Institution:
University of Glasgow

Unit of Assessment:
B15: General Engineering

Title of case study:
New gyroplane design standards improve flight safety

1. Summary of the impact

As a direct result of University of Glasgow research, there have been no deaths in a gyroplane accident in the UK since 2009. Previously, gyroplanes (also known as autogyros) had a questionable safety record. Following fifteen years of comprehensive studies, researchers recommended innovative new design standards to the Civil Aviation Authority. These recommendations led to the introduction of new civil airworthiness requirements in the UK, subsequently adopted by Australia and Canada. The implementation of these revised regulations has forced gyroplane manufacturers to change their designs. Close to 2000 machines have been produced since this design change, revolutionising gyroplane safety worldwide.

2. Underpinning research

A gyroplane is a type of rotorcraft that is supported in flight by a rotor providing lift. Unlike a helicopter, a gyroplane's rotor is driven only by aerodynamic forces (air pressure) once in flight, and thrust is provided by an engine-powered propeller similar to that of a fixed-wing aircraft. Following a spate of unexplained fatal accidents involving light gyroplanes between 1989 and 1991, the UK Air Accident Investigation Branch recommended the funding of a research programme to improve the understanding of aerodynamics and flight mechanics of gyroplanes. A call for tenders was issued by the UK Civil Aviation Authority (CAA). The team of Dr Douglas Thomson (Senior Lecturer Aerospace Sciences, 1986-present) and Dr Stewart Houston (Senior Lecturer Aerospace Sciences, 1991-present), from the School of Engineering at the University of Glasgow, were awarded the contract in 1992. Thomson and Houston were well-placed to carry out this research, with 22 years of proven rotorcraft experience including wind tunnel testing, simulation and modelling expertise between them.

At the outset of the research programme in 1993, the aim was to establish the general stability characteristics of a gyroplane and then determine which aspects of its design were most influential on its dynamic characteristics [1, 2]. The research consisted of mathematical modelling, development of simulations, wind tunnel testing and flight tests. Over the next 15 years the research team secured a series of seven research contracts from the CAA to continue to develop the understanding of gyroplane behaviour [3, 4]. The primary output of these research contracts with the CAA was an engineering mathematical model of the aircraft so that design features, changes and hypothetical situations could be examined without the need for physical testing. The mathematical model, RASCAL, is a high-order, high-fidelity simulation tool previously developed at the University of Glasgow to investigate helicopter-related problems. For the CAA-funded research it was reconfigured to represent the gyroplane – the first time such a comprehensive model had been applied to gyroplanes.

Ongoing research checked the fidelity of the model against flight test data gathered during a number of campaigns with two fully-instrumented light gyroplanes using specialised flight test techniques involving stylised and unusual control inputs [3]. The resulting data was analysed using sophisticated mathematical analysis techniques, demonstrating that the vertical location of the centre of mass in relation to the assumed propeller thrust line is the key parameter leading to aircraft instability. This was a particularly important finding since the incorporation of more powerful engines and larger propellers into gyroplane design had resulted in the propeller being raised to ensure clearance with the craft's keel, thereby raising the centre of mass and reducing stability.

The key research findings from this extensive body of work include:

- Gyroplane aerodynamic properties are relatively insensitive to configurational changes [1, 2]. This was the result of wind tunnel testing.
- Gyroplanes exhibit a mix of stability characteristics typical of those of fixed wing aircraft and helicopters [5, 6].
- Raising the propeller location to ensure clearance with the craft's keel could result in aircraft instability.
- A centre of gravity location above the propeller thrust line, created by lowering the keel, has a significant stabilising effect (on the pitch stability mode).

The key output was the 2008 report to the CAA recommending gyroplane design changes including lowering the keel. The report's findings were integrated into CAA's current British Civil Airworthiness Requirements (BCAR) Section T: Light Gyroplanes, legislation which governs the safety of gyroplanes.

3. References to the research

1. Houston, S.S. (1996) Longitudinal Stability of Gyroplanes. The Aeronautical Journal, **100** (991), pp. 1-6. (Available from HEI) *
2. Houston, S.S. (1998) Identification of Autogyro Longitudinal Stability and Control Characteristics. AIAA Journal of Guidance, Control and Dynamics **21**(3), pp. 391-399, (doi:10.2514/2.4271)
3. Thomson, D.G., and Houston, S.S. (2005) Application of parameter estimation to improved autogyro simulation model fidelity. Journal of Aircraft, **42**, pp. 33-40. (doi:10.2514/1.3964)
4. Houston, S.S. (2002) Analysis of rotorcraft flight dynamics in autorotation. Journal of Guidance Control and Dynamics, **25**, pp. 33-39. (doi:10.2514/2.4872) (Available from HEI) *
5. Bagiev, M., and Thomson, D.G. (2009) Handling qualities evaluation of an autogiro against the existing rotorcraft criteria. Journal of Aircraft, **46**(1), pp. 168-174. ISSN 0021-8669 / (doi:10.2514/1.37289). *
6. Thomson, D.G., Houston, S.S. and Spathopoulos, V.M. (2005) Experiments in autogiro airworthiness for improved handling qualities. Journal of the American Helicopter Society, **50**, pp. 295-301. (Available from HEI)

* best indicators of research quality

4. Details of the impact

Over a period of 15 years, Thomson and Houston developed models and simulations which greatly improved the general understanding of gyroplane aerodynamics and behaviour for manufacturers, regulators and operators across the world.

Implementation of new civil airworthiness requirements in the UK

As a result of this comprehensive University of Glasgow research, stringent requirements are now in place to ensure that only airworthy gyroplanes are permitted to fly in the UK. Reports submitted by Thomson and Houston led directly to the CAA's current British Civil Airworthiness Requirements (BCAR) Section T: Light Gyroplanes, legislation which governs the safety of gyroplanes.

Following a first set of flight trials, Thomson and Houston carried out an analysis of existing BCAR Section T requirements to inform their next phase of research. As the research progressed, regular contractor reports were submitted to the CAA, enabling a process of continual revision of the requirements. University of Glasgow recommendations relating to gyroplane longitudinal stability were incorporated in 2005. In 2011, the requirements were updated again, introducing a number of changes arising from the increased understanding of the flight characteristics of gyroplanes gained by the University's ongoing research into stability and an investigation into rotor dynamics.

International influence of BCAR Section T

Internationally, the 2011 revised requirements have been adopted in Australia and Canada. In Germany, although not adopted, they are treated as advisory requirements.

The implementation of revised regulations for gyroplane design and modifications forced the main European manufacturer, AutoGyro of Germany, to change its designs. Between AutoGyro and RotorSport UK, the leading UK gyroplane manufacturer, close to 2,000 machines have been produced since this design change and are in use worldwide. Even in countries where the UK CAA standards have not been applied, the research is well-known and also influences gyroplane design. Visual evidence of this can be seen in modern gyroplanes where dropped or stepped keels, inclined powerplant thrust lines or lowered powerplant installations can be found. These changes improve the aerodynamic characteristics of the gyroplane, thereby improving safety for the pilots and passengers.

Original straight keel. When the propeller size increased it was necessary to raise the height of the propeller to avoid the keel – this introduced instability.

Dropped/stepped keel introduced as a result of the University of Glasgow recommendations to CAA, adopted in BCAR Section T. The dropped keel enables the propeller to remain low, maintaining stability. (Image courtesy of RotorSport UK Ltd)

Reduced fatalities in the UK

This research has had a direct impact on lowering light gyroplane fatal accidents. The fatal accident rate between 2000 and 2009 was 1 per 2500 hours. Since 2009, there have been no fatal accidents in the UK. For this period, most of the UK fleet are of modern designs influenced by the University of Glasgow research (there has been one fatality in the sector due to deliberate illegal action).

The UK Air Accident Investigation Branch regularly cites the University of Glasgow research in accident reports. In fact, Thomson and Houston's mathematical model, developed since 1993, has been used in simulations to assist in the investigation of every fatal accident since 1996.

5. Sources to corroborate the impact (indicative maximum of 10 references)

- Civil Aviation Authority paper 2009/02 University of Glasgow Report: The Aerodynamics of Gyroplanes. This report describes all work undertaken for the CAA between November 1993 and June 2008. http://www.caa.co.uk/docs/33/Paper2009_02red.pdf.
- British Civil Airworthiness Requirements Section T Light Gyroplanes.
- Australian Aviation Legislation: Overview of the legislative framework enabling sport and recreational aviation, demonstrating the BCAR Section T as adopted by Australian authorities for gyroplanes. http://flysafe.raa.asn.au/regulations/regulations.html
- Auto-gyro GmbH – evidence that their designs comply with BCAR T (page 11)
- Online article that includes a discussion of the gyroplane instability issue and the Glasgow Research related to an accident. http://www.gremline.com/index_files/page0052.htm
- Statement from Managing Director of RotorSport UK, stating that all Rotorsport UK and AutoGyro GmbH gyroplanes are built to comply with BCAR-T and that they have almost 2000 in service (available from HEI).
- Technical Manager, Airworthiness Evaluation and Surveillance, Safety & Airspace Regulation Group, UK Civil Aviation Authority will corroborate the impact that the University of Glasgow research has had on Gyroplane Regulations BCAR-T (contact details provided).