1. Publishable summary

Project acronym: ARISTOTEL
Project full title: Aircraft and Rotorcraft Pilot Couplings – Tools and Techniques for Alleviation and Detection
Grant Agreement no.: 266073
Project web site: http://www.aristotel-project.eu/

Project logo:

Project coordinator: Prof. Dr. Marilena Pavel
Telephone: +31 15 2785374
Fax: +31 15 2789564
E-mail: m.d.pavel@tudelft.nl

Beneficiaries:

N.	Name	Short name	Team leader	Contact
1	Technische Universiteit Delft	TU Delft	Marilena Pavel	m.d.pavel@tudelft.nl
2	Wytwornia Sprzetu Komunikacy Jnego PZL-Swidnik Spolka Akcyjna	PZL-Swidnik	Jacek Malecki	Jacek.malecki@agustawestland.com
3	Office National d'Etudes et de Recherches Aerospatiales	ONERA	Binh Dang Vu	Binh.dangvu@onera.fr
4	Politecnico di Milano	POLIMI	Pierangelo Masarati	masarati@aero.polimi.it
5	Universita Degli Studi Roma Tre	UROMA3	Massimo Gennaretti	m.gennaretti@uniroma3.it
6	The University of Liverpool	UoL	Mike Jump	Mjump1@liv.ac.uk
7	Stichting Nationaal Lucht- en Ruimtevaartlaboratorium	NLR	Hafid Smaili	smaili@nlr.nl
8	SC Straero SA	STRAERO	Achim Ionita	Achim.ionita@straero.ro
9	Federal State Unitary Enterprise The Central Aerohydrodynamic Institute named after Prof. N.E. Zhukovsky	TsAGI	Larisa Zaichik	Zaichik@tsagi.ru
11	European Research and Project Office GmbH	Eurice	Corinna Hahn	c.hahn@eurice.eu

Project context and objectives

Today's high performance rotorcraft are a product of the ever increasing demands of operator requirements. They are faster and more capable, but are consequently more complex than their predecessors. As their complexity increases, it appears that both engineers and pilots must be prepared to deal with an associated increased incidence of unfavourable so-called "Aircraft-and-Rotorcraft Pilot Couplings" (A/RPC). Generally, A/RPCs are oscillations or divergent vehicle responses originating from adverse pilot-vehicle couplings. These undesirable couplings can range in severity from benign to catastrophic; benign A/RPCs affect a mission's operational effectiveness, degrading the aircraft handling qualities; catastrophic A/RPCs result in the loss of the aircraft and lives.

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. As a matter of fact, almost every aircraft equipped with a partial or total fly-by-wire FCS has, at one time or another of development process, experienced one or more A/RPC events. In other words, in the FCS of any modern aircraft, there seem to be some embedded tendencies that predispose the pilot-aircraft system towards A/RPC occurrence.

The European Community has set a joint safety initiative target to cut aviation accidents by 80% by 2020. However the number of A/RPC incidents in modern aircraft is increasing. Thus there is a serious safety problem regarding unpredictable A/RPC especially in the future large/flexible aircraft, high speed civil transport and highly-augmented rotorcraft.

The main goal of ARISTOTEL is to design the tools and methods capable to prevent and detect A/RPCs early in their onset, and hence to reduce the rate of accidents caused by unpredictable A/RPC events. The project identified six key problems specifically related to A/RPC analysis which represent, at the same time, the project's objectives.

1. The first dilemma one needs to solve when analysing aircraft oscillatory behaviour is whether or not a particular event is an A/RPC.
2. The weakest points in A/RPC analyses are pilot models: there is a lack of quantitative pilot behavioural models and a lack of understanding of all the possible interactions between the flight control system (FCS) and the pilot.
3. This problem relates especially to rotorcraft. The current rotorcraft modelling for RPC analysis is rather limited to the particular case analysed and does not consider the multitude of interactions existing between aerodynamics, structures and other control systems; there is no high-fidelity comprehensive model that is generally applicable to RPCs and also no guidelines as to how much detail should be included in the model.
4. There have been numerous attempts to define design criteria that will result in an aircraft free of RPC tendencies. Many of these criteria started as handling qualities criteria and much of the subsequent development work focused upon highly augmented fast-jet military aircraft. Despite these efforts, A/RPC events have stubbornly refused to go away. Highly augmented rotorcraft are becoming more prevalent and the supposition is that the propensity of RPC event encounters will increase.
5. Current simulator and flight tests do not possess the proper practices to unmask the A/RPC signature.
6. There is no coherent design guide or simulator guideline available to the designer for unmasking A/RPCs.

Work performed since the beginning of the project and the main results achieved so far

In ARISTOTEL, A/RPC phenomena have been divided into two groups based on the characteristic frequency range of such phenomena: 1) Rigid body A/RPCs are oscillations in the bandwidth up to 1Hz for aircraft and 3.5Hz for rotorcraft and 2) Aeroelastic A/RPCs are oscillations in the bandwidth between 2Hz and 8Hz. For rigid body RPC an active pilot in the loop is considered. For aeroelastic RPCs, a ‘passive’ pilot subjected to vibrations is considered. It is thought that a parallel rigid body/aeroelastic approach may enhance the understanding of A/RPC phenomena in the critical range of 1-3.5Hz, where many accidents have been observed.

First, a database of A/RPCs cases was collected and updated from open literature in WP1. Main result achieved relates to an updated database of A/RPC events which unmasked the trends for future aircraft A/RPCs. It was concluded that most RPC events involved larger rotorcraft with conventional non-digital flight controls. For modern helicopters, RPCs have become evident and can often be associated with couplings between the pilot and the lower structural modes. Another result relates to a new A/RPC definition which was proposed to be used throughout the project: “An Aircraft- or Rotorcraft-Pilot Coupling (A/RPC) is an unintentional (inadvertent) sustained or uncontrollable vehicle oscillations 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. ” This definition is the result of an exhaustive discussion in the consortium.

Two helicopter models (one of a light utility BO105 and one of a heavier IAR330 Puma) have been developed in WP2 and WP3 using different partner’s simulation environment. For rigid body RPC analysis, trimmed flight control positions, eigenvalue analysis, key aerodynamic and control derivatives and time-response comparison with flight test data have all been used to compare the various models. The models were upgraded with a Stability Control and Augmentation System (SCAS) and tuned by helicopter pilots to capture real rotorcraft behaviour. For aeroelastic RPC analysis, a generic isolated rotor model was developed by each partner and tuned to give similar results, with respect to blade mode frequencies and shapes. Analysis has been conducted both in a vacuum and 'in air', whilst also completed at rotating and non-rotating conditions. For APC aeroelastic analysis, the generalized aircraft model of TsAGI is considered. The characteristics of rigid-body and elastic-body are selected typical of the modern large passenger airliner like Ilushin-96 or Airbus 340.

Early in the project it was decided to perform biodynamic and simulator tests in WP4 in parallel with model development. For helicopters, bio-dynamic tests have taken place in SIMONA simulator at Delft University and HELIFLIGHT-R simulator at Liverpool University. The goal was to understand what particular helicopter vibrations induce adverse biodynamic coupling (BDC) effects and what mission tasks are more prone to such effects. BDC relates to an interaction between pilot limb-manipulator characteristics and aircraft structure which results in involuntary pilot control actions that intensify aircraft oscillations and degrade aircraft handling qualities.

The SIMONA tests revealed two conclusions: 1) BDC depends on the control tasks 2) BDC depends on the control (disturbance) axis; the highest level of BDC is measured in sway direction, followed by the surge direction. This demonstrates that BDC (coming only from neuromuscular adaptation in this experiment) depends not only on pilot weight and posture (which can vary from pilot to pilot) but also on pilot workload and task. The bio-dynamic tests in the HELIFLIGHT-R simulator at Liverpool showed that unstable oscillations could be triggered in the simulator and safely sustained.

ARISTOTEL is almost in the middle of its way. The coming work package will synthesise the analysis performed until now in criteria and means of prevention of A/RPCs. WP5 Design Guidelines and Methodologies for A/RPC Prevention will provide the designer with guidelines for unmasking A/RPCs early in design stage.

Expected final results and their potential impact and use

The ARISTOTEL project:

- will provide an understanding of the causes that can lead to A/RPC events in present and future aircraft designs that use advanced flight control and fly-by-wire systems;
- will analyse the specific human-machine interfaces involved in A/RPC events and how dangerous these are for the safety;
- will provide modelling and reliable simulation for both rigid body and aero-servo-elastic RPC prediction from three perspectives: modelling the human pilot; modelling the vehicle and modelling the interactions between the human pilot and the vehicle, enabling RPC-prone designs to be detected and corrected more efficiently;
- will reduce or remove the A/RPC proneness of an air-vehicle through the development of innovative prediction criteria and guidelines capable of being applied throughout the design process. These new prediction tools will allow the efficient reduction of annoying to dangerous A/RPC in current and future aircraft and rotorcraft;
- will provide training protocols for aircraft/rotorcraft pilots in the simulator, helping to design simulation trials that will uncover adverse A/RPC and thus diminish the chance of accidents.
- will contribute to ensuring reliable and effective human performance operating in an A/RPC-free designed configuration.
- will enhance carefree handling of the aircraft/rotorcraft. Carefree handling means the ability of the pilot to fly throughout the aircraft's operational flight envelope without concern for exceeding structural, aerodynamic or control limits.
- will contribute to the extension of certification standards with A/RPC criteria. Such criteria are at the moment barely considered in the certification standards. The addition of A/RPC criteria will contribute to the improvement of the certification standards.

The innovations envisaged at the moment with respect to the state-of-the-art in A/RPC prediction include:

- New criteria for A/RPC prediction applicable to conventional rotary wings and hybrid configurations, criteria paving the way towards improving the qualification and certification standards;
- Proper models for aero-servo-elastic analysis of RPC problems;
- New flight simulator test methods for recognising adverse A/RPC phenomena.

The project, through its goals of developing innovative guidelines, methods and training protocols for enhancing A/RPC prediction and prevention will speed up the development, testing and certification of the present and future rotorcraft and more important it will create safer designs. It should be underlined that at the moment there are no such guidelines either in Europe or USA for investigating the aero-servo-elastic RPCs of highly augmented rotorcraft. Also, it is not defined how the characteristics of aero-servo-elastic RPCs should be implemented in the rigid body RPC analysis which is finally used for real-time training of aircraft/rotorcraft pilots in the simulator.

All results will be useable by the aerospace industry in the design process for improving flight safety. Since the project is not focused on specific types of aircraft or specific designs, many of the working documents and much of the expected outcome will be publicly available.

Figure 1 Simulators used in ARISTOTEL

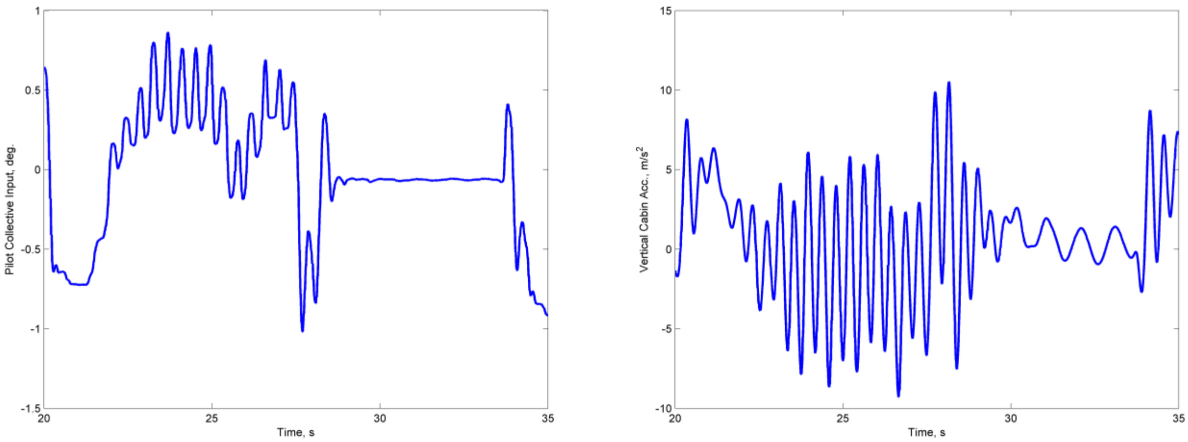

Figure 2 Typical signature of an RPC event: Collective bounce induced in HELIFLIGHT-R simulator at Liverpool. The system was unstable for a vertical acceleration disturbance of 1Hz and pilot gain 0.6. At 29s the pilot released the collective control to stop a diverging oscillation.