuous optimisation of drive operation in real-time.

Timeline & Main Milestones

M04 (Jan '12) Detailed Specification Agreed

M10 (Jul'12) Modelling tools finalised and trade studies for proposed architectures completed

M15 (Dec '12) Preliminary Design Review

M23 (Aug '13) Critical Design Review

M40 (Nov '14) System prototype constructed

M42 (March '14) System characterised and benefits demonstrated.

Environmental benefits

The developed system is capable of capturing and allows re-use of a significant amount energy on the rotorcraft that is current dissipated each time the aircraft is stopped.

The suitability of the developed system to replace existing equipment on the aircraft, reducing total system mass and thereby improving overall fuel efficiency of the aircraft has been shown.

Maturity of works performed

The work resulted in a TRL 5 prototype system in which the architecture, subsystems, components the majority of the packaging, would be representative of those which could be installed in an aircraft demonstrating the potential for flight worthy operation.

Project Summary

Acronym :	HERRB
Name of proposal:	Helicopter Electrical Regenerative Rotor Brake
Technical domain:	Aircraft Electrical Drives
Involved ITD	Green Rotorcraft
Grant Agreement:	
Instrument:	Clean Sky
Total Cost:	698330€
Clean Sky contribution:	523748€
Call:	JTI-CS-2011-01-GRC-03-007
Starting date:	Oct 2011
Ending date:	March 2015
Duration:	42 months

Coordinator contact details: Dr. David Drury

✉ Room 5.03, Merchant Venturers Building

Woodland Road, Bristol, BS8 1UB

United Kingdom

☎ +44 (0) 117 954 5390

d.drury@bristol.ac.uk

Project Officer: Andrzej B. Podsadowski

mailto:Andrzej.Podsadowski@cleansky.eu

Participating members		
	UNIVERSITY OF BRISTOL	UK
	MOTOR DESIGN LIMITED	UK
	ADAPTED SOLUTIONS GmbH	DE