ANX-PR/CL/001-01
LEARNING GUIDE

SUBJECT

143003022 – Astrodynamics & Attitude Dynamics

DEGREE PROGRAMME

14IB - Master of Science in Aeronautical Engineering

ACADEMIC YEAR & SEMESTER

2019/20 – First semester

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	143003022 – Astrodynamics and Attitude Dynamics
No. of credits	6 ECTS
Type	Optional
Academic year	Second year
Semester of tuition	Semester 3
Tuition period	September-January
Tuition languages	English, Spanish
Degree programme	14IB - Master of Science in Aeronautical Engineering
School/Faculty	14 – School of Aerospace Engineering (Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio)
Academic year	2019-20

2. Faculty

2.1. Professors

Name and surname	Office/Room	Email	Tutoring hours *
Manuel Ruiz Delgado	14A.01.068.0	manuel.ruizd@upm.es	Tu - 09:30 - 12:30 Th - 09:30 - 12:30
Jesus Pelaez Alvarez (Coordinator)	14A.01.052.0	j.pelaez@upm.es	M - 09:30 - 12:30 W - 09:30 - 12:30
Ricardo Angel Garcia-Pelayo Novo	14A.01.071.0	r.garcia-pelayo@upm.es	M - 09:30 - 12:30 W - 09:30 - 12:30

Claudio Bombardelli	14A.01.082.0	claudio.bombardelli@upm.es	M - 09:30 - 12:30 Th - 09:30 - 12:30

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

2.2. Research staff in training or similar

Name and surname	Email	Supervisor
Raposo Pulido, Virginia	v.raposo.pulido@upm.es	Pelaez Alvarez, Jesus

3. Prior knowledge recommended to take the subject

3.1. Recommended (passed) subjects

- Flight Dynamics

3.2. Other recommended learning outcomes

- Differential equations

- Classic Mechanics

- Orbital Mechanics

- Numerical Calculus

- High Level Programming Language (C, Fortran)

4. Skills and learning outcomes

4.1. Skills to be acquired

CE-VA-10 - Conocimiento adecuado de los distintos Subsistemas de las Aeronaves y los Vehículos Espaciales.

CE-VA-5 - Comprensión y dominio de la Mecánica del Vuelo Atmosférico (Actuaciones y Estabilidad y Control Estáticos y Dinámicos), y de la Mecánica Orbital y Dinámica de Actitud.

CG1 - Capacidad para proyectar, construir, inspeccionar, certificar y mantener todo tipo de aeronaves y vehículos espaciales, con sus correspondientes subsistemas.

CG10 - Conocimiento, comprensión y capacidad para aplicar la legislación necesaria en el ejercicio de la profesión de Ingeniero Aeronáutico.

CG11 - Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación.

CG12 - Aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio.

CG13 - Ser capaz de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicios.

CG14 - Comunicar sus conclusiones ?y los conocimientos y razones últimas que las sustentan? a públicos especializados y no especializados de un modo claro y sin ambigüedades.

CG15 - Poseer las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo.

CG3 - Capacidad para la dirección general y la dirección técnica de proyectos de investigación, desarrollo e innovación, en empresas y centros tecnológicos aeronáuticos y espaciales.

CG4 - Capacidad de integrar sistemas aeroespaciales complejos y equipos de trabajo multidisciplinares.

CG5 - Capacidad para analizar y corregir el impacto ambiental y social de las soluciones técnicas de cualquier sistema aeroespacial.

CG6 - Capacidad para el análisis y la resolución de problemas aeroespaciales en entornos nuevos o

desconocidos, dentro de contextos amplios y complejos.

CG9 - Competencia en todas aquellas áreas relacionadas con las tecnologías aeroportuarias, aeronáuticas o espaciales que, por su naturaleza, no sean exclusivas de otras ramas de la ingeniería.

CT2 - Capacidad para dinamizar y liderar equipos de trabajo multidisciplinares.

CT3 - Capacidad para adoptar soluciones creativas que satisfagan adecuadamente las diferentes necesidades planteadas.

CT4 - Capacidad para trabajar de forma efectiva como individuo, organizando y planificando su propio trabajo, de forma independiente o como miembro de un equipo.

CT5 - Capacidad para gestionar la información, identificando las fuentes necesarias, los principales tipos de documentos técnicos y científicos, de una manera adecuada y eficiente.

CT6 - Capacidad para emitir juicios sobre implicaciones económicas, administrativas, sociales, éticas y medioambientales ligadas a la aplicación de sus conocimientos.

CT7 - Capacidad para trabajar en contextos internacionales.

4.2. Learning outcomes

RA24 - Conocer y saber usar la teoría básica del movimiento kepleriano

RA26 - Conocer los conceptos involucrados en la propagación de órbitas tanto con esquemas clásicos como con esquemas regularizados

RA27 - Conocer los aspectos básicos del problema de tres cuerpos, los rudimentos de misiones interplanetarias y las maniobras impulsivas.

RA28 - Conocer los aspectos básicos del movimiento relativo y las diferentes teorías que se recogen alrededor del concepto de matriz de transición..

RA31 - Conocer y saber usar las distintas representaciones de la actitud de un vehículo espacial

RA35 - Conocer los elementos básicos de la teoría de estabilidad de vehículos espaciales.

RA30 - Conocer los rudimentos de la optimización de trayectorias impulsadas con motores de bajo empuje

RA21 - Conocer los sistemas de referencia y los modelos geodésicos elementales usados en Misiones Espaciales y en problemas de Astrodinámica y Dinámica de Actitud

RA25 - Conocer y saber usar la teoría de perturbaciones y sus aplicaciones fundamentales RA22 -

Conocer las diferentes formas de medida del tiempo y su uso en Misiones Espaciales

RA23 - Conocer los principales tipos de fuerzas que pueden actuar sobre vehículos espaciales y que condicionan su dinámica. Conocer el concepto de gradiente de gravedad

RA29 - Conocer los aspectos básicos y las técnicas usadas en el campo de la determinación de órbitas. Conocer los rudimentos de las técnicas de navegación y guiado..

RA33 - Conocer las técnicas fundamentales usadas en los problemas de adquisición de actitud y medidas de actitud

RA34 - Conocer y saber plantear las ecuaciones que gobiernan la dinámica de actitud de vehículos espaciales en casos sencillos.

RA32 - Conocer los principios básicos de la cinemática de actitud y saber plantear las ecuaciones cinemáticas

RA36 - Conocer los momentos ambientales y las principales técnicas de estabilización de actitud

5. Brief description of the subject and syllabus

5.1. Brief description of the subject

The aim of this subject is to teach students about the key issues involved in both spacecraft and celestial dynamics. Initially, a spacecraft or any celestial body in space is modelled as a free rigid body, moving subject to directly applied, that is, known, forces. This approach has proved fruitful in multiple situations. The solutions it provides are the starting point of subsequent analyses including spacecraft deformability. This second phase is sometimes unnecessary as the solution according to the non-deformable system hypothesis already provides the desired accuracy. A free rigid body is a system with six degrees of freedom; rigid body movement can be decomposed into the movement of the body's centre of mass *G* and the movement relative to its centre of mass. Generally, both movements are coupled. Coupling takes place when external forces are acting on the path of the body centre of mass whose intensity depends on spacecraft attitude (for example, aerodynamic resistance). However, both problems are often addressed separately either because coupling is small or we are looking for an approximate solution.
Traditionally, the discipline aiming to determine the movement of the centre of mass *G* of a given object is called orbital mechanics or orbital dynamics, whereas the discipline called attitude dynamics focuses on the analysis of the movement related to the centre of mass. Finally, orbital mechanics applied to the study of astronomical bodies is known as celestial mechanics.
This subject addresses both aspects of the celestial object dynamics.

5.2. Syllabus

1. INTRODUCCTION TO GEODESY

2. REFERENCE SYSTEMS IN ASTRODYNAMICS

3. TIME MEASURES

4. KEPLER'S LAWS OF PLANETARY MOTION (REFRESHER)

5. PERTURBATION THEORY

   5.1. Lagrange Planetary Equations

   5.2. Gauss Equations

      5.3. Equinoctial Elements

6. ORBIT PROPAGATION

   6.1. Classical Methods (Cowell, Encke)

   6.2. . DROMO and K-S Regularization

7. RELATIVE MOTION

8. *N* BODY PROBLEM

9. INTERPLANETARY TRAJECTORY

10. IMPULSIVE MANOEUVRE

11. SATELLITE MONITORING AND OBSERVATION MODELS

12. ORBIT DETERMINATION

13. INTRODUCTION TO NAVIGATION AND GUIDANCE

14. INTRODUCTION TO LOW-THRUST TRAJECTORY OPTIMIZATION

15. ATTITUDE KINEMATICS

16. ATTITUDE ACQUISITION

17. RIGID BODY ATTITUDE EQUATIONS

18. EFFECTS OF ENERGY DISSIPATION

19. ENVIRONMENTAL MOMENTS ACTING ON A SPACE VEHICLE

20. GRAVITY STABILIZATION

21. SPIN STABILIZATION

6. Schedule

6.1. Subject Schedule *

Week	Face-to-face classroom activities	Face-to-face laboratory activities	Other face-to-face activity	Assessment activities
1	**Topics 1 and 2** Duration: 03:45 MC: Masterclass		**Setting of EXERCISE 1 (individual)** Duration: 00:15 PR: Problem-solving activity	
2	**Topics 3 and 4** Duration: 04:00 MC: Masterclass			
3	**Theme 5** Duration: 03:45 MC: Masterclass		**Setting of EXERCISE 2 (Groups of 4 or 5 students)** Duration: 00:15 PR: Problem-solving activity	
4	**Topics 5 and 6** Duration: 04:00 MC: Masterclass			**Submission of EXERCISE 1** IW: Independent work for continuous assessment and final test students Duration: 00:00
5	**Theme 6** Duration: 04:00 MC: Masterclass			
6	**Topics 7 (2hours) and 8** Duration: 04:00 MC: Masterclass			**Submission of EXERCISE 2** GW: Group work for continuous assessment students - Duration: 00:00
7	**Topics 8 and 9** Duration: 04:00 MC: Masterclass			
8	**Topics 10 and 11** Duration: 03:45 MC: Masterclass		**Setting of EXCERCISE 3 (individual)** Duration: 00:15 PR: Problem-solving activity	
9	**Topics 12 and 13** Duration: 04:00 MC: Masterclass			
10	**Topics 14 and 15** Duration: 04:00 MC: Masterclass			
11	**Topics 16 and 17** Duration: 04:00 MC: Masterclass			**Submission of EXERCISE 3** IW: Independent work for continuous assessment and final test students Duration: 00:00
12	**Topics 18 and 19** Duration: 03:45 MC: Masterclass		**Setting of EXERCISE 4 (Groups of 4 or 5 students)** Duration: 00:15 PR: Problem-solving activity	

13	**Topic 20** Duration: 04:00 MC: Masterclass			
14	**Topic 21** Duration: 04:00 MC: Masterclass			**Submission of EXERCISE 4** GW: Group work for continuous assessment students - Duration: 00:00
15	**Group presentation** Duration: 04:00 OT: Other training			**Student working groups – assignment presentations (20 minutes). Substitutes final exam for continuous assessment students** GW: Group work for continuous assessment Duration: 04:00
16				**FINAL EXAM, composed of exercise and problems. Students must have submitted individual exercises (1 and 3) beforehand** EX: Written exam Assessment by final test only Duration: 03:00
17				

Independent study is an educational activity during which students should spend time on studying alone or completing individual assignments.

Depending on the curriculum schedule, total values will be calculated according to the ECTS credit unit as 26/27 hours of face-to-face contact and independent study time.

* The subject schedule is based on theoretical subject curriculum planning and could be subject to unforeseen changes throughout the academic year.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Continuous assessment

Week	Description	Technique	Type	Duration	Weight	Minimum grade	Assessed skills
4	Submission of Exercise 1	IW: Independent work	Remote	00:00	10%	5 / 10	CG5 CG12 CG15 CT3 CT4 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CG3 CG6 CG11 CG14
6	Submission of Exercise 2	GW: Group work	Remote	00:00	25%	5 / 10	CG5 CG12 CG15 CT2 CT3 CT4 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CT5 CG3 CG6 CG11 CG14

11	Submission of Exercise 3	IW: Independent work	Remote	00:00	10%	5 / 10	CG5 CG12 CG15 CT2 CT3 CT4 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CT5 CG3 CG6 CG11 CG14
14	Submission of Exercise 4	GW: Group work	Remote	00:00	25%	5 / 10	CG5 CG12 CG15 CT2 CT3 CT4 CT6 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CT5 CG3 CG6 CG11 CG14
15	All work groups will give a roughly 20-minute presentation on group work exercises. This substitutes the final exam for continuous assessment students.	GW: Group work	Remote	04:00	30%	5 / 10	CG5 CG12 CG15 CT2 CT3 CT4 CT6 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4

							CT5 CG3 CG6 CG11 CG14

7.1.2. Final examination

Week	Description	Technique	Type	Duration	Weight	Minimum grade	Assessed skills
4	Submission of Exercise 1	IW: Independent work	Remote	00:00	10%	5 / 10	CG5 CG12 CG15 CT3 CT4 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CG3 CG6 CG11 CG14
11	Submission of Exercise 3	IW: Independent work	Remote	00:00	10%	5 / 10	CG5 CG12 CG15 CT2 CT3 CT4 CT7 CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CT5 CG3 CG6 CG11 CG14
							CG5 CG12 CG15 CT2 CT3 CT4 CT6 CT7

16	FINAL EXAM, composed of exercises and problems. Students must submit individual exercises (1 & 3) beforehand	EX: Written exam	Remote	03:00	80%	5 / 10	CE-VA-5 CE-VA-10 CG9 CG10 CG13 CG1 CG4 CG3 CG6 CG11 CG14

7.1.3. Referred (re-sit) examination

None has been defined.

7.2. Assessment criteria

Continuous assessment: attendance of 80% lectures and submission of all exercises.
Final grade (Grade): FG = (0.1*E1 +0.25* E2 +0.1* E3 + 0.25*E4 + 0.3*PRESENTATION)

Final exam only: the student must successfully pass the final exam but must have previously submitted all individual exercises.
Final grade: FG = (0.20 x E + 0.80x FE)
E=grade for individual exercises, FE= grade for the final exam.
Students must select the preferred assessment option during the first week of class attendance, otherwise, they will be understood as having opted for continuous assessment.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
Orbital Motion, Archie E. Roy, CRC Press, 2004	Bibliography	Classical book on orbital motion
An introduction to the mathematics and methods of astrodynamics, Richard H. Battin, AIAA Education Series, 1999	Bibliography	Classical book
Theory of orbits. The restricted problem of three bodies, Victor G. Szebehely, Academic Press, 1967	Bibliography	Classical book
Satellite Orbits, O. Montenbruck & E. Gill, Springer 2001	Bibliography	Classical book with a good introduction to numerical systems
Interplanetary Mission Analysis and Design, Stephen Kemble, Springer 2006	Bibliography	Classical book on interplanetary missions

Fundamentals of Astrodynamics and Applications, David A. Vallado, Space Technology Library, Microcosm Press, Springer, 2007	Bibliography	Very thorough classical book
Subject notes, J. Peláez	Bibliography	Notes on some parts of the subject
Orbital Mechanics for Engineering Students, Howard D. Curtis, Elsevier 2005	Bibliography	Very educational classical book on key issues
TIME ? From Earth Rotation to Atomic Physics, Dennis D. McCarthy and P. Kenneth SeideMCann, Wiley-VCH 2009	Bibliography	Specialized book on different time measures
Spacecraft attitude dynamics, Peter C. Hughes, Courier Corporation, 2012	Bibliography	Basic book on attitude dynamics of space vehicles
A survey of attitude representations, MalcoMC D. Shuster, The Journal of the Astronautical Science, Vol. 41, No. 4 October-December 1993, pp. 439-517	Bibliography	Special issue on different space vehicle attitude representations
Subject MOODLE space http://moodle.upm.es/	Web resources	Will possibly be used to include additional work materials (like problems or scientific articles that are free and accessible to UPM students)