Basics of Aerospace Lecture Series

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Spring 2024

Introduction

The Basics of Aerospace Lecture Series is intended to introduce members of the AeroDesign Team to the fundamental concepts of Aerospace Engineering. It is planned to cover most of the content presented in AME 105, so it can be particularly useful for those who are not aerospace engineering majors, students starting in the spring, etc. It can also serve as a refresher for veteran 105ers.

The lecture series is modeled following content from John D. Anderson's *Introduction to Flight* (a great read!) It will be hosted in-person but will be recorded via Zoom to be available for posterity. Lecture recordings will be available every week in the Google Drive Aero S&C folder, and a link will be sent to Slack. I also plan on compiling a few problem sets every couple of weeks for topics that are of particular importance.

Overview of Content

An overview of the content is presented below.

The series will start with a quick historical background. John D. Anderson, the author of *Introduction to Flight*, has a huge interest in aerospace history, which is made clear in his books (besides his incredible qualifications, of course - he is none other than the Curator of Aerodynamics for the Smithsonian National Air and Space Museum.) We will look at the first aeronautical engineers and the contributions of major names in the field of aviation, many of whom you have probably already heard of.

The first two weeks will layout the basis of the discussions that will follow. An overview of fundamental quantities that will come up over and over again will be held. Pressure, density, and temperature will be defined. We will later hunt for physical relations between these variables in the context of a flowing fluid. We will also look at the medium through which airplanes fly: the atmosphere. The International Standard Atmosphere (ISA) and its strata will be explored, and the relations between thermodynamic variables at different stages of the atmosphere will be derived (the ISA equations.)

We will then be ready to explore the basics of aerodynamics. In ADT, we are mostly concerned with the consequence of aerodynamics in a more practical sense, which we will cover later on. However, I deem this a good opportunity to take a peek into the underlying physics of aerodynamics and some of the basic derivations. We will spend four weeks here. First, we will look into inviscid flow, that is, flow without friction. We will derive two fundamental equations that govern low-subsonic inviscid flow. We will also explore compressible flow, where a review of basic thermodynamics will be held and the equations for isentropic flow derived. Once we have covered both compressible and incompressible inviscid flow, we will explore some applications of the relations that we found, particularly as it concerns wind-tunnels and measuring airspeed in vehicles. Finally, we will look at viscous flow, introducing the boundary layer and the results for laminar and turbulent flow, which is quite useful in the prediction of drag of real airplanes.

After aerodynamics, we will shift the focus to the topic of aircraft performance. This concerns the determination of key parameters of an airplane - how fast it can fly, how high, how fast it can take off, etc. - as well as basic equations of motion for different flight conditions. We will first cover steady-level flight (or “lift equals weight”) and the equations that govern it. We’ll define thrust and power and explore the necessary conditions to minimize them in flight. We will then move past steady-level flight, looking into climbing flight as well as gliding flight. We will also derive the important Breguet Equations and determine more specifically how to minimize endurance and range for both propeller and jet aircraft. Finally, we will cover other miscellaneous topics in performance, namely takeoff and landing performance, V-n diagrams, and the energy method of performance analysis (accelerated rate of climb.)

To conclude the course, we will cover the principles of stability and control. This is another thing that is used more practically in ADT: tools like AVL calculate basically everything you need to know about the airplane’s stability. Here, however, we will explore the equations that describe the wing and tail’s contributions to the aircraft’s pitching moment, and look into what the static stability condition really dictates with Cm vs alpha plots, trim diagrams, etc. Finally, I will give a very brief introduction to aircraft conceptual design, more specifically the initial sizing of an airplane, using as an example my entry into the 2023 AIAA Design Competition and some code I wrote for it.

Lecture Schedule

Week 1 (01/08 - 01/12): **Preliminaries and History**
- Overview of the lecture schedule
- Why Fly and The First Aeronautical Engineers

Week 2 (01/15 - 01/19): **Fundamental Thoughts**
- Thermodynamic properties of a flowing fluid
- Ideal gas equations of state
- Anatomy of the airplane

Week 3 (01/22 - 01/26): **The International Standard Atmosphere**
- Altitudes and the Hydrostatic Equation
- The ISA and ISA tables
- Pressure, Temperature, and Density altitudes

Week 4 (01/29 - 02/02): **Aerodynamics I: Inviscid, Incompressible Flow**
- An overview of types of flow
- Fundamental relations: momentum, mass, and Newton's second
- Euler's Equation (momentum) and Bernoulli's Equation (energy)

Week 5 (02/05 - 02/09): **Aerodynamics II: Inviscid, Compressible Flow**
- Elementary Thermodynamics
    - Statements of the first law
    - Specific heats
- Isentropic flow equations
- Compressible energy equation

Week 6 (02/12 - 02/16): **Aerodynamics III: Summary of Applications**
- Subsonic wind tunnels
- Measurement of airspeed
    - Subsonic incompressible and compressible
    - Supersonic
- Why Mach > 0.3?

Week 7 (02/19 - 02/23): **Aerodynamics IV: Viscous Flow**
- The boundary layer
- Wall shear stress
- Reynold's Number
- Results for laminar and turbulent boundary layers

Week 8 (02/26 - 03/01): **Practical Aerodynamics I: Airfoils**

- Airfoil definitions
- Lift, drag, and moment coefficients
- Airfoil data
- Stall characteristics and topics in laminar/turbulent separation of airfoils
- Pressure coefficient, its distribution, and applications in airfoil design

Week 9 (03/04 - 03/09): **Practical Aerodynamics II: Wings**

- 2D vs 3D flow: wingtip vortices
- Calculation of induced drag
- Aspect ratio and its effect on lift-curve slope

Week 10 (03/18 - 03/22): **Aircraft Performance I: Steady-Level Flight**

- Drag polar
- Aircraft axes and equations of motion
- Thrust and power required for steady-level flight
- Minimum thrust and power required
- Graphical relations and aerodynamic conditions of minimum T and P

Week 11 (03/25 - 03/29): **Aircraft Performance II: Beyond Steady-Level**

- Thrust and power available: maximum velocity
- Altitude effects
- Rate of climb and time to climb
- Gliding flight
- Range and Endurance: Breguet Equations

Week 12 (04/01 - 04/05): **Aircraft Performance III: Dynamic Performance**

- Takeoff and Landing performance
- Turning flight, load factor, and the V-n diagram
- Energy method: energy height, specific excess power, altitude-Mach diagrams

Week 13 (04/08 - 04/12): **Principles of Stability and Control**

- Static vs. Dynamic stability
- Wing contribution to pitching moment
- Tail contribution to pitching moment: the tail volume coefficient
- Neutral point and static margin

Week 14 (04/22 - 04/26): **Introduction to Aircraft Conceptual Design**

- Review of topics, concepts, and equations
- Introduction to aircraft conceptual design