<table>
<thead>
<tr>
<th><strong>UoS Code</strong></th>
<th>AERO4701</th>
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<tbody>
<tr>
<td><strong>UoS Title</strong></td>
<td>Space Engineering 3</td>
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<tr>
<td><strong>Credit Value</strong></td>
<td>6</td>
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<tr>
<td><strong>Semester Offering</strong></td>
<td>1</td>
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**Precursor Units of Study, (Pre-requisites, Assumed Knowledge) (Mandatory, Recommended)**
- AERO3700 Space Engineering 2 (P)

<table>
<thead>
<tr>
<th><strong>Co-requisite Units of Study</strong></th>
<th>NA</th>
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<tbody>
<tr>
<td><strong>Mutually Exclusive Units of Study</strong></td>
<td>NA</td>
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**Lecturers/ tutors /demonstrators**
- Lecturers: Dr. Mitch Bryson, Prof. Salah Sukkarieh
- Tutor: Mr. Ken Ho
- Email: k.ho@acfr.usyd.edu.au

**Graduate Attributes**
(1) Science and Engineering Fundamentals, Level: Advanced
Students will develop an expertise in the fundamental principles and applications of estimation methods including the use of linear and non-linear least squares approximations for various engineering tasks.
### Discipline Specific Expertise, Level: Advanced
Students will apply estimation and design theory to a number of key problems in aerospace engineering such as global positioning systems, satellite attitude and orbit determination systems and satellite remote sensing and mapping.

### Design and Problem Solving Skills, Level: Intermediate-Advanced
Students will work on implementing solutions to estimation tasks involving the design of different algorithms and sensor systems.

### Information Skills, Level: Intermediate-Advanced
Students will be required to conduct their own literature search in studying past solutions to example problems and draw upon this knowledge during their own design process.

There will be three assignments in this subject that will focus on developing these attributes. Each assignment will have a number of questions relating to the theoretical development and practical realization of the course along with a reflective component. There is an abundance of information in the library and web along with the course notes to which the students will be referred to. The assignment structure will provide directions to this information to which attributes 1-3 will be developed. The feedback process to these attributes will come in the practical implementations of the algorithms as specified in the assignments. Students will be submitting code, results and a report. The report will clarify the results, and also contain the reflective component, which will generally focus on more advanced and deeper levels of understanding. This will develop attribute 4.

### UoS Aims and Objectives
This UoS aims to teach students the fundamental principles and methods of designing solutions to estimation problems in aerospace engineering.

1. The ability to apply learned techniques in estimation theory to solving a wide range of different problems in engineering. (Graduate Attribute Type: Science and Engineering Fundamentals)
2. The ability to recognize and appreciate the coupling between the different elements within an estimation task, such as satellite remote sensing, from a systems-theoretic perspective. (Graduate Attribute Type: Discipline Specific Expertise)
3. The ability to use this system knowledge and basic design principles to design and test a solution to a given estimation task, with a focus on aerospace applications (such as satellite remote sensing). (Graduate Attribute Type: Design and Problem Solving Skills)

### Learning Outcomes
This UoS aims to develop an understanding of:
The fundamental principles and applications of estimation methods including the use of linear and non-linear least squares approximations for various engineering tasks.

The mechanics behind and models used to predict satellite orbits, orbit determination from tracking measurements and the connection between satellite motion and remote sensing mission requirements.

The operating principles, implementation, strengths/weaknesses and error sources of various navigation sensors and systems including Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS).

Attitude determination sensors and systems along with the algorithms used to fuse sensor data from multiple sensors to accurately estimate satellite attitude.

The design and breakdown of sensors/systems/algorithms for aerospace remote sensing missions from mission constraints and requirements and the relationship between the tasks of remote sensing and the localization/navigation of a satellite/remote sensing platform.

This UoS aims to develop the following technical skills:

1. An ability to apply parameter estimation techniques such as least squares in a variety of different engineering applications.
2. An ability to implement equations and models used to accurately simulate satellite motions and determine satellite orbits for tracking data.
3. An ability to implement the equations for GNSS using real satellite data, to model and implement satellite attitude determination algorithms and to accurately localize a remote sensing platform.
4. An ability to perform trade-off studies between remote sensor and navigation sensor accuracy in order to optimize system performance given mission constraints and requirements.

In this UoS, students will gain an appreciation of:

1. The use of the non-linear least squares methods in parameter estimation in a wide range of engineering and aerospace applications.
2. The different models used for orbital motion prediction and the role these models play in satellite tracking and remote sensing.
3. The major limitations and error sources of commonly used aerospace navigation sensors such as GNSS and how these errors reflect on the accuracy of remote sensing.
4. The role of systems engineering in navigation system design and how this fits into the design of the whole remote sensing mission.
### Teaching and Learning Approach

Lectures, Workload: 2 hours per week, presented in 1 session(s) per week for 13 week(s) of semester.

Tutorials, Workload: 2 hours per week, presented in 1 session(s) per week for 13 week(s) of semester.

Independent Study, Workload: 4 hours per week.

The tutorial period is when students will work from computer terminals to implement the algorithms, and will be supervised by the tutors. The tutors will also provide guidance as to how the algorithms should be implemented. The lecture time will comprise of both information transfer, and question/answer time. The latter will be approached both on an individual level between student and lecturer and on a group level. The focus of the question/answer time is to provide encouragement for deeper learning and questioning.

### Assumed Knowledge

The following concepts are expected to have been grasped from previous UoSs in order to be able to understand the concepts taught in this UoS:

1. Ability to code in MATLAB (AERO3760 and AERO2705).
2. An understanding of satellite orbits, motion and dynamics and the systems engineering process when applied to the design of a satellite (AERO3760 and AERO2705).

### Syllabus

Wk1. Introduction to estimation in aerospace applications: Remote sensing and navigation systems, overview of sensors and systems.


Wk4. Introduction to Estimation and Least Squares: Linear least squares, constrained and weighted least squares, non-linear least squares.
<table>
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<tr>
<th>Week</th>
<th>Topic</th>
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<tbody>
<tr>
<td>Wk5</td>
<td>GNSS I: Introduction to GPS, signals and message structure, orbit geometry, orbit calculation using almanac and ephemeris data, ground tracking of GPS satellites, operation of positioning, error sources.</td>
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<tr>
<td>Wk6</td>
<td>GNSS II: Orbit determination using non-linear least squares, GPS accuracy quantification, dilution of precision, introduction to probability and statistics of errors.</td>
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<tr>
<td>Wk7</td>
<td>Attitude Determination Systems (ADS): Magnetic sensing, sun/star tracking, horizon scanners, sensor modeling and error simulation.</td>
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<tr>
<td>Wk8</td>
<td>Attitude Determination Systems (ADS) II: Focus on attitude representation, ADS methods, least squares for ADS.</td>
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<tr>
<td>Wk10</td>
<td>Geometry of Remote Sensing: Ground mapping and geo-location using remote sensing data, methods in photogrammetry, mapping and construction of satellite maps.</td>
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<tr>
<td>Wk12</td>
<td>Simulation and Verification in System Design: Simulation methods for orbits, navigation and remote sensing systems, statistic evaluation of system performance, Monte-Carlo Analysis.</td>
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<tr>
<td>Wk13</td>
<td>Advanced Estimation in Aerospace Applications: Real-time terrain-aided navigation, Simultaneous Localisation and Mapping (SLAM), structure from motion.</td>
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**Workload requirements**

The Contact Hours for this UoS is one 2-hour lecture and one 2-hour tutorial every week.

It is expected that students attend all lectures and tutorials and participate in group discussions that are held in both. The lecture content is driven to encourage class interaction and students are expected to interact with fellow peers and the lecturer in developing a better understanding of the course material. Students are expected to come prepared to tutorial sessions by attempting to at least understand the problem scope of the assignments, and if possible, to have initially attempted part of the assignment.
The average student is expected to spend approximately 4 hours on this UoS per week, outside of the standard contact hours.

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<th>Assessment and/or Examination</th>
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| **Assignment 1** will focus on satellite mission design, the simulation of satellite orbits and the determination of satellite orbit parameters from range and line-of-sight observations. | Weighting 30%, Due Week 5  
Target Outcomes: 1 and 2 |
| **Assignment 2** will focus on application of least squares estimation with relation to the operation of GNSS and satellite attitude determination. | Weighting 30%, Due Week 8  
Target Outcomes: 1, 2 and 3 |
| **Assignment 3** will focus on integrating the elements of estimation, orbital mechanics and navigation systems learnt in the first part of the course towards the design and simulation of a complete solution to a given remote sensing task. | Weighting 40%, Due Week 13  
Target Outcomes: 1, 2 and 3 |

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<th>Grading</th>
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<td>The following grading system outlines the knowledge, skills and understanding expected at the end of the course and the associated grading of pass, credit, distinction and high distinction.</td>
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| **Pass:** A pass student is expected to:  
- Understand the basic notion of estimation and apply a range of given techniques to known problems such a positioning and parameter identification.  
- Identify the different types of estimation algorithms, navigation systems, attitude determination system, GNSS and remote sensors.  
- Understand the basic operating principles of different satellite navigation systems, implement the basic operating principles of a satellite navigation system including sensor equations and error modeling.  
- Understand and identify the equations relating navigation system accuracy to remote sensing accuracy.  
- Use design equations and procedures to match up remote sensor and navigation system accuracy for a given set of mission performance criteria. |
Credit: A credit student is expected to, on top of the abilities of a pass student:
- Firm understanding of estimation, ability to generalize estimation procedures to a wide range of different problems, compare and contrast performance of different algorithms.
- Ability to contrast/compare between different orbital models, understanding of, ability to analyse and explain relationship between model accuracy and complexity.
- Implement complex estimation methods, equations of orbital mechanics, GNSS and satellite navigation sensor operation and error equations, understanding and ability to generalize estimation algorithms for better accuracy and computational performance.
- Design orbital parameters/navigation systems to meet a given set of remote sensing accuracy requirements. Show ability to perform trade-off studies to compare remote sensing accuracy to cost/accuracy/complexity of navigation sensors and algorithms. Reflect and reiterate design procedures to meet system requirements and constraints.

Distinction and High Distinction: A high distinction student is expected to, on top of the abilities of a credit student:
- Deep understanding of estimation, ability to implement highly complex equations and methods for estimation tasks, derive estimation algorithms from first principles of optimization and probability, understand and circumvent limitations of estimation algorithms in real systems.
- Generalise complex orbital model equations from the standard Keplerian orbital model and contrast/compare the differences in accuracy from the effect the parameters play in the model.
- Ability to implement highly complex equations and methods for estimation tasks such as structure from sensor data, research and apply methods outside of the syllabus.
- Deep understanding of connection between orbit, navigation and remote sensing systems, ability to qualify and quantify the theory of satellite mission and navigation system design, theorise own design procedures from theory.
- Ability to design and implement simulation and testing procedures for assuring the cohesion between the elements of sensor accuracy, estimation performance and remote sensing accuracy.
| **Relevance (Where this UoS will lead you)** | At the conclusion of this UoS, students will have a fundamental understanding of estimation methods, orbital mechanics, satellite navigation systems and remote sensing system design and evaluation. Students will be able to immediately use this knowledge in industry in the development of avionics navigation systems.

If students are interested in further developing skills in the area of navigation and control of satellite systems, students can take on the course of Advanced Guidance, Navigation and Control (MECH4700), in second semester which will explore areas of more elaborate data fusion and control techniques. |
| **Examination Policy** | There will be no exam for this course. |