AERO4470: Hypersonics

Assignment

Semester 1, 2024

There are 40 MARKS total for this assignment.

Assessment Criteria

1. Full marks require giving both the correct numerical answer, a demonstrated understanding of the analysis, and the steps used to get that answer (i.e. show your working, with a brief explanation as to why any specific equations and assumptions used are valid).
2. In the event of numerical answers being incorrect, the analysis and working will be inspected and appropriate (partial) credit will be given for the understanding demonstrated. Understanding can only be demonstrated by providing your working. Attach any code that you produce and briefly document its functionality — this is part of showing your working.
3. If an incorrect answer in one section of a question carries over and invalidates the solution to a subsequent section, no further penalty will be applied for that wrong answer, if the subsequent methodology is correct and clearly demonstrated.

Label your attempts at answering the questions so that the marker can easily follow your work.

PART A: High-temperature gas dynamics

Question 1. 12 marks

A blunt capsule is being simulated in UQ's X2 expansion tube. The freestream velocity is 5.2 km/s, and the freestream temperature and pressure are 1,000 K and 500 Pa, respectively. The capsule diameter is 75 mm. The test gas is synthetic air (79% N_2 and 21% O_2 by mole fraction). Assume any trace species in the synthetic air are negligible.

1a. Equilibrium gas model [10 marks]

Assuming thermochemical equilibrium gas behaviour, calculate the post-shock temperature, pressure, density, sensible enthalpy, velocity, and composition by mole fraction. Assume the chemical reaction set below.

$$
\begin{aligned}
O_2 &\rightleftharpoons 2\,O \\
N_2 &\rightleftharpoons 2\,N \\
N + O &\rightleftharpoons NO
\end{aligned}
$$

1b. NASA equilibrium calculator [2 marks]

Calculate the post-shock properties using NASA's CEA program (`https://cearun.grc.nasa.gov/`) running with the "shock" problem type. Are these results consistent with your own calculations in 1a.? Discuss any discrepancies. Include the text output file in your submission

PART B: Estimation of aerodynamic forces

Question 2. **28 marks**

Compute the lift-to-drag ratio (L/D) of a hypersonic lifting body flying through air using modified Newtonian theory. An example geometry is shown in Figure 1; the top and bottom surfaces are shaded separately. Only a half geometry is given. Assume symmetry and that the vehicle flies with zero angle of yaw. Make and state assumptions about the gas properties of the air for your analysis.

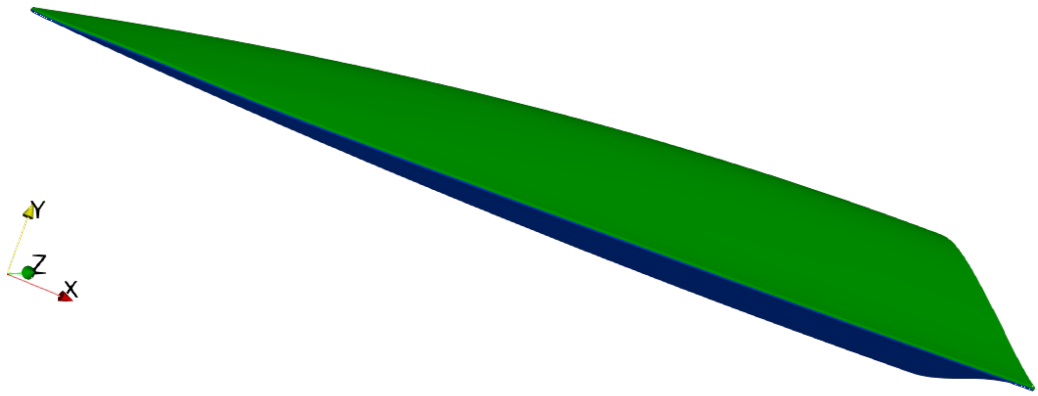

Figure 1: Example of a hypersonic lifting body. Top surface in green. Bottom surface in blue.

Each student has a unique hypersonic lifting body to work with. You can find your geometry in the zip file on Blackboard called `aero4470-all-geometries.zip`. The geometries are split into two parts, a top and bottom surface. Your specific pair of files are encoded with your student login in the filename.

All lifting bodies are flying at the same Mach number and dynamic pressure:

$$M_\infty = 8.0; \quad q_\infty = 50\,\text{kPa}$$

The angle of attack varies based on your student number. Appendix A gives the specific angle of attack that your vehicle is flying at.

Notes:

- The axes are oriented as per the definition in Anderson's textbook with: x running along the vehicle; y pointing upwards; and z out of the page (as shown in Figure 1).
- With this axis definition, $\sin\theta$ at any point on the surface can be computed using

$$\sin\theta = \frac{\vec{V}_\infty}{|V_\infty|} \cdot \hat{n}$$

  where $\vec{V}_\infty$ is the velocity of the free stream and $\hat{n}$ is a unit normal vector at a point on the surface.
- The geometries are STL files. This is a patchwork of triangles, each with a normal vector. You can use each triangle as a panel and apply the modified Newtonian approximation at each panel. More information on the STL file format is available at: `https://en.wikipedia.org/wiki/STL_(file_format)`
- Total (inviscid) force on the body comes from integrating the pressure over the surface

$$\vec{F} = \oiint d\vec{F} = -\oiint p\, dS\, \hat{n}.$$

Tips:

- Think about how to break the problem down into small parts. Attempting the questions in order will help.
- When working in three dimensions, it is easiest to work in the global axes given. Consider using dot products and cross products to help with geometry calculations.

2a. Drag on a prism **[6 marks]**

Write a computer program to compute the drag force for the prism in the Week 7, Q1 tutorial for Case A. Use the same flow conditions and gas properties as given in the Week 7 question. Test your code solution by using the STL file on blackboard: `wk-07.stl`. The STL representation uses 10 triangle patches as shown in Figure 2. This can be seen in the front view (on right). How well does your answer match the one you computed by hand?

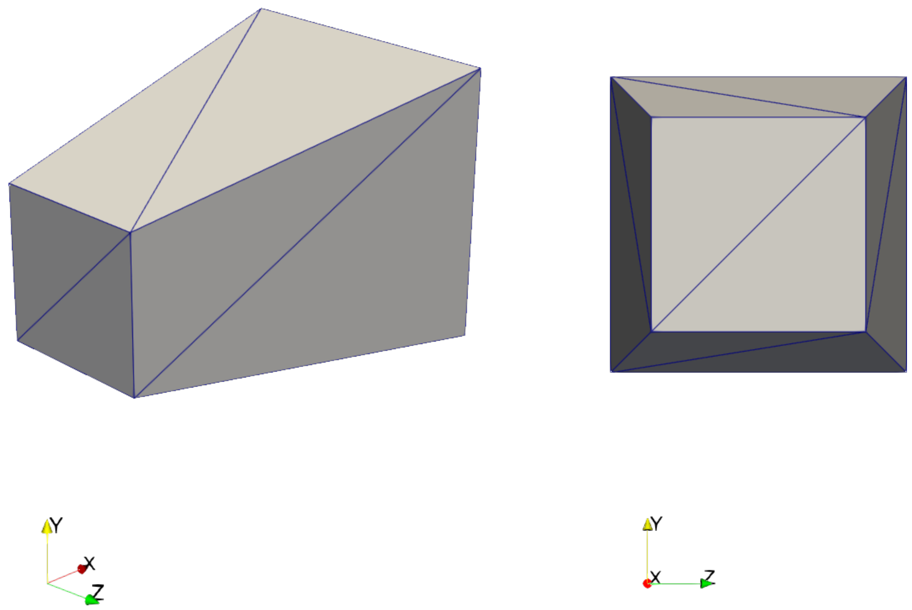

Figure 2: Prism as STL. Left: Perspective view; Right: front view

2b. L/D for the lifting body **[16 marks]**

Write a computer program to compute the lift-to-drag ratio for your specific lifting body, flying at your specific angle-of-attack. Reuse code from 2a. as appropriate.

2c. Breakdown of lift force **[6 marks]**

What is the contribution of lift (as a percentage) of the top and bottom surfaces of the lifting body? (at your angle of attack)

Explain how you determined these values.

Appendix A. Angles of attack for Question 2

Student no.	AoA (degrees)
42057639	4.21
43536935	10.63
43594300	9.87
43931875	5.30
45072183	7.46
45300167	7.05
45301623	8.86
45307670	10.10
45555387	3.84
45620249	3.26
45808775	10.52
45828465	6.89
45884005	9.86
45888674	3.02
45888919	7.01
45895168	9.49
46126775	5.06
46252115	11.51
46387437	11.11
46387802	3.28
46402031	3.23
46406703	7.87
46409982	11.45
46411967	6.43
46413103	4.95
46415198	6.80
46415282	3.26
46417745	5.00
46418229	6.94
46418407	7.46
46422851	5.10
46428974	5.08
46444152	4.97
46467133	7.14
46470236	5.61
46472940	3.19
46475352	10.54
46825452	8.01
46931830	8.78
46959825	4.67
46964164	11.93

Student no.	AoA (degrees)
46964294	10.74
46964977	4.09
46966065	5.99
46966289	9.49
46968014	9.40
46968564	11.43
46968890	6.80
46969169	10.47
46970633	9.03
46970642	5.73
46971591	8.29
46972600	10.94
46972664	10.62
46974716	7.55
46974846	8.30
46977605	3.31
46978273	5.18
46980520	10.18
46981545	6.73
46984470	4.56
46984546	7.94
46987190	9.33
46989738	9.07
46990592	6.37
46992653	6.95
47017900	7.58
47019968	10.01
47024681	7.69
47027310	6.54
47038165	7.41
47039555	3.27
47055788	3.39
47421413	9.33
47427639	11.85
47452332	8.34
47498705	6.54
47524604	4.53
47661808	7.52
47848140	11.84
48602282	9.93
48633482	7.86