CleanLE2 Project

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CleanLE2 Project SUMMARY for Periodic Report 2

1 Publishable summary

1.1 Summary description of the project context and objectives

CleanLE2 is part of the Cleansky1 (CS1) FP7 European research program which develops breakthrough technologies to significantly increase the environmental performances of airplanes and air transport. The aim of the CleanLE2 project is to validate the concept of a wing leading edge cleaning device moving on the wing that can operate in flight. The interest of such a cleaning device is to remove debris, for example insects, that accumulate on the wing during the taxi, take-off and the climb phases which can disrupt the aerodynamic flow and promote transition to turbulent flow on wings designed for low drag laminar flow, (NLF wings). Indeed, contaminants with a height as small as 0.05 mm can cause turbulent flow on wings cruising at high speed and increase total drag and thus fuel consumption.

The present project is a follow-up of the first CleanLE project in which several methods for cleaning the wing have been analysed and the working principles of such a system (kinematics, cleaning methods, and structure of the system) have been defined.

The objective is to bring the concept of an in-flight wing leading edge cleaning system from a TRL of 2 to a TRL of 4/5 (technology validated in laboratory/relevant environment). This is done by designing a prototype and testing the mechanics and the cleaning efficiency on a typical wing geometry on a ground tester. Moreover, wind tunnel tests and CFD simulations allow for a better understanding of the flow field interaction of the cleaning devices and the incurred aerodynamic loads.

1.2 Work performed since the beginning of the project and main results

The system has been designed in WP2 with extensive use of numerical engineering methods: computational fluid dynamics (CFD) for estimating the aerodynamic forces encountered in flight, computational magnetostatics (CMS) to size the magnets holding the cleaning devices on the wing, and computational structural mechanics (CSM) to size the components and estimate loads and deformation of the structural parts.

In WP3 (Pre-tests) a method for contaminating wing surfaces with insects, that is representative of aircraft wing contamination, has been devised, built and tested; it consists of a modified leaf blower capable of shooting insects (drosophilae and crickets) at approximately 180 Km/h. Cleaning tests have been performed on aluminium sheets contaminated with the aforementioned system. Various cleaning tools (brushes, sponges, cloths) have been used for cleaning in both dry and wet conditions using 3 different liquids. For the best combination of sponge and liquid it was possible to clean sufficiently the metal sheets after 4 passes. An important result of WP3 is that dry cleaning proves to be ineffective, which entails that use of a cleaning liquid is necessary.

In WP4 the ground test rig has been designed. It consists of 3 test zones corresponding to wing root, mid wing and wing tip. These are connected by “transition” zones which are made of wood and covered with aluminium sheets to limit the cost. The wing has been built from scratch and mounted on a structure which allows the rotation of the wing to ease the contamination process and the application of weights that simulate the aerodynamic loads.

The CleanLE prototype has been updated, also to take into account practical issues that arised on integration in such a ground tester, to increase the mechanical stability of the prototype (intensive design with CSM simulations have been performed), to ease manufacturing of the parts and to limit the overall cost by choosing as many off-the-shelf parts as possible.

Also in WP4 the geometry for the wind tunnel tests has been defined, and pressure taps locations have been chosen based on CFD results. The setup for the wind tunnel test bench consists in two endplates 4.7m long, 2.6m tall, placed 1.0m apart and installed in the main test section. The wing, equipped with the prototype cleaning device, is held by the rotating guiding devices integrated in the endplates in order to vary precisely the angle of attack. The wing geometry is constructed by taking the airfoil of the reference wing at 1/3 span, scaled at 1:5, and extruding it with the required sweep (10°), to be compatible with the wind tunnel (2.5D tests).

In WP5 the experimental setup, both for wind tunnel tests and ground tests, has been manufactured and mounted.

The wind tunnel tests and the first round of ground tests have been performed in WP6. In the wind tunnel pressure data and oil flow visualisations have been obtained for 3 sideslip angles and angles of attack between -5° and 10°. A trip wire to force the transition to turbulence near the leading edge has been used in some cases to ease the direct comparison with the CFD and evaluate the effect of turbulence on the flow. Test results analysis showed good agreement with CFD results, with the only noticeable discrepancy being that the CFD overestimates the suction peaks at high angle of attack. Interaction with the flow over the wing was analysed in detail, with the natural laminar flow over the device induced distinct flow structures compared to the forced transition case, for example horseshow vortex interactions with leading edge detachment dependent on incidence angle, and the detachment /reattachment of the boundary layer flow.

At the project mid-term review, the timeline of the tests (WP6, WP8) and system optimisation (WP7) has been compressed to fit into the time line of the project. Testing (WP's 6 and 8) and Optimisation (WP7) have been run in parallel with cross-iterations. This has allowed an extension of the design of the ground test rig and the prototype (WP4).

While in WP6 the ground test mainly dealt with the kinematics of the system, WP8 performed the cleaning tests. Good cleaning performances have been achieved on most parts of the leading edge, although for a small strip the cleaning performance was not satisfactory and should be improved in an advanced design.

1.3 Final results and potential impact

A prototype for an in-flight wing leading edge cleaning system has been developed and tested. This has allowed to bring the concept from a TRL 2 to a TRL 4, or even 5 if the wing used in the ground tests can be considered a “relevant environment”.

Wind tunnel tests have validated the CFD simulations used to predict aerodynamic loads on the device. The magnetic coupling used to hold the device on the wing, the most challenging aspect of the project from a mechanical point of view, is thus validated. Indeed, ground tests in WP6 have demonstrated that the guidance system performs as expected and can withstand the aerodynamic forces expected in off-design conditions (maximum speed during ascent and high angle of attack). After some design iterations and changes in the wheels system, the force required to move the system along the wing is reasonable and can easily be achieved using an electric motor. The guidance and cabling system has been designed to be as compact and light as possible.

Cleaning tests show that it is possible to comply with the requirement of debris height of less than 40 µm after cleaning for the majority of cases. The cleaning principle developed in this project works as expected. There is, however, a zone in which neither sponge cleaning nor string cleaning proves effective: the sponge does not have enough pressure, and the wing curvature is too low to allow efficient string cleaning. The problem has been reduced by modifying the profile of the sponge holders; to ultimately resolve this a more sophisticate, and complex, sponge holder has to be designed, so that the normal pressure of the sponge on the wing skin is sufficient all along the sponge.

The system has the potential impact of enabling the use of wings designed for laminar flow on both the suction and the pressure side, which have the potential of cutting fuel consumption by nearly 10% compared to a conventional fully-turbulent wing. This is achieved by avoiding slits on the wing skin, which would promote flow transition, and using a magnetic coupling instead of a mechanical link. Wings designed for laminar flow on the suction side only would also benefit from this system, but in this case a solution with a Krüger flap protecting the leading edge from contamination during the take-off and ascent could be preferred.

1.4 Public website

A public website has been setup to inform the public about the project objectives and achievements. It can be reached at the address **www.cleanle2.org**.