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

ARISTOTEL

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
Coordinator:	Dr. Marilena D Pavel Delft University of Technology Faculty of Aerospace Engineering +31 15 2785374, m.d.pavel@tudelft.nl
Website:	www.aristotel-project.eu

The Project

The term **'Aircraft/Rotorcraft Pilot Couplings (A/RPC)'** relates to a wide category of pilot-vehicle system (PVS) instabilities that arise from the effort of controlling aircraft with high response actuation system. Despite their common undesirable pilot-vehicle coupling effects, underlying causes for A/RPC can be very different. Over the last two decades, the aerospace scientific community has focused its attention on predicting and alleviating these complex events. In October 2010 the European Commission launched, under the umbrella of the 7th Framework Programme (FP7), the project ARISTOTEL - Aircraft and Rotorcraft Pilot Couplings – Tools and Techniques for Alleviation and Detection. 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 aimed at advancing the state-of-the-art in predicting the A/RPC susceptibility for modern aircraft/rotorcraft. In this sense, the project aimed at contributing to the European Union's initiative to reduce aviation accidents by 80% by 2020.

ARISTOTEL Achievements

In the past, it has often been difficult to recognize and then analyse an A/RPC event. This is due not only to the challenge of reconstructing what happened from an accident scene, but also because of the lack of awareness of these events on the part of possible witnesses, even when they are highly trained individuals. Indeed, A/RPC events are always associated with a mismatch between the pilot's mental model of the vehicle's dynamics and actual motion taking place. This is true even as a catastrophic event unfolds. The analysis of these events is complex as it involves rigid body dynamics, aero-servo-elasticity, the automatic flight control system and, of course, biodynamics and piloting. In the preceding years, an effort has been made by the research community to distinguish between A/RPC events by introducing different classes. The most functional classification is based on the frequency content of the dynamics involved, for which Rigid Body A/RPCs (frequency range 0-2 Hz) are separated from Aeroelastic A/RPCs (frequency range 2-8 Hz). In the first class of phenomena, sometimes known as Pilot Induced Oscillations (PIOs), the pilot response is dominated by a behavioural process (a mental mismatch, as stated above), whereas in the latter, known as Pilot Assisted Oscillation (PAO), the pilot becomes an involuntary link between the seat motion and the controls, thus acting like a mechanical impedance. In contrast to the fixed-wing world, where most present APC events are characterized as PIOs, the available records clearly show that PAOs contribute to a significant proportion of RPC-related rotorcraft accidents. A recent database of incidents indicates that 77% of APC can be related to PIO events, whereas in the case of RPC, at least 50% involve aero-servo-elastic phenomena. For the frequency range involved in rotorcraft PAOs, the pilot's unintentional control input actions couple with, for example, rotor blade dynamics, airframe flexibility and servos, amongst others, thus requiring more complex tools for effective computational simulations. Moreover, due to their low frequency nature, some aeroelastic phenomena may play a non-negligible role in helicopters PIOs. The ARISTOTEL project considered that piloted simulation trials are an essential tool in understanding and improving the state-of-the-art in A/RPC. Four motion-based generic simulators (i.e. SIMONA at Delft University & HELIFLIGHT-R at Liverpool University for rotorcraft research and FS-102 simulator at TsAGI and GRACE at NLR for fixed wing research) were involved in the project and different test campaigns (rigid body testing, aeroelastic testing, biodynamic testing) were conducted to assess the A/RPC predictions.

Rigid body RPC Findings

Concerning rigid body RPC, TUD conducted pilot identification experiments in order to find pilot characteristics before and after an A/RPC triggered by a time delay introduced in the simulation model of a Bolkow Bo-105 helicopter flying a stabilization task. The goal was to understand the pilot behaviour in the so-called 'post-transition retention phase', i.e. the phase in which pilots still believe they are controlling the vehicle operated prior to the change of vehicle dynamics followed by the pilots adaptation to the time delay applied in the controls.

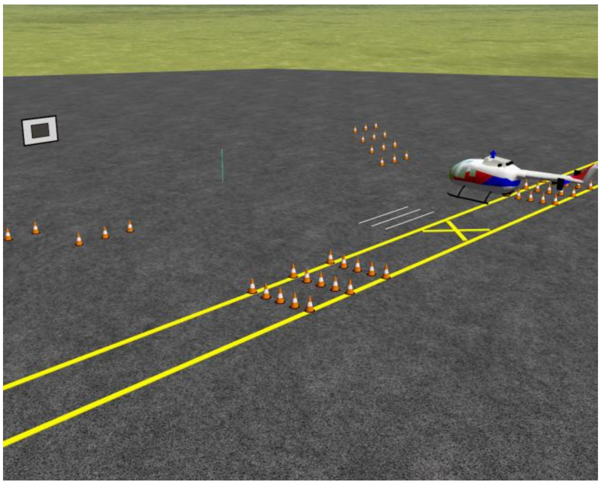

Figure 1a: Precision manoeuvre course

It was found that, once the RPC has been triggered, all pilots try to adapt their strategy to the new dynamics of the aircraft by using a combination of low-frequency lag and high-frequency lead equalisation to compensate for the reduced phase margin they had due to the added time delay. University of Liverpool proposed a new real-time detection tool for A/RPC, the so-called Phase Aggression Criterion (PAC). PAC achieves a 'detection' of an A/RPC through the observation of the PVS phase distortion and the pilot input rate. Observing pilot input allows one to check that the pilot is coupled with the oscillations (a prerequisite for PIO) whilst the phase difference allows one to see whether the commanded input is in-phase with the vehicle response. The combination of the two parameters at a finite point in time allows one to objectively assess whether an A/RPC has materialised. ONERA has verified the applicability of fixed wing PIO prediction tools (such as bandwidth-phase delay and OLOP) to rotorcraft. By increasing the time delay in the pilot input resulted in degradation in handling qualities, a decrease in aircraft bandwidth and an increase in the phase delay. From the different ADS-33 tasks flown in the simulator, it was shown that the precision hover (see Figure 1a) and the roll step (see Figure 1b) are suitable for exposing RPC tendencies while slalom manoeuvre proved to be unsuitable for exposing RPC tendencies.

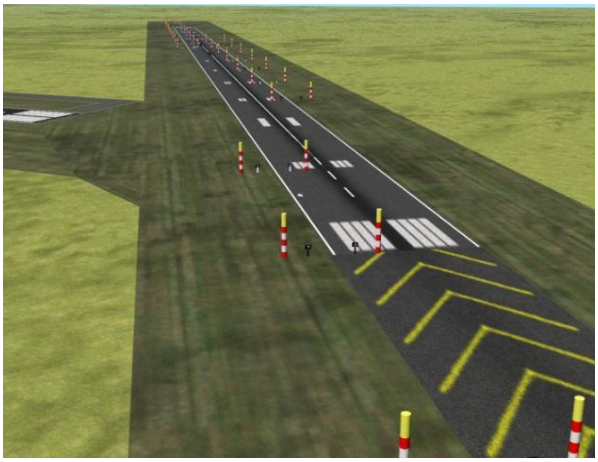

Figure 1b: Roll step manoeuvre unmasking RPC tendencies

University of Liverpool related the so-called 'Boundary Avoidance Tracking Concept' (BAT) and 'Optical Tau' theory to RPC events. BAT assumes that during an A/RPC event, the pilot behaviour is more like tracking and avoiding a succession of opposing events which can be described

ARISTOTELians present at conferences

European Rotorcraft Forums
2011 in Italy (http://www.erf2011.org/)
2012 in The Netherlands (http://www.erf2012.org/)
2013 in Russia (http://www.erf2013.org/)

AHS Annual Forums
2012 in Fort Worth, Texas, USA
2013 in Phoenix Arizona, USA
http://www.vtol.org/annual-forum

International Forum of Aeroelasticity and Structural Dynamics
2011 in Paris, France
http://www.ifasd2011.com/

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

as boundaries. Tau theory is based upon the premise that purposeful actions are accomplished by coupling the motion under control with either externally or internally perceived motion variables. Results have shown that when pilots fly a roll-step manoeuvre there is a close correlation between the optical-tau and BAT.

Aeroelastic A/RPC Findings

Comprehensive helicopter simulation models obtained by coupling flexible fuselage dynamics, main rotor aeroelasticity, control chain dynamics and pilot behavioural dynamics were applied for RPC analysis of the IAR330 Puma and Bolkow Bo-105 helicopters. Results have shown that the passive coupling of the pilot biomechanics with the IAR330 Puma helicopter resulted in lower damped eigenvalues. Numerous couplings between the rotor and the body can occur in rotorcraft such as: the low-damped main rotor regressive lead-lag mode can be easily excited by cyclic stick inputs; the low frequency pendulum mode of external slung loads can be excited by delayed collective and/or cyclic control inputs.

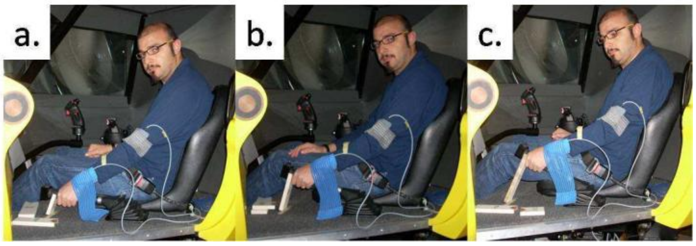

Figure 2 Experimental setup for pilot's left arm biomechanical characterization: 10% (a), 50% (b), and 90% (c) reference position of the collective control inceptor

Other types of rotorcraft-centred deficiencies which might contribute to RPC belong to unfavourable conventional rotorcraft dynamics, such as lightly damped phugoid modes, or unfavourable roll attitude/Dutch roll mode poles. As an example of aeroelastic RPC analysis the project concentrated onto the collective bouncing (vertical bouncing) phenomenon. This is the result of a closed loop instability consisting of the coupling between main rotor collective pitching and coning, airframe (rigid and elastic) vertical motion and the collective lever motion. The instability is driven by the pilot involuntary inputs given due to vertical oscillation of his seat (the so-called pilot biodynamic feedthrough (BDFT)). To understand what particular helicopter vibrations induce adverse biodynamic couplings (BDC) effects and what mission tasks are more prone to such effects, biodynamic test trials were performed in the project for both helicopters and fixed wing aircraft. Figure 2 presents the experimental setup for pilot's left arm biomechanical characterisation. For helicopters, the results revealed some important conclusions, for example: BDFT depends on the control tasks: for the different control tasks (i.e., different neuromuscular settings), a different level of BDFT was measured; BDC depends also on the control (disturbance) axis: the highest level of BDFT is measured in sway direction, followed by the surge direction. The least amount of BDFT 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. TsAGI formulated an approach to assess the effect of structural elasticity on aircraft handling qualities. This approach allows splitting pilot activity into 'active' component 'active pilot' and 'passive' component 'biodynamical' pilot. The splitting is based on a handling qualities pilot rating increment due to high-frequency oscillations which was evaluated into

Worth knowing…

3 ARISTOTEL papers among the 9 best papers of ERF 2012

Three papers on RPC presented at the ERF2012 were selected as best papers (UROMA3, POLIMI and TUD/Max Planck). The ERF IC and the Council of European Aerospace Societies CEAS (in collaboration with Springer) would like to publish these with further 6 papers in a dedicated edition of the CEAS Aeronautical Journal. In the introduction to this special edition their achievements will be addressed. They are:

- Evaluation of Rotary Wing Aeroelastic Stability Using Robust Analysis (POLIMI, UROMA3)
- A practical biodynamic feed through model for helicopters (TUD/Max Planck)
- A Finite-State Aeroelastic Model for Rotorcraft Pilot-Assisted-Oscillations Analysis (UROMA3)

Special ARISTOTEL session at ERF 2013

The ARISTOTEL consortium is proud to have its own session at the European Rotorcraft Forum 2013. (Adverse rotorcraft-pilot coupling: Synthesis of ARISTOTEL).

- Anatomy, Modelling and Prediction of Aeroservoelastic Rotorcraft-Pilot-Coupling
- The Role of Flight Simulation in Exposing Rotorcraft Pilot Couplings
- Biodynamic Pilot Modelling for Aeroelastic A/RPC PIO Susceptibility Accompanying HQ Prospects in Preliminary Rotorcraft Design
- Adverse Rotorcraft-Pilot Couplings: Modelling And Prediction Rigid Body RPC
- An Approach To Assess Aircraft – Pilot Coupling Caused By Structural Elasticity

ARISTOTEL workshop in Delft, The Netherlands

After two successful small workshops during project progress meetings, ARISTOTEL is pleased to have held its final workshop. In September 2013 external experts and the consortium gave talks on ARISTOTEL topics to an interested community. More information on the workshop and the talks can be found at www.aristotel-project.eu/workshop.

Publications

Besides several individual and joint publications of the ARISTOTEL partners, an article has been published in the "Progress in Aerospace Sciences" (July 2013, doi:10.1016/j.paerosci.2013.04.003) **Adverse rotorcraft pilot couplings – Past, present and future challenges** covers many central issues dealt with in the ARISTOTEL project.

simulator trials and compared to the pilot rating of the rigid body aircraft. The experiment at TsAGI demonstrated also 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 also the BDFT. The greatest pilot rating worsening due to biodynamic interaction between the pilot and the elastic accelerations corresponds to the central stick system. This demonstrates that in many modern civil aircraft (such as Airbus A320, Airbus A380 using a side stick manipulator) and military aircraft (such as Daussault Rafale, F-22 Raptor, F-35 Joint Strike Fighter with a side-stick and Eurofighter Typhoon and Mirage III with a centre-stick) BDFT effects are more important than in the past. Also, helicopters and tilt rotors (as V-22 Osprey) use mainly centre-stick manipulators and thus are BDFT sensitive.

A word from the Coordinator

The incidence of A/RPC events could be reduced through more effective and consistent use of tools and capabilities during modelling, analysis, design and testing. We tried in this project to understand 'exotic' couplings that are responsible for A/RPCs. We understood more from the complexity of the pilot and how this relates to vehicle dynamics. We acquired more knowledge on how to test for A/RPC. With this we proposed new approaches to address the A/RPC risk. It will be a future task to integrate these findings into the current design-team efforts to address A/RPC.

The Consortium

Technische Universiteit Delft (TUD)

Wytwornia Sprzetu Komunikacyjnego PZL-Swidnik Spolka Akcyjna (PZL-Swidnik)

Office National d'Etudes et de Recherches Aérospatiales (ONERA)

Politecnico di Milano (POLIMI)

Università degli Studi Roma Tre (UROMA3)

The University of Liverpool (UoL)

Stichting Nationaal Lucht- en Ruimtevaartlaboratorium (NLR)

Institute for Theoretical and Experimental Analysis of Aeronautical Structures (STRAERO)

Central Aerohydrodynamic Institute (TsAGI)

European Research and Project Office GmbH (Eurice)