ARISTOTEL is funded by the
European Commission under
the 7th Framework Programme.

Aircraft and Rotorcraft Pilot Couplings – Tools and Techniques for Alleviation and Detection

NEWSLETTER

Project acronym:	ARISTOTEL
Project full title:	Aircraft and Rotorcraft Pilot Couplings – Tools and Techniques for Alleviation and Detection
Grant agreement:	266073 (7th EU Programme)
Duration:	10 Oct. 2010 – 30 Sept. 2013
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The Project

Fixed and rotary wing pilots alike are familiar with potential instabilities or with annoying limit cycle oscillations that arise from the effort of controlling aircraft with high response actuation systems. These inadvertent undesirable aircraft or rotorcraft instabilities are the so-called **Aircraft/Rotorcraft Pilot Couplings (A/RPC)** because they originate from adverse pilot-vehicle couplings. These undesirable couplings can range in severity from benign to catastrophic; benign A/RPCs affect the vehicle's operational effectiveness; catastrophic A/RPCs result in the loss of the aircraft and lives. Until 1995, A/RPCs were usually known under the name of Pilot Induced/Pilot Assisted oscillations or Pilot in-the loop/Pilot-out-of-the-loop oscillations (PIO/PAO). The reason for this was that, in the past, the key causal factor in A/RPCs appeared to be the pilot. Generally, for modern aircraft, it has become increasingly clear that the pilot is not at fault and that it actually is the rapid advance in the field of Flight-Control-Systems (FCS) that has increased the sensitivity of the pilot-vehicle system to the appearance of unfavourable A/RPC events.

In October 2010 the European Commission launched, under the umbrella of the 7th Framework Programme (FP7), the ARISTOTEL project (Aircraft and Rotorcraft Pilot Couplings – Tools and Techniques for Alleviation and Detection, www.aristotel-project.eu). With a duration of 3 years and involving partners from across Europe – Delft University (TUD) as coordinator and NLR from The Netherlands, ONERA from France, Politecnico di Milano (POLIMI) and Università Roma Tre (UROMA3) from Italy, University of Liverpool (UoL) from the UK, STRAERO from Romania, PZL-Swidnik from Poland, TsAGI from Russia and EURICE from Germany, ARISTOTEL aims to understand the modern aircraft susceptibility to A/RPC. With this understanding will come the ability to design out or suppress vehicle's A/RPC tendencies. The project will therefore contribute to the European Union's initiative to reduce aviation accidents by 80% by 2020.

Some results achieved so far

With this first newsletter published in ARISTOTEL, the Consortium intends to inform about some of the achievements obtained within the first 18 months of the project's duration.

The first dilemma that one needs to solve when analysing aircraft oscillatory behaviour is whether or not a particular event is an A/RPC. According to expert literature, ten different definitions seem to exist at the moment and many times the aerospace community is unable to agree upon whether or not a particular event is an A/RPC. Therefore, the first goal of the ARISTOTELians was to give a unified definition on A/RPCs to be used throughout the project. For this, an exhaustive review was performed of old present incidents indicating A/RPC instabilities in the last 60 years at both aircraft and rotorcraft. This database showed that, in modern helicopters, RPCs are becoming more evident and can often be associated with couplings between the pilot and the lower flexible vehicle modes. The database showed also that there is still a major difference between A-and-RPCs (see Figure 1): 77% of APCs are related to PIOs events, not involving elasticity whereas the RPC situation is much more entangled. At least 50% of reports, in fact, involve aero-servo-elastic phenomena (named PAO, PAO/PIO, Flexible modes, Slung-loads).

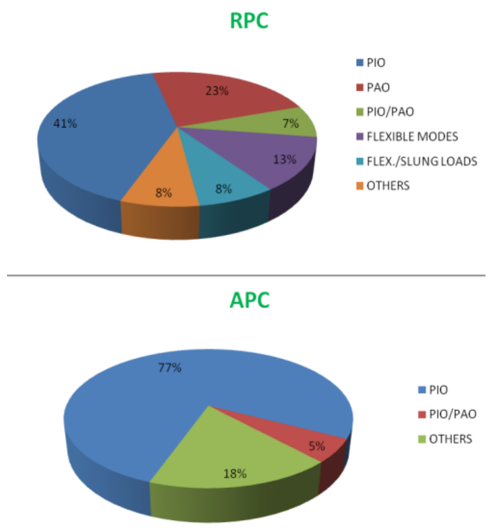

Figure 1 A/RPCs statistical analysis

Based on these first statistical analyses, the following A/RPC definition was then proposed to be used throughout the project:

> *"An Aircraft- or Rotorcraft-Pilot Coupling (A/RPC) is an unintentional (inadvertent) sustained or uncontrollable vehicle* ***oscillation*** *characterized by a* ***mismatch*** *between the pilot's mental model of the vehicle dynamics and the actual vehicle dynamics. The result is that the pilot's control input is* ***out-of-phase*** *with the response of the vehicle, possibly causing a diverging motion."*

The project developed then the tools necessary for A/RPC analysis: vehicle models, pilot models and vehicle-pilot models. As fixed wing configuration, the TsAGI elastic flexible generic model was chosen. As helicopter configurations, two helicopters were chosen: the MBB BO105 and the Aerospatiale Puma. These helicopters did not experience RPCs in real life but possess all the characteristics that make them A/RPC prone. The A/RPC phenomena have been divided into two groups based on their characteristic frequency range, i.e. low frequency and high frequency. In the low frequency range one can discuss about 'rigid body' RPCs – the realm of flight dynamics. In the high frequency range one can discuss about 'aeroelastic' RPCs – the realm of aeroservoelasticity. It is assumed that there exists a certain overlap between rigid body and aeroelastic A/RPC categories. Using this classification, the research was divided into two parallel streams of study concerning rigid body A/RPCs and aero-servo-elastic A/RPCs.

Where ARISTOTELians were present in the past:

Aerodays (30 March – 2 April 2011), Madrid, Spain
http://www.aerodays2011.org

International Forum of Aeroelasticity and Structural Dynamics
(26-30 June 2011), Paris, France
http://www.ifasd2011.com/

36th European Rotorcraft Forum (ERF)
(13-15 September 2011), Gallarate, Italy
http://www.erf2011.org/

The International Conference of the European Aerospace Societies (CEAS 2011)
(24-28 October 2011), Venice, Italy
http://www.ceas2011.org/

Next occasions to meet ARISTOTELians:

AHS 68th Annual Forum and Technology Display
(1-3 May 2012), Forth Worth, Texas, USA
http://www.vtol.org/annual-forum

28th Congress of the International Council of the Aeronautical Sciences (ICAS 2012)
(23-28 September 2012), Brisbane, Australia
http://www.icas2012.com/

Rigid body and aeroelastic models as well as pilot models were developed by the partners and validated against each other. These models were used for a state-of-the-art analysis in current criteria and methods for A/RPC predictions. Novel prediction methods such as the boundary avoidance tracking (BAT) concept for pilot modelling and on-line detection algorithms (HAVE PIO) are currently under investigation for rigid body RPCs. Early in the project it was decided to perform biodynamic and simulator tests in parallel with model development. Finally, it is intended to integrate all the results obtained into design and simulator guidelines for A/RPC prediction.

Simulations

Four facilities, all motion-based generic simulators with six degree of freedom, were involved in ARISTOTEL (see Figure 2): two for fixed wing research - FS-102 simulator at TsaGI and GRACE (Generic Research Aircraft Cockpit Environment) at NLR – and two for rotorcraft research - SIMONA (Simulation Motion and Navigation Technologies) Research Simulator at Delft University and HELIFLIGHT-R at The Bibby flight simulation facility at the University of Liverpool. First simulator tests were performed in March 2012 and the results are under analysis.

Figure 2 Simulators used in ARISTOTEL

The use of multiple simulation facilities brings with it a number of advantages:

- The occurrence of A/RPCs is greatly dependent on the evaluation pilot, his or her training and instructions and the evaluation task the pilot is asked to perform. Simulators can be used to explore different approaches and assess their effectiveness in predicting A/RPC events.
- A simulator's level of fidelity influences its ability to reliably predict A/RPC occurrences. Accuracy of the mathematical model, realism of the control feel system, quality of visual and vestibular cues all play a role in shaping the pilot's behaviour. A systematic study to identify the relative importance of these aspects, as well as the development of guidelines for adjusting a simulator's characteristics, can help A/RPC researchers focus their efforts on tuning their simulator in ways that maximize the accuracy of RPC predictions.

The project involves also biodynamic tests. Trials have taken place in February and July 2011 (SIMONA and HELIFLIGHT-R) and April 2011 (FS-102). The goal of these biodynamic tests is to understand what particular helicopter vibrations induce adverse biodynamic couplings (BDC) effects and what mission tasks are more prone to such effects. For helicopters, the results revealed some important conclusions, for example:

- BDC depends on the control tasks: for the different control tasks (i.e., different neuromuscular settings), a different level of BDC was measured;
- BDC depends also on the control (disturbance) axis: the highest level of BDC is measured in sway direction, followed by the surge direction. The least amount of BDC is measured in the heave direction.

This demonstrates that the biodynamic couplings (coming only from neuromuscular adaptation in this experiment) depend not only on more obvious features such as pilot weight and posture (which can vary from pilot to pilot) but also on more elusive factors such as pilot workload and task.

Worth knowing…

ARISTOTEL among 10 best papers presented at ERF

The paper "Present and Future Trends in Rotorcraft Pilot Couplings (RPCs) – A Retrospective Survey of Recent Research Activities within the European Project ARISTOTEL" has been classified among the 10 best papers presented at ERF.

Internal workshops

The ARISTOTEL consortium was pleased to welcome representatives from the industry at two internal workshops. The workshops contributed to a fruitful exchange between the partners in the project and external experts in the field and gave ARISTOTEL partners direction and new impulse regarding their research and informed relevant industrial companies and researchers about the project progress.

Some publications

Pavel M.D. et. Al., *Present and Future Trends in Aircraft and Rotorcraft Pilot Couplings – a Retrospective Survey of Recent Research Activities within the European project ARISTOTEL*, European Rotorcraft Forum 2011, 13-15 September 2011, Gallarate, Italy

Quaranta, G., Masarati P., Venrooij, J., *Robust Stability Analysis: a Tool to Assess the Impact of Biodynamic Feedthrough on Rotorcraft-Pilot Couplings*, American Helicopter Society 68th Annual Forum, May 1–3 2012, Fort Worth, Texas

Jones, M. and Jump, M., *Generic Research Simulator Requirements for Prediction of Adverse Rotorcraft Pilot Couplings*, American Helicopter Society 68th Annual Forum, May 1–3 2012, Fort Worth, Texas

For fixed wing aircraft it was shown that the lateral accelerations cause involuntary manipulator deflections thus creating parasitic feedback in the pilot-aircraft system; for certain aircraft and manipulator characteristics these parasitic feedback high-frequency oscillations may appear. The experiment at TsAGI demonstrated that varying the manipulator characteristics, i.e. using either a control yoke (wheel) system like in most of the airliners, a central stick like in most military aircraft or a side-stick as in the new fly-by-wire airliners, affects the BDC. The greatest pilot rating worsening due to biodynamic interaction between the pilot and the elastic accelerations corresponds to a central stick system. At the end of 2012 and beginning 2013, new simulator and biodynamic tests are planned involving pilot-in-and-out-of-the-loop for A/RPC analysis.

A word from the Coordinator

Aristotle (384-322 BC), the great ancient Greek philosopher who formulated the basis for much of today's modern science, believed that knowledge comes through empirical observation and experience. Like him, ARISTOTEL project would like to determine form by detailed, systematic work, and thus arrive at final causes. Aircraft and Rotorcraft Pilot Couplings are complex “exotic” happenings where detailed empirical investigations of nature are essential if progress is to be made in understanding them. Many times, aircraft design, simulation, testing, certification or operations do not see A/RPCs as major concern and this lack of awareness should be changed in the future. Already, as indicated by McRuer in the 1990’s in his extensive overview, A/RPCs are often associated with the introduction of new designs, technologies, functions or complexities. As we moved already into a new century with new revolutionary designs where the level of automation is continuously increasing and even extend to smaller aircraft and, as we plan to move personal transportation into the third dimension, it follows that we should be more careful for A/RPCs. Future A/RPCs will be very different and far more complex and varied from those encountered in the past.

The Consortium

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