MECH 5105
Orbital Mechanics and Control

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Course Outline

About the Author

Steve Ulrich is an Assistant Professor at Carleton University. He earned his B.Eng. and M.A.Sc. in electrical engineering from the Université de Sherbrooke, and his Ph.D. in aerospace engineering from Carleton University. From 2006 to 2008, he was Spacecraft GN&C Research Engineer at NGC Aerospace Ltd., and in 2013 he was Postdoctoral Associate at the MIT Space Systems Laboratory. He is a senior member of AIAA, and a member of IEEE and the Canadian Aeronautics and Space Institute. He is a member of the AIAA Guidance, Navigation and Control Technical Committee.

About the Course

The objective of this course is to provide students with an comprehensive treatment of spacecraft orbital dynamics and control, starting with the basic fundamentals of translational kinematics and dynamics to more advanced topics such as the restricted three-body problem and spacecraft formation flying. The material is presented in a consistent manner, and the students are guided through the various derivations and demonstrations in a rigorous way. As a result, students are led to understand the underlying principles governing the main equations.

Prerequisites

MAAE 2101 Engineering Dynamics or equivalent
MAAE 4500 Feedback Control Systems or equivalent
Familiarity with MATLAB/Simulink (or another mathematical programming language).

Contact Information

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Topics

Chapter 1 - Kinematics and Dynamics
Chapter 2 - Two-Body Problem
Chapter 3 - Orbital Perturbations
Chapter 4 - Orbital Maneuvers
Chapter 5 - Circular Restricted Three-Body Problem
Chapter 6 - Spacecraft Formation Flying
Appendix A - Introduction to Modern State-Space Control

Bibliography

There is no required textbook, as these lecture notes will be the primary material. Some useful textbooks upon which the notes were developed include:

1. Bate, R. R., Mueller, D. D., and White, J. E., *Fundamentals of Astrodynamics*, Dover, 1971.

2. Prussing, J. E., and Conway, B. A., *Orbital Mechanics*, Oxford University Press, 1993.

3. P. Micheau, Orbit Control Techniques for Low Earth Orbiting (LEO) Satellites, in: J.P. Carrou (Ed.), *Spaceflight Dynamics*, Cépaduès-Éditions, Toulouse, France, 1995, Chapter 13.

4. Chobotov, V. A., *Orbital Mechanics*, Second Ed., AIAA Education Series, 1996.

5. Sidi, M. J., *Spacecraft Dynamics and Control: A Practical Engineering Approach*, Cambridge University Press, 1997.

6. Wie, B., *Space Vehicle Dynamics and Control*, Second Ed., AIAA Education Series, 1998.

7. Battin, R. H., *An Introduction to the Mathematics and Methods of Astrodynamics*, Revised Edition, AIAA Education Series, 1999.

8. Montenbruck, O., and Gill, E., *Satellite Orbits - Models, Methods, and Applications*, Springer-Verlag, 2000.

9. Ogata, K., *Modern Control Engineering*, Fourth Ed., Prentice Hall, 2001.

10. Fehse, W., *Automated Rendezvous and Docking of Spacecraft*, Cambridge University Press, 2003.

11. Hughes, P. C., *Spacecraft Attitude Dynamics*, Dover, 2004.

12. Vallado, D. A., *Fundamentals of Astrodynamics and Applications*, Microcosm Press, 2004.

13. Schaub, H., and Junkins, J. L., *Analytical Mechanics of Space Systems*, Second Ed., AIAA Education Series, 2009.

14. De Ruiter, A. H. J., Damaren, C., and Forbes, J. R., *Spacecraft Dynamics and Control - An Introduction*, Wiley, 2013.

15. Curtis, H. D., *Orbital Mechanics for Engineering Students*, Third Edition, Elsevier, 2014.

Additionally, the following journal articles were also useful in preparing the material on spacecraft formation flying:

1. Sabol, C., Burns, R., and McLaughlin, C. A., "Satellite Formation Flying Design and Evolution," *AIAA Journal of Spacecraft and Rockets*, Vol. 38, No. 2, 2001, pp. 270-278.

2. Gill, E., D'Amico, S., and Montenbruck, O.,"Autonomous Formation Flying for the PRISMA Mission," *AIAA Journal of Spacecraft and Rockets*, Vol. 44, No. 3, 2007, pp. 671-681.

Course Organization

Lectures (Wednesday, 2:35 pm - 5:25 pm, ME 4236)

There is one 170-minute lecture per week in which the course material will be presented.

Tutorials

There is no tutorial period for this course. Students will then be expected to work through problems related to the course material outside the lecture periods. These problems are in the course notes, at the end of each chapter. It is important to note that these problems also serve as a mean to introduce new concepts and to expand on the ones covered during the lectures, and as such they must be treated as an integral part of the course material.

Online Resources

Course information and lecture notes will be posted on cuLearn.

Evaluation

Grading

Quizzes (x6): 30%
Midterm Exam: 20%
Final Exam: 20%
Individual Project: 30%
STK Certification: 5% (bonus)

Quizzes

To be administered on six randomly-selected lecture sessions (unknown to the students), a quiz consists of a single problem selected amongst the various problems covered thus far in the course notes. Students have 25 minutes to write their quiz.

Examinations

Midterm Exam: closed-book, with 1 double-sided cheat sheet, held on **February 18, 2015** (80 min).

Final Exam: closed-book, with 2 double-sided cheat sheets, held on **April 1, 2015** (170 min).

Academic Accommodation

For more details on the academic accommodation implementation policy summarized below, please visit the Equity Services website: http://www2.carleton.ca/equity/human-rights/policy/human-rights-policies-and-procedures-part-1/#statementacademicaccomm

Pregnancy obligations

Students requesting accommodation on the basis of pregnancy should contact me as soon as possible after a need for accommodation is known to exist.

Religious obligations

Students requesting academic accommodation on the basis of religious obligation must make a formal, written request to me during the first two weeks of the fall term, or as soon as possible after a need for accommodation is known to exist.

Students with disabilities

Students with disabilities requesting academic accommodation must provide the Paul Menton Centre for Students with Disabilities (PMC) with relevant professional supporting documentation as determined by the University, generally from a regulated health professional practitioner (e.g., a physician, psychiatrist, clinical psychologist). The documentation must include a statement that the individual has an ongoing, recognized disability that requires academic accommodation. Students with learning disabilities must provide a summary of the results of a complete psycho-educational assessment conducted by an appropriate registered psychologist. All documentation must be current.

Once students with disabilities identify their individual needs for academic accommodation, PMC staff members assess the appropriateness of the student's requests, and then formally recommend appropriate means of academic accommodation by means of a *Letter of Accommodation*.

A student with a Letter of Accommodation should meet me as soon as possible to discuss the academic accommodations recommended and to reach an agreement on an appropriate accommodation for the course. The instructor may contact PMC for further consultation as needed.

Audio/Video Recording of Lectures

Some students may wish to create their own audio or video recording of a lecture as a personal study aid. As there is no Carleton policy on this matter, whether instructors wish to record their lectures or have their lectures recorded or not is entirely at the discretion of the individual instructor. It is important to know that a lecture is considered the intellectual property of the instructor. Furthermore, video recording of a lecture would also require the express written permission of other students whose presence or statements might also be recorded. In addition, audio and/or video recording may also lead to several problematic cases of students creating recordings of lectures and subsequently sharing these recordings with other students, sometimes on publicly accessible websites, and occasionally for profit.

In this context, students may not create audio or video recordings of lectures with the exception of those students requiring an accommodation for a disability, who are referred to the Paul Menton Centre as they may be able to provide other strategies and/or authenticate the request.

Students creating unauthorized audio and/or video recording of lectures violate an instructor's intellectual property rights and the Canadian Copyright Act.

Systems Tool Kit (STK)

Installing STK

To install the full version of STK on your computer, follow these steps:

STEP 1. Download the free version of STK at: www.agi.com/products/stk/

STEP 2. Open STK.

STEP 3. In the License Manager Wizard window select Get Free STK License.

STEP 4. In the AGI License Manager window, navigate to the Request Free License tab.

STEP 5. Write down the Host ID and Registration ID, both located at the bottom of the window, as illustrated in Fig. 1.

STEP 6. Contact Mr. Bruce Burlton at bruceburlton@sympatico.ca, and provide him with these two IDs.

Note. You do not need the full version of STK to complete the certification; the free version from the web is sufficent.

Becoming STK Certified

To get STK certified (level 1) and get your 5% bonus mark, follow these simple steps:

STEP 1. Complete the STK Fundamentals training at: www.agi.com/training/certification

STEP 2. When you feel ready to take the test, register online for the certification instructions at: https://www.agi.com/my-account/default.aspx

STEP 3. Follow the instructions provided after the registration process.

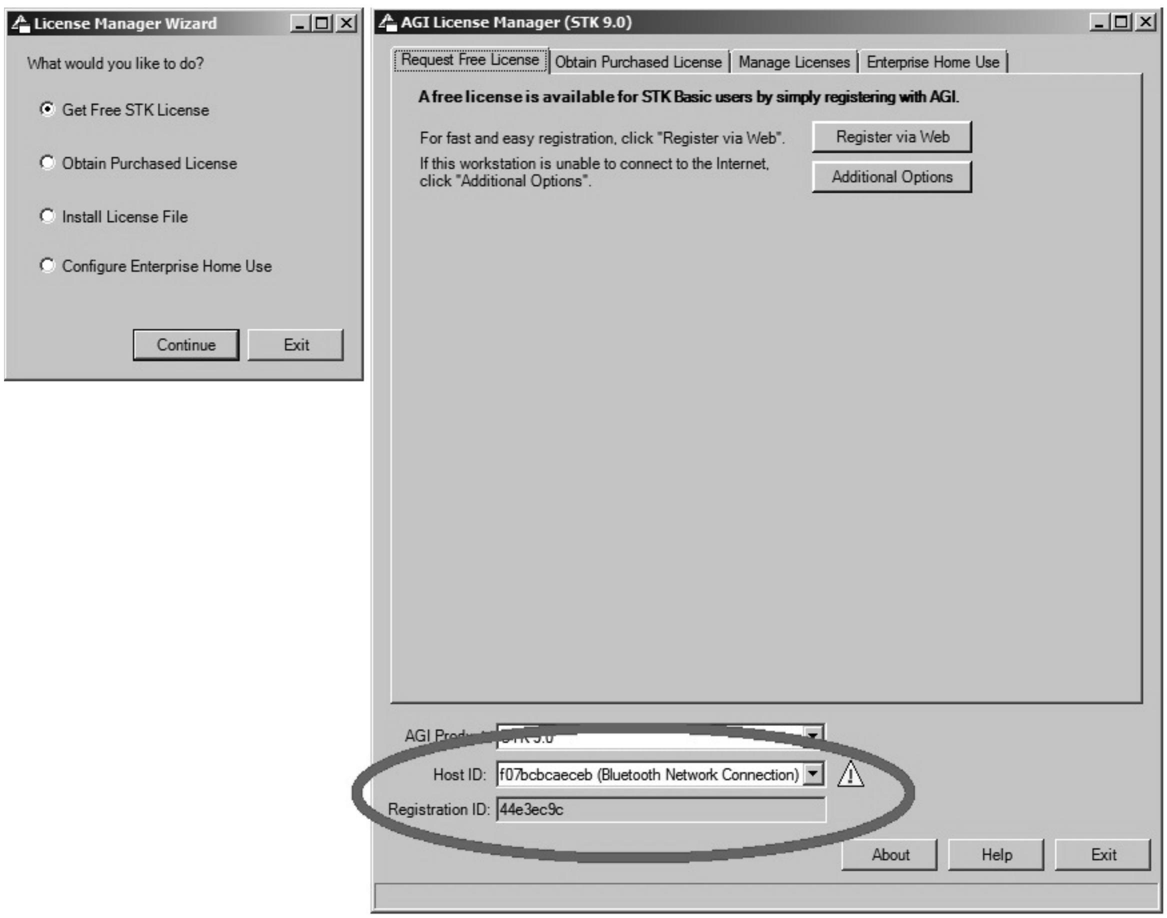

Figure 1: Host ID and Registration ID.

Individual Project

Objective of the Project

Each student will work on a project of their choice. The objective of the project is to expand on a topic covered in class, or to treat a topic not covered in class yet still related to the field of spaceflight mechanics. Typically, a project would consist of investigating and simulating using Matlab/Simulink and/or Systems Tool Kit a technique or a development published in the literature (journal articles or books). Examples of projects include:

design and analysis of interplanetary trajectories;
study of orbital motion for the elliptical three-body problem;
active or passive spacecraft attitude control;
formation flying control;
orbit determination;
attitude determination;
relative navigation in proximity operations; and
rendezvous and docking maneuvers.

Good journals in which you can look for articles include:

AIAA Journal of Guidance, Control and Dynamics
AIAA Journal of Spacecraft and Rockets
Journal of the Astronautical Sciences
Acta Astronautica
Aerospace Science and Technology
Astrophysics and Space Science
Celestial Mechanics and Dynamical Astronomy
IEEE Transactions on Aerospace and Electronics Systems
IEEE Transactions on Control Systems Technology

Approval of the individual topics must be obtained from the instructor by **February 18, 2015**.

Oral Presentation

At the end of the semester, each student will make a 10-minute oral presentation summarizing the results of their project, followed by a 5-minute question period. The presentations will take place on **April 8, 2015**.

Written Report

A written report summarizing the student's project, and prepared in the form of an AIAA conference proceeding will be due one week after the presentation, i.e. on **April 15, 2015 by 4:30 pm**. The submission is to be done electronically, by email.

The report must be prepared using either the Word or the LaTeX template available on the course website. There is a page limit of 25 pages for the content of the report, excluding any Appendices used to provide a printout of your MATLAB code and Simulink models.