An Investigation of the Sweep Effect on Corrugated Wings at Low Reynolds Numbers

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Modern-day living has been defined by automation, with more and more work being done by machines: warfare is no exception, wherein a large magnitude of effort is being generated around the globe to reduce the involvement of humans in risky missions. Unmanned Air Vehicles (UAV), also known as Remotely Piloted Vehicles (RPV) and drones have been used over battlefields since the War of Attrition; however, it was only in the past two decades that their use has glaringly been demonstrated during conflicts in Afghanistan, Iraq, and, most recently, in Ukraine. Micro Air Vehicles (MAV) are small UAVs measuring less than 15 cm in any dimension. The size limit directly impacts aerodynamics, requiring the design to be efficient enough to fully use available space while carrying its own weight and having some purposeful endurance. In this regard, nature provides some efficient and unique opportunities: insects use a thin membrane and corrugated-shaped airfoil wings to fly in a low Re regime.

From the aerodynamics point of view, dragonflies exhibit good glide and hover performance, nimbleness, and precision in executing maneuvering flight at a speed of up to 10·m/s with 2g sustainable acceleration and up to 4g instantaneous accelerations. The cross-sectional shape of corrugation in the wing varies in a spanwise direction. These corrugations trap vortices/eddies, helping in lift enhancement and stall delay. Furthermore, the vortices stay anchored in the bottom of the corrugation, shielding the wing from external flow, and consequently helping in lowering the viscous drag. In the year 2000, Kesel extracted three cross-sectional shapes from the dragonfly forewing. This was the Kesel-2 airfoil which serves as a reference for this study and is shown in Fig. 1.



Tests were conducted in the Brown-Kopel Engineering Student Achievement Center and the Davis Aerospace Building at Auburn University. The four models investigated in this research consist of rectangular planform Kesel-2 profile wings with an aspect ratio of two, serving as the baseline. The other models were obtained by introducing a constant sweep of 15, 30 and 45 degrees at the leading edge. The wind tunnel tests were carried out at three Reynolds numbers of 50,000, 75,000 and 100,000. The lift (L) and drag (D) were obtained from the normal (N) and axial (A) forces measured by the force sensor with a simple transformation:

$$L = N\cos\alpha - A\sin\alpha \tag{1}$$

$$D = N \sin \alpha + A \cos \alpha \tag{2}$$

Qualitative flow visualization was conducted in the close-loop water tunnel in the Vortex Dynamics Lab of Auburn University. A fluorescence powder mixed with sugar was deposited over the wing surface and was illuminated with a UV light to observe the flow features as shown in Fig. 2.

The research investigated the effect of leading edge sweep on a Kesel-2 profile corrugated wing having a small aspect ratio. The results show that the introduction of sweep helped delay the stall angle, and as a result, the maximum lift coefficient *CL,MAX* was also increased. The leading edge sweep without any taper also impacted the stalling behavior by making it sharper

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for the 45-degree sweep. The variance in lift coefficient *CL* showed a more steady lift when Reynolds numbers exceeded 75,000 for higher sweep angles. Flow visualization showed that eddies trapped in the corrugation valleys aided in keeping flow attached over the surface of the wing model, which resulted in a thick, virtual airfoil.



Fig. 2 Water tunnel flow visualization (flow direction from right to left).

Statement of Research Advisor

As a part of Vortex Dynamics Lab, Josh was introduced to and exposed to the fascinating world of Experimental Aerodynamics. During his research he learned to conceive idea through observation of the natural world and transform them into research question and drawing meaningful conclusion from his investigation. He learned to develop an experimental setup, wind tunnel testing to quantify the problem and flow visualization to study the flow physics.

- Syed Hassan Raza Shah PhD Canidate, Aerospace Engineering Department, Samuel Ginn College of Engineering

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Kacmarzyk H. Joshua is a senior-year student pursuing a B.A.E degree in Aerospace Engineering at Auburn University. Funded and advised by Dr. Ahmed in the Dept. of Aerospace Engineering, Joshua served as the primary author and was mentored by Dr. Anwar Ahmed and Syed Hassan Raza Shah for guidance and direction of the project and confirmation of results.



Syed Hassan Raza Shah is a PhD Candidate at Aerospace Engineering, Department. His research includes unsteady low Reynolds number aerodynamics and hydrodynamics of vertical axis turbine.



Dr Anwar Ahmed is a Professor at Aerospace Engineering Department. He has a strong background in experimental aerodynamics and fluid mechanics. In addition, he also has experience in laser diagnostics, anemometry, laser doppler velocimetry, PIV, flow visualization, and wind tunnel testing. His research includes aero optics of airborne lasers, boundary layers, viscous drag reduction, vortex-dominated flows, bluff body wakes, and synthetic jets.