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Drag Reduction by Suppression of Roll Over Vortices on Airframe

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Abstract:

This project focuses on reducing drag caused by roll over vortices on aircraft wings. Roll over vortices increase turbulence, drag and reduce lift. A passive method is proposed to suppress these vortices using surface modifications on a NACA 2424 wing. Different modifications such as grooves, slits, notches and booms are analyzed. CFD analysis is carried out using ANSYS Fluent to study airflow and turbulence. Among all the modifications, the slit and groove show better vortex suppression. The modified wing is then fabricated and tested experimentally in a wind tunnel. Results show that the grooved wing reduces turbulence and suppresses vortices earlier than the normal wing. The grooved wing also increases the lift coefficient by nearly 20%. Thus, passive surface modification is an effective and simple method for drag reduction.

Keywords — Wing, Grooves, Slit, Drag Reduction, Turbulence, Computational Fluid

I. INTRODUCTION

The aerodynamic performance of an aircraft is greatly influenced by the airflow over its wings and fuselage. During flight, airflow may separate from the surface due to adverse pressure gradients, forming vortices. Among these, rollover vortices on the upper wing surface are particularly harmful as they increase turbulence and disturb smooth airflow. This results in higher drag, lower lift, vibration, and reduced efficiency. When airflow remains attached, maximum lift and minimum drag are achieved. However, as the angle of attack increases, the boundary layer loses momentum and begins to separate, forming vortices and increasing pressure drag. Severe separation can even lead to stall conditions. Therefore, controlling rollover vortices is essential for stable flight. A vortex is a rotating region of fluid caused by pressure or velocity differences. Strong vortices create low-pressure zones and interact with the boundary layer, leading to early flow separation and aerodynamic losses. To control vortices, passive methods are preferred over active techniques as they are simpler and do not require external energy. In this project, passive suppressors such as wedges, grooves, booms, and notches are applied to a NACA 2424 aerofoil. The models are designed using CATIA and analyzed using ANSYS tools. The performance is evaluated based on lift, drag, and turbulence. The most effective suppressor is identified by achieving maximum lift and minimum drag, improving overall aerodynamic efficiency and aircraft stability. The placement of these suppressors plays a crucial role in controlling airflow behavior over the aerofoil. By modifying the surface geometry, they help delay flow separation and reduce vortex formation. This leads to smoother airflow and improved pressure distribution along the wing. As a result, aerodynamic losses are minimized, and overall performance is enhanced. The findings of this study can contribute to designing more efficient and stable aircraft systems. The performance is evaluated based on lift, drag, and turbulence. The most effective suppressor is identified by achieving maximum lift and minimum drag, improving overall aerodynamic efficiency and aircraft stability.

II. RELATED WORK

Boursili [1] proposed a passive drag reduction technique to control vortex shedding using a slit cylinder. CFD simulations were carried out for both a normal cylinder and a slit cylinder. The study showed that the slit modification reduced the drag coefficient from 1.35 to 1.162, giving nearly 14% drag reduction. The method also reduced heat transfer by 4.44%, proving that passive slit geometry can effectively suppress vortices.

P. W. Bearman et al. [2] investigated the effect of wavy separation lines on bluff bodies. Their experimental work showed that introducing spanwise waviness reduces drag by nearly 30% when compared to conventional straight bodies. They also observed that vortex shedding can be completely suppressed when the wave height to wavelength ratio exceeds 0.06.

Menon et al.[3] developed a computational framework to identify and track vortices in unsteady aerodynamic flow. Their study used numerical simulations of a pitching airfoil and showed that leading-edge vortices strongly influence lift and drag. The research highlighted the importance of early vortex suppression in improving aerodynamic performance.

Satheeshkumar et al. [4] Satheeshkumar carried out a CFD study on vortex generators mounted on vehicles. The study demonstrated that properly designed vortex generators delay flow separation and reduce pressure drag. Although local turbulence increased near the generator, the overall aerodynamic performance improved significantly.

Tan et al. [5] experimentally investigated grooved wingtip designs for passive vortex suppression. The results showed that the grooved design reduced vortex core strength and swirling intensity without reducing lift. The study concluded that grooves are an effective and simple method for drag reduction and vortex control .

Canivete Cuissa et al. [6] introduced a vortex identification method based on swirling strength. Their work compared swirling strength with conventional vorticity methods and concluded that swirling strength gives more accurate detection of vortices in turbulent flow. The study also explained how vortex generation is influenced by baroclinic and magnetic effects.

Lee .et.al [7] presented a detailed review of vortex methods used in rotorcraft and eVTOL aerodynamics. Their study compared methods such as vortex lattice, lifting line and vortex particle methods. The results showed that these methods can accurately predict wake vortex behavior with lower computational cost than full CFD analysis.

Darabasz [8] carried out an experimental study on a flat-back Ahmed body with passive rear cavity modifications. The study found that the cavity creates longitudinal vortex pairs which stabilize the wake region and reduce base drag by up to 11.5%. This proved that passive vortex control can improve aerodynamic efficiency.

Gharbia [9] reviewed six decades of research on wingtip vortex formation and suppression. The study discussed passive methods such as winglets, grooves and bio-inspired wing shapes, as well as active methods. The review concluded that passive methods are more practical because they are simple, reliable and require no external power

Shen[10] investigated a new vortex reducer for aeroengine cavities using both experiments and numerical analysis. The proposed design effectively reduced vortex strength and pressure losses. The study concluded that passive suppressors improve airflow performance without increasing system complexity

III. PROPOSED METHODOLOGY

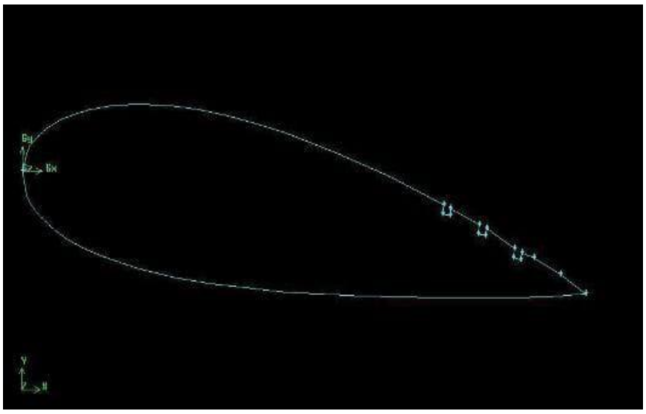
The The proposed method of this project is to suppress roll over vortices on the aircraft wing by using simple passive surface modifications. A NACA 2424 Airfoil having a span of 0.6 m and chord length of 0.15 m is selected as the base model. Since roll over vortices mainly form near the upper surface of the wing and increase drag, turbulence and flow separation, different suppressors are introduced on the upper surface of the wing. The suppressors used in this work are grooves, slits, notches, wedges and booms. These modifications are provided along the span of the wing to disturb the vortex formation and make the vortices decay earlier.

All the modified wing models are first created in CATIA V5. After modelling, the wing geometry is imported into ANSYS Fluent for computational analysis. CFD analysis is carried out at different air velocities and angles of attack to study the airflow around the wing. The parameters observed are velocity contour, pressure distribution, turbulence intensity and the location where vortices are suppressed. The results of the modified wings are then compared with the normal wing to identify which suppressor gives the best aerodynamic performance.

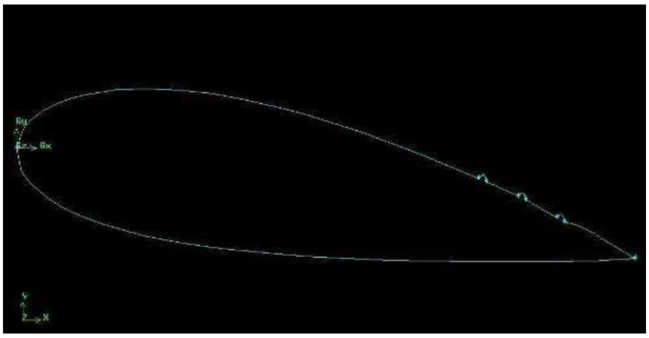
From the CFD results, it is observed that groove and slit configurations suppress the vortices earlier than the other modifications. Therefore, the best-performing wing is selected for fabrication. The fabricated model is then tested in a wind tunnel to validate the CFD results experimentally.

Finally, the drag, turbulence level and lift coefficient of the modified wing are compared with the normal wing. The proposed method is simple, low-cost and does not require any external power, making it more effective and practical than active vortex control methods.

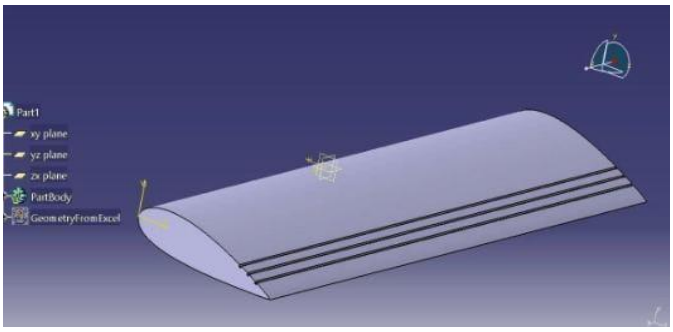
A. NACA 2424 wing with different surface modifications groove



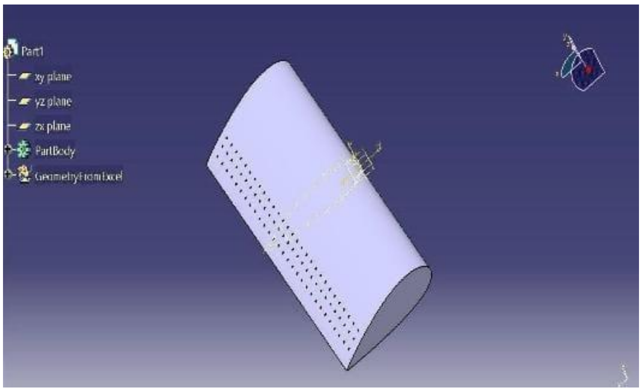
B. *NACA 2424 wing with different surface modifications boom*



C. Catia model of NACA 2424 wing with groove as suppresser type 1



D. Catia model of NACA 2424 wing with groove as suppresser type 2



IV. CONCLUSIONS

The present study investigated the suppression of rollover vortices on a NACA 2424 aerofoil using different passive suppressors such as wedges, grooves, booms and notches. The suppressors were placed at various positions on the wing surface and analysed using CFD tools. The results showed that passive suppressors are effective in reducing turbulence intensity and delaying flow separation over the aerofoil surface.Among all the suppressors considered, the groove-type suppressor provided better aerodynamic performance when compared with the normal wing and other suppressor configurations. The groove suppressor reduced the strength of rollover vortices, which in turn reduced drag and improved the lift characteristics of the aerofoil. The airflow remained attached to the wing surface for a longer distance, thereby decreasing the possibility of stall and vibration.

The study also proved that passive techniques are simpler, less expensive and easier to implement than active flow-control methods. Since no external energy source is required, these suppressors can be practically applied to aircraft wings to improve aerodynamic efficiency. Therefore, the proposed method can be used as an effective solution for drag reduction and rollover vortex suppression in future aircraft design.

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