Masters in Aerospace Engineering

MAE107: Applied Aerodynamics I

On the wing design of a long endurance high altitude drone

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1 Background

Following the success of the Airbus Zephyr program, the demand of High Altitude Long Endurance (HALE) drone is rising rapidly. According to the most recent announcement of Airbus the solar powered Zephyr can accomplish missions of more than 25 days due to their enhanced aerodynamic performance. Since the vehicle is expected to operate as a pseudo-satellite at around 67,500ft to 85,000ft for several months, the long endurance prescribed by the mission places a tight limitation on power requirements and hence drag reduction is at the focus of the design. The total drag is given as

$$C_D = C_{D_0} + C_{D_i} \tag{1}$$

Where the profile drag, C_{D_0} is given as

$$C_{D_0} = C_f + C_{D_f} \tag{2}$$

C_f, represents the skin friction drag, C_{D_f}, the form drag and the induce drag, C_{D_i}

$$C_{D_i} = \frac{C_L^2}{\epsilon \pi AR} \tag{3}$$

At cruise condition the flow is expected to be attached over the whole wing and therefore the skin friction drag will be a major part of the profile drag. In this case a laminar flow wing is preferred as opposed to a turbulent one which will generate higher skin friction drag but is more resilient to flow separation. The main aim is to achieve as much laminar flow as possible over the wing by delaying boundary layer transition. Considering the altitude and the Reynolds number at which the vehicle will cruise this objective seems to be highly achievable. However, the design of a laminar flow wing is a very challenging task as a laminar boundary layer can undergo rapid transition to turbulence due to pressure gradients or surface non-uniformity, such as localised surface deformation or roughness. The power requirement imposes a large area of solar panel which is placed primarily on the wing and therefore the wings are stretched outwards to increase the aspect ratio, AR and this result in a reduction in induce drag. However, the highly extended wings will introduce further structural complexity and aeroelasticity issues, thus placing a physical limit on the maximum span.

2 Problem Definition

You have recently joined BoeBus a start-up company wishing to exploit the rapidly increasing HALE pseudo-satellite market. A meeting was called couple of days ago where some of the team members presented the Mark I wing and the result from the recent experimental campaign in the wind tunnel at the Handly page lab which has a turbulence intensity of 0.5%. They are now proposing to fix the aerofoil profile shape and to start manufacturing the prototype for flight test. However, you are not convinced that the aerofoil selected is optimal and the experimental results is not in line with the results from the initial calculations on the Mark I wing. You have raised these concerns to your team leader who suggested that:

1. one shall conduct an independent analysis to demonstrate why the results from the Handley Page wind tunnel test is not showing a good agreement with the initial calculations and also point out the issues with testing in the Handley Page wind tunnel.

2. demonstrate that the aerodynamic performance of the Mark I can be further improved by selecting a more optimal profile.

The operating conditions for the current design is based on those of Facebook's HALE drone reported in [1]. At cruise altitude the turbulence intensity, Tu, is considered to be very low, as the vehicle is operating in static air and the atmospheric turbulence is negligible. After a literature survey you came across Mack's relation given by Crouch [2], which provides a criterion for transition as a function of freestream turbulence intensity expressed by equation 4, valid for wind tunnel of turbulence intensity ranging from 0.1% to 1%. The N (or the N-factor) is a parameter that defines how the transition position can be affected, due to turbulence intensity in this case.

Following further discussion with the structures team and the team developing the solar panels, you have some concerns about the steps and gaps between the solar panels which can trip the boundary layer. Therefore, it will be worthwhile to asses the effect of lost in laminarity on the overall endurance of the aircraft at cruise and make suggestion on where to position the panels along the profile. As the initial design phase is already running late you have been given 1 week to complete this task.

$$N = -8.43 - 2.4 \ln Tu \tag{4}$$

3 Recommendations for Analysis

XFLR5 or XFOIL are based on the viscous and inviscid coupling technique where the inviscid flow around an aerofoil is calculated using the panel method and the viscous calculation is through the momentum integral equations. The main advantage of this tool is the very rapid computational time and it has been proven to be very robust for low Reynolds number calculations.

1. The UIUC aerofoil database contains an extended list of aerofoil profile for a large variety of applications which can be selected for the current application.
2. Using XFLR5 or XFOIL analyse the selected aerofoil for the conditions at cruise, check Reynolds number and N-factor.
3. The effect from a fully turbulent boundary layer can be studied by tripping the boundary layer very close to the leading edge, say $x/c = 1\%$. Similarly, the transition position can be varied by choosing the corresponding transition chordwise position where it is expected to occur.
4. The full wing can be analysed using the wing analysis tool in XFLR5
5. What are the effects of transition on the pressure distribution, lift, drag, endurance and boundary layer integral quantities?
6. Compare these results and discuss the main differences.
7. Based on your findings make a recommendation on how to proceed, following your choice of aerofoil profile.

4 Marking scheme

Write a short report which consists of a summary, introduction, results and discussion and recommendations based on your findings from the numerical analysis. If the analysis is limited to that in section 3 then an automatic cap to 70% will be applied. The further 30% will be given to individual contribution based on further research in this subject and the current design proposed by Facebook or the Airbus Zephyr.

Important: If the report exceeds 3 pages, but is less than 4 pages an automatic 5% deduction is applicable and if it is more than 4 pages then the penalty extends to 10%. The text and figure should be well presented and readable when printed on an A4 sheet, 10% of the mark is allocated to presentation and layout of the report. Please refrain from making verbatim copy of the text from this assignment sheet as it will be counted as plagiarism.

References

[1] Dorian F. Colas, Nicholas H. Roberts, and Vishvas S. Suryakumar *HALE Multidisciplinary Design Optimization Part I: Solar-Powered Single and Multiple-Boom Aircraft.* AIAA Aviation Forum, Atlanta, Georgia, 2018.

[2] J. D. Crouch *Modeling Transition Physics for Laminar Flow Control.* 38th Fluid Dynamics Conference and Exhibit, AIAA, Seattle, Washington, 2008.