University Of California, Berkeley
Department of Mechanical Engineering

AEROSPACE ENGINEERING C162/MECHANICAL ENGINEERING C162 (AERO ENG C162/MEC ENG C162) – Introduction to Flight Mechanics (3 units)

Undergraduate Elective Course

Syllabus

CATALOG DESCRIPTION:

This course introduces flight mechanics and a wide range of analysis and design techniques of relevance to the flight and performance characteristics of aerospace vehicles. The course consists of 6 major modules with the following topics: introduction, flow types, lift and drag, aircraft performance, stability and control, and, prominently, space flight. The entire course is enriched with numerous practical examples from real life that help to understand the practical use of the subject matter.

COURSE PREREQUISITES & COREQUISITES:

❑ Prerequisites: Math 1B and Physics 7A; Co-requisite: MEC ENG 106

TEXTBOOK(S) AND/OR OTHER REQUIRED MATERIAL:

- **Class Notes**
- **J.D. Anderson and M. Bowden, *Introduction to Flight*, 9th edition, Graw-Hill, New York, 2021, (chapters 1 → 8)**

Additional references:

- R.C. Nelson, Flight Stability and Automatic Control, 2nd edition, McGraw-Hill, New York, 1997
- J.J. Sellers, *et al*., Understanding Space: An Introduction to Astronautics, 2nd edition, McGraw-Hill, New York, 2000

COURSE OBJECTIVES:

This course intends to introduce undergraduate engineering majors with an interest in aerospace engineering to analysis and design techniques of relevance to the flight and performance characteristics of aerospace vehicles in a self-contained manner and in anticipation of the engineering science coursework in the upper division. Simultaneously, the course intends to make tangible connections between the theory and relevant practical examples in aerospace engineering by means of the discussion of research facilities at NASA Ames (wind-tunnels and simulators), X-planes, relevant airliner accidents, launch and re-entry telemetry data, *etc*.

DESIRED COURSE OUTCOMES:

Upon completion of this course, students should be able to:

- Calculate lift and drag of a 2D airfoil and a 3D wing in subsonic and supersonic speed regimes

- Calculate thrust and power required for level flight
- Compute the range and endurance of propeller-driven as well as jet-powered aircraft
- Compute the necessary runway length for takeoff and landing
- Analyze aircraft trim conditions
- Assess longitudinal balance and static stability of an aircraft
- Find orbit parameters from the orbital geometry
- Design a Hohmann orbit transfer and compute the total DV
- Calculate peak deceleration and speed at touchdown in a re-entry path for ballistic as well as gliding flight.
- Describe and discuss various design methodologies and their trade-offs.

TOPICS COVERED:

Full Description for COCI purposes:

❑ This is a 3-unit undergraduate-level course which introduces students to a wide range of analysis and design techniques of relevance to the flight and performance characteristics of aerospace vehicles. The entire course is enriched with numerous practical examples from real life that help to understand the practical use of the subject matter. The course will be organized around 6 different modules. The course will have twice weekly 80-minute lectures. The different modules include:

1. *Introduction:*

The introduction consists of a single class in which the course is introduced, some fundamental properties are briefly recapitulated and in which the concept of the International Standard Atmosphere is explained with the different atmospheric layers. This discussion also shows the maximum altitude ceilings for a range of representative aerospace vehicles.

2. *Flow types*

This module refreshes some basic flow types that will be used frequently in the remainder of the course. It starts with covering and highlighting the differences between incompressible and compressible flows, as well as viscous and inviscid flows. This module will also discuss the Unitary Plan Wind-tunnel and the National Full-Scale Aerodynamic Complex at NASA Ames. The next part of this module is the discussion how the airspeed is measured, which also focuses on the differences between the various airspeed definitions. For the viscous flow types, practical examples are given such as the European BLADE research project, as well as NASA's research projects involving Boundary Layer Control and the F-16XL Supersonic Laminar flow control.

3. *Lift and drag*

The second aerodynamics review module focuses on lift and drag and starts with the basic properties of a 2D airfoil. Next step is transonic and supersonic flight and its influence on the lift and drag properties. This section also studies the impact of the Mach cone on the aircraft design and NASA's X-59 QueSST experimental aircraft. The finite wing section introduces the concept of wingtip vortices and illustrates their danger with a recent aviation accident related to wingtip vortices. The impact of finite wings on the lift and drag characteristics is elaborated, and it is also shown how wingtip devices reduce some of these negative influences. High lift devices are also treated here. The last topic from this module is wing sweep and its influence on the aerodynamic characteristics. Variable wing sweep is discussed, and practical examples are given such as the Grumman X-29 with a swept forward wing and NASA's AD-1 oblique wing experimental aircraft.

4. *Aircraft performance*

This module will discuss some basic performance metrics for aircraft, and how they can be calculated based on preliminary design parameters and aerodynamic properties. It starts with steady level flight, where the equations of motion are used to determine thrust required for steady level flight. It is also shown how the equations of motion can be derived for a wide range of aerospace vehicles (tiltrotors/vtol, helicopters, airships). Next step is calculating maximum speed and power required, where the distinction is made between propeller driven and jet powered aircraft. Altitude effects on performance are studied, and aerodynamic stall is revisited, including a recent airliner accident and some NASA research on giving pilots guidance on how to recover from a stall, for which the NASA Ames Vertical Motion Simulator was used. The next section elaborates on maximum climb rate, maximum climb angle and the difference between both, gliding flight and how to maximize range, and maximum altitude ceiling. This section wraps up with a discussion of the altitude and speed records of the X-15 and two recent airliner accidents that involved gliding flight. Range and endurance are the next performance metrics discussed, enriched with the longest duration and the longest distance non-stop flights ever. NASA's X-57 Maxwell and the high aspect ratio transonic truss-braced wing are also introduced here. After the topic of turning flight and the V-n diagram, this module is wrapped up with the discussion of the takeoff and landing distances. Practical examples are added such as the concepts of flight envelope protection, reduced thrust takeoff, brake to vacate landing technology, and extreme takeoffs and landings such as on an aircraft carrier.

5. *Stability and control*

This module starts with the definitions of static and dynamic stability, followed by the conditions for longitudinal balance and static stability. This section wraps up with emphasizing the contrast between stability and maneuverability and discussing a few variable stability aircraft. It is also shown how to 'trim' an aircraft by means of the stabilizer via the moment around the center of gravity. Also, directional static stability is discussed, and this module wraps up with the discussion of some aircraft design considerations for static stability, including for flying wings and tailless aircraft.

6. *Space Flight*

This last module will focus on space flight and orbital mechanics. The four shapes of orbits and their characteristic parameters are introduced. The concept of gravity assist is introduced and as an example the Voyager transfer orbit is studied. Also orbit transfers, the Lagrange points (case study of the James Webb Telescope) and launches are discussed in detail, including telemetry data analysis of a SpaceX Falcon 9 launch and first stage recovery. Next topic is re-entry for ballistic as well as gliding vehicles. As an example, telemetry data is studied of the Perseverance Rover entry, descent, and landing on Mars. Also, the Space Shuttle re-entry and the need of NASA's Vertical Motion Simulator for astronauts training is discussed. This module wraps up with the challenges of re-entry heating and how NASA Ames's Arc Jet Complex has been instrumental for the development of thermal protection systems for every major NASA Space program. Possible additional topics to be integrated in this module include planetary defense and NASA Dart mission, as well as NASA's Artemis mission with the unique lunar orbit which is explored by the Capstone spacecraft, and the skip entry.

7. *Invited Guest Lecture*

Time permitting, one of the last lectures will be a guest lecture with an invited speaker from industry or a research agency. Past and possible future topics include the Ingenuity Mars Helicopter, X-59 QueSST, Virgin Galactic space launch program, Artemis program, Adaptable Deployable Entry and Placement Technology (ADEPT), etc.

CLASS/LABORATORY SCHEDULE:

The course will have twice weekly 80-minute lectures.

COURSE SUPPORT:

This course will *require* GSI and reader support to assist with homework/project preparation and grading.

CONTRIBUTION OF THE COURSE TO MEETING THE PROFESSIONAL COMPONENT:

The course provides a link between theory and practice which is critical to the professional component.

RELATIONSHIP OF THE COURSE TO ABET PROGRAM OUTCOMES:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic physical and performance constraints
(d) an ability to function in teams (MATLAB project in teams of two)
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) a recognition of the need for, and an ability to engage in life-long learning
(i) a knowledge of contemporary issues
(j) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

ASSESSMENT OF STUDENT PROGRESS TOWARD COURSE OBJECTIVES

20%: homework assignments
25%: midterm exam covering modules $1 \rightarrow 4$
25%: project (MATLAB-based) calculating V1 (max rejected takeoff speed) and corresponding distance for a MTOW widebody airliner taking off from SFO.
30%: final exam

ATTENDANCE AND LATE-WORK POLICY

Attendance of lectures is strongly recommended but will not be enforced. Late work will not be accepted unless it is by prior arrangement as part of DSP accommodation request for extension to homework deadlines.

DSP ACCOMMODATION POLICY

All campus-originating DSP accommodation requests will be honored to the maximum practical extent.

SAMPLE OF WEEKLY AGENDA

Week	Course	Title	Book chapter	Homework

1	1	Introduction Fundamental thoughts International Standard Atmosphere	1 2 3	1
	2	Basic Aerodynamics: flow types	4	2
2	3	Basic Aerodynamics: viscous flow	4	
	4	Airfoil, Lift and Drag: basics	5	3
3	5	Airfoil, Lift and Drag: transonic and supersonic	5	
	6	Airfoil, Lift and Drag: finite wings	5	
4	7	Airfoil, Lift and Drag: swept wings	5	4
	8	Aircraft Performance: steady level flight	6	
5	9	Aircraft Performance: max speed, power required	6	5
	10	Aircraft Performance: climb, glide, ceiling	6	6
6	11	Aircraft Performance: range and endurance	6	
	12	Aircraft Performance: takeoff and landing	6	7
7		**Review Session – Mid Term Preparation**		
		MID TERM		
8	13	Aircraft Stability and Control: definitions and concepts	7	
	14	Aircraft Stability and Control: moments	7	8
9	15	Aircraft Stability and Control: assessment	7	
		PROJECT		
10	16	Space Flight: orbital mechanics	8	
	17	Space Flight: orbital geometry	8	9
11	18	Space Flight: transfer orbits – launch	8	
	19	Space Flight: introduction to re-entry	8	10
12	20	Space Flight: re-entry heating	8	
	21	Space Flight: Lagrange points – NASA Dart mission	-	
13	22	Space Flight: Artemis: near rectilinear halo orbit – skip entry	-	
		Review Session – Final Exam Preparation		
14		**Invited Guest Lecture from Industry / Research Agency**		
		* Spare *		
		FINAL EXAM		

ADDITIONAL COMMENTS/CONCERNS:
None.

PERSON(S) WHO PREPARED THIS DESCRIPTION
Thomas Lombaerts and Panos Papadopoulos

DETAILED WEEKLY SCHEDULE OF TOPICS
As above.

ABBREVIATED TRANSCRIPT TITLE (19 SPACES MAXIMUM): [ss completes]
TIE CODE: [ss completes]
GRADING: Letter or P/NP
SEMESTER OFFERED: Fall and/or Spring
COURSES THAT WILL RESTRICT CREDIT: Students will receive no credit for Aerospace Engineering

C162/Mechanical Engineering C162 after taking Aerospace Engineering C162/Mechanical Engineering C162.
INSTRUCTORS: Thomas Lombaerts, Panos Papadopoulos
DURATION OF COURSE: 15 Weeks
EST. TOTAL NUMBER OF REQUIRED HRS OF STUDENT WORK PER WEEK: 9 hours/wk
IS COURSE REPEATABLE FOR CREDIT? No.
CROSSLIST: Mechanical Engineering C162