Fall 2024

Orbital Mechanics 1 (with Python)

An Online Group Class
Offered by Eric Anthony Comstock,
a PhD student and Davidson Young Scholar alumnus

About the instructor

I have a BS in aerospace engineering degree with engineering honors and minors in math and chemistry from Texas A&M University in College Station. I graduated, *magna cum laude,* in December, 2022. I am currently a PhD student in aerospace engineering at Georgia Tech. I can be reached at:
eric.comstock@gatech.edu

Course Overview

Are you interested in space travel? Have you ever wondered why movement in space is different from movement on Earth? If you are intellectually curious and interested in these questions, and if you have the background of basic algebra, the Pythagorean theorem, basic programming, the ability to catch on to mathematical concepts quickly, and the willingness to participate in class and complete homeworks, then this class is for you!

From these building block prerequisites, we will generally cover a first semester of calculus, introductory orbital mechanics, introductory physics, and an introduction to Python coding as applied to orbital mechanics. The main product of the course will be a project involving a Python modeling of the launching of a spacecraft into a circular orbit from a planet with an atmosphere.

There is no age requirement for this class. Having grown up as an academically accelerated Davidson student, I realize that age has no bearing on intellectual merit.

I. Topics covered

I expect to cover one to three of these topics per hour long lecture.

1. **Basic differential calculus (with proofs)**
    a. Definition of the derivative
        i. Slopes
        ii. Infinitesimals
        iii. Derivatives
    b. Properties of the derivative
        i. Intro to proofs

ii. Sum and difference rule
iii. Product rule

c. Derivatives of functions
   i. Derivatives of polynomials
   ii. x^{-1} and e^x
d. The Finite Difference Method
   i. Application in Excel or LibreOffice Calc
   ii. General application
   iii. Use for high-order partial differential equations

2. **Orbital mechanics math**
   a. The basics
      i. Position, velocity, and acceleration
      ii. Newton's laws
      iii. Operating principle of rockets
      iv. Delta-V and fuel
   b. Gravitation
      i. Vector length and direction formulae
      ii. Scalar gravity
      iii. Vector gravity
   c. Orbits
      i. Why they exist
      ii. Effects of orbital maneuvers
   d. The rocket equation
      i. Derivation
      ii. Use and examples
3. **Orbital mechanics simulation with the Python programming language**
   a. Python coding
      i. Installation
      ii. Variables and printing
      iii. If-then statements
      iv. For-loops
      v. Functions
      vi. numpy vectors
      vii. More advanced simulation techniques (e.g. RK45)
   b. Simulating initial value problems in Python
      i. scipy.integrate.solve_ivp function
      ii. Forces acting on a spacecraft
   c. Orbital spaceship modeling
      i. Basic orbit modeling
      ii. Applying accelerations
      iii. Orbit transfers
   d. Launch modeling (no drag)
      i. Tuning the engine thrust
      ii. Gravity turns

iii. Residual eccentricity
iv. Correcting residual eccentricity

e. Additional parameters
   i. Drag
   ii. Staging
   iii. Variable acceleration/thrust
f. Higher-order models
   i. Earth oblateness
   ii. Solar and lunar gravitational effects (third-body forces)

II. Homework and Grading

Homework will be present in approximately half to two thirds of the weeks, and will be assigned one class and generally due at 11:59 PM the day before the next class. Homeworks will consist of 3-4 questions per homework. Every week that the homework is late will deduct from the student's grade, as follows:

0 to 1 days late	-3% reduction
1 day to 1 week late	-15% reduction
1 week to 2 weeks late	-30% reduction
2 weeks to 3 weeks late	-45% reduction
Greater than 2 weeks late	-60% reduction

Homeworks that are incomplete may be submitted, and questions that are answered later will have their grades deducted individually based on the above rubric. My fundamental goal is helping these students learn and not punishing them for turning in homework late. While some standards are necessary for any learning environment, I want my learning environment to be sensitive to the needs of young learners in order to encourage and foster a love of math and science.

I generally expect to give short but thought-provoking homeworks, designed to test understanding of as much of the material as possible as quickly as possible. Students are thus highly encouraged to come to office hours to ask questions about the homework – I will be happy to help them through the solution to a similar problem. Extra credit will be available on some homeworks, but its inclusion is up to my discretion. If included, it will usually involve some kind of proof or generalization.

No exams are given, but the materials learned in the course will contribute towards a project, the improvement of which is likely to be the majority of the homeworks later in the semester. The project will be writing Python code to simulate the launching of a spacecraft into a circular orbit from a planet with an atmosphere. The details of the project, such as which planet, which spacecraft, and what the atmosphere is made of, can be up to the student, but of course, must fall within realistic ranges. This project is a major product of this class and can serve to be added to the student's personal portfolio.

The student's total grade will be determined as follows:

Homework weighted average	90%
Attendance	10%

III. Prerequisites

Students are recommended to enter the course with knowledge of algebra I or equivalent, the Pythagorean theorem, and basic programming (any language). Enthusiasm for learning, as well as the ability to pick up math concepts quickly, will also enhance the experience significantly, since much of the course is designed to be driven by individual curiosity.

Experience in trigonometry, algebra II, or physics will be useful, but is not required.

IV. Schedule

Classes will be held on Sunday afternoons 2:30-3:30 pm ET, beginning Sunday, August 18 according to the schedule below. My office hours will be Wednesdays between 6:30 and 7:30 pm ET for questions related to the homework, a resource which students are strongly encouraged to use. The number of students for each section of this class is capped at 5.

How fast the class goes depends upon how well the class goes. If most students are having trouble then I will likely slow down so that they are better able to understand the material. And, if the class is doing well, then I will likely speed up to present them a challenge. For these reasons, I do not have a specific end date, but I expect the class to last on the order of a school semester.

Preliminary Schedule (First three blocks)	
Date	***Class number***
First Block: $100	
Aug 18	1
Aug 25	2
Second Block: $250	
Sep 1	3
Sep 8	4
Sep 15	5
Sep 22	6
Sep 29	7
Third Block: $250	
Oct 6	8
Oct 13	9
Oct 20	10

Oct 27	11
Nov 3	12

Blocks are how tuition is billed. Please see the tuition section below for more information. Note that a fourth block is likely, but its length will depend on class progress during the third block.

V. Tuition

Tuition will be $50 per class. Two weeks tuition will be due up front to secure your spot in the class with no ongoing obligation. Upon payment receipt, a link will be sent to join the online class.

Tuition may be paid via Zelle to
Eric Comstock, eric.comstock@gatech.edu.

After the first two weeks, if you decide to continue in the class, five weeks tuition will be due by 11:59 pm the day before the third class. An updated link for the third through eighth classes will be sent out the day of class upon tuition receipt. Since it is not yet known how many classes we will have, tuition payment will be managed in this manner until the end of the course.

That is, if we begin Sunday, August 18, 2024

$100 is due immediately to secure your spot in the class
$250 due by 11:59 pm on August 31, 2024 (just prior to third class)
$250 due by 11:59 pm on October 5, 2024 (just prior to eighth class) – this would take us through the class on November 3, 2024

One additional block of around 3 to 6 classes is likely, but due to lack of information on the preferred learning speed of the students, the exact number of classes cannot be determined.

VI. Textbook

There will be no textbook. Lectures will be based on my lecture notes which will be provided.

VII. Online meeting platform

We will be using an application that I have access to that does not require any software for the student. It is very easy to use. All the student needs is an internet connection, a browser, microphone and camera. The student will merely

click on a link sent via email and allow access to their microphone and camera, then they will join the meeting. Most browsers work with this platform.

VIII. General Expectations

Given that this class is open to all ages, I must emphasize that students must behave in a manner that is appropriate to all ages during the class. That is, older students must refrain from speaking about any topics that are inappropriate for younger students. This rule will be strictly enforced.