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Development and Optimization of Synthetic Jets to Control Active Flow

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ABSTRACT:

The goal of the project is to simulate and analyze the near C-130 Hercules flow field and then evaluate the influence of passive and active flow control method. This carrier aircraft has been extensively used and is essential while cargos, troops or material supplies has to be delivered rapidly in difficult access areas to military troops or during disasters that require humanitarian supply. The upsweep region in the aft fuselage leads to an increased drag, due to the highly detached flow and to strong upsweep vortices. The latter can be dangerous, by several means, during airdrop operations. For instance parachutes, while caught on the upsweep vortices can touch the empennage if they exit from the rear door . A good knowledge of the flow pattern around the aircraft is thus of particular interest to be able to control this flow by, for instance, attenuating the upsweep vortices. The ultimate goal of control device is to cancel any undesirable effect in the aft fuselage and enhance airdrop capability. In this sense it was proved that the aft fuselage region is the site of highly complex flow. Indeed this region is characterized by a massive separation, highly three-dimensional, where one can observe a pair of counter-rotating vortices also called upsweep vortices. These vortices then interact with the lower side of the empennage and cause the flow to detach resulting in counter rotating vortices also called induced vortices.

INTRODCUTION:

ISAE is counted among the best aeronautical universities in Europe and benefits directly from being located in Toulouse, the heart of the aerospace industry in France. The aerodynamic, propulsion and energetic department (DAEP) is located in the Ensica campus and boasts 15 researcher-professors and a technical team composed of 21 people. Among the many facilities available to staff and students, the DAEP is equipped with one shock tube and seven wind tunnels; four small subsonic, two small supersonic and a medium subsonic wind tunnel (3m*2m). The wind tunnels are used by students in the framework of their project and by the researchers in the framework of the various partnerships that exist with aerospace industries. Among the many projects that exist, my final project study was within the Airflow Influence on Airdrop (AIA). The previous project started in July 2002 and is a multi-national project which involve various countries; the United States with the Natick Soldier Research, Development and Engineering Center and the United States Air Force Academy (USAFA), Germany with the Federal Office for Defense Technology and Procurement (IABG), the United Kingdom with the Air Warfare Center (AWF) and the Joint Air Transport Evaluation Unit (JATEU) with the Royal Air Force (RAF) and France with ISAE. The goal of the project is to simulate and analyze the near C-130 Hercules flow field and then evaluate the influence of passive and active flow control method. This carrier aircraft has been extensively used and is essential while cargos, troops or material supplies has to be delivered rapidly in difficult access areas to military troops or during disasters that require humanitarian supply. The upsweep region in the aft fuselage leads to an increased drag, due to the highly detached flow and to strong upsweep vortices. The latter can be dangerous, by several means, during airdrop operations. For instance parachutes, while caught on the upsweep vortices can touch the empennage if they exit from the rear door. A good knowledge of the flow pattern around the aircraft is thus of particular interest to be able to control this flow by, for instance, attenuating the upsweep vortices. The ultimate goal of control device is to cancel any undesirable effect in the aft fuselage and enhance airdrop capability. In this sense it was proved that the aft fuselage region is the site of highly complex flow. Indeed this region is characterized by a massive separation, highly three-dimensional, where one can observe a pair of counter-rotating vortices also called upsweep vortices. These vortices then interact with the lower side of the empennage and cause the flow to detach resulting in counterrotating vortices also called induced vortices. In order to efficiently control such a complex flow, characterized by a highly unsteady behavior, both in closed configuration and in open cargo bay, it is particularly important to have a strong and clear knowledge of the dynamics associated with the use of control methods. As it will be explained in the bibliographic review, a strong theory behind control method is still lacking. Thus acquiring a good understanding on how control methods interact with the flow, one must go back to simple and wellknown configurations, for which the dynamic of the wake is already mastered. With these configurations, one can investigate how 3D forcing or synthetic jets affect the instabilities present in the wake, and more importantly how they affect the origin of these instabilities. Once control methods effects at this level is better understood and efficiently implemented, in terms of drag reduction, vortex shedding cancelation, lock-on regime …, one would eventually be able to analyze their effect on more complex flow with already a strong background on the area. Circular cylinders offer excellent opportunities to test active flow control method. Indeed the flow around circular cylinders has been extensively studied for many years and became the archetype for the study of unsteady flows. Although simple from a geometrical point of view, it offers a wide variety of flow phenomena, clearly visible, well understood and broadly documented in the literature. The circular cylinder also presents a highly detached flow, which is of direct relevance in the AIA project contest.

Bibliographic Review low control behind aerodynamic and bluff bodies has been investigated since decades and has been one of the main areas of research for the past ten years. Since then many new steps were performed all around the world allowing new knowledge on the field resulting in some cases at a drag reduction () of 70%. Still, this is an open topic and despite an increasing number of projects on the flow control field, the theory behind flow control remains unclear. 1.1. Control methods Classification In this chapter, the main insights on the area are presented. Flow control methods are usually divided into two groups, namely active and passive methods. Passive flow control methods refer to mechanism where there is no power input. Among them, one can mention surface modifications such as change in surface roughness, presence of dimples or longitudinal grooves. One can also mention geometric modification in the spanwise direction such as a segmented or wavy trailing edge. On the other hand active flow control methods refer to mechanisms using a power supply. Highfrequency rotation of the circular cylinder, base bleed, synthetic jets, single dielectric barrier discharge plasma all belong among these methods. When well implemented, these methods can turn out to produce drastic reduction of . However, even though these methods proved to perform well, their implementation in an industrial context is one of its main challenges, due to their lack of efficiency. Active flow control method can themselves be divided into open-loop or closed-loop methods. The latter refers to control methods that require sensing and actuation while active open-loop control methods do not require feedback sensors. Feedback control methods present the advantage that it continuously modify the control input depending on the flow system response. Flow past bluff bodies usually present multiple global modes; each of these modes becomes unstable at a certain point. At low Re, when only one of these mode becomes unstable, linear feedback control is possible using a single-sensor actuator feedback loop. Conversely, at high Re the wake has multiple unstable modes, which require multiple feedback sensors to have complete flow-field information. However, not all of these information are required to have feedback control. In other words, low-dimensional description of the flow features may be sufficient to control the flow. This is precisely the idea behind control methods based on reduced-order models. Finally optimal and suboptimal control theory represent the last closed loop active flow control category. The idea is to minimize a "cost function" defined differently in each case. The "cost function" can be the lift or drag coefficient, the difference between the velocity field and the steady laminar flow… The efficiency of these methods is closely linked with the choice of the cost function, and a clear knowledge of the flow is required to apply such a control method. For instance Min & Choi (1999) showed that drag is reduced more when the cost function is the difference between the real and potential-flow surface pressures than when the cost function is the drag itself. Another, more related to fluid mechanics, classification of control method is the division based on which part of the flow the control wants to modify. If the control method aims to delay separation, either through boundary-layer transition or though early separation and reattachment, the literature refers to "Boundary-layer control methods". On the other hand if flow control is performed directly through wake-modification not caused by separation delay, the literature refers as "Direct-wake control methods". Boundary-layer control methods are certainly the most spread, well-known, and famous method, in the sense that triggering boundary-layer instability in order to decrease drag coefficient comes immediately to mind for anyone who has little knowledge in fluid mechanics. In fact it is well-known that a laminar boundary-layer, has little resistance to an adverse pressure gradient, due to its low near-wall momentum. As the flow evolves, the adverse pressure gradient will cause the boundary layer to separate. If the Re number is high enough, one can trigger transition to turbulence before the boundary-layer separates. The new turbulent boundary layer has a strong near-wall momentum. As a consequence the friction drag will increase in a turbulent boundary-layer, but the pressure drag which has a considerable effect on the drag coefficient will decrease. Forced transition can be achieved by a trip device such as zigzag or plastic tape, dimples and surface roughness. Another way is to use a vortex generator, such as jet turbulators, which will produce strong near-wall momentum and thus delay main boundary layer separation. These ideas have been extensively used in all kind of fields. In sports for instance, most golf balls are covered by approximately 350 dimples. The dimples cause the boundary layer to transition from laminar to turbulent, and hence reduce pressure drag. Even in football, the presence of seams around the ball encourages turbulent behavior, resulting in drag reduction. In these two cases transition lower the wake thickness and enable the ball, for certain configuration, to fly higher and longer than a smooth ball. In aerospace, some airplanes are equipped with vortex generators. They consist of small plates about an inch deep in a row spanwise along the wing (Fig.1). When implemented on aircrafts they delay flow separation and thus aerodynamic stalling and ensure aileron effectiveness. They were for instance used in the two seat one engine Symphony SA-160, the C-17 Globe master III and the EMBRAER EMB-120. Boundary layer control methods can also consist of early separation and reattachment as mentioned previously. For instance, at a certain Re, the drag coefficient over a circular cylinder or a sphere significantly decreases, and one can observe the so-called “drag crisis”. In fact in the case of the separating laminar boundary layer, the flow often transitions just behind the separation point. The high-momentum shear-layer is entrained towards the surface, so that a normal, attached turbulent boundary layer forms, resulting in the delay of the main separation. Because there is a small region of reverse flow, streamlines form a bubble-shaped pattern. A few researchers investigated the control input to generate early separation and reattachment. Jeon et al. (2004) used a local time-periodic blowing and suction over a sphere at the subcritical Re. They showed that disturbances from high-frequency forcing (much higher than the vortex shedding frequency) rapidly grows along the separated shear-layer which leads to the reattachment of the boundary layer. The main separation is thus delayed, i.e. the drag coefficient is significantly decreased. After having presented the main insights of the boundary layer control, it is of particular interest to discuss direct-wake control. It has the advantage to act directly on one of the main contributions to the bluff-body drag; the wake. It is important to point out that the control changes the wake field directly and not through separation delay. Thus it can be used on any bluff body whether it has a fixed or movable separation point.

CONCLUSION:

The primary goal of this project and this manuscript has been to investigate the effect of active flow control on the wake of a circular cylinder at low Re. To that end, numerical investigations were performed in Fluent, based on a DNS approach, and results were analysed through Matlab, Tecplot and VIP_R. The active flow control tested consisted of 2D and 3D forcing. These forcing brought altogether new insights on the active control field. First the vortex formation process was dramatically altered at Re=300 when the exact mode A instability wavelength forcing was applied. As a consequence the drag and lift coefficient exhibits no more oscillation. Secondly synthetic jets were proved to significantly affect the aerodynamic coefficient from Re=500. At this level, the lock-on regime was observed while the synthetic jets were forced close to the natural shedding frequency. However the lock-on regime was proved to be accompanied by a significant increase in lift and drag oscillation amplitude and an alteration of the shedding process. Finally it was proved that 3D forcing effect on the flow does not consist neither on a simple superposition of a simple blowing and suction part nor on a delay of the separation point but on more subtle change on the wake leading to an alteration of the vortex formation process. In parallel a valid grid was created and computed for the ogive-cylinder at Re=1500. Two modes are observed in the wake, the Von-Karman mode and the helical mode. The unforced-wake computation can now serve to initialize the active control methods. All the knowledge gained from the investigation around the circular cylinder is to benefit to future investigation on active control method effect on the ogive-cylinder. Once investigated, the ogivecylinder can then be slanted and investigated, in order to have a more similar shape form than the Hercules C -130. Thus it is hoped that the ultimate goal of the AIA project, i.e. to enhance airdrop capability on the rear Hercules C-130,

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would be achieved. Finally the results provide scope for future research such as noise control. Therefore, more studies should be conducted in this area to obtain significant noise reduction. Also it was found that a clear knowledge of the unstable modes present in the wake is of prime importance while building up control method. Thus before applying control method at any ends, one should first concentrate on the most unstable mode on the wake and try to cancel them.

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