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Applied Aerodynamics

Mini-Project

Summary

This project report has two main aims, namely-

1) Verifying the performance parameters of the Mark I wing while checking their agreement with the experimental results obtained at the Handley Page Lab.
2) Proposing an optimized profile as compared to the Mark I wing while making sure the new wing fulfills all the design requirements.

A laminar wing is the optimal choice of type of wing for the altitude and Reynolds number at which the drone is expected to operate. However, a laminar wing design involves coupling different disciplines in order to maintain both aerodynamic as well as structural integrity.

Introduction

The analysis looks at parameters of endurance factor Cl^(3/2)/Cd, lift (Cl) and drag (Cd) to compare the performances of the airfoils. Since this drone is solar powered, the location of the solar panels that are fitted on the wing is important to predict how it will affect the flow. The operating conditions of Reynolds number and cruise speed as well as some wing dimensions are based on those of the Facebook HALE drone. These parameters are listed below.

Reynolds numbers	175,000 (tip) 262,000 350,000 (root)
Velocity of cruise	7.32m/s
Aspect ratio of the wing	30
Airfoil thickness at root	13.5%
Airfoil thickness at 40% semi span	12%
Airfoil thickness at tip	11%
Angle of attack	-3° to 20°

Results and Discussion

One important question is the credibility of the wind tunnel test results conducted for the Mark I wing. The operating conditions of the wind tunnel provide a turbulence intensity of 0.5%. According to Mack's relation, a turbulence intensity of 0.5% corresponds to N=4.28. The drone operates in static air and high altitudes at typically low values of turbulence intensities and low Reynolds numbers so, high values of turbulence intensity such as 0.5% will not be encountered by the drone. Hence, the wind tunnel does not create the real operating conditions of the drone.

The **NACA 6412** airfoil has been proposed as a better alternative to the Mark I wing for a HALE drone.

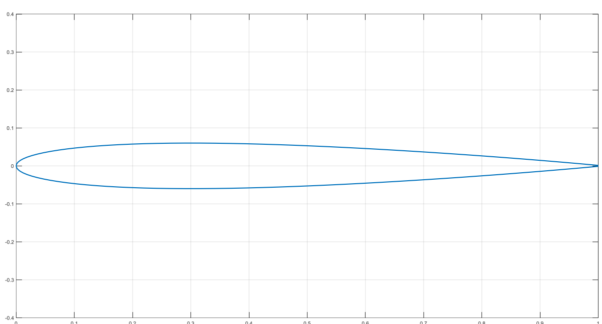

Figure 1: Mark1 Airfoil

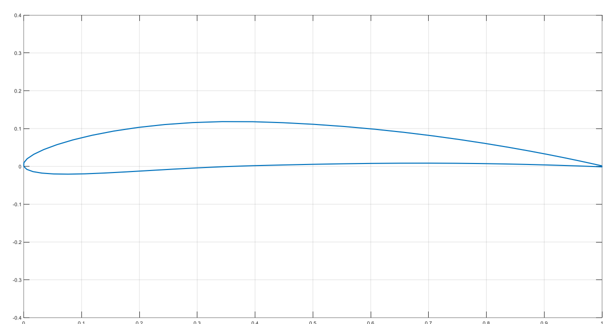

Figure 2: NACA 6412 Airfoil

Mark1 and NACA 6412 performance

For the analyses between the two airfoils, Ncrit=9 is chosen as the standard value for e^n transition criteria. The NACA 6412 clearly provides a higher endurance factor and lift for all given Re values. This is due to the high camber of the airfoil. A high cambered airfoil results in more drag than a symmetric airfoil, however, the increase in lift is much more and it more than compensates for it by achieving a high endurance level which is useful and important for long missions at low Re numbers. The higher lift achieved is albeit for slightly lower angle of attack. The following table provides the maximum endurance factor achieved and the corresponding angle of attack. It also shows the lift achieved at that angle.

Reynolds Number	Maximum Endurance factor	Angle of attack	Lift coefficient achieved	Stall Angle
175,000	93.11	9.4	1.61	10.9
262,000	111.63	8.8	1.57	10.9
350,000	124.63	8.3	1.52	10.6

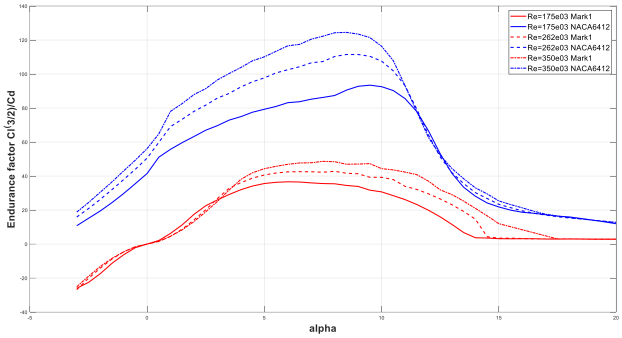

Figure 3: Endurance factor vs α

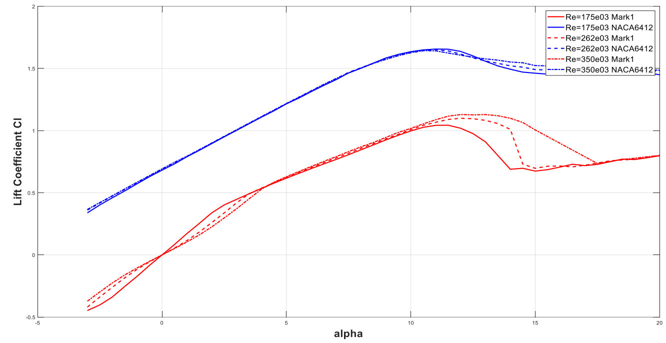

Figure 4: Lift Coefficient vs α

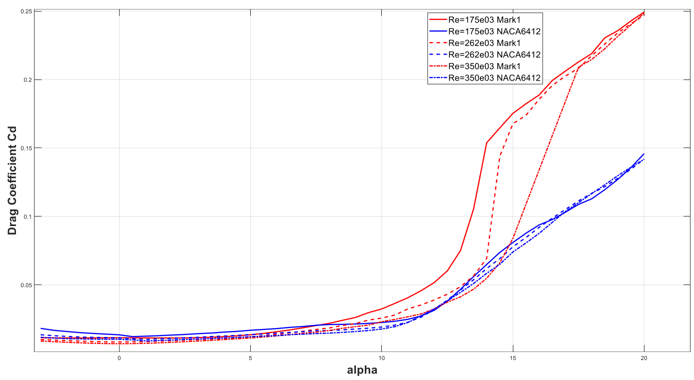

Figure 5: Drag Coefficient vs α

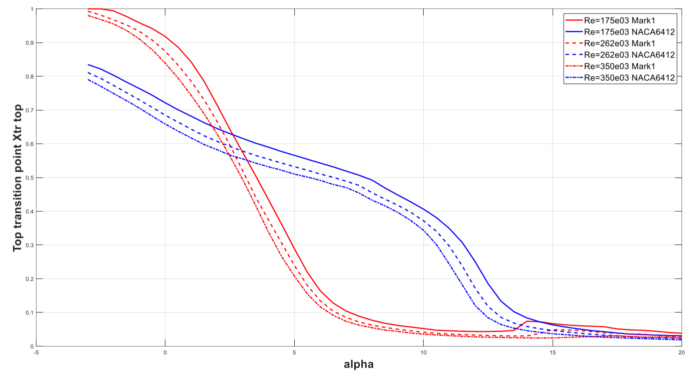

Figure 6: Transition location vs α

For the range of Low Re numbers, we always get maximum endurance at an angle lower than the stall angle. This is important to know since this increases the utility of the airfoil. We can achieve maximum endurance by maintaining the required angle of attack whilst avoiding stall.

Based on Figure 6, we can see that NACA 6412 also pushes the transition location for different angles of attack above 2.5°. At α=2.5°. both the airfoils have the same transition location on their chords. Since the airfoil should operate at angles close to the maximum endurance angles (about 8-10°), we see that this airfoil produces favorable results of pushing the transition location further back than the Mark1 airfoil and hence reduce overall frictional drag.

Effect of Transition on NACA 6412

Tripping the boundary layer before its naturally occurring transition location gives increased frictional drag while tripping it after has no effect on the flow. Figure 7 shows the effect of transition on increasing angle of attack. The transition point shows up as a kink in the pressure distribution curve where Cp drops suddenly before reattaching again. The transition point moves up the surface as we increase α. In order to satisfy power requirements, the wing is fitted with solar panels on its surface. These panels introduce some gaps on the surface of the airfoil that can act as surface non-uniformities and cause the laminar flow over the wing to trip and turn turbulent. Figure 8 shows the variation of endurance vs α at different transition locations. These calculations have been done at an average Re=262,000. As expected, an x/c=1%, which corresponds to a turbulent boundary layer since the trip is located very close to the leading edge, produces the worst endurance value. The following table lists the loss in endurance factors at different trip locations.

Trip Location	Endurance factor	% loss in Endurance factor
1%	58.7427	47.31
10%	67.2638	39.66
20%	80.0029	28.24
30%	96.2656	13.65
40%	110.4250	0.95
50%	111.4885	0
No trip	111.4885	0

1. The gap location of the solar panels must be chosen in such a way that it has no effect on the nature of the flow. This would be the case if the solar panels are located at the closest point to the leading edge where the flow would transition naturally anyway.
2. While cruising, the angle of attack should always correspond to the maximum endurance which in this case is close to α=9°. It is shown in Figure 7 that the flow naturally transitions at 41.8% chord length at α=9°. Therefore, the solar panels should be placed at a chord length of 41.8% from the leading edge.
3. If the solar panels are placed closer to the leading edge, there will be an increase in the frictional drag as the flow would transition earlier which ultimately results in loss of endurance.
4. Conversely, if the solar panels are placed further down the airfoil, there would be no effect on the flow as the flow at that point would already be turbulent, however, we would be compromising on our power requirements as the solar panels would have a smaller surface area.
5. We also see in Figure 9 & 10, that the lift and drag polars at 40% transition are closest to the 'no trip' case and any trips located further down the airfoil have little effect on the flow.

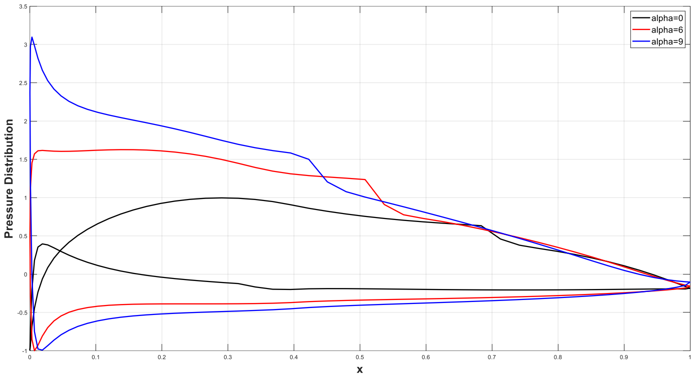

Figure 7: Pressure Distribution vs x/c

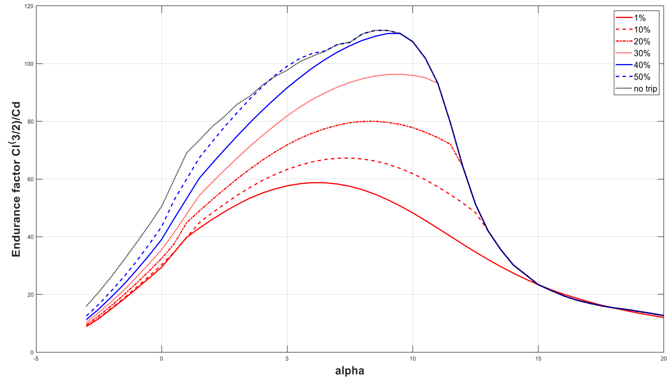

Figure 8: Endurance Factor vs α for different transition locations

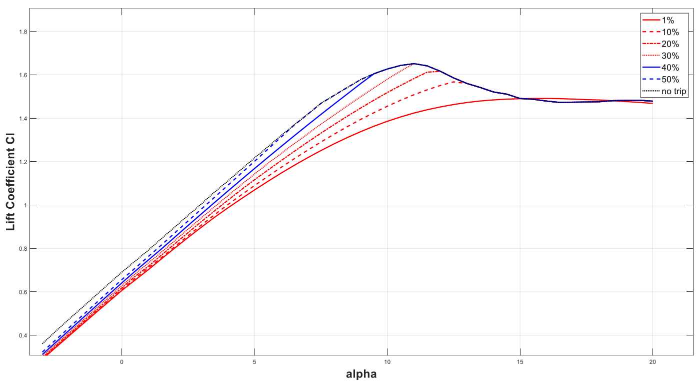

Figure 9: Lift Coefficient vs α

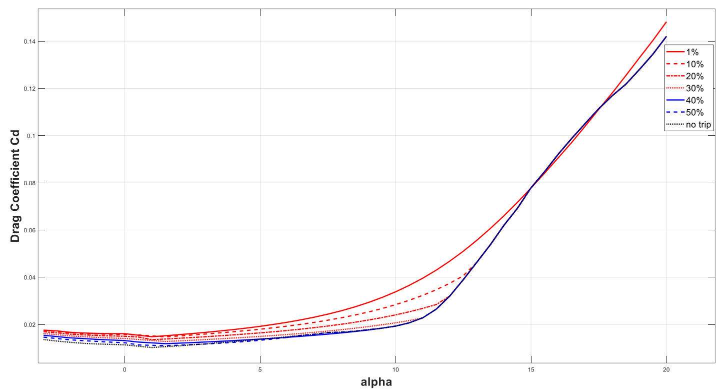

Figure 10: Drag Coefficient vs α

Wing Analysis of Mark1 and NACA 6412

In 3D finite wings, we must consider induced drag from tip vortices which come into play. In our case, Reynolds Number varies along the span from 375,000 at the root to 175,000 at the tip. NACA 6412 achieves a better endurance factor value which plateaus a little bit over a range of angles of attack. This means that the wing can access maximum endurance at different angles of attack. Lift has also drastically improved without changing the stall angle. The viscous drag coefficient remains unchanged as well.

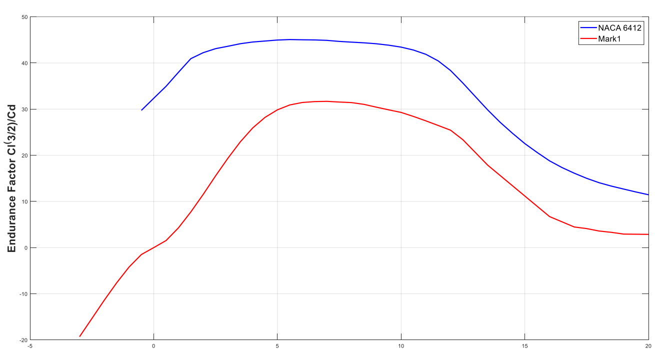

Figure 11: Endurance factor vs α

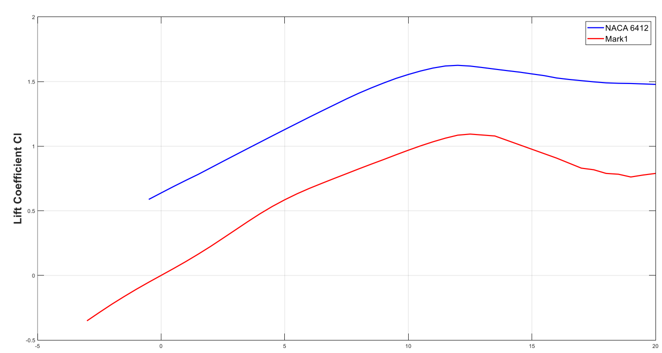

Figure 12: Lift Coefficient vs α

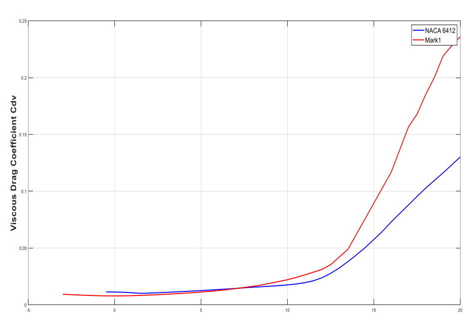

Figure 13: Viscous Drag Coefficient vs α