Fall 2024

Orbital Mechanics 2 (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 Orbital Mechanics I (vector algebra, basic differential calculus, basic Python, and basic trigonometry), 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 integral calculus, introductory differential equations, orbital elements, orbit determination, interplanetary and interstellar trajectories, and satellite navigation. The main product of the course will be a project involving a Python modeling of a custom satellite navigation system around a gravitationally rounded nonstellar object (the choice of which will be up to the student).

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. **Integral calculus (with proofs)**
   a. Review of differential calculus
      i. Definition of the derivative
      ii. Applications of the derivative
      iii. Derivatives of trigonometric functions

        iv. Review of limits
- b. Riemann sums and integrals
  - i. Physical intuition of the integral
  - ii. Definition of the Riemann sum
  - iii. Evaluating Riemann sums
  - iv. Solids of revolution
- c. Integrals of functions
  - i. Integrals of polynomials
  - ii. Integrals of trigonometric functions
  - iii. x^{-1} and e^x
- d. Newton's method for solving nonlinear equations
  - i. Application in Excel or LibreOffice Calc
  - ii. General application
  - iii. Use for multidimensional problems
  - iv. Ways to enhance model stability
  - **v.** Newton fractals (which are cool to look at and generate, and will provide a good break from the intense math)

2. **Orbital mechanics math**
   - a. Differential equations
     - i. Separation of variables
     - ii. Linear differential equations
     - iii. How to guess solutions effectively
   - b. Hyperbolic trigonometry
     - i. Motivation
     - ii. Hyperbolic trig functions
     - iii. Derivatives and integrals
   - c. Gravitation
     - i. Review of gravitation
     - ii. Solving the simplified two-body problem
   - d. Reference frames
     - i. Rotation matrices
     - ii. Why we need reference frames
     - iii. Ways to get around needing these in your code
   - e. Orbits
     - i. Orbital parameters and their derivations
     - ii. Orbital periods
     - **iii.** Orbit analytical propagation

3. **Orbit determination with the Python programming language**
   - a. Orbital parameters and orbit position and velocity
     - i. How to get parameters from position and velocity
     - ii. How to get position and velocity from parameters
     - iii. Edge cases, and how to get around them
     - iv. Hyperbolic orbits
   - b. Universal variable models
     - i. Conservation of angular momentum
     - ii. Linear deduction of future orbital states

        iii. Comparison with previous analytical and numerical methods
    c. Gauss' method of orbit determination
        i.   Introduction and use cases
        ii. Theoretical framework
        iii. Implementation
4. **Advanced topics**
    a. Interplanetary and interstellar orbits
        i.   Patched conics
        ii. General approximations
        iii. Interplanetary trajectories
        iv. Relativistic brachistochrone
        v. Interstellar travel
        vi. Advanced propulsion (fission, fusion, microquasar, antimatter, quantum vacuum thrusters, and warp drive, in order of effectiveness)
        vii. Intro to General Mission Analysis Tool (GMAT) and use cases (this will be explored more fully in a later dedicated course which I plan to offer in the Spring of 2025 – GMAT analysis I.)
    b. Satellite navigation
        i.   Atomic clocks and position determination through light delay
        ii. Coverage radius
        iii. Orbit constellations
        iv. Effectiveness spotlight: Global Navigation Satellite System (GLONASS) – strengths and weaknesses (as an example to inform your project)

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 main product of the course will be a project involving a Python modeling of a custom satellite navigation system around a gravitationally rounded nonstellar object (the choice of which will be up to the student). The details of the project, such as which object (e.g. planet or moon), what the spacecraft capabilities will be, and which constellation model is used, 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 the topics covered in Orbital Mechanics I, which include vector algebra, basic differential calculus, basic Python, and basic trignonometry. 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.

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

IV. Schedule

Classes will be held on Saturday mornings 10:30-11:30 am ET, beginning Saturday, Aug. 17 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 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 17	1
Aug 24	2
Second Block: $250	
Aug 31	3
Sep 7	4
Sep 14	5
Sep 21	6
Sep 28	7
Third Block: $250	
Oct 5	8
Oct 12	9
Oct 19	10
Oct 26	11
Nov 2	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 Saturday, August 17, 2024

$100 is due immediately to secure your spot in the class
$250 due by 11:59 pm on August 30, 2024 (just prior to third class)
$250 due by 11:59 pm on October 4, 2024 (just prior to eighth class) – this would take us through the class on November 2, 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. Since I have not taught this class before, it is possible that it will unexpectedly run longer, but I will do my best to keep it short and information-dense.

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.