AAE 3520: Flight Vehicle Dynamics

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August 22, 2017

Introduction

- The objective of this course is to perform an *introductory* analysis of dynamics and stability of *flight vehicles.* The course title is ambiguous in the sense it doesn't clarify what *kind of dynamics* and what *nature of flight vehicles* it focuses on:

  Kind of dynamics:

  (1.) Translational motion: motion of an object modeled as a particle, i.e., with no physical dimension. In essence, answers the question: what path is the object on?

  (2.) (Rigid) Rotational motion: study of an object's orientation, a.k.a. "attitude" with respect to an inertial reference frame. The object is assumed to be rigid (as opposed to flexible).

  Nature of flight vehicles:

  (a.) Atmospheric Flight Vehicles: flight vehicles (primarily aircraft) that operate well within the Earth's atmosphere and are strongly affected by aerodynamic forces (e.g. lift and drag) and moments

  (b.) Spacecraft: flight vehicles that operate outside of the Earth's atmosphere, e.g. geocentric satellites

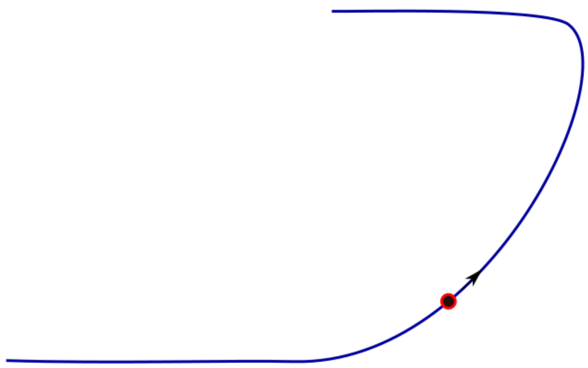
  (c.) Trans-atmospheric Vehicles: Flight vehicles whose flight-path includes both atmospheric and exo-atmospheric phases, e.g. rockets and long-range missiles

- The bulk of this course will deal with translational and rotational motion of *traditional* aircraft. By "traditional", we mean low Mach number aircraft with orthodox geometry. However, the way we will introduce concepts of particle mechanics and rotational dynamics, it will be relatively easy to extend them to motion in space. Given that the current core undergraduate curriculum of Aerospace Engineering at OSU does not offer a dedicated course on astrodynamics, we will find time to study motion of spacecraft in orbit, mostly as a particle and (a little bit) as a rigid object.

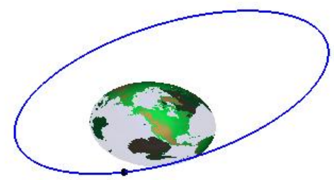
- It is important to note the level of interaction, or coupling, between translational and rotational motion. Inside the atmosphere, translational and rotational motion are strongly coupled with each other. In other words, translational motion affects rotational motion and rotational motion strongly affects translational motion. Why do you think that is? The coupling between the two inside the atmosphere is so strong that it is impossible to study translational or rotational motion in isolation.

- On the other hand, translational motion in space is dissociated from rotational dynamics. Interestingly, the decoupling is stronger in one direction – rotational motion (almost completely) does not affect translational motion in space. However, translational motion does slightly influence rotational mechanics. The decoupling is strong enough that spacecraft translational and rotational dynamics are often taught in two separate courses at the undergraduate level.

- It is important to emphasize that **both** translational and rotational motion (whether they are coupled to each other or not) are equally important aspects of flight vehicle dynamics. See Fig.(1) for an illustration of translational motion and Fig.(2) for an illustration of rotational motion.

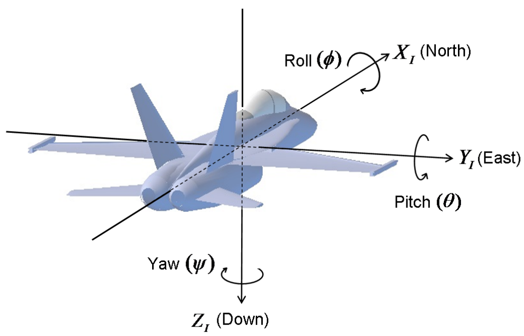


(a) Flight Path of An Aircraft Executing a Pull-Up Maneuver

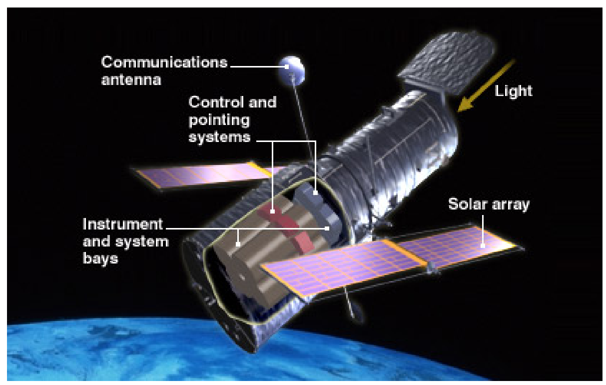


(b) Orbit of a Spacecraft Showing its Motion Around Earth as a Particle

Figure 1: Illustration of Translational Motion of Flight Vehicles, Treated as Dimensionless Particles



(a) Attitude of An Aircraft: Its Orientation Determines the Aerodynamic Forces Acting on it.



(b) The Hubble Space Telescope: It is Incredibly Important Which Way the Spacecraft is Pointing!

Figure 2: Illustration of Attitude of Flight Vehicles, Treated as Three Dimensional Rigid Objects

- Below is the sequence of topics that we will cover in this course:

  A. Particle Mechanics: **Kinematics.** In essence, "kinematics" comprises of relationships among the position, velocity and acceleration vectors. We will begin with the most essential construct in the study of motion of particles; namely, *reference frames* and the representation of vectors in reference frames. We will also consider transformation between reference frames. In other words, what is the relationship between representations of the same vector in two different reference frames? We will introduce the *transport theorem* - an all important result that allows us to formulate the equations of particle kinematics.

  B. Particle Mechanics: **Kinetics.** Kinetics deals with the manifestation of Newton's second law ("$\mathbf{F} = m\mathbf{a}$"); i.e., what forces act on the particle and how do these forces influence its motion? Clearly, a particle will undergo different types of motion when different types of forces act on it. E.g. motion inside the atmosphere, influenced by aerodynamic forces (and thrust and almost constant gravity) is different from motion in space, under the force of variable gravity (and thrust).

  C. **Attitude Representations** and Rigid Body Kinematics. Next, we will study the motion of flight vehicles as rigid objects and find ways to describe their orientation. In translational motion, the kinematic variables are position, velocity and acceleration. Similarly, in rotational motion, the kinematic variables are *angular position*, *angular velocity* and *angular acceleration*. Rigid body kinematics is the study of interrelationships among these vectors.

D. Rigid Body Kinetics. We will consider the rotational motion of flight vehicles (aircraft) under aerodynamic moments.

E. Aircraft **6DOF EOM.** Equations of translational mechanics and rotational dynamics will be compiled together for aircraft to develop their six-degree-of-freedom (6DOF) equations of motion (EOM). Three of the six DOFs are in translation and the other three in rotation. That all these equations need to be considered *simultaneously* speaks to the "coupling" between translational and rotational dynamics inside the atmosphere mentioned above.

F. **Small Perturbation Theory.** We will simplify the 6DOF-EOM of aircraft via an amazing engineering tool called *linearization*. The simplified models will be significantly easier to analyze and gain insight from. Linearization is also known as small perturbation theory.

G. **Stability.** We will analyze the *stability* of the simplified equations of aircraft motion. In essence, the question asked is the following: if a disturbance (e.g. a gust) were to hit the aircraft – will the aircraft, **own its own accord**, be able to override the disturbance and return to its original flight condition? Or will the disturbance, if not actively eliminated, cause the aircraft to enter a dangerous flight condition?

- **What is not covered in this course..** Note that the final topic mentioned above (stability) leaves open the following tantalizing question – what if the aircraft is unstable? Or, in some vague sense, "not stable enough"?

- The answer is – you design a **control system** to make it stable. And while you are at it, add in some extras that allow you to extract the kind of performance from the aircraft that would be impossible for it to deliver without the control system you designed. This course will not talk about control systems – and how you can design them to stabilize aircraft and make them perform in ways that would otherwise not be possible.

- We talked about three pillars in this short document:

  I. **DYNAMICS**: kinematics and kinetics of translation and rotation.

  II. **STABILITY**: nature of response (of translational and/or rotational motion) to disturbances.

  III. **CONTROL**: making flight vehicles behave in ways (in terms of its translational/rotational motion) it wouldn't if it were left to its own accord.

  There is major coverage of (I.) in this course, minor coverage of (II.) and no coverage of (III.).