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AERODYNAMIC ANALYSIS OF MORPHING WING

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Abstract:

This thesis presents a modelling and design exploration study of a novel twisting wing whose motion is enabled by a tensegrity mechanism. First, the aerodynamic characteristics of the twisting wing, which does not require control surfaces to modulate its shape, are compared with those of a conventional wing having a control surface. It is shown via computational fluid dynamics analyses that the twisting wing displays higher lift-to-drag ratio than the conventional wing and hence the twisting wing is more aerodynamically efficient. In addition, due to the reduction of discontinuous rudder surfaces, morphing wings can further improve the stealth performance. A finite element model with geometrical nonlinear effects is then proposed to correct the errors of the linear analysis and verify the effectiveness of the optimization method. This design is shown to be able to reduce the overall weight of the structure and achieve control of the macro mechanical performance of the wing. The work provides a general optimization design method for similar modular structures, allowing independent programmable adjustment of the parameters of each single structural cell

Keywords: Morphing wing,types of morphing wings, morphing mechanism, aerodynamic analysis

1**INTRODUCTION**:

The concept of morphing has attracted widespread attention from present aircraft designers. It is found that morphing wings can improve the overall flight efficiency by adapting to different flight conditions by adjusting their shapes, and can improve their performance within a certain airspeed range, reduce vibration, increase maximum lift, reduce drag, or enhance aircraft manoeuvrability and aeroelastic performance. In addition, due to the reduction of discontinuous rudder surfaces, morphing wings can further improve the stealth performance. Modern aircrafts use discontinuous flight control surfaces, such as ailerons, flaps, slats, and elevators, to manoeuvre during flight. These control surfaces alter the geometry of the wing or tail stabilizers to affect yaw, pitch, and roll. The presence of these traditional discrete control surfaces in the wing results in vortex formation, and hence generation of unwanted drag from the gaps and hinges between the control surface and the wing [1]. Unlike birds' wings that can seamlessly and flexibly change in shape, traditional wings are incapable of such adaptation to various flight conditions.

Commercial airplane wings are designed for specific conditions that the airplane experiences for the most of its flight. Hence, they are most efficient during cruising, but the performance during other flight scenarios, like take-off and landing, is sub-optimal. Smaller aircrafts, like unmanned aerial vehicles (UAVs), exhibit various flight conditions, and therefore need wings that can adapt to those conditions while remaining aerodynamically efficient. Lightweight continuous morphing wings capable of transforming in flight are desired for improving the overall flight performance There are three major categories of wing morphing: planform, out-of-plane, and airfoil morphing. Planform morphing includes resizing the span and chord lengths and modifying the sweep angle. Out-of-plane reshaping the airfoil profile and thickness. Morphing includes twisting, change in dihedral angle, camber-morphing, and span-wise bending. It has been shown that each type of shape morphing enabled in a wing can improve the aerodynamic efficiency of the aircraft in specific flight conditions. For example, Joshi et al. [8] compared the predicted performance of a BQM-34 Firebee unmanned target drone aircraft with a fixed wing, a wing capable of airfoil morphing, and a wing capable of planform morphing. Eleven different flight conditions were compared, and the performance of the aircraft was significantly improved with the use of morphing wings in most of the considered conditions. Beaverstock et al. [9] quantified the improved performance in aerodynamic efficiency and range by using spanmorphing and camber-morphing wings on a UAV at various speeds.

1.1 **HISTORICAL BACKGROUND**:

The Wright Flyer I, in 1903, had wings made of fabric and wooden ribs, and was able to twist its wings to roll [10]. Since then, the fabric wings that were capable of twistmorphing were replaced by a more rigid structure to support the increased demand of higher cruise speeds and larger aerodynamic loads [11]. Twist-morphing is one of the most practical morphing techniques. This type of out-of-plane morphing allows for a seamless change in the angle of attack (AOA) along the span of the wing. Hence, it can decrease a wing's induced drag by removing the discontinuous surfaces of ailerons and flaps [12]. Twist-morphing can also improve roll and pitch performance, and efficiency.

increase the amount of lift generated, and expand the flight envelope of the aircraft [13]. Twist-morphing can be applied gradually along the entire span of the wing, or locally concentrated in a single segment. Currently, one of the most difficult challenges in designing a morphing wing is the outer skin. The reason for this is that it must satisfy two conflicting requirements: high out-of-plane stiffness and low in-plane stiffness. This means that the skin must be stiff enough to withstand aerodynamic pressure loads while being sufficiently compliant for the morphing actuation [14,15]. Jenett et al. [16] designed a gradual twist-morphing wing that has modular elements to create a composite lattice structure.

1.2 **THEORETICAL EXPLANATION:**

The morphing wing is the body shape changing wing based on its requirements. Morphing wing is developed from the flying birds. Many scientists and engineers observed the wings of the birds while flying how its changing its wing shape and resisting the drag (air friction). This observation lead the development of a normal aircraft wings into morphing wings using morphing technology. Morphing wing controls the aerodynamic characteristics and aircraft performance. morphing wing increases the efficiency of the aircraft. Morphing wing can change sweep, chord, camber and it can flap. It can increase and decrease the lift and drag of an aircraft. Morphing wing can make the aircraft stable, controllable and manoeuvrable. The one more reason for the developing the morphing wing is fuel consumption, it decreases the fuel consumption and increases the economy of the aviation industries. But in reality, morphing of the wing does not occur easily like it occurs in the birds. We use different mechanisms in morphing technology. These mechanisms help the wings to change its body shape. The we use servos or servos and five or six bar mechanisms. 2 The development of smart materials has advantage of making the morphing wing. The smart materials are light weight, flexible, thermal resistance. The smart materials are also called as “composite materials”. The morphing technology applied in the few UAVs, but this technology not developed to the whole wing. It is developed to the parts of the wing like trailing edge morphing, camber morphing, twisting, sweeping etc.

The servo motors are connected to the particular part of the wing and mechanises that particular part. It is found that morphing wings can improve the overall flight efficiency and can improve their performance within a certain speed, range, reduce vibration, increase maximum lift, reduce drag or enhance manoeuvrability and aeroelastic performance. In addition, due to the reduction of discontinuous rudder surfaces, morphing wings can improve the stealth performance. For a long time, continuous increase in flight speed and altitude has increased the demand for the structural rigidity because of aeroelastic problems. This means deformation of wings has become more difficult. This lead the almost complete stalling of development in morphing wings, with continuous improvement of awareness of aircraft designers, materials and structural design technologies, engineers are now examining the structural designs of aircrafts from a completely different perspective. Some researchers tried to produce morphing wings, blades or some adaptive structures driven by actuators of piezoelectric materials and have developed some ingenious and effective deformable devices. However, the weight of the basic structure still remains a formidable challenge, resulting in the limited applications of heavy traditional actuators.

2**MATERIALS AND METHODOLOGY**:

2.1 **MATERIALS:**

Engineering advancements in the area of polymers have allowed materials to be more durable, flexible, elastic, and have a higher recovery percentage.

POLYURETHANE:

Polyurethane is popular because it has the ability to provide the elasticity of rubber, while having the advantages of toughness and durability of metal. Since polyurethane is a synthetic material, there are different chemical formulas which allow the material to have a different hardness.

COPOLYSTER:

Copolyester is a type of material that is easy to process and has the characteristics of thermoset elastomers. There are two specific materials that were tested that fall under the copolyester category. One material is Arnitel and the other is Riteflex , specifically these materials are a type of thermoplastic. One reason why these materials were chosen to test is the availability of these materials.

SHAPE MEMORY MATERIAL:

Another family of material that was investigated was shape memory materials (SMM). Within the family of SMM there are different types, such as, shape memory polymer (SMP), shape memory alloy (SMA), and liquid crystalline elastomers (LCE). SMM “are materials that can be deformed into a temporary and dormant shape under specific conditions of temperature and stress and will later, under thermal, electrical, or environmental stimuli, relax to their original, stress-free conformation due to the elastic energy stored during the initial deformation.

2.2**PRACTICAL AND CONCEPTUAL APPROACH:**

The wing morphing can be simulated and tested using basic following methods:

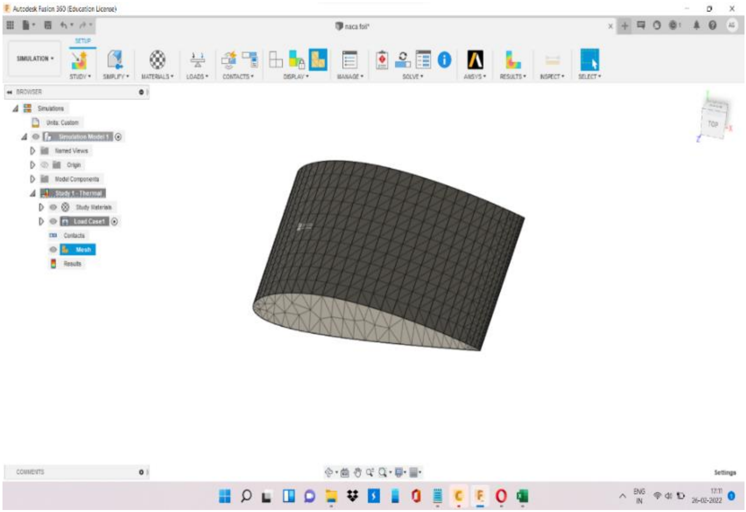
1. Wind tunnel test method

2. Computational fluid dynamics (CFD) method
3. Finite element method (FEM) method

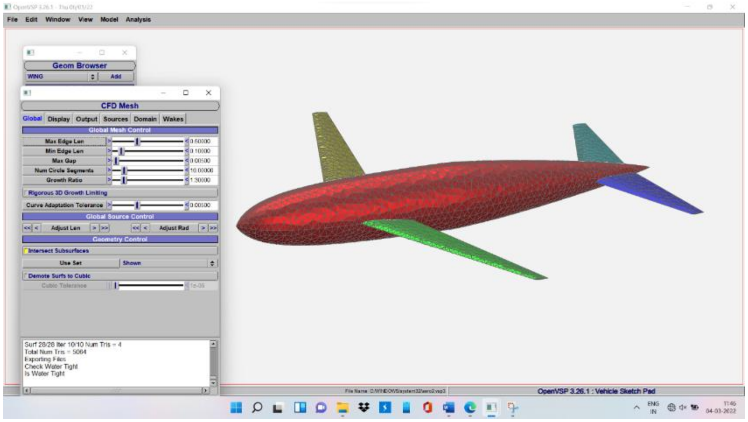
Out of these methods, CFD and FEM methods are performed in the open VSP and ANSYS.

2.3EXPERIMENTAL SETUP:

The aim of this work was to study the effect of all design parameters on the torsional and out of plane compliances of the twist morphing skin in order to guid the design process and the selection of suitable actuators for this application. The naca 2415 airfoil was taken and for the high stall angle of attack of its airfoil which potentially allows for larger twist angles to be achieved without stalling any portion of the wing. Furthermore, using a functional model as the base design presents the feasible prospect of testing the final morphing. The three-dimensional CFD analyses are conducted in Ansys engineering simulation software to explore the aerodynamic performance of the twisting wing design and the original wing with a trailing flap. The coordinates of the points defining the outline of the naca airfoil, it is imported from fusion into Ansys and connected and extrude to form the three-dimensional models of the wings. Computational models of the twisting wing adaptation and its original form that includes a single control surface. The reference angle of attack is defined as that between the chord line at the wing root and the airflow direction while the twist angle is defined as the difference between the local angle of attack at the wing tip. To conform the validity of the CFD model, simulations are conducted for the morphing wing airfoil shape with angle of attack. The sectional lift coefficient (Cl) obtained from the CFD computations is then compared against the wing tunnel data. The CFD approach employed in this work was demonstrated.



Wing meshing in fusion 360



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Exporting Files
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CFD meshing of sweeping wing in open vsp

3CALCULATIONS:

The five considered design parameters are: 1. The number of plies in the twistkin CFRP laminate, denoted $\boldsymbol{NL}$, 2. The fibre orientation angle of the CFRP plies, denoted $\propto$, 3. The torsional rigidity of the elastomers, denoted $\boldsymbol{kel}$, which combines the thickness and elastic modulus of the elastomeric material, 4. The number of elastomeric sections, denoted $\boldsymbol{NeS}$, the width ratio, β, defined as the ratio of elastomeric section width, $\boldsymbol{wes}$to the twistkin width, $\boldsymbol{wcf}$, expressed as the

$$\beta = \frac{w_{e_s}}{w_{c_f}} \times 100$$

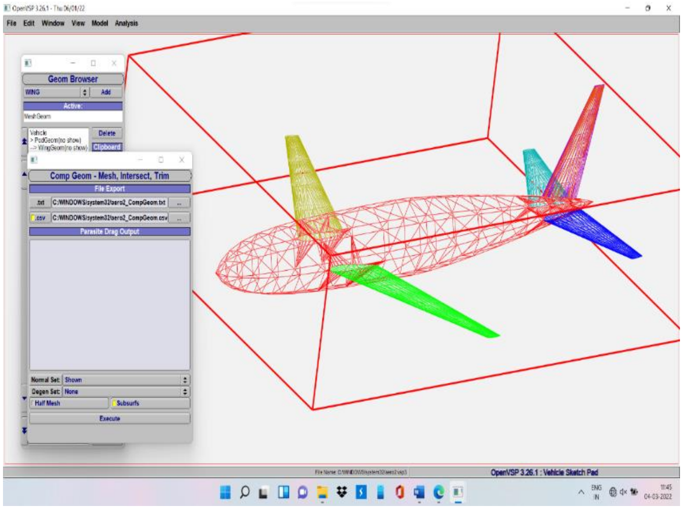
Reynolds number for the aircraft flying at its design point is therefore

$$\mathrm{Re} = \frac{\rho \cup c}{\mu}$$

4RESULTS:

Although the benefits of morphing wings have been proven in many studies in the last few decades, the wing skin design remains one of the challenges to advancing and implementing the morphing technology. This is due to the conflicting design requirements of high out-of-plane stiffness to withstand aerodynamic loads and low in-plane stiffness to allow morphing with the available actuation forces. Advancements in the design of hybrid and flexible composites might allow for design solutions that feature this balance in stiffness required for this application. These composites offer new design parameters, such as the number of plies, the fiber-orientation angle of each ply in the skin laminate, and the spatial distribution of the plies on the skin surface. 3 This paper presents a parametric study of a composite skin for a twistmorphing wing. The skin is made of periodic laminated composite sections, called “Twistkins”, integrated in an elastomeric outer skin. The twisting deformation is localized in the elastomeric sections between the Twistkins. The design parameters considered are the number of plies in the composite Twistkins, the fiber-orientation angle of the plies, the torsional rigidity of the elastomer, the width ratio, and the number of elastomeric sections.

The computational analysis results showed that the torsional compliance can be increased by increasing the width ratio, decreasing the number of elastomeric sections, number of composite plies and the elastomer’s torsional rigidity. However, this would also lead to a decrease in the out-ofplane stiffness. The nonlinearity and rates at which these parameters affect the skin’s behaviour are highlighted, including the effect of the fiber-orientation angle of the laminate plies. Hence, the study guides the design process of this twist-morphing skin.



MeshGeom

Vehicle
\> PodGeom(no show)
--> WingGeom(no show)

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Normal Set: Shown
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Fig.meshing of an aircraft in open vsp

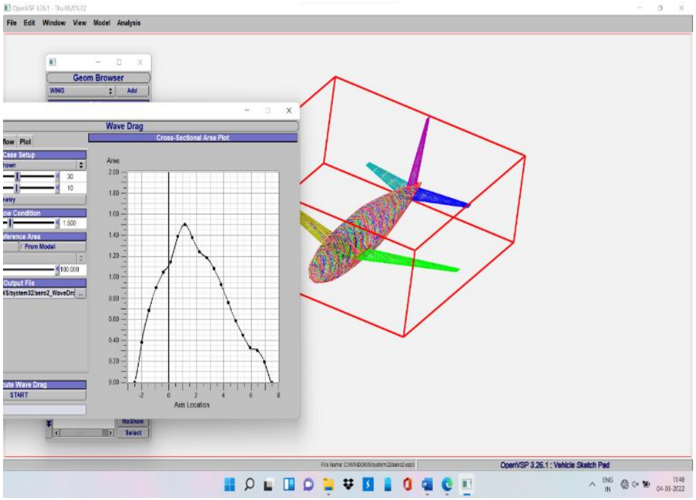

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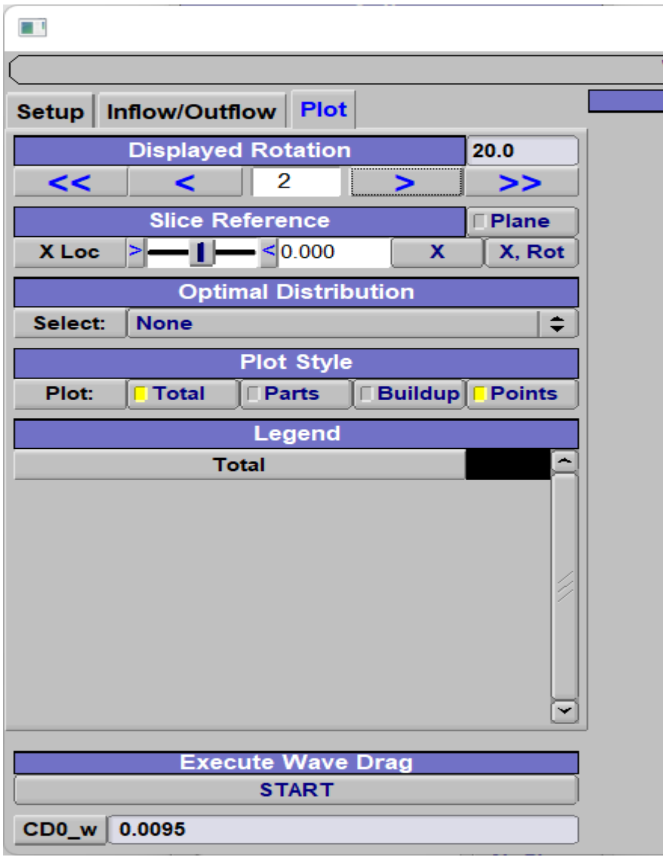
Fig. analysis of wave drag and geometric meshing in open vsp



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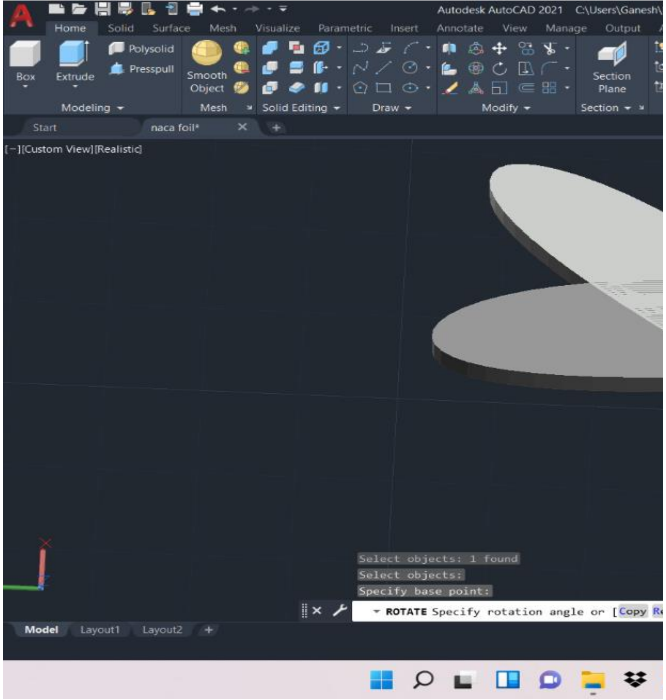

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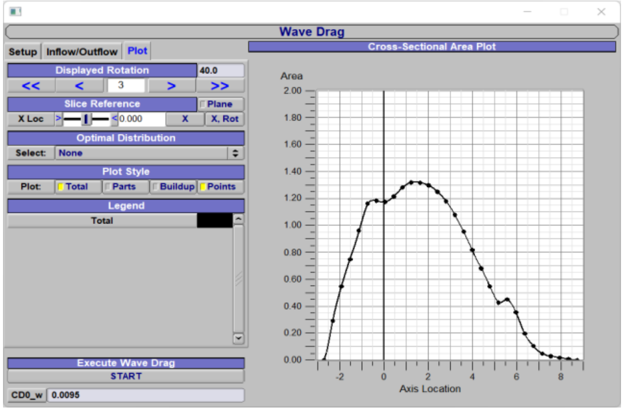

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X Loc 0.000

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Plot: ■ Total ☐ Parts ☐ Buildup ■ Points

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5.CONCLUSION:

The use of morphing allows wings to have more than one characteristic it is very useful application achieving future development in UAV sector, civil and military aviation sector by performing the characters by its changing its configurations. It is also showing the impact on the economy and environment. The production of the morphing can create less weight and less cost. It decreases the fuel consumption and increases the aircraft performance. We have described a design method and an analysis model for a morphing wing with the cellular structures of non-uniform density, where the structure weight is taken into consideration, and each cell in the structure is carefully considered by the variable density optimization method. This paper presented a novel conceptual design of an SDOF mechanism. Brief kinematics analysis was given. CFD and FEM simulations were conducted to study the aerodynamic performance of a morphing wing model and find the maximum stress within the mechanism. Some conclusions can be drawn here: The deployment of the mechanism has slight influence on the lift or drag coefficient while having a relatively strong influence on the lift to drag ratio L/D. This feature makes the mechanism very useful for aircraft to perform multi-mission tasks in which the requirements on the flight speed and the range/endurance change from time to time. A local peak of the maximum stress appears when the mechanism extension is around 30◦,i.e., when the mechanism extends to half of its full extension range. And the maximum stress goes up again starting from about 45◦ extension until it reaches the global maximum value at 90◦ extension. The largest maximum stress is much less than the yielding stress of the selected material, indicating the mechanism is safe to be used for the current airplane model. During the extension of the mechanism, the maximum stress appears at two different locations.

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