AE2130-II: Low-speed wind tunnel test
Instructions for lab report

General instructions:

- The preferred layout/contents of the lab report is presented underneath.
- Make sure that your report is "unique" (i.e. Copy-Paste from available sources without proper referencing is not accepted. Copy-Paste from other group's reports is considered as fraud and will lead to exclusion from the practical).
- In addition to the marks allocated to each question as indicated below, **10 marks** will be allocated for the overall quality of the report. This includes factors such as language and grammar, consistency in nomenclature, and the quality of figures. Please refer to Appendix C in the manual for guidelines on best practices for plotting.
- The total length of the body of the report (excluding the front page, table of contents, summary, nomenclature, and appendix) must not exceed **40 pages**.
- Total marks attainable of the report: **100 marks**

Front page

Make sure you use the standard form on Brightspace and fill in:

- name
- student number
- email address
- date of the test
- group number
- name of the supervisor

Summary

Summarise the contents of this report and state the most important findings.

Nomenclature

- All relevant symbols, subscripts, superscripts and abbreviations used in the report, should be included in this list.
- Make sure the symbol for a certain quantity is the same throughout the report (this includes the axis labels in figures)

1 Introduction

Provide a brief introduction of the motivation, background, and scope of the report.

2 Methodology (10 marks)

Provide a detailed description of the experimental setup, the measurement techniques employed, and their working principles. Additionally, include a brief summary of the numerical methods used within the chosen software. You may follow the outline suggested below.

2.1 Wind tunnel

2.2 2D and 3D models

2.3 Measurement techniques

- **Pressure taps**
- **Wake rake**
- **Force balance**
- **Stethoscope**
- **Tufts**

2.4 Reference wind tunnel speed

2.5 Wind tunnel corrections

- **Model blockage**
- **Wake blockage**
- **Lift interference**

2.6 Numerical methods

- **XFOIL - 2D panel method**
- **XFLR5 (or AVL) - 3D methods**

3 Experimental results

3.1 Ambient conditions and reference speed

Provide a detailed description of the ambient conditions of the wind tunnel experiment, and calculate the reference speed using acquired raw data. This task can be executed through the steps below:

- **Calculate air density using ideal gas law (2 marks)**

  $$\rho = \frac{M_{air} p_{atm}}{RT}, \tag{1}$$

  where M_{air} is the molecular weight of air, p_{atm} is the measured atmospheric pressure, R is the gas constant, and T is the air temperature. Note that the measured temperature is in °C, and it needs to be converted to the absolute temperature (in K) for the equation above.

- **Calculate dynamic viscosity of air μ using Sutherland's law [2] (2 marks)**

  $$\mu = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \frac{T_0 + S}{T + S}, \tag{2}$$

  where $\mu_0 = 1.716 \times 10^{-5}$ kg·m^{-1}s^{-1} is the viscosity of air at a reference temperature of $T_0 = 273.15$ K, and $S = 110.4$ K is the Sutherland's temperature.

- **Compute reference dynamic pressure q_∞ (1 marks)**

  In the wind tunnel, we do not use a pitot-static tube to directly measure dynamic pressure during our tests, as its readings can be influenced by the presence of the model, the contraction, or the diffuser. The dynamic pressure q_∞ is found by converting ΔP_b, the measured pressure difference between the total pressure in the settling chamber and the static pressure in the contraction through a calibration curve. The calibration curve is generated by inserting a pitot-static tube into an empty test section, and fit a polynomial to establish the correspondence between ΔP_b the dynamic pressure measured by the pitot-static tube.

  A second-order polynomial with the form below is used to convert ΔP_b to q_∞:

  $$q_\infty = 0.211804 + 1.928442\Delta P_b + 1.879374 \times 10^{-4} \Delta P_b^2 \tag{3}$$

- **Compute reference static pressure p_∞ and compare it with the measurement in the tunnel (1 marks)**

  The presence of the airfoil disturbs the static pressure in the test section, but not the total pressure $p_{t,\infty}$. The reference static pressure can then be related to the measured total pressure $p_{t,\infty}$ and the calculated dynamic pressure q_∞ as

  $$p_{s,\infty} = p_{t,\infty} - q_\infty. \tag{4}$$

- **Compute reference free-stream velocity U_∞ and the Reynolds number (1 marks)**

  The next step is to compute U_∞ from the total and static pressure, using Bernoulli's principle.

3.2 2D airfoil

3.2.1 Flow near the aerofoil surface

- **Compute pressure coefficient, show a few example curves, and discuss the trend with α (3 marks)**
- **Relate the C_p curves to transition (stethoscope) and separation (tufts) locations (2 marks)**

3.2.2 Wake flow analysis

- **Compute wake velocity profiles at various α (3 marks)**
- **Based on the wake profiles, reason why wind tunnel corrections are necessary (1 marks)**

3.2.3 Aerodynamic forces

- **Compute lift, drag and moment using surface pressure data (no need to apply corrections at this step) (8 marks)**
- **Compute the center of pressure from pressure tap readings. (1 marks)**
- **Compute drag using wake rake data and discuss the differences with the surface pressure results (5 marks)**

  Another approach to calculate the drag is to integrate the velocity deficit measured by the wake rake:

  $$D = \rho \int \left(U_\infty - U(y)\right) U(y) \mathrm{d}y - \rho \int \overline{u'^2} \mathrm{d}y + \int \left(p_\infty - p(y)\right) \mathrm{d}y. \tag{5}$$

  Apart from the contribution from the mean velocity deficit (first term), the velocity fluctuations (second term) in the turbulent wake will also add to the drag. However, we were not able to measure these fluctuations using pitot-static tubes, so we leave this term out in our calculations. Given that the wake rake is relatively close to the model, the wake pressure does not have a sufficient distance to make full recovery, therefore, its contribution to drag should also be accounted for (third term).

3.2.4 Wind tunnel corrections

- **Show and discuss the contribution of each source of correction (3 marks)**
- **Compare raw and corrected aerodynamic forces (4 marks)**

3.3 3D wing

- **Compare the aerodynamic forces with their 2D counterpart, and discuss the effect of finite span. Where applicable, use stethoscope and tuft results to support the discussion (5 marks)**
- **Estimate the efficiency factor τ from the lift slope (5 marks)**
- **Assuming the same efficiency factor for drag and lift, i.e. $\delta = \tau$, estimate the contribution of induced drag to the total 3D drag. (4 marks)**

  Note that δ (efficiency in induced drag) and τ (efficiency in lift slope) are <u>different</u> functions of the A_n coefficients in the Fourier approximation of the wing, but their numerical values are similar for large aspect ratios. For more details please refer to §5.3.3 in Anderson [1].

4 Numerical results

4.1 2D aerofoil

- **Compare the aerodynamic forces from XFOIL with experimental data (5 marks)**
- **Compare the pressure distribution from XFOIL with experimental data at selected angles (5 marks)**

4.2 3D finite wing

- **Compare the aerodynamic forces from XFLR5 with experimental data (5 marks)**
- **Compare the induced drag in the XFLR5 output with experimental results, using the same efficiency factor as calculated in §3.3 (2 marks)**

5 Discussion

5.1 Flow regimes (6 marks)

Discuss the flow regimes at low, medium, and high angle of attack, for both 2D and 3D wings. Provide schematics of different flow patterns, and highlight the location of flow separation and transition, when applicable.

5.2 Effect of viscosity (6 marks)

Compare experimental and numerical (especially inviscid) data, and discuss the role of viscosity in flow over aerofoils. Link the discussion to specific flow regimes and events described in the previous question.

6 Conclusions

References

[1] J. D. Anderson. *Fundamentals of Aerodynamics.* McGraw Hill, 2011.

[2] W. Sutherland. Lii. the viscosity of gases and molecular force. *London Edinburgh Dublin Philos. Mag. & J. Sci.*, 36(223):507–531, 1893.