Periodic Report M18

PUBLISHABLE SUMMARY

Summary of the project context and the main objectives

The general background of the PELskin project is the reduction of CO_2/NOx emissions on aircrafts, by improving the aerodynamic efficiency using a passive flow control actuator. To achieve this goal, we investigate a novel aeronautic coating inspired by the pop-up of birds feathers in certain flight modes, in order to improve the aerodynamic performances of airfoils.

The concept of flow control is to use a Porous and ELastic (PEL) coating, able to reconfigure and adapt to the separated flow around the wing, and reduce form drag by decreasing the intensity and the size of the recirculation region. This concept of flow control is novel, more efficient than classical actuators, and can lead to significant increase in the aerodynamic performances by delaying stall and reducing vibrations induced by e.g. gust loading; especially during take-off and landing where boundary layer separation plays a crucial role. Though not the direct focus of this work, noise reduction is another potential benefit. An important feature of the PEL coating is that it has zero energy cost of activation and is capable to move, deform and adapt/react to the surrounding flow field. In contrast to classical Vortex Generators, which are fixed, and act upstream of the separation point, the PEL coating is dynamic and flexible, and can be activated only when the boundary layer is separated, and interact with the flow recirculation zone to reduce drag via interaction with the near wall flow. When it is not needed (during cruise phases for instance), the PEL coating can remain inactive, flush to the surface of the wing, which reduces the parasitic drag of classical vortex generators induced by the presence of an obstacle in the flow.

The performances enhancements properties of this concept of PEL actuator are studied theoretically, numerically and experimentally, considering a prefabricated coating composed of a densely packed arrangement of flexible fibres or rigid flaps that can be attached directly onto a wing or aerodynamic surface, in the region of separated flow.

The research endeavours to deliver a clear physical understanding of the action of the PEL coating on the separated flow for flows at moderate Reynolds number, relevant for UAVs (Unmanned Aerial Vehicle) flight modes.

Within this context, the main expected achievements of the PELskin project are:

1. Validation of the numerical codes and techniques using comparisons with experiments on configurations involving moving/flexible elements in interactions with unsteady flows.
2. Identification and understanding of the behaviour of a PEL coating in adverse pressure boundary layers, using a two-fold numerical/experimental study and cross validation. Quantified assessment of the impact of main PEL design parameters on the flow structure, especially in terms of flow control properties.

3. Development of a homogenized model of porous medium with dynamically varying porosity using a multiscale approach. Validation on low Reynolds numbers configurations using comparisons with finite volume Navier Stokes solvers resolving all the pores.
4. Investigation of the effect of the PEL coating on the 3D separated flow around a generic bluff body configuration (circular cylinder) at low-to-moderate Reynolds numbers. Cross validate all results between numeric and experiments.
5. Identification of parameters for which a PEL coating achieves drag reduction around an airfoil in flight-relevant configurations for small UAV (numerically or experimentally), and a deeper insight into the flow mechanism by which this improved efficiency occurs.
6. Implementation of the homogenized model of porous medium in a Navier Stokes solver via a volume force formulation to enable the interaction of PEL coating with a turbulent boundary layer to be simulated numerically.
7. Early integration of PEL coating on a small scale UAV wing carried out under wind tunnel conditions and numerical setting as close as possible to realistic flight conditions.

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

The seven main expected achievements listed in previous section are recalled here, together with a description of the relative works done on each of them:

1. Validation of the numerical codes and techniques using comparisons with experiments on configurations involving moving/flexible elements in interactions with unsteady flows. The immersed boundary method has been implemented in various numerical codes in the PELskin project: incompressible Navier Stokes solvers using finite differences and Cartesian staggered grids (AMU, CITY) and using finite volume body fitted grids (AMU, CITY, UniMAN, WGE). The method has been successfully validated with experiments on a configuration involving moving rigid flaps in an oscillating pressure gradient channel flow (AMU-TUBAF collaboration). Time history of the position of the tips of the flaps has been compared between numerics and experiments, as well as velocity contours and PIV velocity fields. The agreement is very good so far, but we are still working on the numerical inlet and outlet boundary conditions which do not presently exactly match the experimental conditions. The second validation step concerns the validation of the numerical methodology on a flexible flaps configuration in an oscillating pressure gradient channel flow (CITY-TUBAF collaboration). At this stage of the project, this step only requires small adjustments related to the numerical model to obtain a perfect agreement. The validation of the immersed boundary approach on both rigid and flexible configurations constitutes a solid basis for the results of WP2 and WP3, and also allows one to make sure that the bending rigidity, gravity effects and clamped boundary conditions are correctly taken into account in the numerical models.
2. Identification and understanding of the behaviour of a PEL coating in adverse pressure boundary layers, using a two-fold numerical/experimental study and cross

validation. Quantified assessment of the impact of main PEL design parameters on the flow structure, especially in terms of flow control properties. The frequency response of an array of rigid flaps submitted to an oscillating pressure gradient has been studied, both numerically and experimentally. The vorticity generated around the tips of the flaps, and in between the flaps has also been characterised. Both numerical and experimental approaches are in good agreement. The effect of the structural properties of the PEL coating are currently being investigated, e.g. the length and spacing of the flaps.

3. Development of a homogenized model of porous medium with dynamically varying porosity using a multiscale approach. Validation on low Reynolds numbers configurations using comparisons with finite volume Navier Stokes solvers resolving all the pores. A theoretical approach based a multiscale expansion based on a small parameter relative to the size of the pores has been developed and validated on a direct numerical simulation resolving all the pores, on a 2D lid driven cavity flow where the bottom wall is coated with a porous medium. Several issues have been raised and solved and the theoretical model has been successfully calibrated on this configuration.
4. Investigation of the effect of the PEL coating on the 3D separated flow around a generic bluff body configuration (circular cylinder) at low-to-moderate Reynolds numbers. Cross validate all results between numeric and experiments. The influence of the PEL coating on the 3D vorticity properties on the cylinder wake has been studied numerically. In particular, it has been highlighted that an effect of the coating is to trigger a transition from mode A to mode B (see results below in section 2.3). Numerical results are still being compared in detail to experiments, for both flexible and rigid configurations.
5. Identification of parameters for which a PEL coating achieves drag reduction around an airfoil in flight-relevant configurations for small UAV (numerically or experimentally), and a deeper insight into the flow mechanism by which this improved efficiency occurs. Early experiments have been run so far on airfoil configurations coated with rigid flaps. We already have precious first insights on the efficiency parameters of the coating with respect to separation control (position of the flaps, length, effect in the span-wise direction). These results are used as a starting point for the present and future numerical and experimental investigations on this configuration. Preliminary and encouraging numerical results on the cylinder configuration are now being studied to progress on that point.
6. Implementation of the homogenized model of porous medium in a Navier Stokes solver via a volume force formulation to enable the interaction of PEL coating with a turbulent boundary layer to be simulated numerically. (Not at this stage yet/expected to start in 2015).
7. Early integration of PEL coating on a small scale UAV wing carried out under wind tunnel conditions and numerical setting as close as possible to realistic flight conditions. (Not at this stage yet/expected to start in 2015).

Description of the expected final results and their potential impacts and use (including socio-economic impact and the wider societal implications of the project so far)

Although the spectrum of configurations studied in the project is focussed on low-to-moderate Reynolds number flow configurations, it is expected that the understanding of the physical mechanisms will pave the way to the development of breakthrough control strategies for separated flows at higher Reynolds-numbers for larger aircraft. The project thus proposes a long-term innovation concept of flow control that will have an impact on the reduction of fuel consumption and CO/NOx emissions, by improving the aerodynamic performances and safety of the next generation of aircrafts. By having an action on boundary layer separation, improved flight conditions are expected especially during take-off and landing, such as stall delay and a reduction of the vibrations induced by gust loading. Additionally, a reduction of aerodynamic noise can be expected as a direct consequence of the boundary layer separation control.

The approach of reducing fuel consumption is crucial in transport industry and key to increase its competitiveness, since it is now accepted that the optimisation of a configuration for minimum fuel burn is more beneficial than the optimization of other operating costs. Indeed, fuel costs can be up to 40% of the direct operating costs of an aircraft. An important point is that the cost of re-designing the aircraft shape to achieve the guaranteed performance is substantial and can be counted in the millions of Euros. Significant efforts are then dedicated to avoid, if possible, this costly and time consuming task by the implementation of control actuators on existing designs, whose role is to interact with the surrounding flow to increase the aircraft aerodynamics.

This new technology of PEL coating will also be relevant for the market of flow control devices, which is of great interest for aircraft manufacturers, from small UAV to commercial airliner. The PEL coating presents significant advantages compared to existing flow control actuators, classically commercialised and used in aeronautics. Indeed, it does not require any energy of activation, and is able to self-adapt to the flow only when it is needed. During cruise phases the coating remains flush to the surface of the wing, unlike classical wall mounted devices which constitutes an obstacle in the fluid flow, and perturb drastically the boundary layer dynamics. By acting only when the boundary layer is separated, the action of control is optimal and the form drag reduction ratio resulting from the control of the recirculating zone is maximized.

Furthermore, by contributing to design of "greener" and "smarter" European transport systems, the outcome of the PEL-SKIN project will be for the benefit of all European citizens, to reinforce and spread the image and the results of a strong European R&D framework, based on innovation and efficient integration between European SME and European research groups. Transport is one of Europe's strengths - the air transport sector contributes to 2.6% of the EU GDP with 3.1 million jobs and the surface transport field generates 11% of the EU GDP employing some 16 million persons. Thus, through the increased capability for design of greener aircraft and strengthen of European Aircraft industries, the PEL-SKIN project will also have a direct impact on competition and employment and address the challenges set in the EC communication on "Europe 2020 – A strategy for smart, sustainable and inclusive growth".

The challenges addressed (greener air-transport, supporting the European aeronautic sector through innovation in key-enabling technologies, creating new jobs in Europe, etc.) and the expected outcomes of this project (namely to deliver a novel airfoil coating to improve the global aerodynamic performance and manoeuvrability of future air transport) are relevant for the entire European Union.